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COURSE

Aviation Machinist's Mate 3 & 2

NAVEDTRA 14008

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PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its reference to useful information in other publications. The well-prepared Sailor will take the time to look up the additional information.

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- *Sep 1991*: *Original edition released. Prepared by ADCS(AW) Terence A. Post.*
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CHAPTER 1

JET ENGINE THEORY AND DESIGN

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- State the theory of jet propulsion.
- Identify the different types of engines and their major assemblies.
- Identify the two types of engine designation standards.
- Identify the common terms and variables effecting engine performance.

Every rating or specialty has a language of its own. The Aviation Machinist's Mate is no different. To be a good technician, you must learn and understand the language (terms and theories) necessary for a thorough understanding of your specialty. With this basic understanding, you will develop the skills to recognize, analyze, and correct problems with jet engines. Without it, you become a "parts changer" unable to recognize possible reasons for the problem and analyze them.

This chapter explains the basics necessary for the Aviation Machininst's Mate to build a strong foundation. You'll learn the theory, terms, types of engines, and major parts of jet engines.

BASIC THEORY OF JET PROPULSION

Jet propulsion is the propelling force generated in the direction opposite to the flow of a mass of gas or liquid under pressure. The mass escapes through a hole or opening called a jet nozzle. A familiar example is the nozzle at the end of a fire hose. The nozzle forms a smaller passageway through which the water must flow. The nozzle increases the velocity of the water, giving us the term, "a jet of water."

Another example of the theory of jet propulsion is an inflated balloon. With the opening in the balloon closed (fig. 1-1) there is no action because the pressure of the gas inside the balloon is equal in all directions. When you allow the

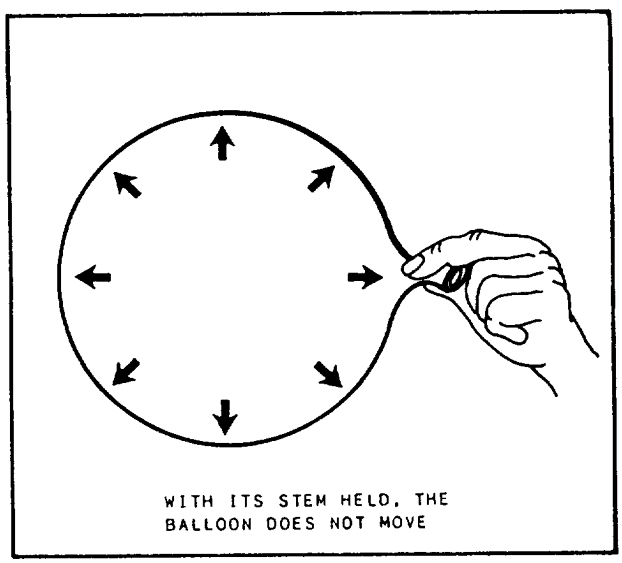


Figure 1-1.-Balloon example of restricting jet propulsion.

opening to release the air (fig. 1-2) the balloon moves, Its movements appear to be in all directions. Actually, it is always moving in the opposite direction from the open end where the air is exiting.

Let's look at the balloon example from the mechanics point of view. Igniting a hydrocarbon fuel (compound containing only hydrogen and carbon) and oxygen in a closed container (fig. 1-3) releases heat. The burning fuel causes the trapped gases to expand rapidly. Since the force of the pressure is balanced, the container does not move.

ROCKET

When combustion takes place in a container, the expanding gases rush out at a high velocity (fig. 1-4). The release of internal pressure at the nozzle end of the container leaves an unbalanced pressure at the other end. The released pressure propels the container (rocket) in the direction opposite of the exhaust gases. Obviously, propulsion depends solely upon internal conditions. The container does not "push against" external air. In fact, a complete vacuum would produce greater force. This is the basic operating principle for all jets. The rocket (propulsion unit) is one of the four main classes of jet engines.

Before we move on to the physical principles of jet engines, let's review the basic principle to the three other types of jet engines.

THE ATHODYD (RAMJET)

Suppose you attach a plain cylinder with open ends under the wing of an aircraft flying at high speed. Air enters the front of the duct and leaves at the rear. Nothing increases the force of flow through the duct. There is a loss of energy because of skin friction and airflow disturbances at the entrance and exit.

If you add heat energy to the air as it passes through the duct, the air would expand and increase the jet velocity. (Figure 1-5 shows a duct

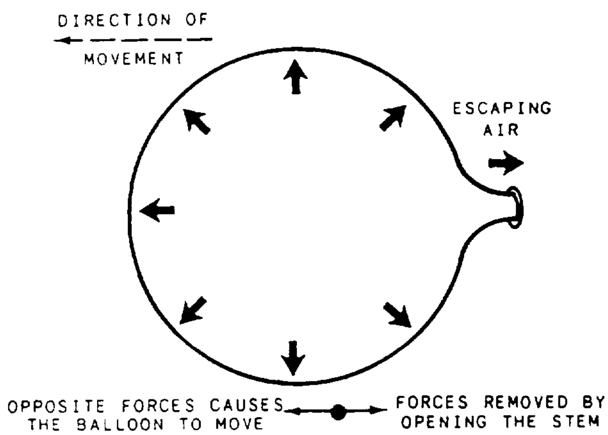


Figure 1-2.-Balloon example of jet propulsion theory.

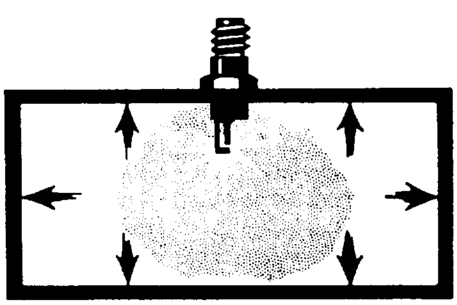


Figure 1-3.-Combustion in a closed vessel.

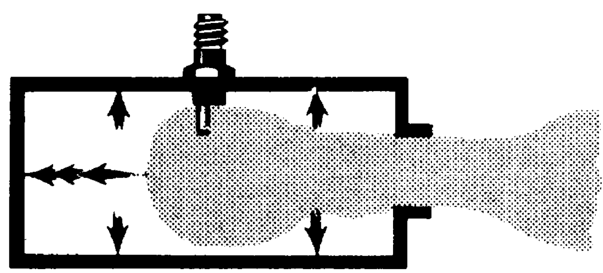


Figure 1-4.-Principle of jet propulsion.

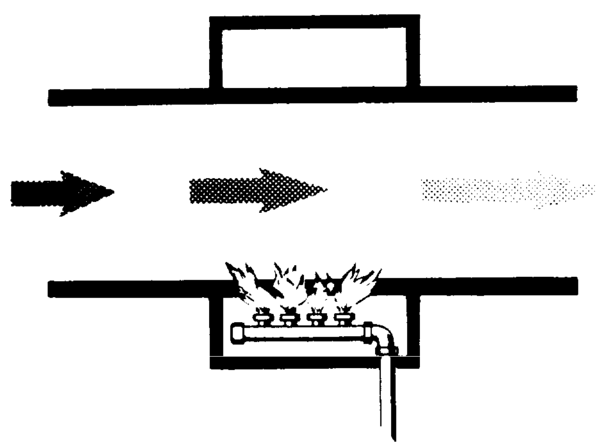


Figure 1-5.-Thermal duct with heat added externally to accelerate the airflow.

heated externally by burning oil sprays.) The amount of heat you can add is largely dependent upon the pressure of the air treated. A simple method of raising the pressure is to pass the air through a DIVERGENT entry nozzle. A divergent entry nozzle decreases the velocity of the air and increases the pressure. This also provides a forward pressure wall for the jet to react. A CONVERGENT exit nozzle further increases the jet velocity. The simple gas unit (fig, 1-6) created has little practical use because of the following:

1. Air compression depends solely on "ram effect."
2, A limited amount of heat is added.
3. Considerable heat is lost by radiation.

The next step is to improve the method of adding heat, through internal combustion. Figure 1-7 shows a divergent-convergent duct. Fuel is injected and burned, releasing heat directly into the airstream. This simple "Aero THermO DYnamic Duct" (ATHODYD) or RAM JET is used in remotely piloted vehicle (RPV) and cruise missiles.

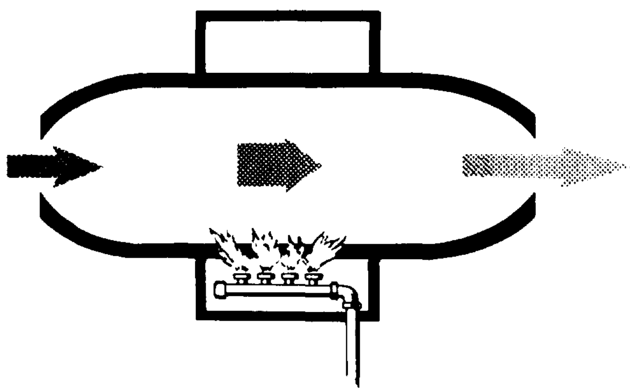


Figure 1-6.-A convergent discharge nozzle.

THE PULSEJET ENGINE

The "intermittent impulse" jet engine (fig. 1-8), known as the aeropulse or pulsejet improves compression by sacrificing the principle of continuous power generation. The pulsejet is like the ramjet, but with a series of nonreturn shutter valves. Fuel injection nozzles located just aft of the shutter valves provide fuel. As the engine travels through the air, pressure on the nose opens the valve and rams air into the duct, mixing air with fuel. Igniting the combustible mixture creates a high pressure (from the expanding gases), closing the valves. The violent ejection of the gases forms a relatively low-pressure area inside the duct, admitting a fresh charge of air through the flat spring valves. Because of the temperature of the duct and the return of part of the flaming exhaust gases, the rest of the charges burn without an igniter plug. This operating cycle or pulsations creates a loud buzzing sound. "Buzz bomb" described an early application of this unit, the German V-1 flying bomb.

We learned the basic principle of jet propulsion with the rocket. The ram jet taught us that adding heat would expand the gases and increase velocity. It also showed the amount of heat that is possible to add is dependent upon the amount

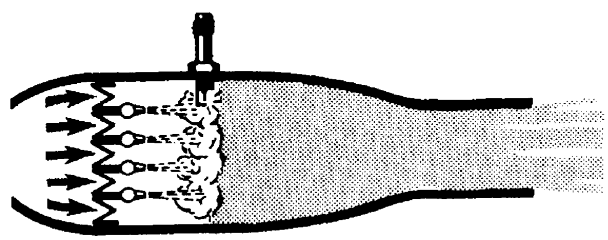


Figure 1-8.-The aeropulse or pulsejet.

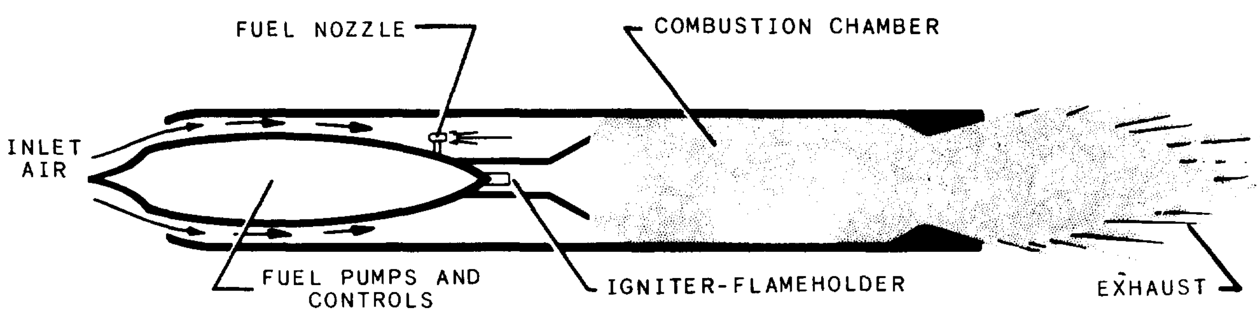


Figure 1-7.-The ramjet engine.

of air available. The pulsejet proved that the more air an engine could compress the greater the power (thrust) it produced. Now we will learn how a gas turbine engine increases air compression to develop the tremendous amount of thrust used in modern aircraft.

GAS TURBINE ENGINE

The compressor is the greatest single reason the gas turbine engine runs and produces the thrust needed in modern aircraft. We will discuss compressors in greater detail later, but for now let's keep with the basics. A basic axial-flow compressor is a shaft with blades attached in rows, called a rotor. When the rotor shaft turns, the blades pull air into the engine. It is directed to a set of stationary blades, called stator vanes (fig. 1-9). The stator vanes direct air into the next set of compressor vanes. Each set of blades and vanes increases the compression of the air used for combustion. The greater the number of stages, the higher the compression ratio.

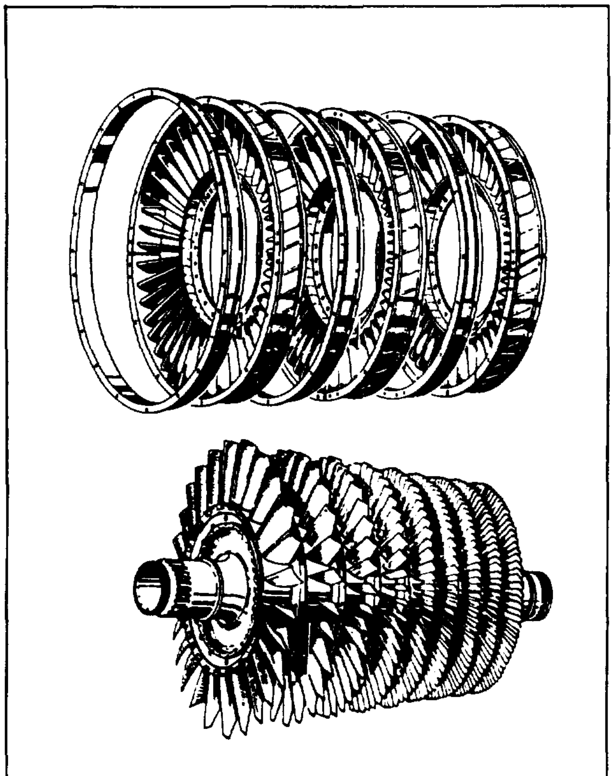


Figure 1-9.-Rotor and stator elements of an axial-flow compressor.

Air from the compressor section goes to the combustion chamber. This is the area where fuel and air are mixed and ignited. The burning of this fuel/air mixture produces hot, expanding gases that rush into the turbine rotors. The turbine rotors attach to the same shaft as the compressor rotors; so the turbine drives the compressor making the engine self-sustaining. Finally, the exhaust gases exit the engine (fig. 1-10) as jet thrust.

Now that you have a basic understanding of jet propulsion, let's look at the physical principles of jet propulsion.

PHYSICAL PRINCIPLES OF JET PROPULSION

Physical principles govern the action of matter, motion, force, and energy. You study the actions in physics. An English scientist, Sir Isaac Newton, stated three laws of motion explaining jet propulsion. Another scientist, Bernoulli, explains the principle behind the convergent/divergent ducts we discussed earlier. These laws and principles have words or terms with specific meanings. Understanding the exact meaning of the words is the key to understanding the principles of physics. So let's define some of the basic terms of physics we need for a good understanding of jet propulsion.

DEFINITION OF TERMS

Force is the action or effect on a body that changes the state of motion of the body. A force may move a body at rest, or it could increase/decrease the speed of a body, or change the direction of motion. The application of a force does not necessarily result in a change in motion. A force is any push or pull acting on a body. Water in a can exerts a force on the sides and bottom of the can. A tugboat exerts a push or pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead.

Matter is anything that occupies space and has weight.

Mass is the quantity of matter in a body measured in relation to its inertia. Mass and weight are similar terms, and they are often confused with each other. Weight is the common measurement to determine the quantity of matter wit h the pull of gravity on it. The following example will help you understand the difference between weight and mass. A person weighing 164

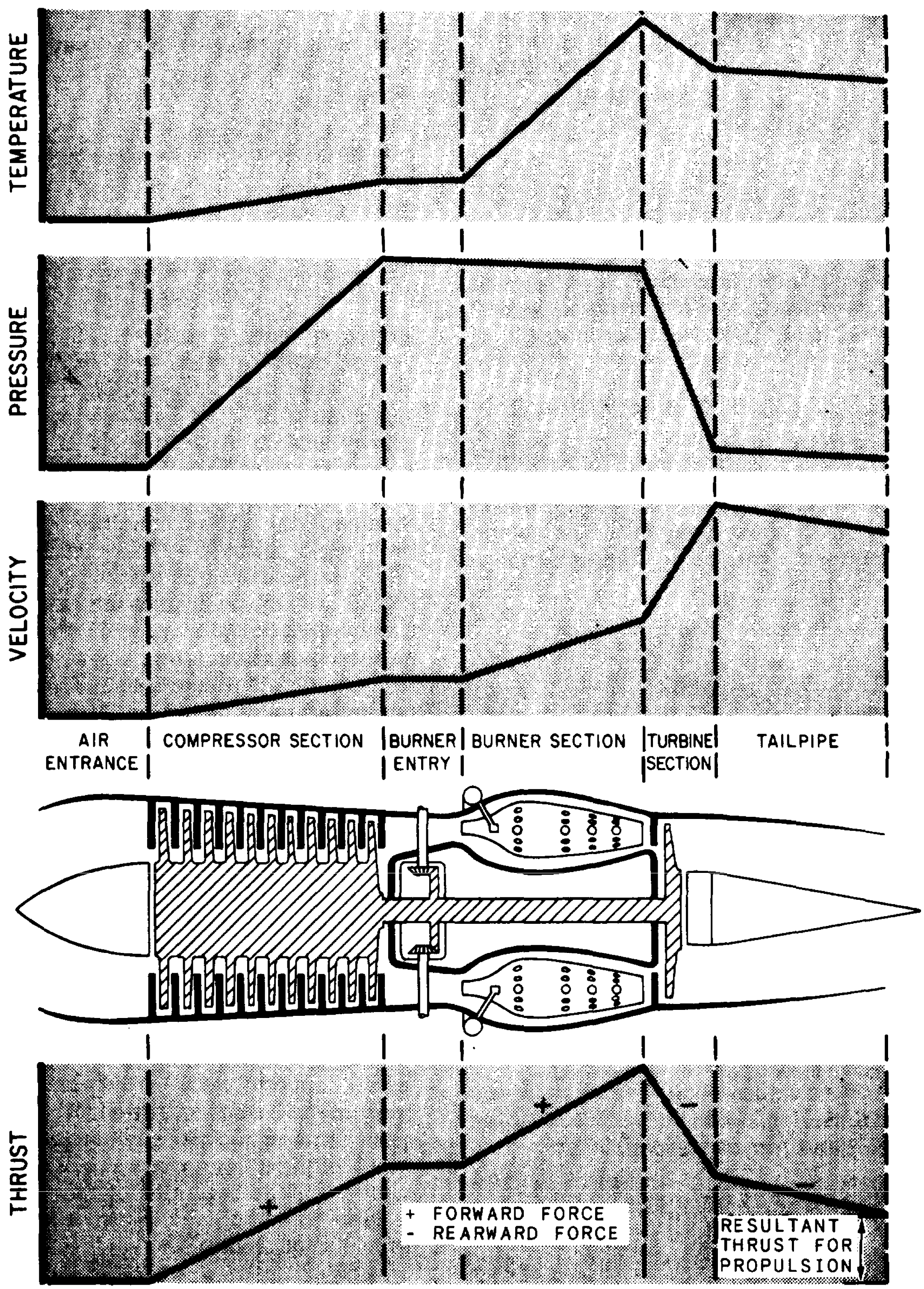


Figure 1-10.-Effects on airflow through an engine.

pounds on earth weighs 32 pounds on the moon because of the difference in the pull of gravity. Yet the mass of the person is exactly the same. A mathematical formula for mass is as follows: Mass is equal to the weight of the object divided by the acceleration due to gravity, or

$$M = \frac{W}{g}.$$

Slug is an English measurement of mass. A slug is mass with force and acceleration (due to gravity) taken into consideration. So, a 1-pound slug is the mass accelerated by 32 feet per second per second (32 ft/sec^2) when acted upon by a force of 1 pound.

Energy is the capacity for doing work.

Work is done when a force moves a mass through a distance (work = force x distance). For example, if you raise a 100-pound weight 10 feet, 1,000 foot pounds of work was done. The amount of work is the same, regardless of how much time (rate) is involved.

Power is the rate of doing work, or

$$\text{power} = \frac{\text{work}}{\text{time}}.$$

In the above example, if the work was done in 10 seconds, power expended was 100 foot pounds per second. If it took 5 minutes (300 seconds), the rate of power is 3.3 foot pounds per second. We often talk of power in terms of horsepower.

Horsepower is the English measurement for mechanical power and is 33,000 foot pounds per minute, or 550 foot pounds per second. (Foot pound is the energy required to lift a 1-pound weight 1 foot in height.)

Speed is the distance a body in motion travels per unit of time. Expressed in terms like *miles per hour* (MPH) and *feet per second.*

$$\text{speed} = \frac{\text{distance}}{\text{time}}.$$

Velocity is speed in a given direction. The symbol *V* represents the term *velocity.*

Acceleration (a) is the rate of velocity change. This definition is not based on distance traveled. Acceleration is the gain or loss of velocity with time. Negative acceleration is commonly called deceleration.

Acceleration = change in velocity divided by unit of time,

or

$$\text{Acceleration} = \frac{\text{final velocity } (V_2) - \text{initial velocity } (V_1)}{\text{time (t)}}$$

or

$$a = \frac{V_2 - V_1}{t}.$$

Acceleration due to gravity is 32.2 feet per second per second (or feet per second squared). This means that a free-falling 1-pound object accelerates at 32.2 feet per second each second that gravity acts on it. We use the lower case *g* to express the acceleration due to gravity.

Standard day is a reference or standard. Standard day shows conditions at sea level: barometric pressure—29.92 inches of mercury (Hg); temperature—59.0°F.

All gas turbine engines are rated with air at the standard temperature of 59°F. Operation of engines at a temperature above or below this temperature will proportionally affect thrust output by as much as 15 or 20 percent. As the temperature of a slug of air increases, the molecules move faster. They run into each other with more impact, and move further apart. This decreases the density of the air. With the decrease in density, the weight of the air is less, and the thrust produced is proportional to the weight of the slug of air.

Pressure effect is an increase in pressure, resulting in more molecules per cubic foot, which, in turn, increases the weight of the slug of air. The weight of the air affects thrust output.

Ram effect is defined simply as more air arriving at the engine intake than the engine can ingest. Ram recovery is the airspeed at which ram pressure rise is equal to friction pressure loss. This speed varies with duct design factors. Mach 0.2, or 150 miles per hour, is a representative reference number for the beginning of ram effect.

Now let's apply the terms we learned to the principles of thrust.

NEWTON'S LAWS OF MOTION

Newton's first law states "A body (mass) at rest tends to remain at rest, and a body in motion tends to move at a constant speed, in a straight line unless acted upon by some external force."

Newton's second law states "An unbalance of force on a body tends to produce an acceleration in the direction of force, and that acceleration, if any, is directly proportional to the force and inversely proportional to the mass of the body." The law simply stated is "force is proportional to the product of mass and acceleration."

or

$$F = M \times A,$$

where

F = force, in pounds;

M = mass, in slugs; and

A = acceleration, in feet per second per second.

His third law states that "for every acting force (action) there is an equal and opposite reacting force (reaction)." We learned this principle earlier with the rocket.

JET ENGINE TYPES AND DESIGNATIONS SYSTEMS

We learned the four basic types or classes of jet engines: rocket, pulsejet, ramjet and jet turbine. As an AD, you will work with the gas turbine engines. Under jet turbine engines are four types: turbojet, turboprop, turbofan, and turboshaft. There are 2 engine designation systems in use today to identify the different types of gas turbine engines.

TURBOJET

Turbojet engines are the basis for all other gas turbine engines. We already know their cycle. Air is drawn into the turbojet engine compressed, mixed with fuel, and burned continuously. The exhaust product of this burning operates the turbine, for the compressor, producing thrust which propels the aircraft. Adding fans, propellers, or free turbines, change the basic turbojet into a turboshaft, turboprop, or turbofan.

Turboshaft

Turboshaft engines use the free turbine principle. Exhaust gases drive the gas generator turbine and a power turbine. The power turbine (fig. 1-11) drives the helos rotor blades, through drive shafts and gearboxes.

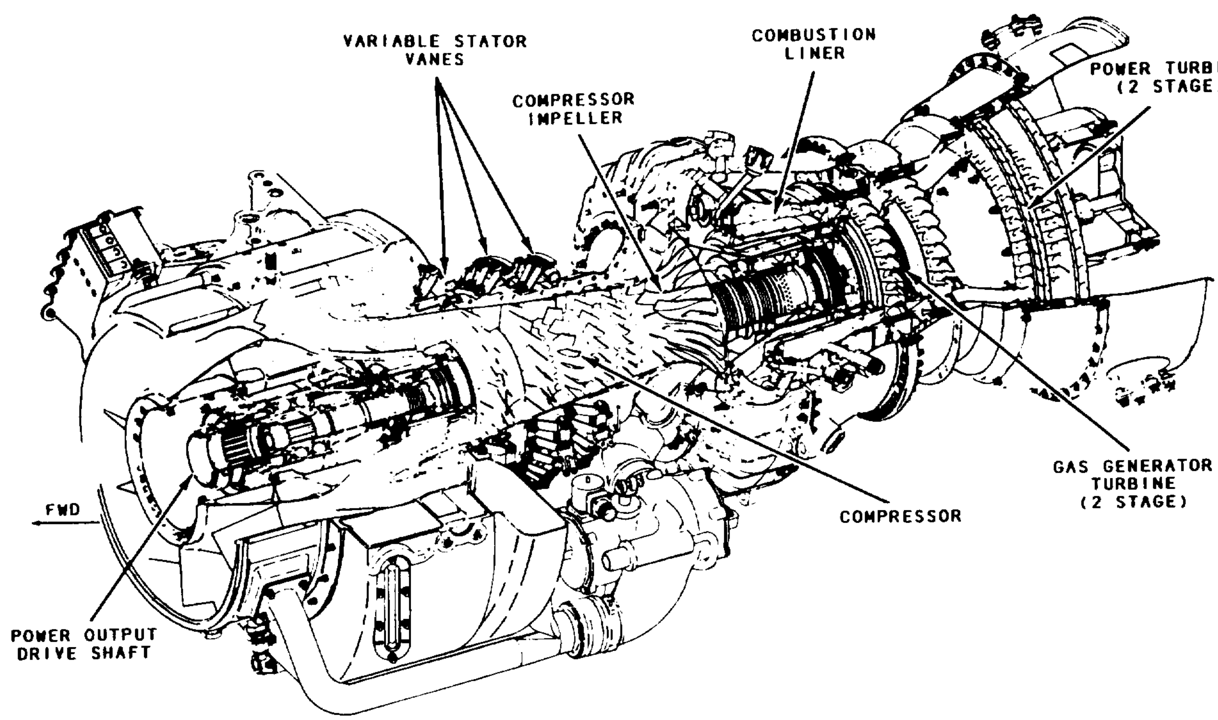


Figure 1-11.-Turboshaft engine.

Turboprops

Turboprops have a compressor, combustion chamber (or chambers), turbine, and jet nozzle, all of which operate in the same manner as their counterparts in the turbojet. The difference is the turbine. It sends increased power, generated by the exhaust gases passing through additional stages of the turbine, forward to a reduction gearbox (fig. 1-12). A propeller mounted on the gearbox provides thrust for the plane.

Turbofan

The turbofan gas turbine engine is the same as a turboprop. Except a duct-enclosed, axial-flow fan (fig. 1-1 3) replaces the gearbox and prop. The fan is either part of the first-stage compressor blades or mounted as a separate set of fan blades. The fan uses 30 to 60 percent of the available propulsive energy. The propulsive efficiency, thrust, and specific fuel consumption for the turbofan engine falls somewhere between those of the turbojet and the turboprop engines.

ENGINE DESIGNATION SYSTEMS

The engine designation systems use standard symbols to represent the type, manufacturer, and model of aircraft engines used in military. Knowing the designation systems gives you basic information about the engine.

Two engine designation systems are in use today. The old system is under *Air Force-Navy Aeronautical (ANA) Bulletin* No. 306. The new system is under MIL-STD-879 and includes all newly developed gas turbine engines of the Air Force, Army, and Navy. ANA Bulletin No. 306 will remain in effect until all engines manufactured before the introduction of MIL-STD-879 have had a change to the configuration, the performance or dropped from service.

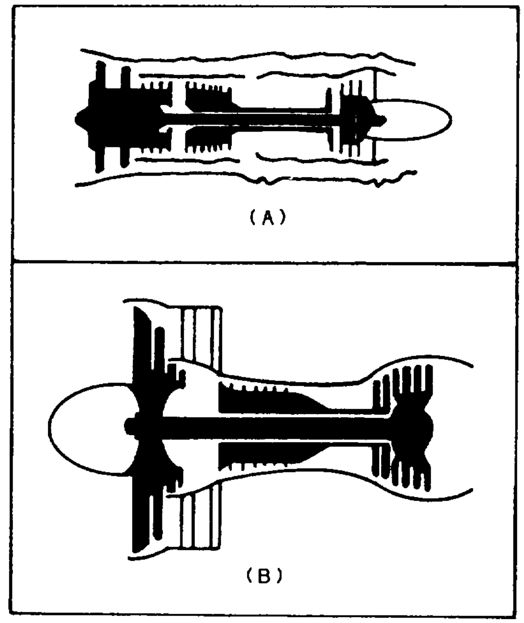


Figure 1-13.-Turbofan engine. (A) With fully ducted fan; (B) with short duct fan.

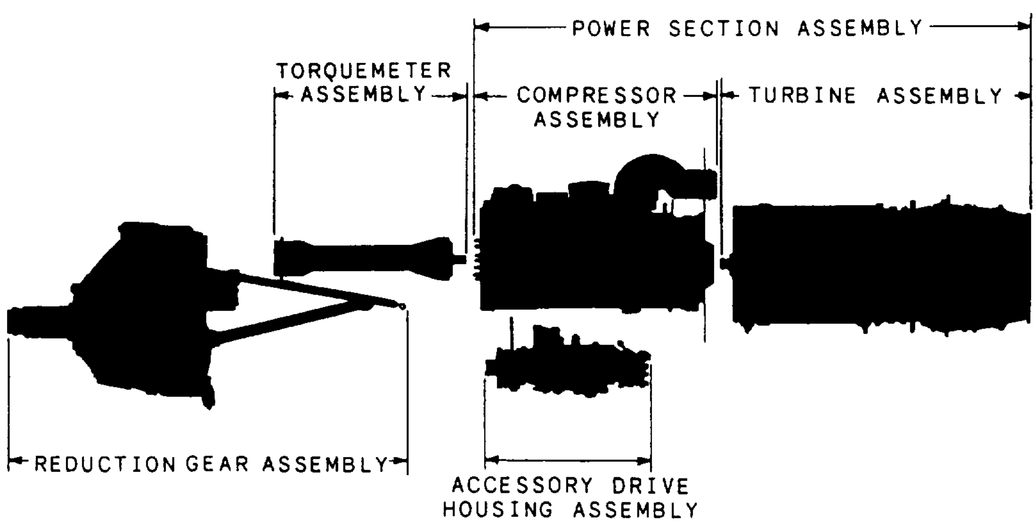


Figure 1-12.-T56 major engine components.

ANA Bulletin Number 306

As stated before, this bulletin is an Air Force-Navy bulletin. It is the older system, and it has no provisions for Army designations.

Type Symbols

The first part of the designation consists of a letter (or letters) with a number showing each basic engine type.

The following are letter-type symbols:

R .... Internal-combustion, air-cooled, radial engine (reciprocating)

J .... Aviation gas-turbine (turbojet)

T .... Aviation gas-turbine (turboprop and turboshaft engines for helicopters)

TF .... Turbofan engine

PJ .... Pulsejet engine

RJ .... Ramjet engine

RM........... Rocket motors

Following the letter symbol(s) is a number. The Navy or-Air Force assigns numbers with the letter. These numbers are arbitrary; they do not represent any characteristics of the units involved. The Navy uses even numbers beginning with 30. The Air Force uses odd numbers beginning with 31.

Although an engine may carry an odd or an even number, it does not restrict the engine to the service sponsoring or approving them. Engines selection and use, by the various services, depends on their satisfactory application for a particular airframe.

SPECIAL DESIGNATIONS

The letter *X* or *Y* before the basic designation shows an experimental or restricted engine.

The letter *X* used as a prefix show experimental and service test of a particular engine. After exhaustive tests confirming the ability of an engine to perform under all operating conditions, you remove the *X* prefix.

The letter *Y* shows restricted service designation. Its application is self-explanatory in the sense that it will not perform satisfactorily under all operating conditions. The designation applies to an engine or device that has a specific function rather than a general one, or that the engine has only completed a 50-hour qualification test. Upon satisfactory completion of the 150-hour qualification testing, the engine is approved as a *J* type.

MANUFACTURER SYMBOLS

The second part of the designation is a dash and the manufacturer's letter(s) symbol.

The following are some prominent engine manufacturers:

GE .... General Electric

A .... Allison

WE .... Westinghouse Electric Co.

P .... Pratt and Whitney

W .... Wright

AC .... Allis Chalmers

BA .... Bell Aircraft Co.

LA .... Lockheed Aircraft Co.

MD .... McDonald Aircraft Co.

V .... Packard

MODEL NUMBERS

The third part of the designation consists of a dash and a numeral showing the model number. Model numbers, like type symbols, use odd numbers for Air Force models and even numbers for Navy models. Air Force model numbers for each type of jet engine begin with 1 and continue with consecutive odd numbers. Navy numbers begin with 2 and continue with consecutive even numbers. Model numbers show the service that approves the model. The Naval Air Systems Command approves all even model numbers. The Air Materiel Command approves all odd model numbers.

A given engine design has only one type and model designation for both services. For example, if the Navy uses an Air Force-approved engine without any changes, the Navy uses the numbers assigned. If the Air Force uses a Navy-approved engine that requires minor changes, the Air Force uses the Navy-type designation and assigns its own model designation. It begins with the number 1 and progresses with consecutive odd numbers to the modified engine. This model number is actually a modification number that tells which service made the last production change in it for a particular aircraft.

For example, J79-GE-10 breaks down as follows:

J .... Turbojet

79 .... Air Force developed

GE .... Manufactured by General Electric Company

10 .... Navy model

and

T56-A-16

T .... Turbine (turboprop in this case)

56 .... Navy sponsored

A .... Manufacturer (Allison)

16 .... Eighth model (Navy)

MIL-STD-879

The new system applies to all the armed services—Army, Navy, and Air Force. It consists of three parts; a type indicator, manufacturer's symbol, and a model indicator. All newly developed gas turbine engines use this designation. Existing engines change to a new three-digit model number with major changes in configuration or design. However, the engine usually keeps the old two-digit type indicator.

Special designations *(X* or *Y)* used in the new system are the same as the old system.

Type Indicator

The type indicator, the first part of the designation, consists of the appropriate type letter symbol together with the type numeral.

Type letter symbols:

J .... Turbojet

T .... Turboshaft, turboprop

F .... Turbofan

Each service consecutively assigns type numbers with the type letter symbol. Beginning type numbers for the three armed services are:

100. .... Air Force

400 .... Navy

700 .... Army

Manufacturer's Symbols

The second part of the designation consists of a dash and a two-letter symbol showing the manufacturer, as follows:

AiResearch Division, Garrett Corp. ...... GA

Allison Division,
General Motors Corp ....AD

Continental Aviation
and Engineering Corp ....CA

General Electric Company .... GE

Lycoming Division, Avco Corp. .... LD

Pratt and Whitney Aircraft Division,
United Aircraft Corp ....PW

Rolls Royce, Ltd ....RR

United Aircraft of Canada, Ltd. .... CP

Curtiss-Wright Corp ....WA

Special manufacturer symbols show when two manufacturers are jointly producing an engine. In that case, the manufacturer symbol consists of one letter from the symbol for each manufacturer.

NOTE: Manufacturer letter symbols are not the same as manufacturer code symbols. The code symbols are with the Federal Supply Code for manufacturers.

Model Indicator

The model indicator consists of a dash and a model number, or a dash and a model number with a suffix letter you assign, and a model number for each configuration of a given engine. Each service has a block of numbers they use consecutively, just like the type indicator number. The following is the beginning number for each service.

100 .... Air Force

400 .... Navy

700 .... Army

NOTE: Should any service use another's designated engine, the designation remains the same unless there is a model change. In this case, only the model indicator is changed, showing the engine has been modified.

The following are examples of the various designations:

MIL-STD-879

F401-PW-400

F = Turbofan

401 = Second Navy turbofan in new designation system

PW = Pratt and Whitney Aircraft Division, United Aircraft Corporation

400 = First Navy model of this particular engine

Mixed designation

T56-A-416

416 = Shows the incorporation of configuration and performance changes to the T56-A-16

Table 1-1 lists by engine type some of the more common designations and their associated

Table 1-1.-Navy Aircraft and Associated Engines

ENGINE TYPE	DESIGNATION	AIRCRAFT
TURBOJET	J85-GE-13	F-5, T-38, T-2C
	J79-GE-10	F-4
	J79-JIE[1]	KFIR[2] (F-21A)
	J60-P-6	T-2B
	J57-P-10	A-3
	J52-P-8	A-6E, EA-6B, KA-6D, A-4, TA-4
TURBOFAN	F404-GE-400	F/A- 18
	F402-RR-404	TAV-8A, AV-8C
	F110-GE-400	F- 14D
	TF41-A-2	A-7E, TA7C
	TF34-400A	S-3A, US-3A
	TF30-P-414	F14-A
TURBOPROP	529-8X[1]	TC-4C
	T-76-GE-10/12	OV-10
	T-56-A- 14	P-3, C-130, C-2, E-2
	PT-6A	UC12B[2], T-34[2]
TURBOSHAFT	T700-GE-401	H-60
	T400-CP-400	H-l J
	T64-GE-413	H-53
	T58-GE-10	H-3 , H-2, H-46
	T53-L-13	H-1

[1] ENGINES UNDER CONTRACT MAINTENANCE
[2] AIRCRAFT UNDER CONTRACT MAINTENANCE

Navy/Marine aircraft. You will notice that included with the turboprop engines are two civilian engines, which have the manufacturer's designations.

JET TURBINE ENGINE MAJOR ASSEMBLIES

There are many different models of jet engines in the Navy today. Developments over the years has produced a more efficient engine, both from a performance and maintenance point of view. These modern engines are more complex, but they still operate according to the same basic principles. This section discusses the major parts found in various gas turbine engines; their name (nomenclature), construction, purpose and operating characteristics. Major components of all gas turbine engines are basically the same. The nomenclature of the various engines in current use, however, may vary slightly because of differences in manufacturers' terminology. Through experience and reading the many and varied publications, the mechanic recognizes the engine components, regardless of the terminology used.

A turbojet engine consists of the following sections and systems:

1. Air entrance section
2. Compressor section
3. Combustion section
4. Turbine section
5. Exhaust section
6. Accessory section
7. Systems necessary for starting, lubrication, fuel supply, and auxiliary purposes, such as anti-icing, cooling, and afterburning

AIR ENTRANCE SECTION

The air entrance directs incoming air to the compressor entrance with a minimum of energy loss. Additionally, it must deliver this air under all flight conditions with as little turbulence and pressure variation as possible.

Normally, the engine inlet is part of the airframe. Because of its important part in engine performance we include it here. Proper duct design contributes to aircraft performance by increasing ram recovery and limiting pressure drops. Divergent inlet designs change ram air velocity into high static pressure at the compressor inlet. Friction due to air passing through the duct surfaces and bends in the duct cause pressure drops and differences. Performance achieved through proper duct design is only half the story. Careful construction and maintenance is essential to maintain designed performance. Small amounts of airflow distortion result in loss of engine efficiency and unexplainable compressor surges. This is caused by poor sheet metal work, protruding rivet heads, or poor welds.

Engine inlet ducts take a variety of shapes, depending on the position of the engine and purpose of the aircraft. Two methods of classifying inlet ducts are as follows:

1. Single entrance and divided entrance

2. Subsonic and supersonic ducts

Single Entrance/Divided Entrance

The simplest type of air ducts are on engines mounted in pods under the wing. The single entrance (fig. 1-14, view A) gets maximum ram pressure through the straight flow. It's used where an unobstructed entrance lends itself readily to a single, short, straight duct.

Some aircraft, because of fuselage design or internal parts, have to use a dual or divided entrance, as shown in figure 1-14, view B. These dual entrances are in the wing root, or in scoops on the side of the fuselage. Either type presents more problems to the aircraft and engine designers than the single entrance. Problems are caused by boundary layer airflow and the difficulty in obtaining enough entrance area without creating too much drag.

Subsonic/Supersonic Ducts

Modern Navy aircraft capable of supersonic flight pose another problem to aircraft designers because the airframe can withstand supersonic velocity air, but the engine cannot. There are two methods commonly used to diffuse the intake air and slow its flow to subsonic speeds during supersonic flight. One is to create a shock wave in the intake airstream, which will disrupt the flow and cause a decrease in velocity. The other method

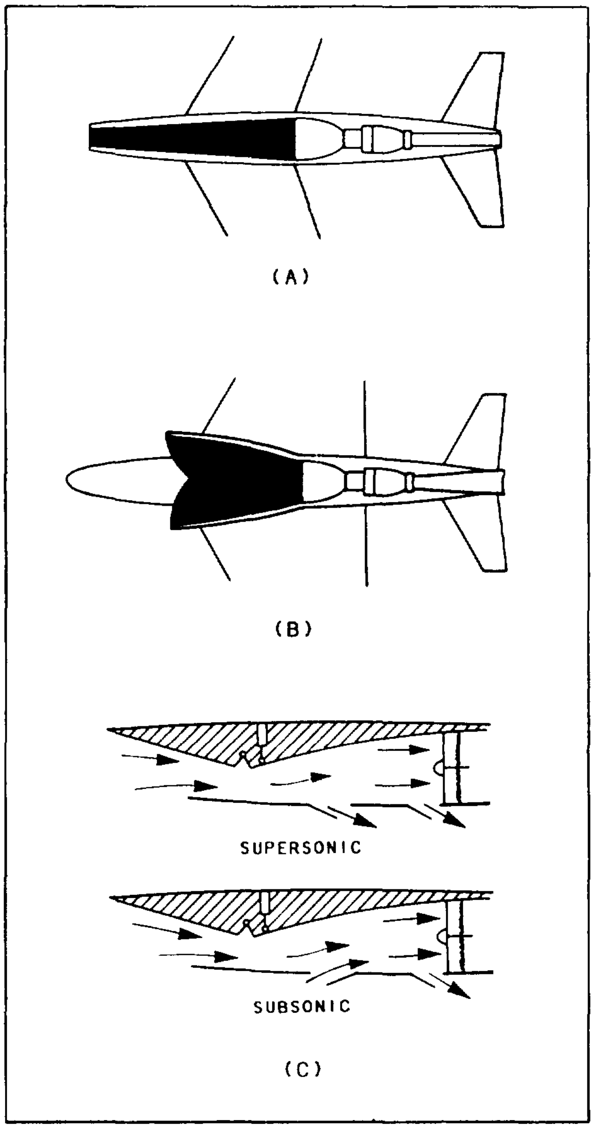


Figure 1-14.-Air entrance designs. (A) Single entrance; (B) dual entrance; (C) variable entrance.

is to vary the area, or geometry, of the intake duct. Navy aircraft use this method, incorporating movable ramps as shown in figure 1-14, view C, to change the area and shape of the intake duct.

COMPRESSOR SECTION

The primary function of the compressor is to supply air in enough quantity to satisfy the requirements of the combustion burners. Specifically, the compressor increases the air mass received from the air inlet duct and directs it to the burners in the quantity and at the pressures required. A secondary function is to supply compressor bleed air for various purposes in the engine and aircraft. The compressor provides space for mounting accessories and engine parts.

There are two basic types of compressors. The compressor type is also the engine type, so a centrifugal-flow compressor is in a centrifugal engine. Centrifugal-flow compressors have a compression ratio of 5:1. Present-day axial-flow compressors have compression ratios approaching 15:1 and airflows up to 350 lb. The addition of a fan raises these values to 25:1 and 1,000 lb/sec.

Centrifugal-Flow Compressors

The single entry centrifugal-flow compressor (fig. 1-15) consists of an impeller (rotor element), a diffuser (stator element), and a manifold. The impeller picks up and accelerates air outward to the diffuser. The diffuser directs air into the manifold. The manifold distributes air into the combustion section. Double entry centrifugal-flow

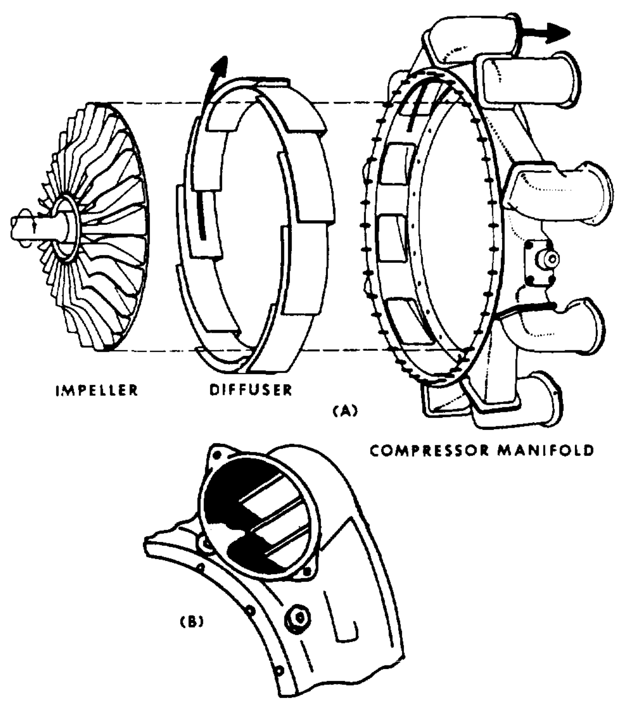


Figure 1-15.-(A) Elements of the centrifugal compressor; (B) air outlet elbow with turning vanes for reducing air pressure losses.

compressors (fig. 1-16) handles the same airflow with a smaller diameter. Small multi-stage centrifugal-flow engines used in aircraft (fig. 1-17) or as APUs take advantage of these features.

Axial-Flow Compressors

The term *axial flow* applies to the axial (straight-line) flow of air through the compressor section of the engine. The axial-flow compressor has two main elements—a rotor and a stator. Each consecutive pair of rotor and stator blades makes a pressure stage. The rotor is a shaft with blades attached to it. These blades impel air rearward in the same manner as a propeller, by reason of their angle and airfoil contour. The rotor, turning at high speed, takes in air at the compressor inlet and impels it through a series of stages. The action of the rotor increases the compression of the air. At each stage it accelerates rearward through several stages. The stator blades act as diffusers at each stage, partially converting high velocity to pressure. Maintaining high efficiency requires small changes in the rate of diffusion at each stage. The number of stages depends on the amount of air and total pressure rise required. The greater the number of stages, the higher the compression ratio. Most present-day engines use from 10 to 16 stages.

An axial-flow compressor follows the same rules and limitations of an aircraft wing. The concept is more complicated than a single airfoil, because the blades are close together. Each trailing edge blade affects the next leading edge. This cascade effect is of prime importance in determining blade design and placement.

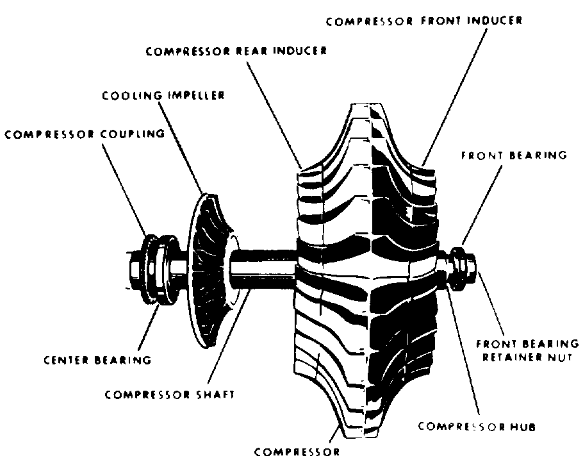


Figure 1-16.-Impeller with inducer vanes as separate pieces.

The axial-flow compressor has its disadvantages, the most important of which is the stall problem. If, for some reason, the angle of attack—the angle at which the airflow strikes the rotor blades—becomes too low, the pressure zones, shown in figure 1-18, will be of low value, and the airflow and compression will be low. If the angle of attack is high, the pressure zones will be high, and airflow and compression ratio will be high.

If the angle of attack is too high, the compressor will stall. The airflow over the upper foil surface will become turbulent and destroy the pressure zones. This will decrease the compression airflow. The angle of attack will vary with engine rpm, compressor-inlet temperature, and compressor discharge or burner pressure. Any action that decreases airflow relative to engine speed will increase the angle of attack and increase the tendency to stall. The decrease in airflow may result from a too-high compressor-discharge pressure.

During ground operation of the engine, the prime action that causes a stall is choking. If there is a decrease in the engine speed, the compression ratio will decrease with the lower rotor velocities. With a decrease in compression, the volume of air in the rear of the compressor will be greater. This excess volume of air causes a choking action in the rear of the compressor with a decrease in airflow. This, in turn, decreases the air velocity in the front of the compressor and increases the tendency to stall. If no corrective action is taken, the front of the compressor will stall at low engine speeds.

Another reason for engine stall is high compressor inlet air temperatures. High-speed aircraft may experience an inlet air temperature of 250°F because of ram effect. These high temperatures cause low compression ratios (due to air density changes) and will also cause choking in the rear of the compressor. This choking-stall condition is the same as the stall condition caused by low compression ratios due to low engine speeds.

Each stage of a compressor should develop the same pressure ratio as all other stages. When the engine slows down or the compressor inlet air temperature climbs, the front stages supply too much air for the rear stages to handle, and the rear stages will choke.

There are five basic ways manufacturers can correct this front-end, low-speed, high-temperature stall:

1. Lowering the angle of attack on the front stages so the high angles at low engine speed are not stall angles
2. Installing a bleed valve in the middle or rear of the compressor to bleed air and increase airflow in the front of the compressor at low engine speeds
3. Splitting the compressor into two rotors and designing the front rotor rpm to decrease more than the rear rotor at low speeds, so low front-rotor speed will equal the low choked airflow
4. Installing variable inlet-guide vanes and variable stators in the front of the first series of compressor stages so the angle of attack is changed at low engine speed
5. Using a variable-area exhaust nozzle to unload the compressor during acceleration

NOTE: A combination of any of the above may be used.

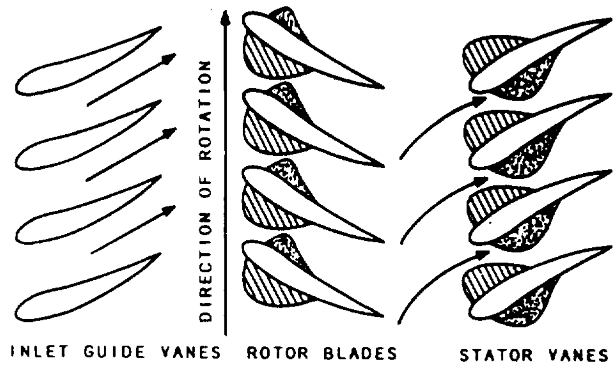
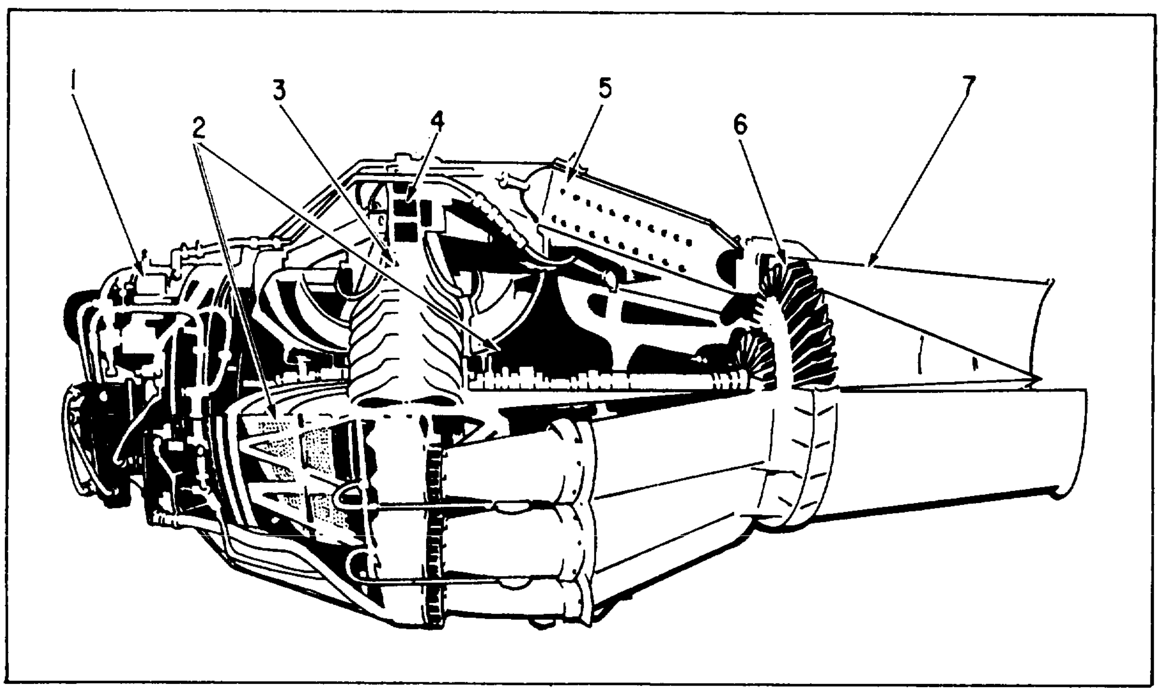


Figure 1-18.-The cascade effect.

The stator has rows of blades or vanes dovetailed into split rings and attached inside an enclosing case. The stator vanes project radially toward the rotor axis and fit closely on either side of each stage of the rotor.

The compressor case, into which the stator vanes fit, is horizontally divided into halves.



1. Accessory cage
2. Air inlet
3. Compressor
4. Diffuser
5.Combustion chamber
6.Turbine
7.Exhaust duct

Figure 1-17.-Centrifugal-flow engine (J33).

Either the upper or lower half is removed for inspection or maintenance of the rotor and stator blades.

The function of the vanes is twofold. They receive air from the air inlet duct or from each preceding stage of the compressor. It is delivered to the next stage or to the burners at a workable velocity and pressure. They also control the direction of air to each rotor stage to get the maximum compressor blade efficiency.

The rotor blades are in front of the inlet guide vane assembly. The guide vanes impart a swirling motion to the air entering the compressor in the direction of engine rotation. This motion improves the aerodynamic characteristics of the compressor by reducing the drag on the first-stage rotor blades. The inlet guide vanes are curved and airfoil shaped. The vanes are made of steel alloy, many with a protective coating to prevent erosion. They are welded to steel inner and outer shrouds. The variable inlet-guide vanes are fitted and pinned to spherical bearings that are retained in the compressor front frame.

At the discharge end of the compressor, the stator vanes straighten the airflow to cut turbulence. These are straightening vanes or the exit guide vanes.

The casings of axial-flow compressors support the stator vanes and provide the outer wall of the axial path the air follows. They also tap off compressor air for various purposes, such as cockpit pressurization and heating, or fuel tank pressurization. There are outlet ports for bleeding off compressor air at different stages, depending on the pressure or temperature desired. (The temperature rises proportionately with pressure increase.)

The stator vanes are made of steel with corrosion- and erosion-resistant qualities. Frequently they are enclosed by a band of suitable material to simplify the fastening problem. The vanes are welded into the shrouds; then, the outer shroud is secured to the compressor housing inner wall by radial retaining screws.

The rotor blades are made of stainless or semistainless steel. Methods of attaching the blades in the rotor disc rims vary in different designs. They commonly fit into discs by either bulb (fig. 1-19) or fir-tree (fig. 1-20) type roots. The blades then lock by grub screws, peening, locking wires, pins, or keys.

Compressor blade tips reduce in thickness by cutouts, and are referred to as blade "profiles." These profiles allow rubbing, when rotor blades come into contact with the compressor housing or shroud without serious damage. This condition may occur if rotor blades become excessively loose or by reduction of rotor support by a malfunctioning bearing. Even though blade profiles reduce such chances, occasionally a blade may break under duress of rubbing and cause considerable damage to compressor blades and stator vane assemblies.

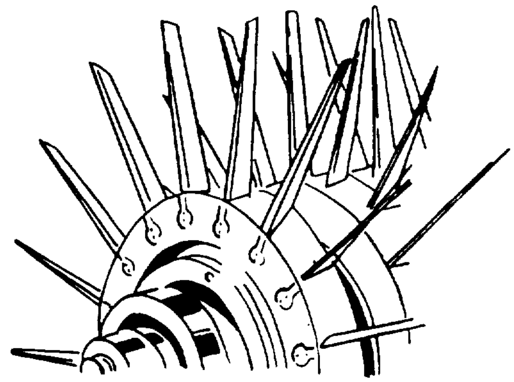


Figure 1-19.-Bulb root-type rotor blades.

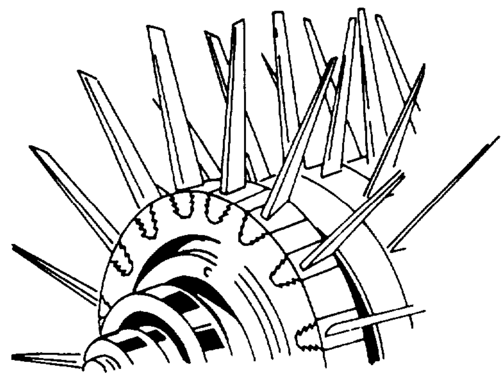


Figure 1-20.-Fir-tree root-type rotor blades.

The blades vary in length from entry to discharge. The annular working space (drum to casing) reduces progressively toward the rear by the increase in the rotor drum diameter. The rotor may feature either drum-type or disc-type construction.

The drum-type rotor is machined from a single aluminum alloy forging. Dovetail grooves are machined around the circumference of the drum for blade retention. Provisions for bearing supports and splined drive shafts are on the front and rear faces of the drum.

The disc-type rotor consists of separately machined discs and spacers flanged to fit one against the other in sequence. The entire assembly is held together by through-bolts, tie-bolts, or bolted individually to one another. Blades may be attached to the disc rim by the dovetail or bulb design locking feature. Similar provisions to those on the drum-type assembly are made for bearing supports and splined drive shafts.

Another method of rotor construction is to machine the discs individually, and shrink fit the discs over a steel drive shaft (heating the disc and freezing the shaft to assemble the rotor). However, this type of compressor construction is only satisfactory for compressors where rotor and centrifugal stresses are relatively 10 w.

The drum and disc-type rotor assemblies are shown in figures 1-21 and 1-22. Many engine designs now use combination disc and drum compressor rotor assemblies due to their split-spool design concept. The F404-GE-400 and the TF34-GE-400 are examples of the combination compressor rotor assembly.

The coverage of axial-flow compressors up to this point has dealt solely with the conventional single-rotor type. Actually, there are two configurations of the axial compressor now in use. The single rotor and the dual rotor, sometimes referred to as solid spool (fig. 1-23) and split spool (fig. 1-24).

One version of the solid-spool compressor uses variable inlet guide vanes. This is the arrangement found on the J79-GE-10 engine. The engine has a 17-stage compressor. The angles of the inlet guide vanes and the first six stages of the stator vanes are variable. During operation, air enters the front of the engine. Air is directed into the compressor at the proper angle by the variable inlet guide and variable stator vanes. The air is compressed and forced into the combustion section. A fuel nozzle extending into each combustion liner atomizes the fuel for combustion. These variables are controlled in direct relation with the amount of power the engine requires to produce the pilot's power lever position.

One version of the split-spool compressor is in Pratt and Whitney's J52 engine. It uses two

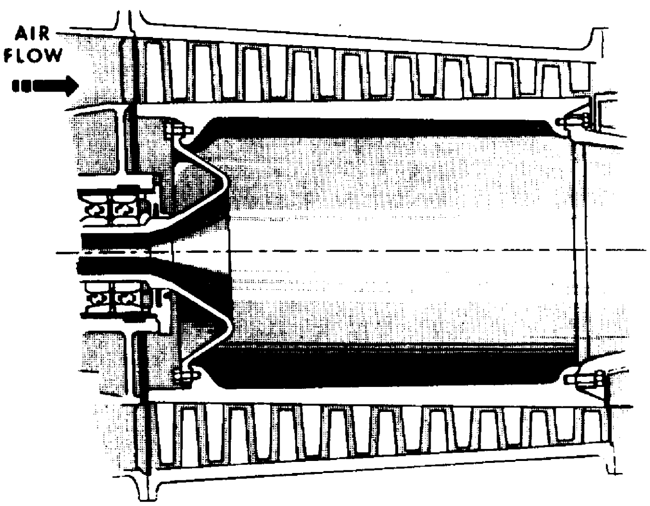


Figure 1-21.-Drum-type compressor rotor.

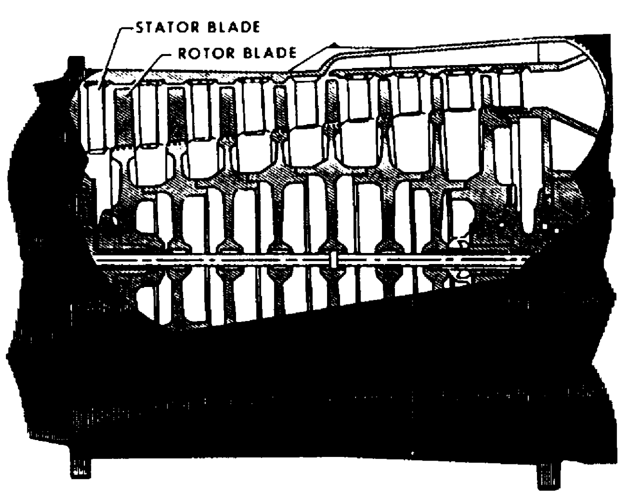


Figure 1-22.-Disc-type compressor rotor.

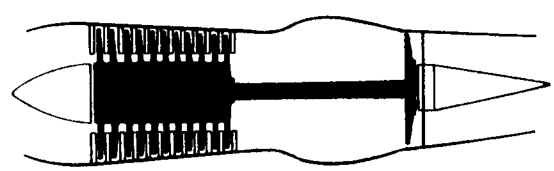


Figure 1-23.-Solid-spool compressor—single rotor turbine.

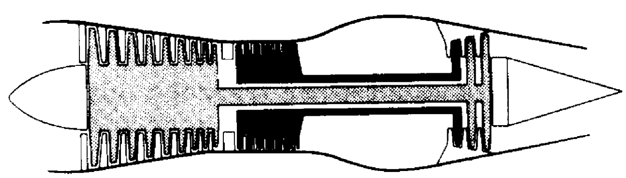


Figure 1-24.-Split-spool compressor—dual rotor turbine.

compressors with their respective turbines and interconnecting shafts that form two independent rotor systems.

The axial-flow type of engine has definite advantages. The advent of the split-spool axial compressor made these advantages even more positive by offering greater starting flexibility and improved high-altitude performance.

The advantages of the axial-flow compressor are as follows:

1. High peak efficiencies
2. Low frontal area for given airflow
3. Straight-through flow, allowing high ram efficiency
4. Increased pressure rise by increasing the number of stages, with negligible losses

The disadvantages of the axial-flow compressor are as follows:

1. Good efficiencies are possible over narrow rotational-speed range only
2. Difficulty of manufacture and high cost
3. High starting-power requirements

Relative to compressors, the fan of a turbofan engine should be mentioned now. The fan accelerates a large mass of air rearward. It requires relatively low drive power, and has a pressure ratio of 2 to 1 or less. It can be thought of as a precompressor, as air enters the compressor inlet at a pressure about 1.5-2.0 to 1 atmosphere.

COMBUSTION SECTION

The combustion section provides the means for and houses the combustion process. Its function is to raise the temperature of the air passing through the engine. This process releases energy contained in the air and fuel. The major part of this energy drives the compressor. The remaining energy creates the reaction (or propulsion) and passes out the rear of the engine in the form of a high-velocity jet.

The primary function of burning the fuel-air mixture includes:

1. Providing the means for proper mixing of the fuel and air to assure good combustion
2. Burning this mixture efficiently
3. Cooling the hot combustion products to a temperature that the turbine blades can withstand under operating conditions
4. Directing the hot gases to the turbine section

The location of the combustion section is directly between the compressor and the turbine sections. The combustion chambers are arranged coaxially with the compressor and turbines. The chambers must be in a through-flow position to function efficiently.

About one-fourth of the air entering the combustion chamber area mixes with the fuel for combustion. This is primary air. The remaining air (secondary air) serves as flame control. Keeping the temperature of the heated gases down to a level at which the liners, turbine nozzles, or blades will not burn. These basic requirements apply to all combustion sections.

Another general requirement of combustion chambers is air pollution emission reduction. Pollution emissions are particles of matter, such as smoke, carbon monoxide, partially burned hydrocarbons, and nitric oxides. In general, exhaust smoke becomes a problem when combustors operate at pressure greater than 10 atmospheres and when the fuel-air ratio in the primary zone of the combustor is rich. For example, in the idle range of operation, both smoke particles and partially burned hydrocarbons emit. During the combustion process, emission levels of nitric oxide increase with temperature increases to about 2,600°F. At this temperature, these emission levels begin to taper off. There is research being conducted to correct problems, but many new factors may influence the solution of the pollution problem. Present approaches to reducing exhaust emissions include:

1. Cut visible smoke by improving primary zone fuel-air mixing, but not sacrifice altitude relight capability.
2. Reduce carbon monoxide and unburned hydrocarbon emissions. Increase fuel atomization and optimizing the fuel-air ratio in the primary combustion zone.
3. Reduce nitric oxide emissions by minimizing the amount of time the fuel-air mixture spends in the combustor (by using short cans) or lowering the temperature in the primary zone of combustion.

Remember that these approaches are not solutions. Only ideas to give you some insight to the problems and possible solutions.

All combustion chambers contain the same basic elements: a casing, a perforated inner liner, a fuel injection system, some means for initial ignition, and a fuel drainage system to drain off unburned fuel after engine shutdown.

The three basic types of combustion chambers are as follows:

1. The multiple chamber, or can
2. The annular, or basket
3. The can-annular

Can Type

The can-type combustion chamber is typical of the type used on axial-flow engines. Can-type combustion chambers are arranged radially around the axis of the engine. The amount of chambers will vary in number. In the past (or development years) as few as 2 and as many as 16 chambers have been used. The present trend shows the use of about 8 or 10 combustion chambers. Figure 1-25 shows the liner of a can-type combustion chamber. These chambers are numbered in a clockwise direction. As you face the rear of the engine and look forward, the number 1 chamber is at the top.

Some provision is made in the combustion chamber case or in the compressor air outlet elbow for the installation of a fuel nozzle. The fuel nozzle delivers the fuel into the liner in a finely atomized spray. The finer the spray, the more rapid and efficient the burning process.

The two types of fuel nozzles being used in the various types of combustion chambers are the simplex nozzle and the duplex nozzle. The fuel nozzles are constructed so they can be installed in various ways. The two methods used most frequently are external mounting and internal mounting. In external mounting, a mounting pad is provided for attachment of the nozzle to the case or the inlet air elbow, with the nozzle tip projecting into the chamber liner, usually near the dome. When internal mounting at the liner dome, the chamber cover is removed for replacement or maintenance of the nozzle.

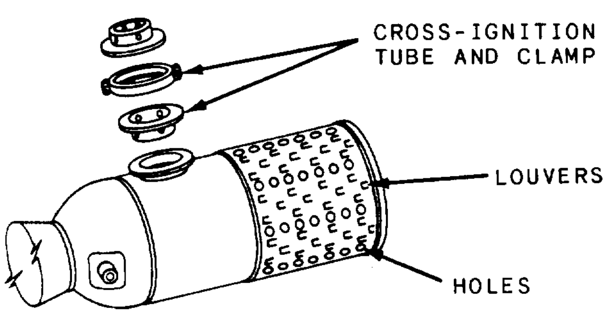


Figure 1-25.-Cars-type combustion liner.

The simplex nozzle, with its single orifice, does not provide a satisfactory spray over a wide range of operating conditions. Therefore, its use on current models of jet engines is limited.

The duplex nozzle has good spray characteristics. Its use does require a pressurizing valve (flow-divider) to divide flow to the primary and main fuel manifolds. During starting and idling, the small primary orifice of the duplex nozzle provides a high degree of atomization under low pressures. As sufficient pressure builds, the pressurizing valve opens the main line; the larger orifice supplies increased fuel in a atomized form. Newer engines use single-or multiple-unit duplex nozzles for satisfactory sprays under various operating conditions.

The cross-ignition tubes are a necessary part of the can-type combustion chambers. Since each of the cans is in reality a separate burner, each operates independently of the other. Combustion is spread during the initial starting operation by simply interconnecting all the chambers. As the flame is started by the spark igniter plugs in the two lower chambers, it passes through the tubes and ignites the combustible mixture in the adjacent chambers. This process, similar to the action of a pilot light on a gas stove, continues until all the chambers are ignited. Actually only a few seconds are needed for this process. Then the two spark igniters are no longer needed, and they cut off automatically.

To be sure the can-annular type combustion chambers have positive ignition during the starting cycle, two spark igniters are used and located in the two lower chambers.

Another very important requirement in the construction of combustion chambers is providing the means for draining unburned fuel. The drainage requirement involves many factors, such as the prevention of residual fuel deposits (gum) after evaporation in the fuel manifold, nozzles, and combustion chambers. Also, if fuel is allowed to accumulate after shutdown, an afterfire could occur. Another possibility is at the next starting attempt, the excess fuel in the combustion chamber could ignite. Tailpipe temperature could go beyond safe operating limits.

The liners of the can-type combustors (fig. 1-25) have the usual perforations of various sizes and shapes. Each hole has a specific purpose and effect on the flame propagation within the liner. The air entering the combustion chamber is divided by the proper holes. Louvers and slots divide the main streams—primary and secondary air. The primary or combustion air is directed inside the liner at the front end, where it mixes with the fuel and is burned. Secondary or cooling air passes between the outer casing and the liner and joins the combustion gases through larger holes toward the rear of the liner. Combustion gases are cooled from about 3,500°F to about 1,500°F forward of the turbine. Holes are provided to aid in atomization of the fuel. These holes are located around the fuel nozzle in the dome or inlet end of the liner. Louvers are also provided along the axial length of the liners to direct a cooling layer of air along the inside wall of the liner. This layer of air controls the flame pattern by keeping it centered in the liner. This air layer prevents the 3,000°F temperatures of the combusting gases from burning the liner walls. Figure 1-26 shows the flow of air through the louvers in the double-annular type of combustion chambers.

Annular or Basket Type

The annular combustion chamber, the type usually found in axial-flow engines, consists basically of a housing and a liner, similar to the can type. The difference lies in the construction

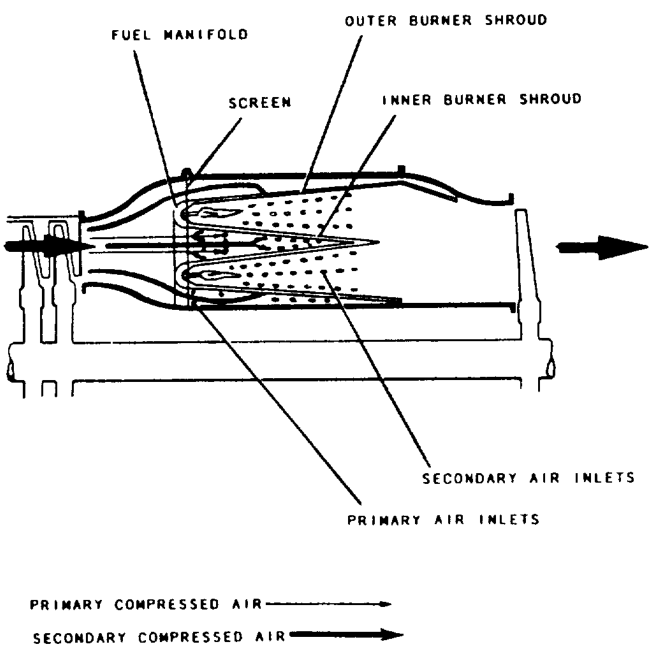


Figure 1-26.-Components and airflow of a double-annular combustion chamber.

details of the liner. The liner consists of an undivided circular shroud extending all the way around the outside of the turbine shaft housing (fig. 1-27). The chamber is constructed of one or more baskets. If two or more chambers are used, they are placed one outside of the other in the same radial plane. The double-annular chamber is shown in figure 1-27.

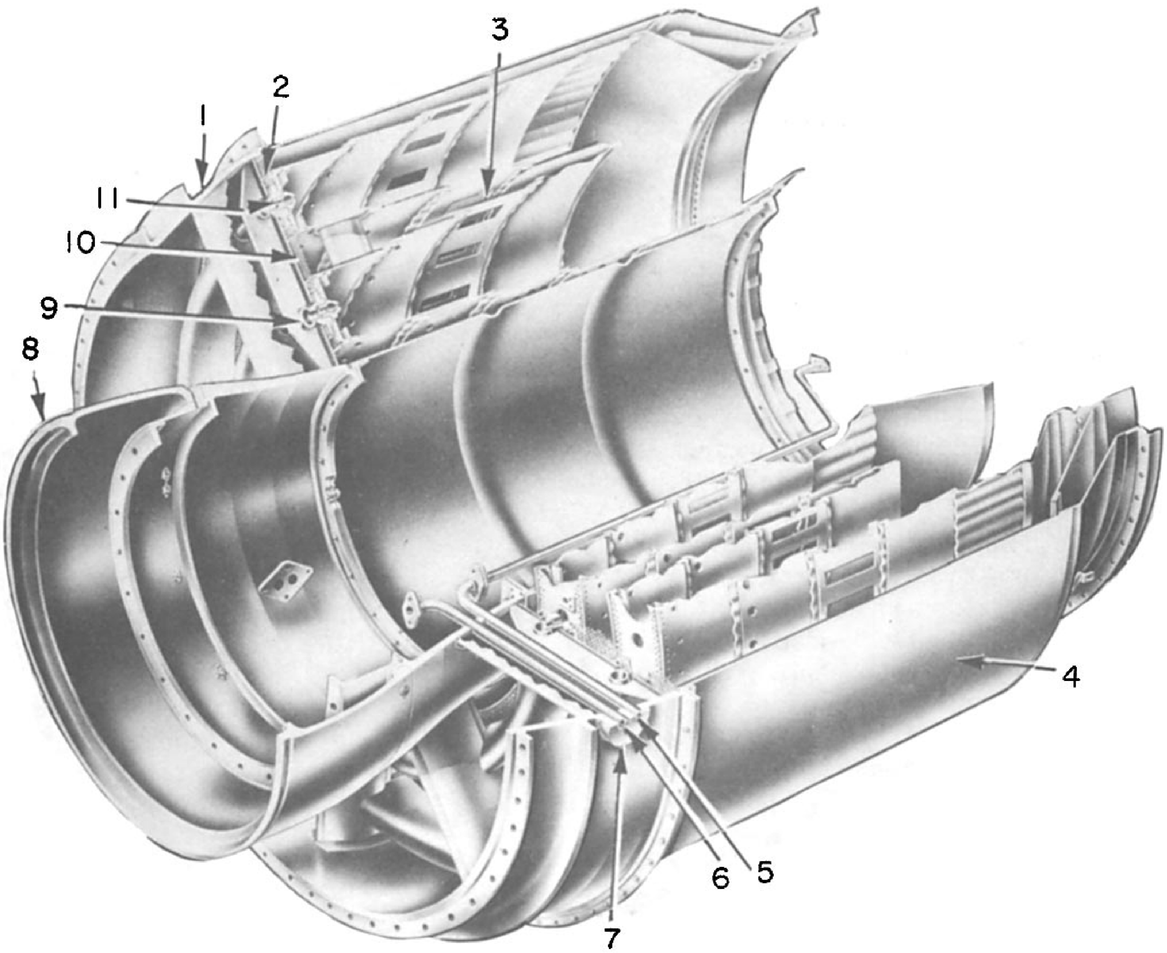
The combustion chamber housing is made in three sections. These sections are the inlet, center, and rear sections.

The inlet section receives the air from the axial-flow compressor. This section is a diffuser. It slows the velocity of the air by providing a larger area just before the liner area, thus raising air pressure. Also present is a coarse wire screen, whose function is to increase turbulence to aid in fuel atomization.

The center section of the chamber housing surrounds the liner, providing an outer wall for the axial path of the air. The center section provides the mounting pads for the installation of fuel drain valves. The drain valves drain residual or accumulated fuel out of the combustion chamber after engine shutdown. This action prevents afterfires or excessive starting temperatures during the next start. Located on the bottom of the housing are the spring-loaded combustion chamber drain valves. These valves drain automatically whenever internal chamber pressures approach atmospheric pressure. This fuel is drained to an overboard drain compartment in the airframe.

The rear section converges to form a narrow annulus. This type of construction speeds up airflow before it enters the turbine section.

Fuel is introduced through a series of nozzles at the upstream end of the liner. The fuel nozzles are screwed into fuel manifolds, located within two concentric fairings. If the chamber liner is of double-annular construction, there are two fuel manifolds. Only one manifold would be required if it were of single-annular construction. The two concentric fairings that support the fuel manifolds also perform the function of dividing the entering airflow into three concentric annular streams. The outer stream is delivered to the space between the combustion chamber liner and the chamber housing. The middle stream is delivered to the space between the inner and outer sections of the liner. The inner stream is delivered to the space between the liner and the rotor shaft housing. The two concentric fairings are supported by radial struts in the diffuser section.



1. Outlet ring diffuser
2. Diffuser screen
3. Combustion chamber liner
4. Combustion chamber housing
5. Lubrication line to No. 3 bearing
6. Lubrication line to No. 2 bearing
7. Mounting boss for pressure oil line
8. Diffuser extension
9. Fuel manifold—inner
10. Diffuser screen
11. Fuel manifold-outer

Figure 1-27.-Double-annular combustion chambers.

Figure 1-26 shows a cross section of the parts of the double-annular combustion section quite clearly. Also included in the figure is the flow of air from the axial-flow compressor discharge through the liner on the turbine section. Primary air and secondary air are indicated by arrows.

The rotor shaft housing, shown in figure 1-28, provides the inner wall for the axial path of the air. This housing unit is attached to the rear face of the inner ring of the diffuser section. The housing is supported in the rear by components of the turbine section, not shown in figure 1-28.

The spark igniter plugs of the annular combustion chamber are the same basic type used in the can combustion chambers. There are usually two plugs mounted on the boss provided on each of the chamber housings. The plugs must be long enough to protrude from the housing into the outer annulus of the double-annular combustion chamber.

Can-Annular Type

The can-annular type combustion chamber is a development by Pratt and Whitney for use in their J57 axial-flow turbojet engine. Since this engine features the split-spool compressor, it requires combustion chambers capable of meeting the stringent requirements of maximum strength, limited length, and high overall efficiency. These attributes are necessary because of the high air pressures and velocities present in a split-spool compressor, along with the shaft length limitations.

The split-spool compressor requires two concentric shafts joining the turbine stages to their respective compressors. The front compressor, joined to the rear turbine stages, requires the longest shaft. This shaft is inside the other. A limitation of diameter is imposed, so that the distance between the front compressor and the rear turbine must be limited if critical shaft lengths are to be avoided. High torque is present if there is a long shaft of small diameter.

Since the compressor and turbine are not susceptible to shortening, shaft length limitation is absorbed by developing a new type of burner. The burner designers had to develop a design that would give the desired performance in much less relative linear distance.

The can-annular combustion chambers are arranged radially around the axis of the engine; the axis in this instance being the rotor shaft housing. Figure 1-28 shows this arrangement to advantage.

The combustion chambers are enclosed by a removable steel shroud, which covers the entire burner section. This feature makes the burners readily available for any required maintenance.

The burners are interconnected by projecting flame tubes, which help the engine-starting process in the can-type combustion chamber. These flame tubes perform a function identical with those previously discussed, the only difference being in construction details.

Figure 1-28 also reveals that each of the combustion chambers contains a central bullet-shaped perforated liner. The size and shape of the holes are predetermined to admit the correct quantity of air at the velocity and angle required to control the flame pattern. Cutouts are provided in two of the bottom chambers for installation of the spark igniters. Notice in figure 1-28 how the combustion chambers are supported at the aft end by matching outlet ducts in the turbine nozzle assembly.

Figure 1-28 shows how the forward face of the chambers presents size apertures that align with the six fuel nozzles of the corresponding fuel

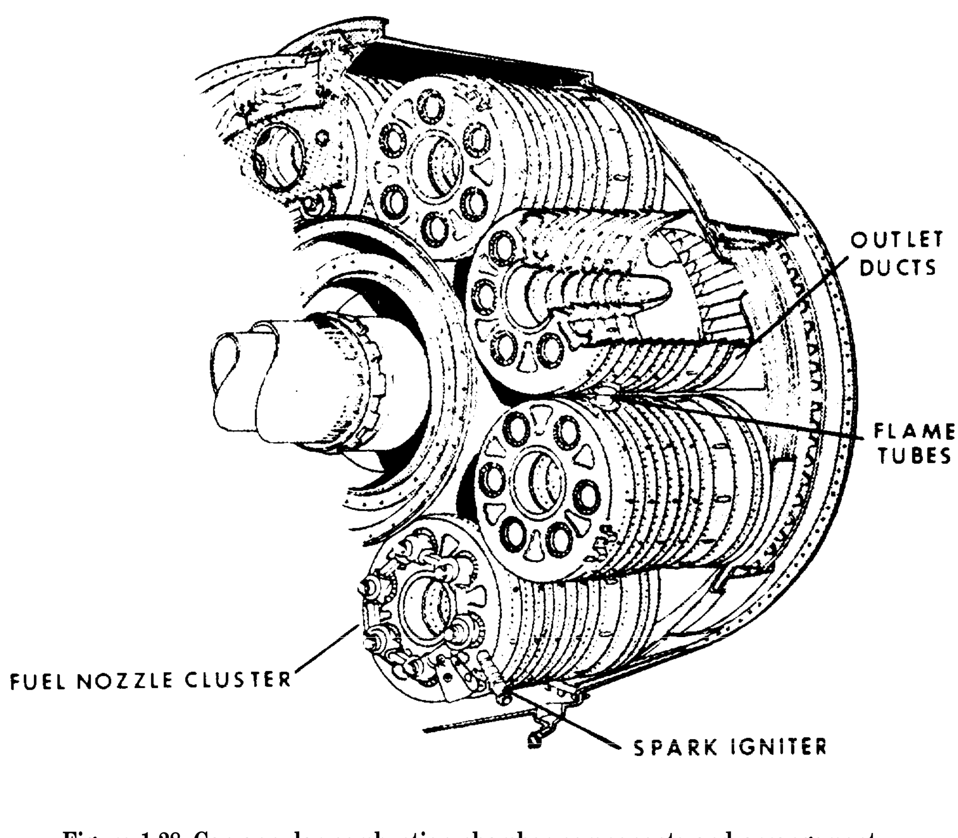


Figure 1-28.-Can-annular combustion chamber components and arrangement.

nozzle cluster. These nozzles are the dual-orifice (duplex) type that require the use of a flow-divider (pressurizing valve), as mentioned above in the can-type combustion chamber. Preswirl vanes are located around each of the nozzles for imparting a swirling motion to the fuel spray. This results in better atomization of the fuel, thus better burning and efficiency.

The swirl vanes perform two important functions imperative to proper flame propagation:

1. High flame speed: Better mixing of air and fuel, ensuring spontaneous burning.
2. Swirling prevents the flame from moving rapidly rearward.

The swirl vanes greatly aid flame propagation, since a high degree of turbulence in the early combustion and cooling stages is desirable. The vigorous mechanical mixing of the fuel vapor with the primary air is necessary, since mixing by diffusion alone is too slow. This same mechanical mixing is also established by other means, such as placing coarse screens in the diffuser outlet, as is the case in most axial-flow engines.

The can-annular combustion chambers also must have the required fuel drain valves, located in two or more of the bottom chambers, thereby assuring proper drainage and eliminating the possibility of residual fuel burning during the next start cycle.

The flow of air through the holes and louvers of the can-annular chambers is the same as the flow through other types of burners. Figure 1-29 shows the flow of combustion air, metal-cooling air, and the diluent or gas-cooling air. Pay particular attention to the direction of airflow, indicated by the arrows.

TURBINE SECTION

The turbine transforms a portion of the kinetic (velocity) energy of the exhaust gases into mechanical energy to drive the compressor and necessary accessories. This is the sole purpose of the turbine. This function absorbs about 60 to 80 percent of the total pressure energy from the exhaust gases. The exact amount of energy absorption at the turbine is determined by the load the turbine is driving. The compressor size, type, accessories, and a propeller and its reduction gears if the engine is a turbo-propeller type also effect absorption.

The turbine section of a turbojet engine is located aft, or downstream, of the combustion chamber section. Specifically, it is directly behind the combustion chamber outlet.

The turbine assembly consists of two basic elements, the stator and the rotor, as does the compressor unit. These two elements are shown in figures 1-30 and 1-31.

The stator element is known by a variety of names. Turbine nozzle vanes, turbine guide vanes,

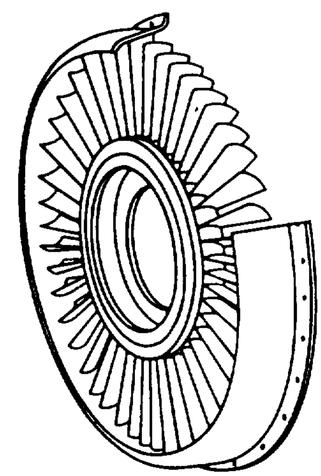


Figure 1-30.-Stator element of the turbine assembly.

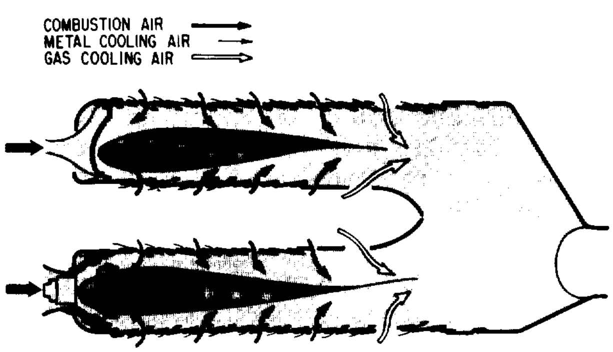


Figure 1-29.-Airflow through a can-annular chamber.

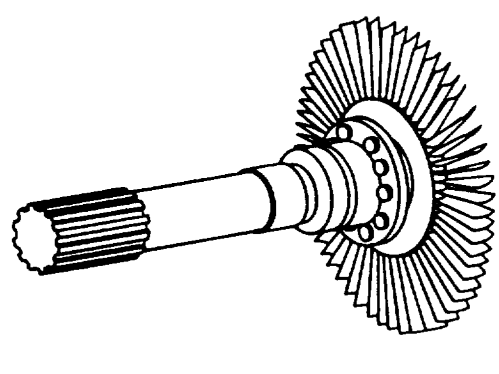


Figure 1-31.-Rotor element of the turbine assembly.

and nozzle diaphragm are three of the most commonly used. The turbine nozzle vanes are located directly aft of the combustion chambers and immediately forward of the turbine wheel.

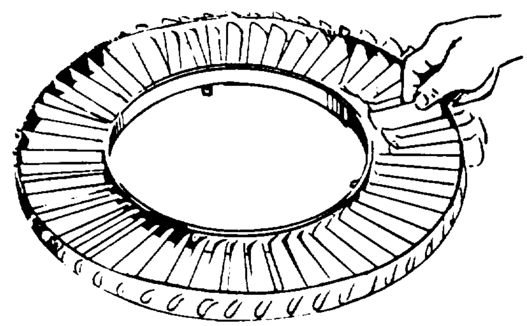
The function of the turbine nozzle is twofold. First, after the combustion chamber has introduced the heat energy into the mass airflow and delivered it evenly to the turbine nozzle, it becomes the job of the nozzle to prepare the mass flow for harnessing of power through the turbine rotor. The stationary vanes of the turbine nozzle are contoured and set at such an angle that they form small nozzles. They discharge the gas as extremely high-speed jets. Thus, the nozzle converts a varying portion of the heat and pressure energy to velocity energy. It can then be converted to mechanical energy through the rotor blades.

The second purpose of the turbine nozzle is to deflect the gases to a specific angle in the direction of turbine wheel rotation. Since the gas flow from the nozzle must enter the turbine blade passageway while the turbine is still rotating, it is essential to aim the gas in the general direction of turbine rotation.

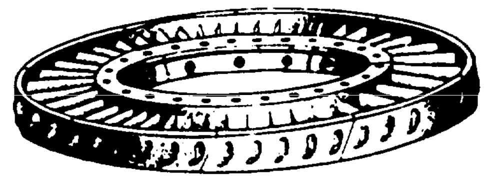
The elements of the turbine nozzle assembly consist of an inner shroud and an outer shroud, between the nozzle vanes. The number of vanes employed varies with different types and sizes of engines. Views A and B of figure 1-32 show typical turbine nozzles featuring loose and welded vane fits, respectively.

The vanes of the turbine nozzle are assembled between the outer and inner shrouds or rings in a variety of ways. Although the actual elements may vary slightly in their configuration and construction features, there is one characteristic peculiar to all turbine nozzles; that is, the nozzle vanes are constructed to allow for thermal expansion. Otherwise there would be severe distortion or warping of the metal parts because of rapid temperature variances.

The expansion feature of the turbine nozzle is accomplished by one of several methods. One method has the vanes assembled loosely in the supporting inner and outer shrouds (fig. 1-32, view A). Each of the vanes fits into a contoured slot in the shrouds. They conform with the airfoil shape of the vanes. These slots are slightly larger than the vanes to give a loose fit. The inner and outer shrouds are encased by an inner and an outer support ring, which give increased strength and rigidity. These supports also help remove the nozzle vanes as a unit. Otherwise, the



(A)



(B)

Figure 1-32.-Turbine nozzle vane assembly. (A) With loose fitting vanes; (B) with welded vanes.

vanes could fall out of the shrouds as the shrouds are removed.

Another method of thermal expansion construction is to fit the vanes into inner and outer shrouds. However, this method welds or rivets the vanes into position (fig. 1-32, view B). Some means provide for the inevitable thermal expansion; therefore, either the inner or the outer shroud ring cuts into segments. These saw cuts dividing the segments will allow enough expansion to prevent stress and warping of the vanes.

The rotor element of the turbine section consists essentially of a shaft and a wheel (fig. 1-31).

The following brief discussion of impulse and reaction turbines should help clarify their function. The turbine blades are of two basic types—impulse and reaction. Most aircraft engines use a blade with both impulse and reaction sections. The impulse is usually at the base of the blade.

The impulse turbine can be defined as a turbine that derives its rotation from the weight and velocity of the air striking its blades. The reaction turbine derives its rotation from the air pressure across its blades, as in an airfoil. See figure 1-33.

The impulse-reaction turbine combines the rotational forces described in the two previous turbines. It derives its rotation from the weight of air striking the turbine blades and the airfoil reaction of air passing over the blade's surface.

The turbine wheel is a dynamically balanced unit with blades attached to a rotating disc. The disc is attached to the main power-transmitting shaft of the engine. The jet gases leaving the turbine nozzle vanes act on the blades of the turbine wheel, causing the assembly to rotate at a very high speed. The high rotational speed causes heavy centrifugal loads on the turbine wheel. The elevated temperatures result in a lowering of the strength of the material. The engine speed and temperature must be controlled to keep turbine operation within safe limits.

The turbine wheel, without blades, is known as a turbine disc. The disc acts as an anchoring part for the turbine blades. Since the disc is attached to the rotor shaft, the exhaust gas energy extracted by the blades is imparted to the shaft.

The disc rim exposes the hot gases passing through the blades and absorbs considerable heat from these gases. In addition, the rim also absorbs heat from the turbine buckets by conduction. Hence, disc rim temperature slopes are quite high and well above the temperatures of the more remote inner portion of the disc. As a result of these temperature slopes, thermal stresses are added to the stresses due to rotation.

There are various methods provided to relieve, at least partially, these stresses. One such method is the incorporation of an auxiliary fan somewhere ahead of the disc. Usually rotor-shaft driven, it forces cooling air back into the face of the disc.

Another method of relieving the thermal stresses of the disc follows as incidental to blade installation. The disc rims are notched to conform with the blade root design. The disc is made adaptable for retaining the turbine blades. At the same time, space is provided by the notches for thermal expansion of the disc.

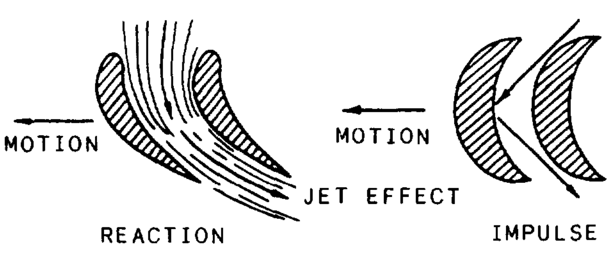


Figure 1-33.-Impulse and reaction blades.

The turbine shaft, shown in figure 1-31, is made from low-alloy steel. It must be capable of absorbing high torque loads, such as when a heavy axial-flow compressor is started.

The methods of connecting the shaft to the turbine disc vary. One method used is welding. The shaft is welded to the disc, which has a butt or protrusion provided for the joint. Another method is by bolting. This method requires that the shaft have a hub that matches a machined surface on the disc face. The bolts are then inserted through holes in the shaft hub and anchored in tapped holes in the disc. Of the two methods, bolting is more common.

To join the turbine shaft to the compressor rotor hub, make a splined cut on the forward end of the shaft. The spline fits into a coupling device between the compressor and turbine shafts. If a coupling is not used, the splined end of the turbine shaft may fit into a splined recess in the compressor rotor hub. The axial compressor engine may use either of these methods.

There are various ways of attaching turbine blades or buckets, some similar to compressor blade attachment. The most satisfactory method used is the fir-tree design, shown in figure 1-34.

The blades are retained in their respective grooves by a variety of methods; some of the more common ones are peening, welding, locking tabs,

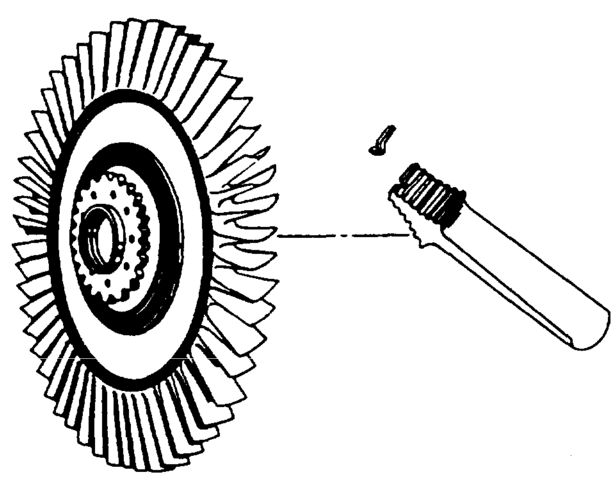


Figure 1-34.-Turbine blade with fir-tree design root and tab lock method retention.

and riveting. Figure 1-35 shows a typical turbine wheel using riveting for blade retention.

A method of blade retention used quite frequently is peening, and it applies in various ways. Two of the most common applications of peening are described in the following paragraphs.

One method of peening requires that a small notch be ground in the edge of the blade fir-tree root before blade installation. The blade inserts into the disc. The notch is filled with the disc metal, which is "flowed" into it through a small punch mark made in the disc, adjacent to the notch. The tool used for this job is similar to a center punch, and is usually manufactured locally.

Another method of peening is to construct the blades root in such a way as to contain all the elements necessary for its retention. This method is shown in figure 1-36. The blade root has a stop on one end of the root. The blade is inserted and moves in one direction only, while on the opposite end of the blade is a tang. This tang is peened over to secure the blade in the disc.

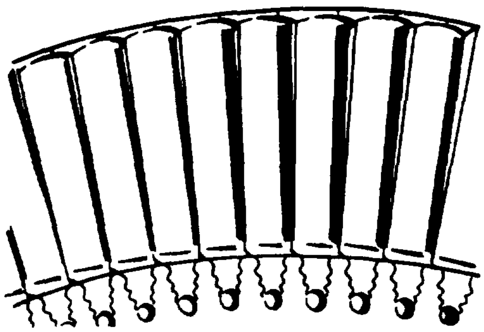


Figure 1-35.-Riveting method of turbine blade retention.

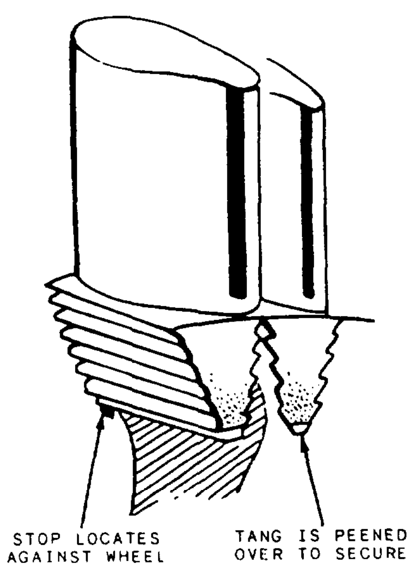


Figure 1-36.-Turbine bucket, featuring peening method of blade retention.

Turbine blades may be either forged or cast, depending on the composition of the alloys. Most blades are precision cast and finish-ground to the desired shape.

Most turbines in use are open at the outer perimeter of the blades; there is a second type called the shrouded turbine. The shrouded turbine blades, in effect, form a band around the outer perimeter of the turbine wheel. This improves efficiency and vibration characteristics and permits lighter stage weights; on the other hand, it limits turbine speed and requires more blades (fig. 1-37).

In turbine rotor construction, it may be necessary to use turbines of more than one stage. A single turbine wheel often cannot absorb enough power from the exhaust gases to drive the parts dependent on the turbine for rotative power. In a turbojet engine, these parts are the compressor and engine-driven accessories. In the turboprop engine, these parts are the propeller and its reduction gearing.

A turbine stage consists of a row of stationary vanes or nozzles, followed by a row of rotating

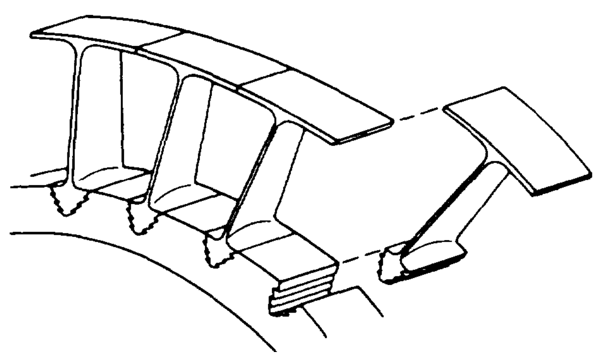


Figure 1-37.-Shrouded turbine blades.

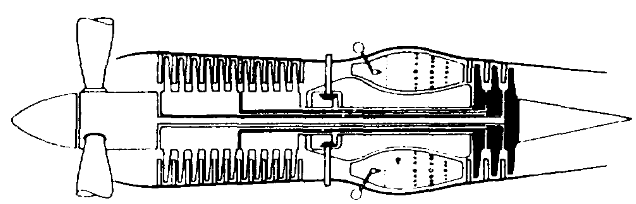


Figure 1-38.-Multi-rotor turbine.

blades. Some models of turboprop engines use as many as five turbine stages. You should remember that regardless of the number of wheels necessary for driving engine parts, there is always a turbine nozzle in front of each wheel.

The occasional use of more than one turbine wheel is necessary in cases of heavy rotational loads. Heavy loads that require multiple-stage turbine wheels often make it advantageous to use multiple rotors. Shafts are bolted to the appropriate turbine on one end and at the other end to the unit requiring the rotative power. Typical of this situation are split compressors or propellers, or a gas generator for helicopters, In each of these situations, the turbine for each of the rotors may have one or more stages.

In the single-rotor turbine, shown in figure 1-23, the power is developed by one rotor. All engine-driven parts are driven by this single wheel, This arrangement uses engines where the need for low weight and compactness predominates. The single-rotor turbine may be either single or multiple stage.

In the multiple-rotor turbine, the power is developed by two or more rotors. It is possible for each turbine rotor to drive a separate part of the engine. For example, a triple-rotor turbine may be so arranged that the first turbine drives the rear half of the compressor and the accessories. The second turbine drives the front half of the compressor, and the third turbine furnishes power to a propeller (fig. 1-38).

The turbine rotor arrangement for a dual-rotor turbine, such as required for a split-spool compressor, is similar to the arrangement in figure 1-38. The difference is in the use of the third turbine for a propeller,

The remaining elements concerning the turbine is the turbine casing or housing. The turbine casing encloses the turbine wheel and the nozzle vane assembly. It gives either direct or indirect support to the stator elements of the turbine section. It always has flanges to provide for the front and rear bolting of the assembly to the combustion chamber housing and the exhaust cone assembly, respectively. Figure 1-39 shows a turbine casing.

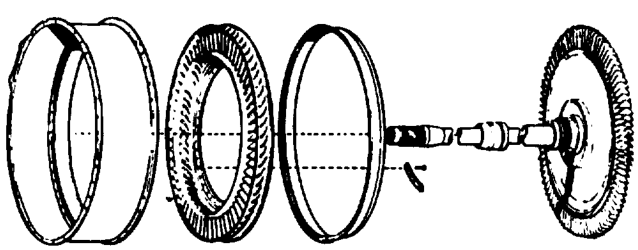


Figure 1-39.-Turbine casing assembly.

EXHAUST SECTION

The exhaust section of the turbojet engine is made up of several parts, each of which has its individual functions. Although the parts have individual purposes, they also have one common function. They must direct the flow of hot gases rearward in such a manner as to prevent turbulence, while causing a high final or exit velocity to the gases.

In performing the various functions, each of the parts affects the flow of gases in different ways, as described in the following paragraphs.

The exhaust section is directly behind the turbine section. It ends with the ejection of gas at the rear in the form of a high-velocity jet.

The parts of the exhaust section include the exhaust cone, tailpipe (if required), and the exhaust, or jet nozzle, Each of these parts is discussed individually so the exhaust section will be quite familiar to you.

The exhaust cone collects the exhaust gases discharged from the turbine assembly and gradually converts them into a solid jet. During this operation, the velocity of the gases will decrease slightly, and the pressure will increase. This is caused by the diverging passage between the outer duct and the inner cone. The annular area between the two units increases rearward (fig. 1-40).

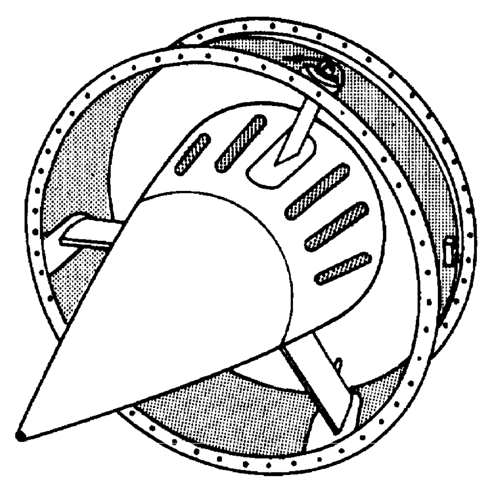


Figure 1-40.-Exhaust collector and welded support status.

The elements of the exhaust cone assembly consist of an outer shell or duct, an inner cone, and three or four radial hollow struts or fins. Tie rods aid the struts in supporting the inner cone from the outer duct.

The outer shell or duct, made of stainless steel, is attached to the rear flange of the turbine case. This element collects and delivers the exhaust gases. The gases flow either directly or through a tailpipe to the jet nozzle, depending on whether or not a tailpipe is required. There is no need for a tailpipe in some engines. For instance, the required engine-installation space in wing roots, pods, or wings is short and requires very little tailpipe. In which case the exhaust duct and exhaust nozzle will suffice. The construction of the duct includes such features as a predetermined number of thermocouple bosses for installing exhaust gas temperature thermocouples. Also, there must be insertion holes for the supporting tie rods. In some cases, there are no requirements for tie rods for supporting the inner cone from the outer duct. If such is the case, the hollow struts provide the sole support of the inner cone; the struts being spot-welded in position to the inside surface of the duct and to the inner cone, respectively.

The radial struts actually have a twofold function. They not only support the inner cone in the exhaust duct, they also perform the important function of straightening the swirling exhaust gases, which otherwise would leave the turbine at an angle of about 45 degrees. If tie rods are required for inner cone support, these struts also form fairings around the rods.

The centrally located inner cone fits rather closely against the rear face of the turbine disc. This fit prevents turbulence of the gases as they leave the turbine wheel. The cone is supported by the radial struts, which are usually vertical and horizontal in relation to the normal position of the engine. In some configurations, there is a small hole located in the exit tip of the cone (fig. 1-40). This hole allows cooling air to circulate from the exit end of the cone. The pressure of the gases is relatively high in the interior of the cone and against the face of the turbine wheel. The flow of air is positive, since the air pressure at the turbine wheel is relatively low due to rotation of the wheel, thus air circulation is assured. The gases for cooling the turbine wheel return to the path of flow by passing through the clearance between the disc and the cone. The clearance between the turbine disc and the inner cone must be checked periodically since the higher pressures aft tend to push the inner cone against the turbine wheel.

The exhaust cone assembly is the terminating part of the basic engine. The remaining parts (the tailpipe and jet nozzle) are usually considered airframe parts.

The tailpipe pipes the exhaust gases out of the airframe. Actually, the tailpipe imposes a penalty on the operating efficiency of the engine in the form of heat and duct (friction) losses. These losses materially affect the final velocity of the exhaust gases and, hence, the thrust.

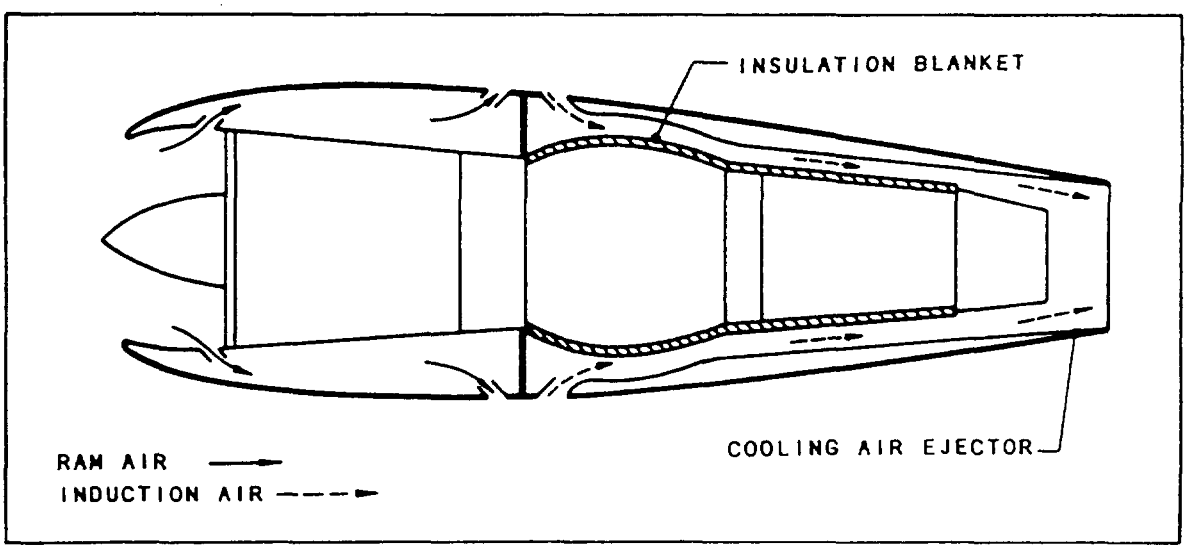


Figure 1-41.-Exhaust system insulation blanket.

The tailpipe ends in a jet nozzle, located just forward of the end of the fuselage. Most installations employ a single direct exhaust to get the advantages of low weight, simplicity, and minimum duct losses.

The construction of the tailpipe is semiflexible. Again, the need for this feature is dependent on its length. On an extremely long tailpipe, a bellows arrangement allows movement both in installation and maintenance and in thermal expansion. This cuts stress and warping, which would otherwise be present.

The heat radiation from the exhaust cone and tailpipe could conceivably injure the airframe parts surrounding these units. For this reason some means of insulation had to be devised. There are several suitable methods for protection of the fuselage structure; two of the most common are insulation blankets and shrouds.

An insulation blanket type of configuration, shown in figures 1-41 and 1-42, consists of several layers of aluminum foil, each separated by a layer of bronze screening or some other suitable material. Although these blankets protect the fuselage from heat radiation, they primarily reduce heat losses from the exhaust system. Since engine temperature limits are of little concern after the gases pass the turbine, the reduction of heat losses improves engine performance by retaining the maximum permissible temperatures, resulting in maximum velocity in the jet. A typical insulation blanket and the temperatures at the various locations in the exhaust section are shown in figure 1-42. This blanket contains fiber glass as the low-conductance material and aluminum foil as the radiation shield. The blanket is covered to prevent its becoming soaked with oil. The heat shroud type of configuration consists of a stainless steel envelope enclosing the exhaust system (fig. 1-43).

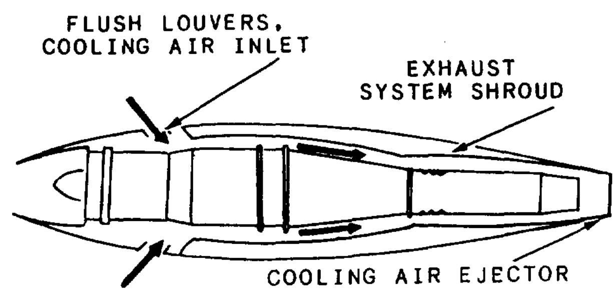


Figure 1-43.-Exhaust system shroud.

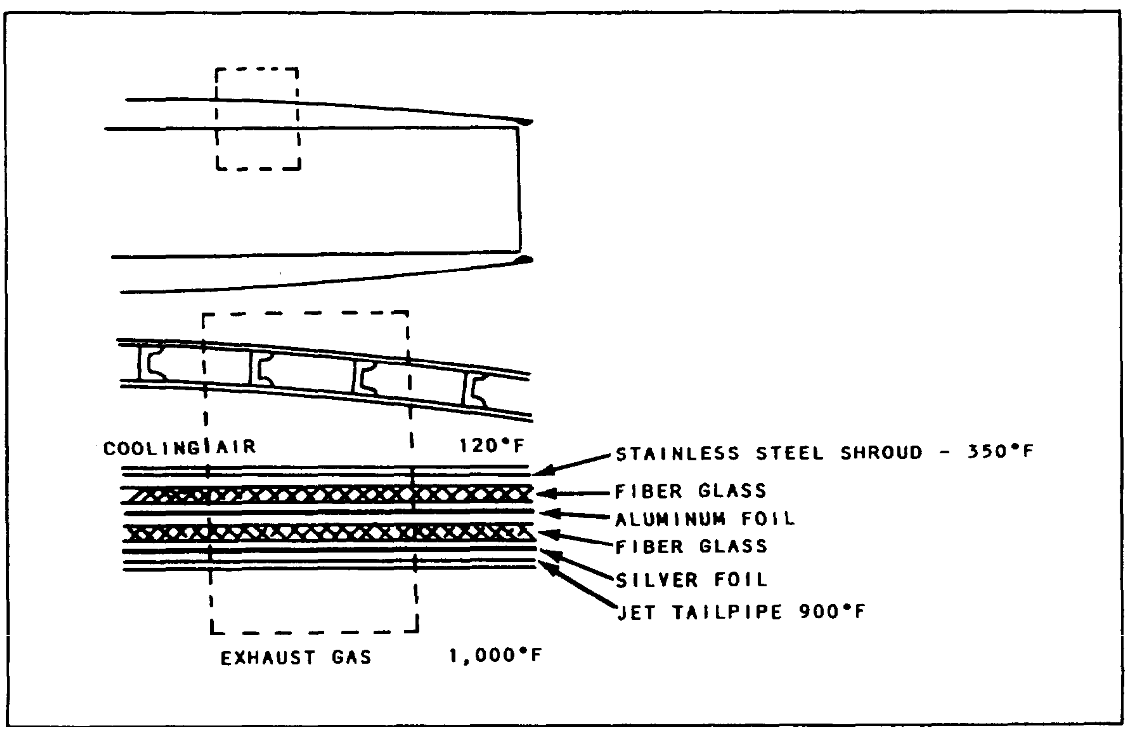


Figure 1-42.-Insulation blanket, with the temperatures that would be obtained at the various locations shown.

NOTE: The exhaust or jet nozzle gives to the exhaust gases the all-important final boost in velocity. The jet nozzle, and the tailpipe, is not a part of the basic power plant, but is supplied as a part of the airframe. The nozzle attaches to the rear of the tailpipe if there is a need. It is attached to the rear flange of the exhaust duct if a tailpipe is not necessary. There a re basically two types of jet nozzles—fixed-area and variable-area.

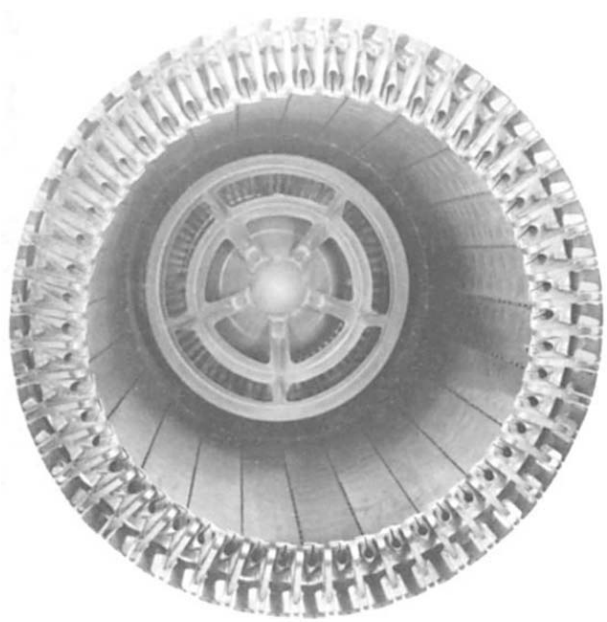


Figure 1-44.-Segment-type nozzle assembly.

There are two types of jet nozzle design. They are the converging design, used on most freed-area nozzles for subsonic velocities, and the converging-diverging design, for supersonic gas velocities.

The fixed-area type is the simpler of the two jet nozzles, since there are no moving parts. It is attached to either a tailpipe or exhaust cone, and any adjustment in nozzle area is mechanical.

Adjustments in a fixed-area nozzle are sometimes necessary because the size of the exit orifice will directly affect the operating temperature of the engine. There are several ways to adjust a fixed-area nozzle. One method is to trim or cut away strips from the conical section of the exhaust nozzle. Provided, of course, the temperature was too high. If the inlet temperature is too low, a nozzle of less area is used to replace the inadequate one.

Another method of reducing the nozzle area is to use inserts. The inserts fit inside a joggled retainer held in place by two screws.

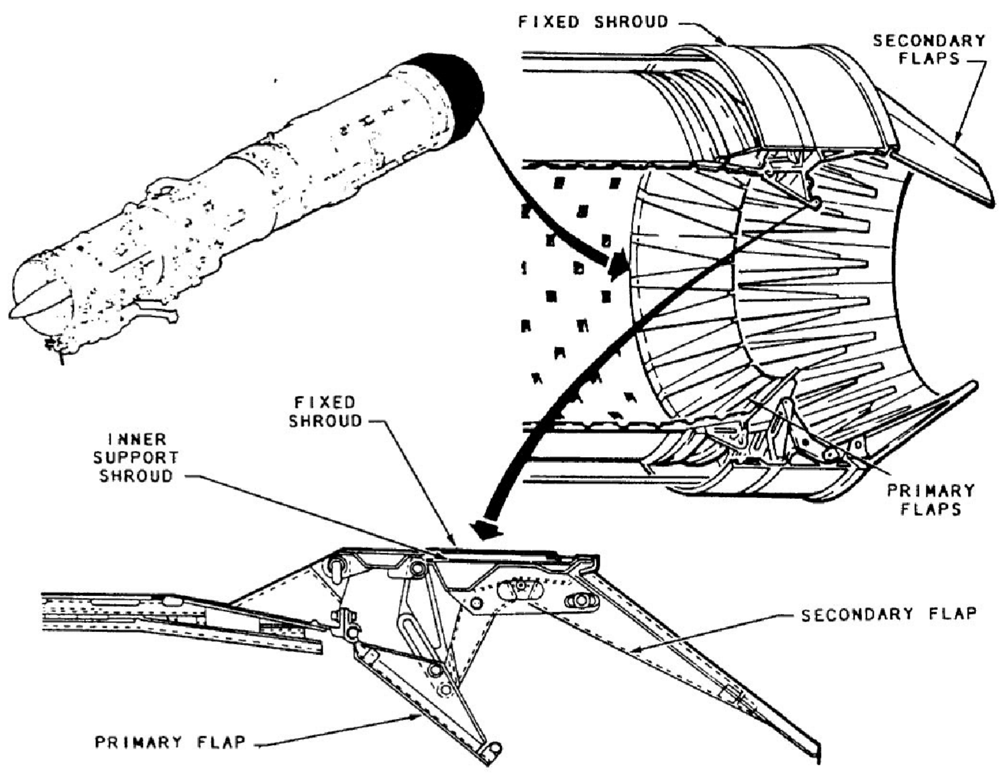


Figure 1-45.-Variable exhaust nozzle assembly.

Usually a set of 10 inserts of various curvatures is provided with each aircraft. The different size inserts allow a total change of 10 square inches in nozzle area in 1-inch increments. Thus, through experience, a mechanic can run the engine at maximum speed with one combination of inserts. Check the temperature, and substitute another combination to make up a temperature deficiency or remedy an excess temperature situation.

NOTE: All advanced-technology engines now used by the Navy have state-of-the-art electronic parts that eliminate the need for physically changing the exhaust nozzle area.

The variable-area nozzle at the exhaust exit is automatic. A very important use of this type of nozzle is to increase the exit area during afterburning.

The segment-type nozzle area opens and closes by individual overlapping sliding segments. See figure 1-44.

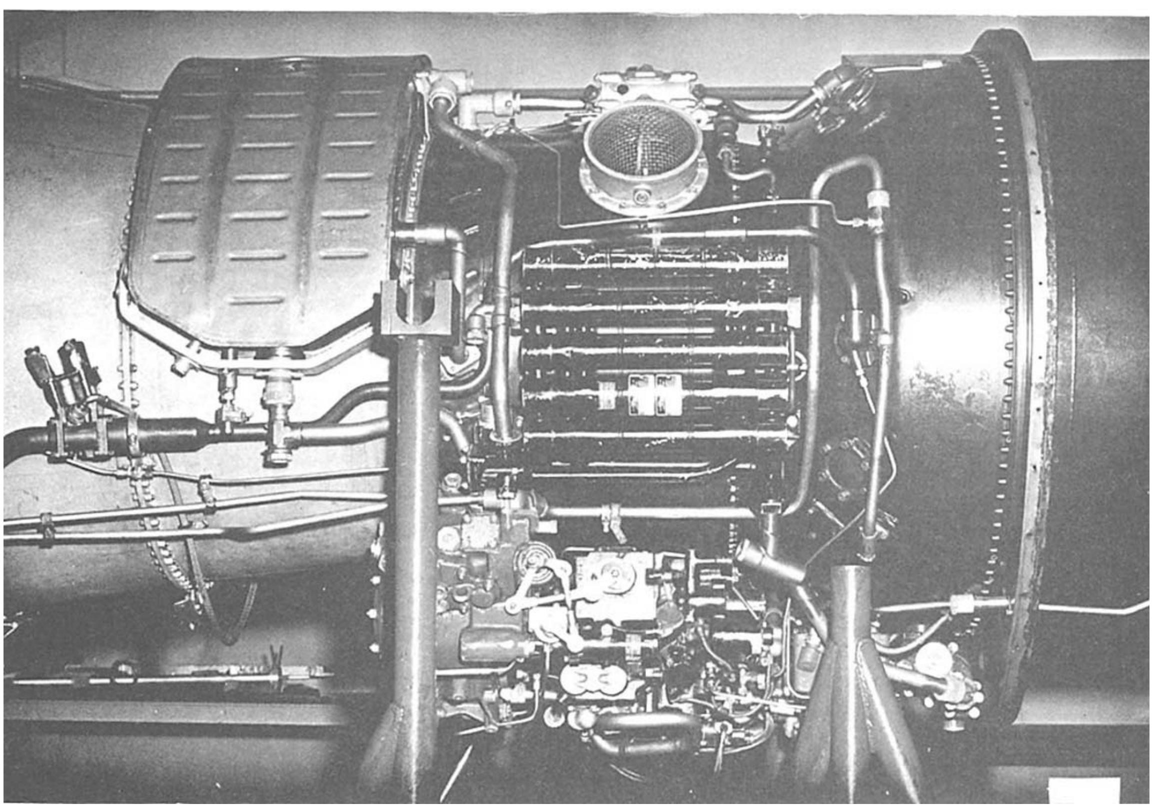
Some engines use the inner- and outer-flap variable nozzle assembly, shown in figure 1-45. The assembly has an internal primary nozzle with sectional flaps and an external secondary nozzle with sectional flaps. The flaps of the primary nozzle are hinged to the rear of the tailpipe. The secondary nozzle is secured by a stationary supporting shroud, on which the pivot points for the flap-operated mechanisms are located. The flaps are slotted to permit thermal expansion and are mounted onto the tailpipe. The flaps are controlled by four synchronized hydraulic actuators.

ACCESSORY SECTION

The accessory section of the turbojet engine has various functions. The primary function is to provide space for the mounting of accessories necessary for the operation and control of the engine. It also includes accessories concerned with the aircraft, such as electric generators and fluid power pumps. The secondary purpose includes acting as an oil reservoir, oil sump, and providing for and housing of accessory drive gears and reduction gears.

The arrangement and driving of accessories have always been major problems on gas turbine engines. Driven accessories are mounted on common pads either ahead of or next to the compressor section.

Figure 1-46 shows the accessory arrangement of an axial-flow engine.



The parts of an axial-flow engine accessory section are the accessory gearbox and a power takeoff assembly. These units contain the necessary drive shafts and reduction gears. Views A and B of figure 1-47 show the location of the accessory gearbox.

The accessory gearbox and the power takeoff are located near each other. There are two factors that affect the location of gearboxes in general. These factors are engine diameter and engine installation.

Designers strive to reduce engine diameter to make the engine more streamlined, thereby increasing performance by reducing drag. Also, engine installation in a particular aircraft may dictate the location or rearrangement of the accessory gearboxes.

The accessories on engines are the fuel control with its governing device, the high-pressure fuel pump(s), and a breather screen or other means for venting the oil system. Other parts are oil sump, oil pressure and scavenge pumps, auxiliary fuel pump, starting fuel pump, and other accessories, including starter, generator, and tachometer. Although these accessories are essential, the particular combination of engine-driven accessories depends upon the use for which the engine is designed.

The accessories mentioned above (except starters) are of the engine-driven type. There are the nondriven-type accessories such as booster coils or ignition exciters, fuel and oil filters, barometric units, drip valves, compressor bleed valves, and relief valves.

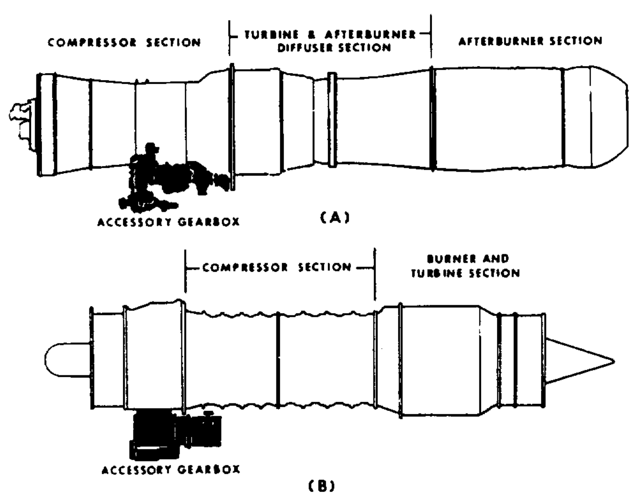


Figure 1-47.-Accessory gearbox. (A) Mounted beneath the compressor; (B) mounted beneath the front bearing support.

AFTERBURNER SECTION

The afterburner increases or boosts the normal thrust rating of a gas turbine engine. There are times when the maximum normal thrust of an engine is not enough. For instance, it is conceivable that although the in-flight requirements are met satisfactorily by an engine of moderate size, the aircraft still may not have good takeoff performance. With afterburning, maximum thrust is obtained without sacrificing the economy of the small basic gas turbine. Increased thrust is required for takeoff, emergencies, and combat conditions.

The afterburner duct replaces the usual aircraft tailpipe. Actually, it is more like a converted tailpipe. It functions as the engine tailpipe during nonafterburning (cold) operation and is also the main working element of the afterburner. The entire afterburner is projected from the engine. It is supported only at the exhaust end where it is bolted to the engine.

The essential working element of the afterburner is an afterburner duct. A flameholder or diffuser and a variable-area exhaust nozzle are the other parts (fig. 1-45).

The afterburner duct is the main working element of the afterburner. It's designed so that the normal pressure relationship between the air entering the main engine turbine and the air leaving the turbine is not upset. Since the duct acts as a burner, the inlet air velocity must be sufficiently low to support stable combustion and to avoid excessive pressure losses. For these purposes a diffuser is located between the turbine outlet and the tailpipe burner inlet. Thus, the burner section of the duct can reduce gas velocities so they do not exceed the flame propagation rate. Otherwise, the flame could not get a foothold, because the onrushing turbine exhaust would simply push the burning mixture right out the exhaust nozzle. In addition to the diffuser, some mechanical mixing of the fuel and air is necessary. Mixing by diffusion is too slow a process to be an aid in forming a combustible mixture.

The flameholders provide local turbulence and reduce velocity, which aids combustion stability. The flameholders are located downstream from the fuel-injection nozzles, thereby allowing time for proper mixing of the fuel and air before reaching the burner area. The flameholders are circular, concentrically mounted, and supported in position by tie rods that project through the wall of the duct. Two of the tie rods are in a horizontal position, and the remaining two are vertical.

The afterburner, tailpipe burner, or reheater get their names because the air going through the engine is subjected to additional burning after the basic cycle is completed. The unburned oxygen in the air used for cooling the exhaust gases is the afterburner air supply. Since no cooling is required past the turbine assembly, all or any part of this air may be burned for augmentation. Additional energy is given to the exhaust gases by burning additional fuel sprayed in the exhaust stream aft of the turbine.

CHAPTER 2

TOOLS AND HARDWARE

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Identify the purpose and procedures of the tool control program.
- Recognize the use and safety procedures for common hand tools.
- Recognize the use and safety procedures for special tools (torque wrenches and micrometers).
- Recognize the selection, identification, and proper use of different aircraft hardware.

Each year, thousands of dollars of damage to aircraft engines and serious injuries to personnel result from the wrong use of tools and hardware. Using the wrong type of hardware or improper safetying of hardware may cause flight controls to jam or come loose. Engines experience foreign object damage (FOD) because of the improper use of tools and hardware. Tools are found in aircraft fuel cells and engine bays even though a Tool Control Program guards against these mistakes. With so much at stake, we must continually emphasize basic tool and hardware use.

TOOLS

You must have a well-rounded knowledge of many different types of tools. You must know the purpose for which the tools were designed. An important attribute that a mechanic must have is the ability to use the right tool for the job. The correct tool must be used whether that job is a minor adjustment or a major engine overhaul.

You have often heard that a mechanic is only as good as his tools. That is a half-truth. The mechanic must not only have the correct tools but must know the proper use of these tools. You can't drive spikes with a tack hammer; yet, some may try. It is your responsibility to keep your tools in good condition and ready for use. A screwdriver that has been damaged by use as a chisel or pry bar has no place in a mechanic's toolbox. Damaged tools may cause damage to parts or injury to the worker.

The material in this chapter emphasizes information from other training manuals and should be studied with them. For a complete description of different tools and their use, refer to *Tools and Their Uses,* NAVEDTRA 10085 (series).

TOOL CONTROL PROGRAM (TCP)

The Tool Control Program was established to reduce FOD-related mishaps. The program is intended to ensure tool accountability both before and following the performance of aircraft-related maintenance tasks.

The CNO is the overall sponsor. NAVAIRSYSCOM is the responsible agent for development and issuance of a Tool Control Plan for each type of aircraft and engine. This TCP is a guide to aviation maintenance activities in the implementation of their own TCP. The following information is part of each TCP:

1. An allowance list for tool containers

2. A standard tool list and layout diagram for each container

3. Procurement information necessary to procure tool containers and other associated hardware

Aircraft Controlling Custodians (ACCs) are required to implement each TCP after it has been formulated and released. Each ACC sets forth a specific policy by means of instructions. Examples of these publications are the CNALINST 4790.16 (series), CNAPINST 4790.18 (series), and NAVAIRINST 10290.2 (series) instructions. The Naval Air Engineering Center will process revisions to the tool allowance list, as well as error lists, Each local command, ship, and squadron should prepare a local command maintenance instruction (MI) to assign the responsibilities for the TCP. The material control officer is responsible for ensuring that tools are procured and issued on a controlled basis. Some commands may establish a tool control center under the material control officer. In activities operating aboard ships, where a tool control center is not practical, the commanding officer designates, in writing, a tool control coordinator.

The TCP contains the listing of each tool container. The TCP acts as an inventory for each type, model, and series of aircraft and equipment worked on. The container exterior will clearly identify the work center, tool container number, and organization. The tools in each container will have the work center code, organization code, and container number etched onto them. Special accountability procedures will be established locally for those tools not suitable for etching. Drill bits (too hard), jeweler's screwdrivers (too small), and beryllium hand tools (dust is hazardous to personnel) are not suitable for etching.

Tool pouches are to be considered as tool containers, and most are manufactured locally. The position for each tool in the container will be silhouetted against a contrasting background. The silhouetted tool outline will highlight each tool location within the container. Those containers not silhouetted will contain a diagram of the tool locations. Containers will include an inventory as well as a separate listing of tools in calibration or requiring replacement.

The AD who has custody of a toolbox must prevent the loss of the tools or the toolbox through neglect or misuse. Although hand tools are normally classified as consumable items, they are expensive and must be paid for when lost or damaged. OPNAVINST 4790.2 (series) outlines the policies and procedures for control of hand tools. Usually, your activity will have a local MI concerning the inventory interval and methods for reporting lost or damaged tools.

NOTE: Broken or damaged tools can damage equipment, hardware, and parts. They can also cause personal injury to the worker or others.

All personnel have specific responsibilities under the TCP. All tool containers should have a lock and key as part of their inventory. When work is to be completed away from the work spaces, complete tool containers should be taken to the job. If you need more tools than the tool container contains, tool tags may be used to check out additional tools. These tools come from other tool containers in the work center or from another work center. The following is a list of some of your responsibilities under the work center Tool Control Program:

1. Upon task assignment, note the number of the tool container on copy 1 of the VIDS/MAF. Place this note to the left of the Accumulated Work Hours section. Conduct a sight inventory before beginning each task. All shortages must be noted. Every measure must be taken to make sure missing tools do not become a cause of FOD: Perform inventories before a shift change, when work stoppage occurs, and after maintenance has been completed. Perform an inventory before conducting an operational systems check on the equipment.

2. After you account for all tools and complete all maintenance actions, the work center supervisor signs the VIDS/MAF.

3. If any tool is found to be missing during the required inventories, conduct an immediate search. The search should occur before reporting the work completed or signing off the VIDS/MAF. If the tool cannot be located, notify maintenance control to ensure that the aircraft or equipment is not released.

If the tool cannot be located, the person doing the investigation will sign a lost tool statement and the VIDS/MAF. The statement indicates that a lost tool investigation was conducted and that the tool was not found. After the investigation, follow the normal VIDS/MAF completion process.

COMMON HAND TOOLS

In this chapter the term *common hand tools* is used to refer to small, nonpowered hand tools that are common to the AD rating. This term includes such common tools as hammers, socket sets, wrenches, screwdrivers, and pliers.

Hammers

Hammers are dangerous tools when used carelessly and without consideration, Practice will help the inexperienced to learn how to use a hammer properly. Hold the handle near the end with your fingers underneath and your thumb along the side or on top of the handle. Your thumb should rest on the handle and never overlap your fingers. Oils on the face of the hammer will cause it to glance off the work. Wipe the oil off with a rag and rub the face with coarse sandpaper or emery cloth. Never use a hammer that has a loose head or cracked handle. Most hammer accidents are caused by a loose head or a slippery handle. So remember these tips when using any kind of striking tool. Tighten the loose hammer-head by driving a wedge in the end of the handle. The wedge spreads the handle tightly inside the head. Do not strike a hardened steel surface with a steel hammer. Small pieces of steel may break and injure someone or damage the work. Use a soft hammer in striking hardened steel or highly. polished stock. If a soft hammer is not available, use a piece of copper, brass, lead, or wood to protect the hardened steel. It is permissible to strike a punch or chisel directly with the ball-peen hammer because the steel in the heads of punches and chisels is slightly softer than that of the hammerhead.

There are various types of hammers, all of which are used to apply a striking force where the force of the hand alone is insufficient. Each of these hammers has a head and a handle, even though these parts differ greatly from hammer to hammer. So that you may have a better idea of their differences and uses, let's consider the types of hammers used most frequently. See figure 2-1.

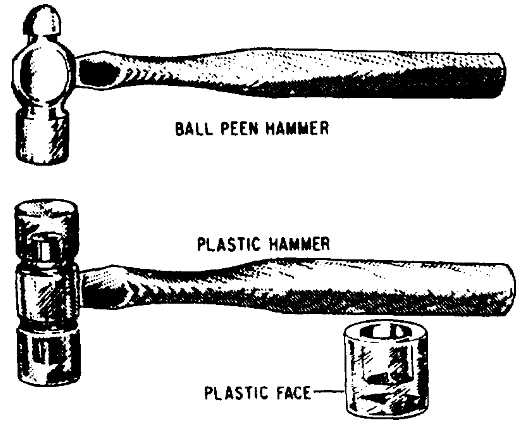


Figure 2-1.-Hammers.

BALL PEEN HAMMER.— The ball peen hammer is sometimes referred to as a machinist's hammer. It is a hard-faced hammer made of forged tool steel.

The flat end of the head is called the face. This end is used for most hammering jobs. The other end of the hammer is called the peen. The peen end is smaller in diameter than the face and is useful for striking areas that are too small for the face to enter.

Ball peen hammers are made in different weights, usually 4, 6, 8, and 12 ounces and 1, 1 1/2, and 2 pounds. For most work, a 1 l/2-pound or a 12-ounce hammer will do.

MALLET.— A mallet is a soft-faced hammer. Mallets are made with brass, lead, tightly rolled strips of rawhide, and plastic heads, Sometimes the plastic head has a lead core for added weight.

Plastic mallets similar to the one shown in figure 2-1 are the type normally found in your toolbox. The weight of the plastic head may range from a few ounces to a few pounds. Use the plastic mallet for straightening thin sheet ducting or when installing clamps.

Socket Sets

The socket set is one of the most versatile tools in the toolbox. Basically, it consists of a handle and a socket-type wrench that can be attached to the handle. A complete socket wrench set consists of several types of handles along with bar extensions, universals, adapters, and a variety of sockets. See figure 2-2.

SOCKETS.— A socket has an opening cut in one end to fit a drive on a detachable handle. The handle drive is usually square. On the other end of the socket is a 6-point or 12-point opening very much like the opening in the box-end wrench. The 12-point socket needs to be swung only half as far as the 6-point socket before it may be lifted and fitted on the nut for a new grip. It can be used in closer quarters where there is less room to move the handle. Most sockets have 12 points. Use the 6-point socket with nuts made of stainless steel. Stainless steel is a harder metal than that of the wrench. Extensive use of a 12-point socket on such nuts or bolts would cause excessive wear on the 12 points. The socket might fail to hold. By contrast, because of the greater holding surface, a 6-point socket holds the stainless steel nut better. The 6-point socket offers less chance for wear of the wrench.

Sockets are classified for size according to two factors. One is the drive size or square opening, which fits on the square drive of the handle. The other is the size of the opening in the opposite end, which fits the nut or bolt. The standard toolbox has sockets that have 1/4- and 3/8-inch-square drivers. The openings that fit the bolt or nut are graduated in 1/16-inch sizes. Sockets are also made in deep lengths to fit over spark plugs and long bolt ends.

There are four types of handles used with these sockets. See figure 2-2. Each type has special advantages, and the good mechanic chooses the one best suited to the job at hand. The square driving lug on the socket wrench handles has a spring-loaded ball that fits into a recess in the socket receptacle. The tool design holds the assembly together. This mated ball-recess feature prevents the parts of the wrench from falling apart during normal usage, but a slight pull disassembles any wrench connection.

RATCHET HANDLE.— The ratchet handle has a reversing lever that operates a pawl (or dog) inside the head of the tool. Pulling the handle in one direction causes the pawl to engage in the ratchet teeth and to turn the socket. Moving in the opposite direction causes the pawl to slide over the teeth, permitting the handle to back up without moving the socket. This feature allows rapid turning of the nut or bolt after each partial turn of the handle. With the reversing lever in one position, the handle can be used for tightening. In the other position, it can be used for loosening.

HINGED HANDLE.— The hinged handle is also very convenient. To loosen a tight nut, swing the handle at right angles to the socket. This gives the greatest possible leverage. After loosening the

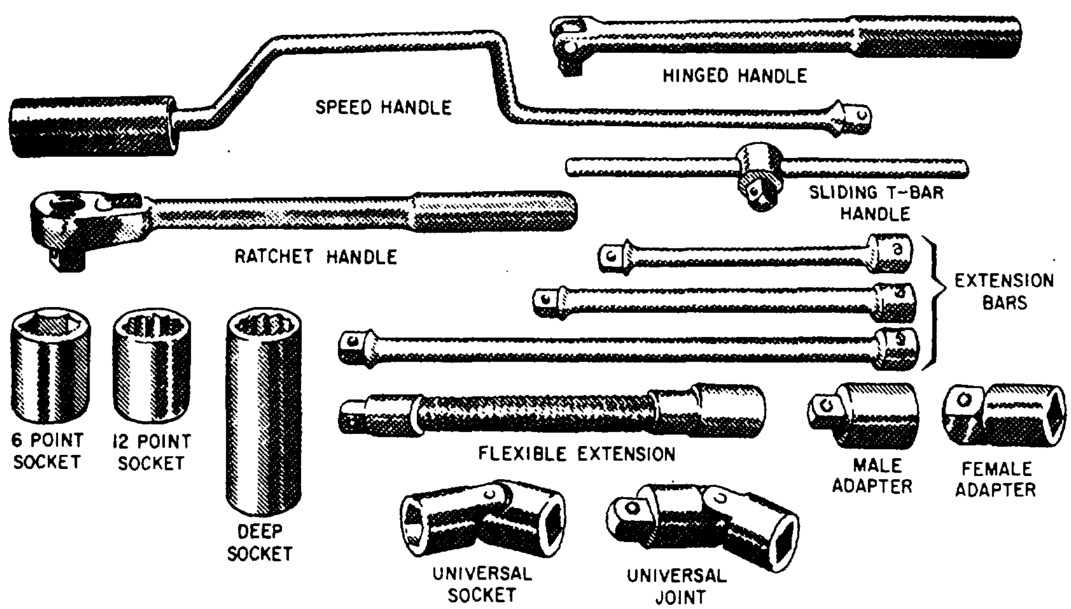


Figure 2-2.-Typical socket wrench set.

nut to the point where it turns easily, move the handle into the vertical position, and then turn the handle with your fingers.

SLIDING T-BAR HANDLE.— While using the sliding bar on the T-handle, the head can be positioned at either the end or the center of the sliding bar. Select the position that is needed for the job at hand.

SPEED HANDLE.— After the nuts are loosened with the sliding bar handle or the ratchet handle, the speed handle will help remove the nuts in a hurry. In many instances, the speed handle is not strong enough to be used for breaking loose or tightening. Use the speed socket wrench carefully to avoid damaging the nut threads.

ACCESSORIES.— Several accessory items complete the socket wrench set. Extension bars of different lengths are made to extend the handles to any length needed. A universal joint allows the nut to be turned with the wrench handle at an angle. A universal socket is also available, and universal socket joints, bar extensions, and universal sockets in combination with appropriate handles make it possible to form a variety of tools that will reach otherwise inaccessible nuts and bolts.

Another accessory item that comes in handy is an adapter, which allows you to use a handle having one size drive with a socket having a different size drive. For example, a 3/8- by 1/4-inch adapter would make it possible to turn all 1/4-inch-square drive sockets with any 3/8-inch-square drive handle.

There are special sockets that are used to adapt various types of screwdriver bits to a speed handle. See figure 2-3. This socket-type screwdriver is used to remove recessed head screws from access panels on equipment.

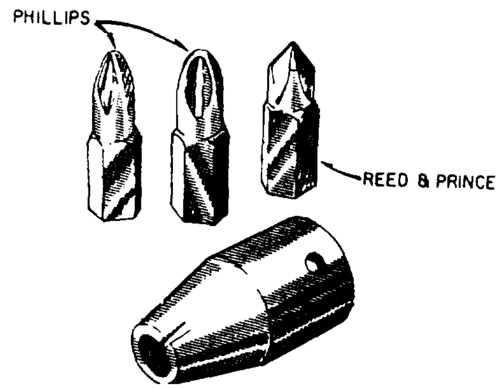


Figure 2-3.-Screwdriver adapter.

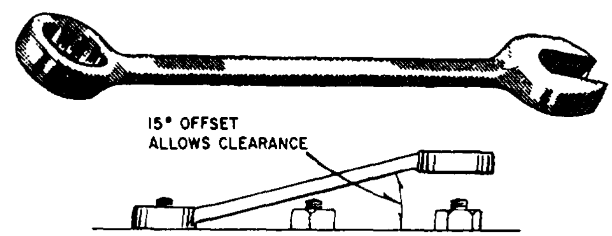


Figure 2-4.-Combination wrench.

Combination Wrenches

Most toolboxes contain a set of combination wrenches. As shown in figure 2-4, the combination wrench has an open-end wrench on one end and a box-end (of the same size) on the other end. For speed and light stress operations, use the open-end. Then switch to the box-end for safety under stress. For ease of explanation, each end of the wrench is discussed separately. Adjustable wrenches are also briefly discussed.

BOX-END WRENCH.— The box-end fits completely around the nut or bolt head. The box-end is usually constructed with 12 points. The advantage of the 12-point construction is that the wrench will operate between obstructions where space for the swing angle is limited. A very short swing of the handle will turn the nut far enough to allow the wrench to be lifted and the next set of points to be fitted to the corners of the nut. It is possible to use this wrench in places where the swing angle is limited to as little as 30 degrees.

The box-end portion of the wrench is designed with an offset in the handle. Notice in figure 2-4 how the 15-degree offset will allow clearance over nearby parts. One of the best features of the box-end is that there is little or no chance that the wrench will slip off the nut or bolt. However, there is the disadvantage of slow work with the box-end of the combination wrench. Each time the wrench is backed off, it has to be lifted up and refitted to the head of the work. To save time, use the nonslip box-end of the wrench to break loose tight bolts or to snug up work after the bolt has been seated with a faster type of wrench that might slip under stress.

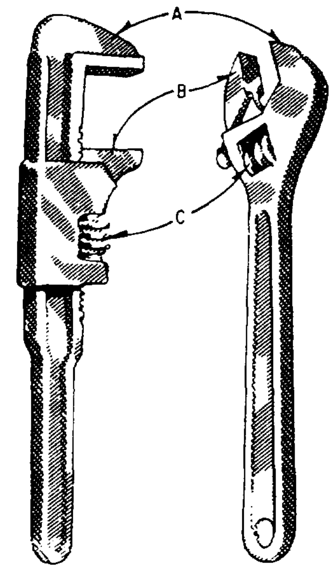
OPEN-END WRENCH.— The jaws of the open-end portion of the combination wrench are machined at 15 degrees from parallel in respect to the center line of the handle. This permits the use of the wrench where there is room to make only a part of a complete turn. If the wrench is turned over after the first swing, it will fit on the same flats and turn the nut farther. After two swings on the wrench, the nut is turned far enough so that a new set of flats are in position for the wrench.

Use the open end of the combination wrench on tubing nuts and in cramped places. Sometimes the cramped space is too small for a socket or box-end to be slipped over the nut or bolt head. When using any open-end type wrench, always make sure the wrench fits the nut or bolt head, and pull on the wrench—never push. Pushing a wrench is dangerous. The threads could break loose unexpectedly and cause damage to adjacent equipment or injury to the person using the wrench.

ADJUSTABLE WRENCHES.— Adjustable wrenches are not intended to replace open-end or box-end wrenches, but they are useful in working in restricted areas. In addition, they can be adjusted to fit odd size nuts. Adjustable wrenches are not intended for standard use but rather for emergency use. The wrenches were not built for use on extremely hard-to-turn items. As shown in figure 2-5, adjustable wrenches have a fixed jaw (A) and an adjustable jaw (B), which is adjusted by a thumbscrew (C). By turning the thumbscrew, the jaw opening may be adjusted to fit various sizes of nuts. The size of the wrenches ranges from 4 to 18 inches in length. The maximum jaw openings vary in direct proportion to the length of the handle.

Adjustable wrenches are often called "knuckle busters" because mechanics frequently suffer the consequences of improper usage of these tools.

There are four simple steps to follow in using these wrenches. First, choose one of the correct size. Do not pick a large 12-inch wrench and adjust the jaw for use on a 3/8-inch nut. This could result in a broken bolt and a bloody hand. Second, be sure the jaws of the correct size wrench are adjusted to fit snugly on the nut. Third, position the wrench around the nut until the nut is all the way into the throat of the jaws. If not used in this manner, the result is apt to be as bloody as before. Fourth, pull the handle toward the side having the adjustable jaw. This will prevent the adjustable jaw from springing open and slipping off the nut. If the location of the work will not allow all four steps to be followed, select another type of wrench for the job.



A. Fixed jaw
B. Adjustable jaw
C. Thumbscrew

Figure 2-5.-Adjustable wrenches.

Adjustable wrenches should be cleaned in a solvent, and a light oil applied to the thumbscrew and the sides of the adjustable jaw. They should also be inspected often for cracks, which might result in failure of the wrench.

Screwdrivers

Two basic types of screwdriver blades are used: the common blade for use on conventional slotted screws, and a crosspoint blade for use on the recessed head Phillips or Reed and Prince type of screws. See figure 2-6. The common and crosspoint blade types are used in the design of various special screwdrivers, some of which are also shown in figure 2-6.

COMMON SCREWDRIVERS.— The combination length of the shank and blade identifies the size of common screwdrivers. They vary from 2 1/2 to 12 inches. The diameter of the shank and the width and thickness of the blade tip, which fits the screw slot, are in proportion to the length of the shank. The blade is hardened to prevent it from being damaged when it is used on screws. It can easily be chipped or blunted when used for other purposes. The blade of a poor quality

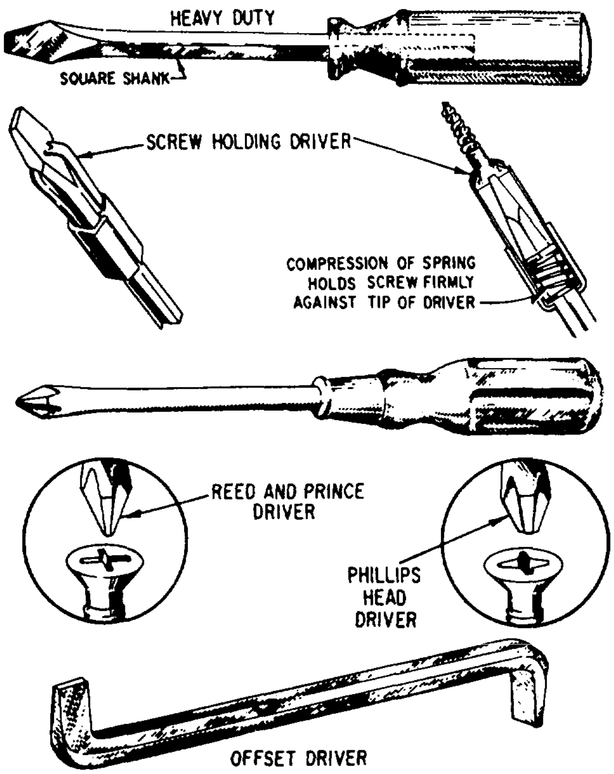


Figure 2-6.-Typical screwdrivers.

screwdriver will sometimes become damaged even when being used properly. Do not used damaged screwdrivers.

CAUTION

When using any type of screwdriver, do not hold the work in your hand. If the point slips, it can cause a bad cut. When removing a screw from an assembly that is not stationary, hold the work on a solid surface, in a vise, or with some other holding tool. Never get any part of your body in front of the screwdriver point. This precaution is a good safety rule for any sharp-pointed tool.

CROSSPOINT SCREWDRIVERS.— There are two types of crosspoint screwdrivers in common use: the Reed and Prince and the Phillips. The Reed and Prince screwdrivers and Phillips screwdrivers are not interchangeable. Always use a Reed and Prince screwdriver with Reed and Prince screws, and a Phillips screwdriver with Phillips screws. The use of the wrong screwdriver will result in mutilation of the screwhead.

OFFSET SCREWDRIVERS.— An offset screwdriver may be used where there is not sufficient vertical space for a standard screwdriver. See figure 2-6. Offset screwdrivers are constructed with one blade forged in-line with and another blade forged at right angles to the shank handle. Both blades are bent 90 degrees to the shank handle. By alternating ends, you can seat or loosen most screws even when the swinging space is very restricted. Offset screwdrivers are made for both standard and recessed head screws.

Pliers

Many different types of pliers are in use today. Some of these are the vise grip, the channel-lock, the duckbill, the needle nose, the diagonal, and the safety wire pliers.

VISE GRIP PLIERS.— Vice grip pliers can be used a number of ways. See figure 2-7. These pliers can be adjusted to various jaw openings by turning the knurled adjusting screw at the end of the handle. Vise grips can be clamped and locked in position by pulling the lever toward the handle. They may be used as a clamp, portable vise, and for many other uses where a locking, plier-type jaw may be employed.

CAUTION

Vise grip pliers should be used with care since the teeth in the jaws tend to damage the object on which they are clamped. They should not be used on nuts, bolts, tube fittings, or other objects that must be reused.

CHANNEL-LOCK PLIERS.— Channel-lock pliers can be easily identified by the extra-long

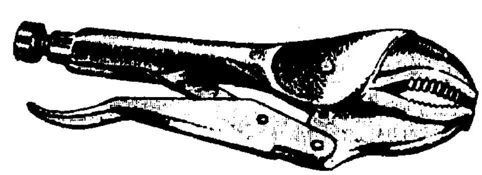


Figure 2-7.-Vice grip pliers.

handles. See figure 2-8. These pliers are very powerful gripping tools. The inner surfaces of the jaws consist of a series of coarse teeth formed by deep grooves. This construction makes a surface usable for grasping cylindrical objects. Channel-lock pliers have grooves on one jaw and lands on the other. The adjustment is effected by changing the position of the grooves and lands. Channel-lock pliers are less likely to slip from the adjustment setting when gripping an object. Use the channel-lock pliers where it is impossible to use a more adapted wrench or holding device. Many nuts and bolts and surrounding parts have been damaged by improper use of channel-lock pliers.

DUCKBILL PLIERS.— Duckbill pliers have long wide jaws and slender handles. Duckbills are used in confined areas where the fingers cannot be used. The jaw faces of the pliers are scored to aid in holding an item securely. See figure 2-9, view A.

NEEDLE-NOSE PLIERS.— Needle-nose pliers are used in the same manner as duckbill pliers. See figure 2-9, view B, There is a difference in the design of the jaws, Needle-nose jaws are tapered to a point, which makes them adapted to installing and removing small cotter pins. The pliers have serrations at the nose end and a side cutter near the throat. Use needle-nose pliers to hold small items steady, to cut and bend wire, or to do numerous other jobs that are too intricate or too difficult to be done by hand alone.

NOTE: Duckbill and needle-nose pliers are especially delicate. Care should be exercised when using these pliers, to prevent springing, breaking, or chipping the jaws. Once these pliers are damaged, they are practically useless.

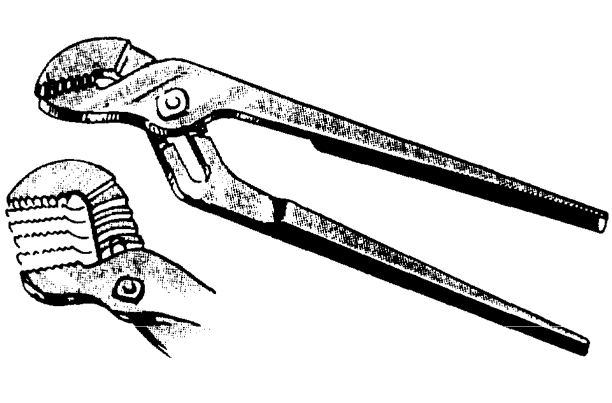


Figure 2-8.-Channel-lock pliers.

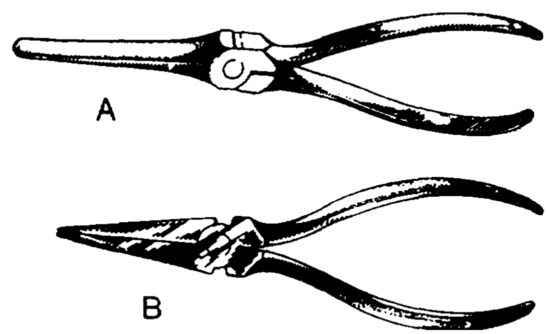


Figure 2-9.-Pliers (A) duckblll; (B) needle-nose.

DIAGONAL PLIERS.— Diagonal cutting pliers are an important tool for you to use. They are used for cutting small wire and cotter pins, and so forth. Since they are small, they should not be used to cut large wire or heavy material. The pliers will be damaged by such use and will not be effective to cut what they were designed to cut. They can also be used to remove small cotter pins where a new pin is to be used when the work is finished. This is done by gripping the pin near the hinge of the pliers and lifting up on the handles, releasing the pin, getting a new grip, and repeating until the pin is removed.

The inner jaw surface is a diagonal straight cutting edge offset approximately 15 degrees. This design permits cutting objects flush with the surface. The diagonal cutting pliers are not designed to hold objects. To use enough force to hold an object, the pliers will cut or deform the object. The sizes of the diagonal pliers are indicated by the overall length of the pliers.

SAFETY-WIRE PLIERS.— When installing equipment, you may need to lockwire (usually referred to as safety wire) designated parts of the installation. The process of lockwiring can be accomplished faster and neater with the use of special pliers. See figure 2-10.

Safety-wire pliers are three-way pliers—they hold, twist, and cut. They are designed to make a uniform twist and to reduce the time required in twisting the safety wire.

To operate, grasp the wire between the two diagonal jaws of the pliers. As the handles are squeezed together, the thumb and forefinger brings the outer (locking) sleeve into the locked position. A pull on the knob of the pliers can make a uniform twist. The spiral rod may be pushed back into the pliers without unlocking

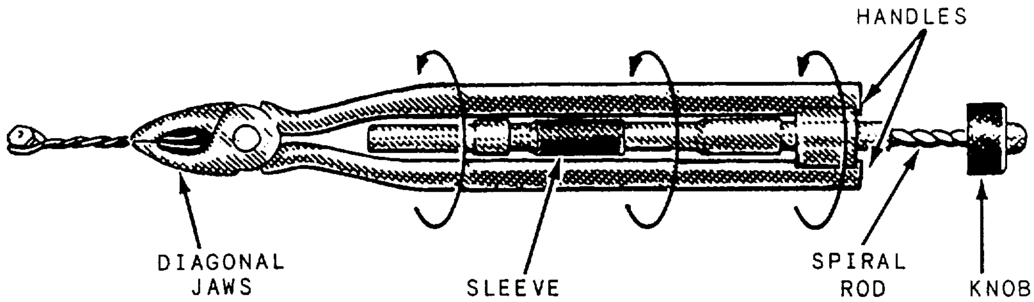


Figure 2-10.-Safety-wire pliers.

them, and by again pulling on the knob, you can make a tighter twist. The wire should be installed snugly but not so tight that the wire is overstressed. A squeeze on the handles unlocks the pliers, and the wire can then be cut to the proper length with the cutting jaws.

Special Tools

Special tools are normally maintained in a central toolroom and signed out when needed. A tool falls into the *special* category for one of the following five main reasons.

1. It is an item of special support equipment. These tools are designed, manufactured, and issued for supporting or maintaining one particular model of aircraft, engine, or support equipment.
2. It is a seldom used tool. When needed, its use is essential in aircraft maintenance. Most of the time it would not be required and would just take up room in the toolbox.
3. It is a high-cost item. A central location is necessary to permit better use or for security.
4. The large size or awkward shape of the tool makes it difficult, if not impossible, to put in a toolbox.
5. It is a instrument type of tool that requires calibration.

A wide variety of special tools are furnished by the manufacturers of the support equipment, engines, and related equipment. These special tools are listed in the Allowance List Registers published by the Aviation Supply Office. Their use is explained in the manual that covers the specific support equipment, engine, or item of equipment for which they were designed. Special tools that you use frequently may be kept in your toolbox if permitted by your tool control plan. Torque wrenches and micrometers are special tools.

TORQUE WRENCHES.— There are times when, for engineering reasons, a definite pressure must be applied to a nut, bolt, screw, or other fastener. In such cases a torque wrench must be used. The torque wrench is a precision tool consisting of a torque-indicating handle and appropriate adapter or attachments. Use the wrench to measure the amount of turning or twisting force applied to a nut, bolt, or screw.

The three most common torque wrenches are the deflecting beam, dial indicating, and micrometer setting types. See figure 2-11. When using the deflecting beam and the dial-indicating torque wrenches, the torque is read visually on a dial or scale mounted on the handle of the

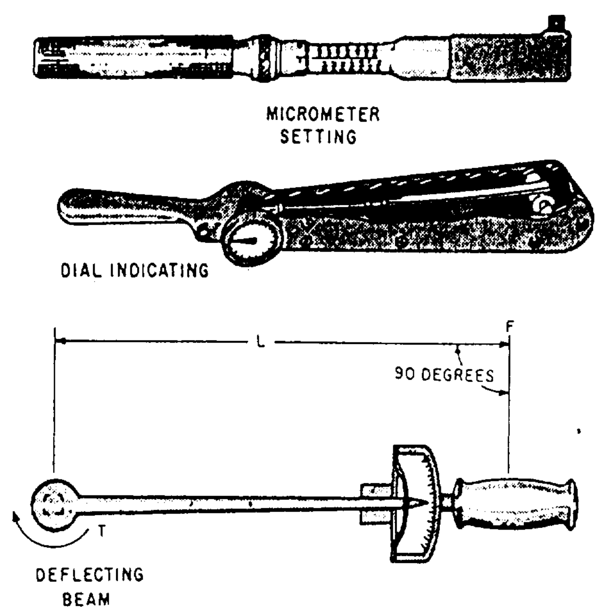


Figure 2-11.-Torque wrenches.

wrench. These torque wrenches are all used in a very similar manner.

To use the micrometer setting type, unlock the grip and adjust the handle to the desired setting on the micrometer scale. Relock the grip. Install the required socket or adapter to the square drive of the handle. Place the wrench assembly on the nut or bolt and pull in a clockwise direction with a smooth steady motion. A fast or jerky motion will result in an improperly torqued unit. When the torque applied reaches the torque value indicated on the handle setting, the handle will automatically release or "break" and move freely for a short distance. The release and free travel is easily felt, so there is no doubt about when the torquing process is complete.

The following precautions should be observed when using torque wrenches:

1. Do not use the torque wrench as a hammer.
2. When using the micrometer setting type, do not move the setting handle below the lowest torque setting. Place the micrometer at its lowest setting before returning it to storage.
3. Do not use the torque wrench to apply greater amounts of torque than its rated capacity.
4. Do not use the torque wrench to break loose bolts that have been previously tightened.
5. Never store a torque wrench in a toolbox or in an area where it may be damaged.

Torquing can be described as the twisting stress that is applied to the fasteners to secure components together. These fasteners can be nuts, bolts, studs, clamps, and so forth. Torque values for these fasteners are expressed in inch-pounds or foot-pounds. Unless otherwise stated, all torque values should be obtained with the manufacturer's recommended thread lubricant applied to the threads.

Torque values are listed in the appropriate section of the applicable instruction manual. In case there is no torque specified, standard torque values can be found in the *Structural Hardware Manual,* NA 01-1A-8, or in your particular aircraft general information MIM. Regardless of whether torque values are specified or not, all nuts in a particular installation must be tightened alike amount. This permits each bolt in a group to carry its share of the load. It is a good practice to use a torque wrench in all applications.

Using the proper torque allows the structure to develop its design strength and greatly reduces the possibility of failure due to fatigue. One word of caution—never rely on memory for torque information, but look up the correct torque value each time it is needed. A nut or bolt that is not torqued to the proper value may cause damage to the component or equipment.

The proper procedure is to tighten at a uniformly increasing rate until the desired torque is obtained. In some cases, where gaskets or other parts cause a slow permanent set, the torque must be held at the desired value until the material is sealed. When applying torque to a series of bolts on a flange or in an area, select a median value. If some bolts in a series are torqued to a minimum value and others to a maximum, force is concentrated on the tighter bolts and is not distributed evenly. Such unequal distribution of force may cause shearing or snapping of the bolts.

Torque wrench size must be considered when torquing. The torque wrenches are listed according to size and should be used within this recommended range. Use of larger wrenches that have too great a tolerance results in inaccuracies. When an offset extension wrench is used with a torque wrench, the effective length of the torque wrench is changed. The torque wrench is so calibrated that when the extension is used, the indicated torque (the torque that appears on the dial or gage of the torque wrench) may be different from the actual torque that is applied to the nut or bolt. The wrench must be preset to compensate for the increase when an offset extension wrench is used.

Occasionally, it is necessary to use a special extension or adapter wrench together with a standard torque wrench. To arrive at the resultant required torque limits, use the following formula:

$$S = \frac{T \times L}{(E + L)}$$

Where:

S = reading of setting of torque wrench;

T = recommended torque on part;

L = length of torque wrench (distance between center of drive and center of hand grip); and

E = length of extension of adapter (distance between center of drive and center of broached opening measured in the same place as L).

EXAMPLE: Recommended torque is 100 inch-pounds. Using a 12-inch torque wrench and a 6-inch adapter, determine reading on torque wrench.

$$S = \frac{100 \times 12}{(6 + 12)} = \frac{1200}{18} = 66.6$$

An example of the measurement of this formula is shown in figure 2-12. When the extension is pointed back toward the handle of the torque wrench, subtract the effective length of the extension from the effective length of the torque wrench. If the extension is pointed at a right angle to the torque wrench, then the actual value does not change.

An engineering study revealed a widespread lack of understanding as to what happens when an adapter is used with a torque wrench, To see if you understand the effects of adapters and extension handles, read the situation below and answer the questions.

Situation: Given a dial-indicating torque wrench, an adapter, and an extension handle, perform the following steps:

- Torque a nut to a predetermined indicated value, gripping the torque wrench at the end of the extension handle. Return to this torque value twice to ensure the nut is fully seated.

- Remove the extension handle and apply the same indicated torque again.

Question: Will the nut rotate before the previously indicated torque is reached?

Answer: Yes! Think it through—if you decrease the handle length (L), you increase the torque (T) if the indicated torque (S) remains constant.

Question: What would happen if a micrometer torque wrench was used?

Answer: Nothing would change. The type of torque wrench has no effect at all. It is simply a function of the length of the lever arm between the torque wrench square drive and where the hands are placed on the handle.

Using solid-handle torque wrenches with extension handles can cause significant over- or undertorquing. This problem exists based on the handle length chosen for the computation and where hand force is actually applied on the handle. When applying the formula, force must be applied to the handle of the torque wrench at the point from which the measurements were

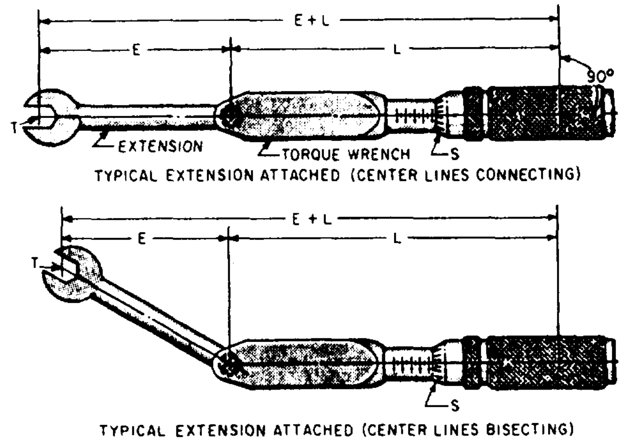


Figure 2-12.-Torque wrench with extensions.

taken. If this is not done, the torque obtained will be in error.

MICROMETERS.— It is important that a person repairing and building up engines thoroughly understand the use, and care of the micrometer. Micrometers are used to set clearances and to measure damage or repair limits. Figure 2-13 shows an outside micrometer caliper with the various parts clearly indicated. Micrometers are used to measure distances to the nearest one thousandth of an inch, The measurement is usually expressed or written as a decimal. You must know the method of writing and reading decimals.

Types of Micrometers.— There are three types of micrometers that are most commonly used throughout the Navy. They are the outside micrometer caliper (including the screw thread micrometer), the inside micrometer, and the depth

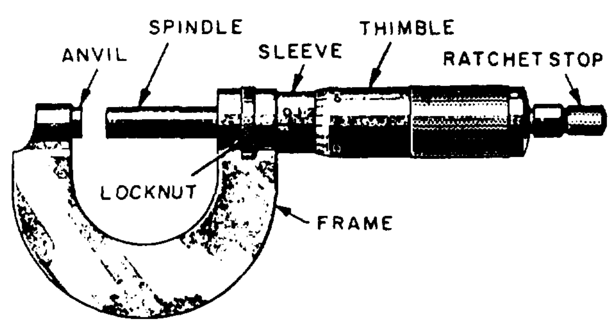


Figure 2-13.-Nomenclature of an outside micrometer caliper.

micrometer. See figure 2-14. The outside micrometer is used for measuring outside dimensions, such as the diameter of a piece of round stock. Use the screw thread micrometer to determine the pitch diameter of screws. The inside micrometer is used for measuring inside dimensions. Use inside micrometers to determine the inside diameter of a tube or hole, the bore of a cylinder, or the width of a recess. Use the depth micrometer for measuring the depth of holes or recesses.

Care of Micrometers.— Keep micrometers clean and lightly oiled. Make sure they are placed in a case or box when they are not in use. Anvil faces must be protected from damage and must not be cleaned with emery cloth or other abrasives.

HARDWARE

The importance of aircraft hardware is often overlooked because of the small size of most items. The safe and efficient operation of any aircraft depends upon the correct selection and use of aircraft hardware. You must make sure that items of aircraft hardware remain tightly secured in the aircraft.

Inflight mishaps continue to happen at an alarming rate. Many of these mishaps are due to improper hardware selection and installation. For example, mishaps involving aircraft fires can often be attributed to the chafing of fluid lines and wire bundles, caused by improperly clamped parts.

THREADED FASTENERS

In modern aircraft construction, thousands of rivets are used. Many parts require frequent dismantling or replacement. It is more practical for you to use some form of threaded fastener. Some joints require greater strength and rigidity than can be provided by riveting. We use various types of bolts and nuts to solve this problem.

Bolts and screws are similar in that both have a head at one end and a screw thread at the other. However, there are several differences between them. The threaded end of a bolt is always relatively blunt. A screw may be either blunt or pointed. The threaded end of a bolt must be screwed into a nut. The threaded end of the screw may fit into a nut or directly into the material being secured. A bolt has a fairly short threaded section and a comparatively long grip length (the unthreaded part). A screw may have a longer threaded section and no clearly defined grip length. A bolt assembly is generally tightened by turning a nut. The bolt head mayor may not be

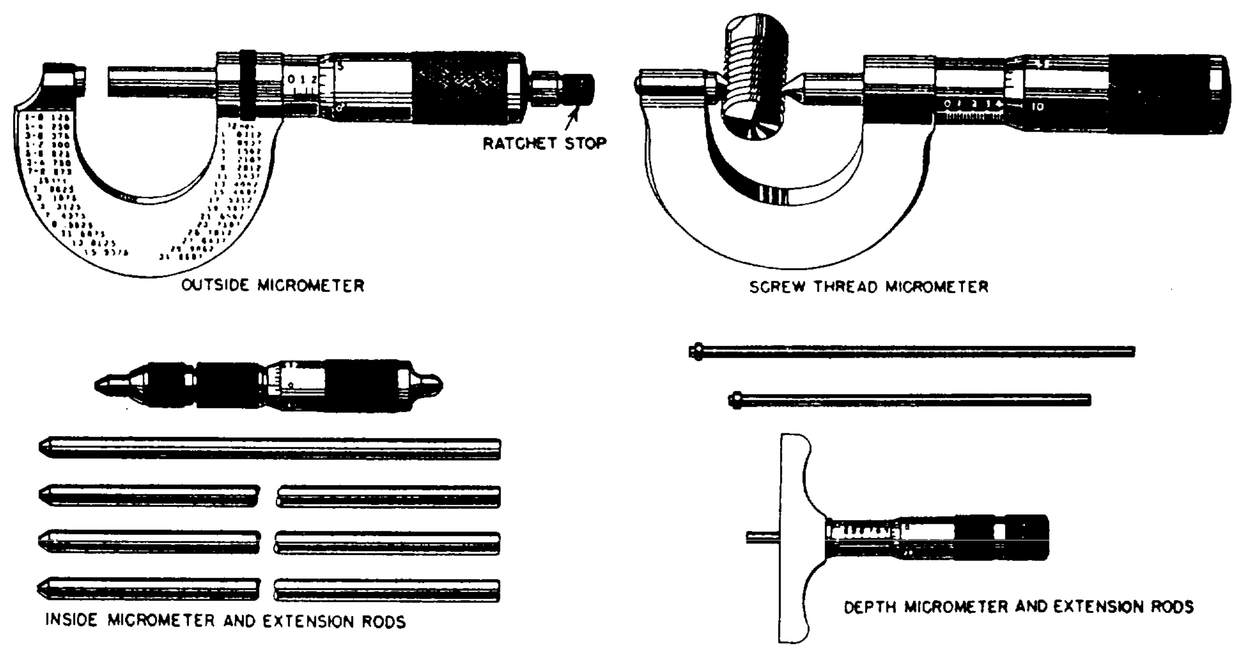


Figure 2-14.-Common types of micrometers.

designed to be turned. A screw is always designed to be turned by its head. Another minor difference between a screw and a bolt is that a screw is usually made of lower strength materials.

Threads on aircraft bolts and screws are of the American National Aircraft Standard type, This standard contains two series of threads—national coarse (NC) and national fine (NF). Most aircraft threads are of the NF series.

Bolts and screws may have right- or left-hand threads. A right-hand thread advances into engagement when turned clockwise. A left-hand thread advances into engagement when turned counterclockwise.

Bolts

Many types of bolts are used in modern aircraft, and each type is used to fasten something in place. Before we discuss some of these types, it might be helpful to list and explain some commonly used bolt terms. You should know the names of bolt parts and be aware of the bolt dimensions that must be considered in selecting a bolt.

The three principal parts of a bolt are the *head, grip,* and *threads,* as shown in figure 2-15. Two of these parts might be well known to you, but perhaps grip is an unfamiliar term. The grip is the unthreaded part of the bolt shaft. It extends from the threads to the bottom of the bolt head. The head is the larger diameter of the bolt and may be one of many shapes or designs.

To choose the correct replacement for an unserviceable bolt, you must consider the length of the bolt. As shown in figure 2-15, the bolt length is the distance from the tip of the threaded end to the head of the bolt. Correct length selection is indicated when the bolt extends through the nut at least two full threads. If the bolt is too short, it will not extend out of the bolt hole far enough for the nut to be securely fastened. If it is too long, it may extend so far that it interferes with the movement of nearby parts.

In addition, if a bolt is too long or too short, its grip will usually be the wrong length. As shown in figure 2-16, the grip length should be approximately the same as the thickness of the material to be fastened. If the grip is too short, the threads of the bolt will extend into the bolt hole. The bolt may act like a reamer when the material is vibrating. If the grip is too long, the nut will run out of threads before it can be tightened. In this event, a bolt with a shorter grip should be used. If the bolt grip extends only a short distance through the hole, a washer maybe used.

A second bolt dimension that must be considered is diameter. As shown in figure 2-15, the diameter of the bolt is the thickness of its shaft.

The results of using a wrong diameter bolt should be obvious. If the bolt is too big, it cannot enter the bolt hole. If the diameter is too small, the bolt has too much play in the bolt hole.

The third and fourth bolt dimensions that should be considered when you choose a bolt

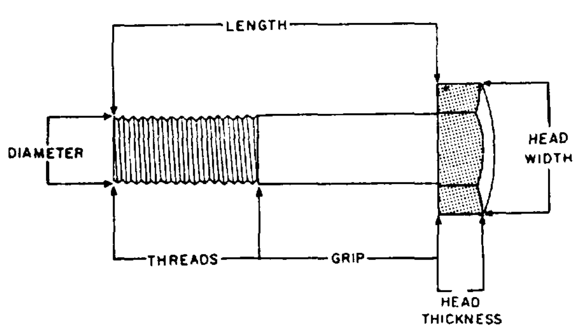


Figure 2-15.-Bolt terms and dimensions.

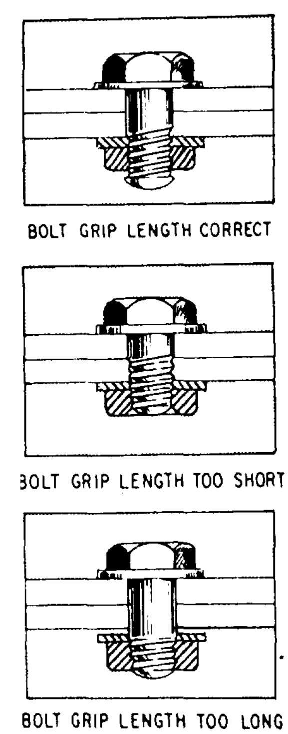


Figure 2-16.-Correct and incorrect grip lengths.

replacement are head thickness and width. If the head is too thin or too narrow, it might not be strong enough to bear the load imposed on it. If the head is too thick or too wide, it might extend so far that it interferes with the movement of adjacent parts.

AN bolts come in three head styles—hex head, clevis, and eyebolt. NAS bolts are available in countersunk, internal wrenching, and hex head styles. MS bolts come in internal wrenching and hex head styles. Head markings indicate the material of which standard bolts are made. Head markings may indicate if the bolt is classified as a close-tolerance bolt. See figure 2-17. Additional information, such as bolt diameter, bolt length, and grip length, may be obtained from the bolt part number. Refer to the *Structural Hardware Manual,* NAVAIR 01-1A-8, for complete identification of threaded fasteners.

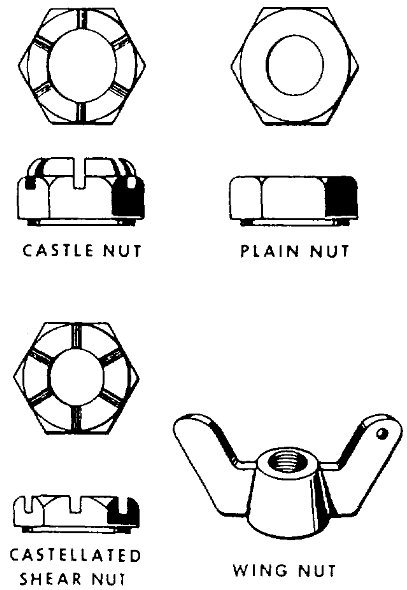


Figure 2-18.-Non-self-locking nuts.

Nuts

Aircraft nuts may be divided into two general groups: non-self-locking and self-locking nuts. Non-self-locking nuts are those that must be safetied by external locking devices, such as cotter pins, safety wire, or locknuts. The locking feature is an integral part of self-locking nuts.

NON-SELF-LOCKING NUTS.— The most common of the non-self-locking nuts are the castle nut, the plain hex nut, the castellated shear nut, and the wing nut. Figure 2-18 shows these non-self-locking nuts.

Castle nuts are used with drilled-shank AN hex-head bolts, clevis bolts, or studs. They are designed to accept a cotter pin or lockwire for safetying.

Castellated shear nuts are used on such parts as drilled clevis bolts and threaded taper pins. They are normally subjected to shearing stress only. They must not be used in installations where tension stresses are encountered.

Plain hex nuts have limited use on aircraft structures. They require an auxiliary locking device such as a check nut or a lock washer.

Use wing nuts where the desired tightness can be obtained by the fingers and where the assembly is frequently removed. Wing nuts are commonly used on battery connections.

SELF-LOCKING NUTS.— Self-locking nuts provide tight connections that will not loosen under vibrations. Self-locking nuts approved for use on aircraft must meet critical specifications. These specifications pertain to strength, corrosion resistance, and heat-resistant temperatures. Use new self-locking nuts each time components are installed in critical areas throughout the entire aircraft. Self-locking nuts are found on all flight, engine, and fuel control linkage and attachments. There are two general types of self-locking nuts. They are the all-metal nuts and the metal nuts with a nonmetallic insert to provide the locking action.

The elastic stop nut is constructed with a nonmetallic (nylon) insert, which is designed to lock the nut in place. The insert is unthreaded and has a smaller diameter than the inside diameter of the nut. Its use is limited to engine cold sections, since high heat could melt the nonmetallic insert.

Self-locking nuts are generally suitable for reuse in noncritical applications provided the

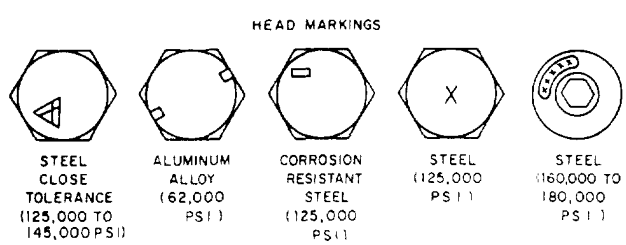


Figure 2-17.-Bolt head markings.

threads have not been damaged. If the locking material has not been damaged or permanently distorted, it can be reused.

NOTE: If any doubt exists about the condition of a nut, use a new one!

Installation of Nuts and Bolts

It is of extreme importance to use like bolts in replacement. In every case, refer to the applicable maintenance instruction manual and illustrated parts breakdown. Be certain that each bolt is of the correct material, size, and grip length. Examine the markings on the head to determine whether a bolt is steel or aluminum alloy. This knowledge is especially important if you are to use the bolt in the engine hot section.

Use washers under the heads of both bolts and nuts unless their omission is specified. A washer guards against mechanical damage to the material being bolted. A washer also prevents corrosion of the structural members. An aluminum alloy washer used under the head and nut of a steel bolt securing aluminum alloy or magnesium alloy members will corrode the washer rather than the members. Steel washers should be used when joining steel members with steel bolts.

Whenever possible, the bolt should be placed with the head on top or in the forward position. This positioning helps prevent the bolt from slipping out if the nut is accidentally lost.

WASHERS

Washers used in aircraft structures may be grouped into three general classes: plain, lock washers, and special washers. Figure 2-19 shows some of the most commonly used types.

Plain Washers

Plain washers are widely used under AN hex nuts to provide a smooth bearing surface. They act as a shim in obtaining the correct relationship between the threads of a bolt and the nut. They also aid in adjusting the position of castellated nuts with respect to drilled cotter pin holes in bolts. Plain washers are also used under lock washers to prevent damage to surfaces of soft material.

Lock Washers

Lock washers are used whenever the self-locking or castellated-type nut is not used.

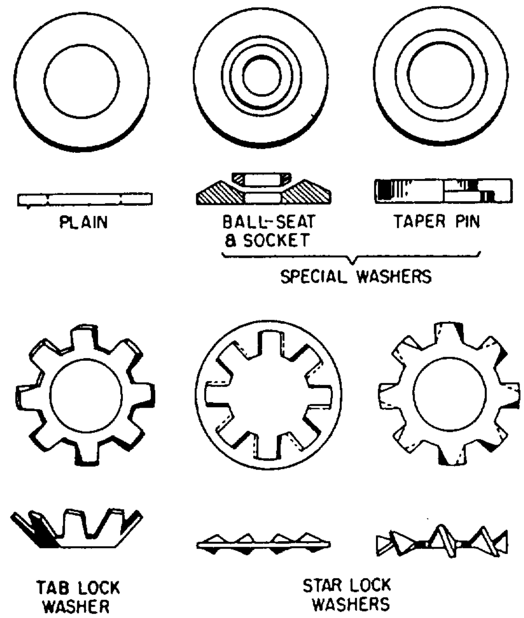


Figure 2-19.—Various types of washers.

Sufficient friction is provided by the spring action of the washer to prevent loosening of the nut because of vibration. Lock washers must not be used as part of a fastener for primary or secondary structures.

The star lock or shakeproof washer is a round washer made of hardened and tempered carbon steel, stainless steel, or Monel. This washer can have either internal or external teeth. Each tooth is twisted, one edge up and one edge down. The top edge bites into the nut or bolt, and the bottom edge bites into the working surface. It depends on spring action for its locking feature. This washer can be used only once because the teeth become compressed after being used.

Tab lock washers are round washers designed with tabs or lips that are bent across the sides of a hex nut or bolt to lock the nut in place. There are various methods of securing the tab lock washer to prevent it from turning. An external tab bent downward 90 degrees into a small hole in the face of the unit, an external tab that fits a keyed bolt, or two or more tab lock washers connected by a bar are some of the present methods used. Tab lock washers can withstand higher heat than other methods of safetying. The washer can be used safely under high vibration conditions. Use tab lock washers only once because the tab tends to crystallize when bent a second time.

Special Washers

Special washers such as ball-seat and socket washers and taper pin washers are designed for special applications. For example, the ball-seat and socket washer is used where the bolt may be installed at an angle to the surface. The washer is also used where perfect alignment with the surface is required, such as engine mount bolts.

CLAMPS

Clamps used on aircraft engines prevent lines from chafing on parts or against other lines. They can also connect two lines or pieces of material, Figure 2-20 shows examples of the Adell clamp to maintain line clearance and prevent chafing.

The Adell clamp shown in figure 2-20 comes in two different types. One is made of a rubber or Teflon® cushion for low-range temperatures. The second type has an asbestos cushion for high temperatures.

When installing clamps, be sure to use the proper size and material. Although clamps may be reused, make sure reused clamps are in good condition. Inspect support clamps for deterioration of the cushion material, to prevent the metal

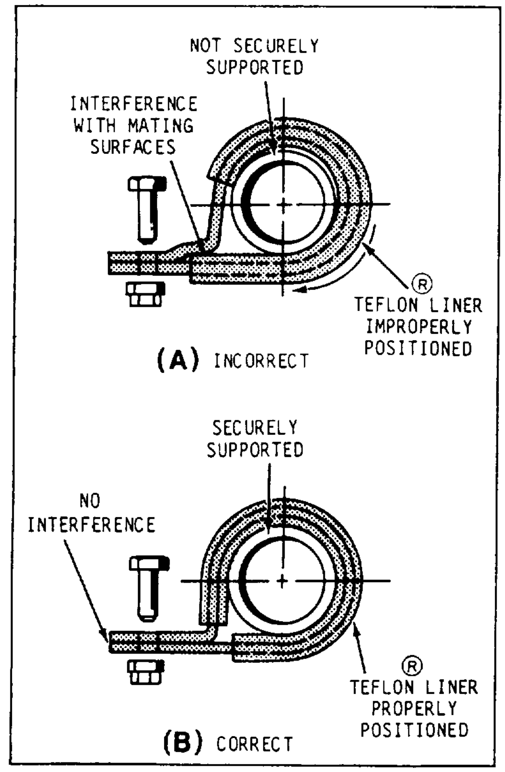


Figure 2-21.-Examples of (A) incorrect and (B) correct installation of hinged clamp.

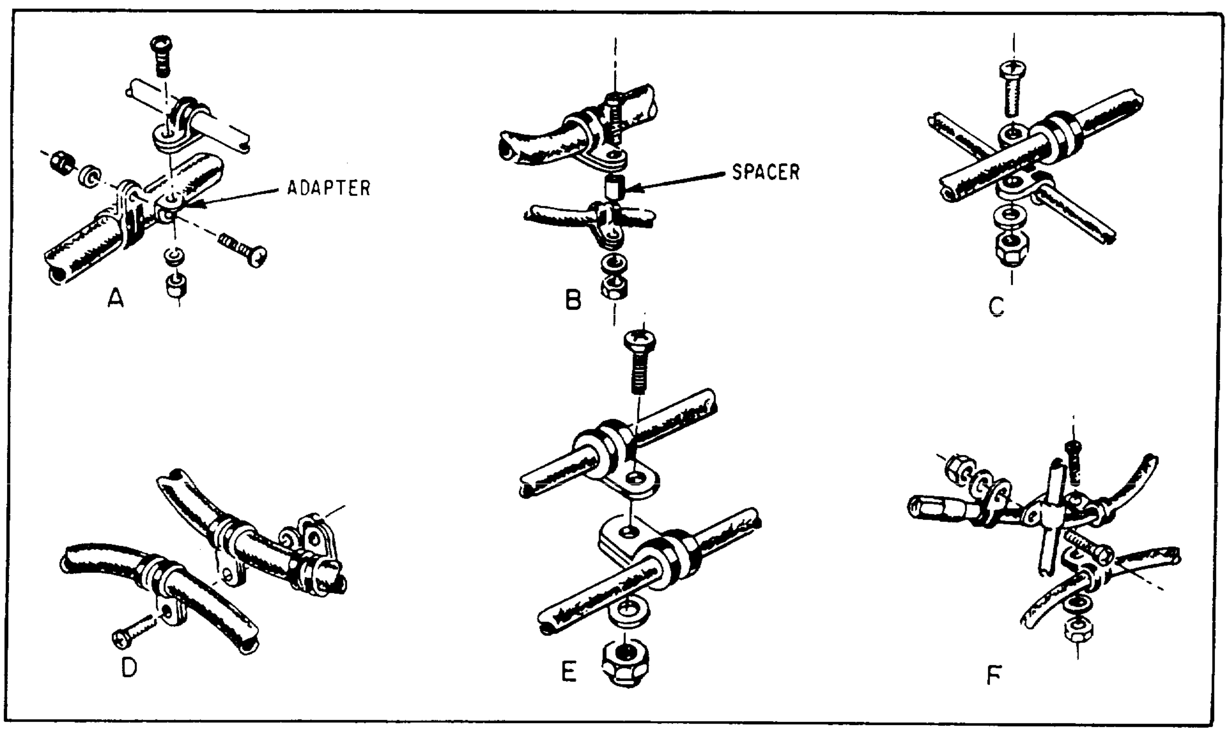


Figure 2-20.-Securing lines using support clamps.

part of the clamps from cutting or chafing the supported line. Carefully inspect clamps for proper installation. Figures 2-21 and 2-22 shows two examples of correct and incorrect installations, Figure 2-23 shows how improperly installed or wrong size clamps hide the damage they cause.

SAFETY METHODS

Safetying is a process of securing all aircraft bolts, nuts, capscrews, studs, and other fasteners. Safetying prevents the fasteners from working loose due to vibration. Loose bolts, nuts, or screws can ruin engines or cause parts of the aircraft to drop off. To carry out an inspection on an aircraft, you must be familiar with the various methods of safetying. Careless safetying is a sure road to disaster. Always use the proper method for safetying. You should always inspect for proper safetying throughout the area in which you are working.

There are various methods of safetying aircraft parts. The most widely used methods are safety

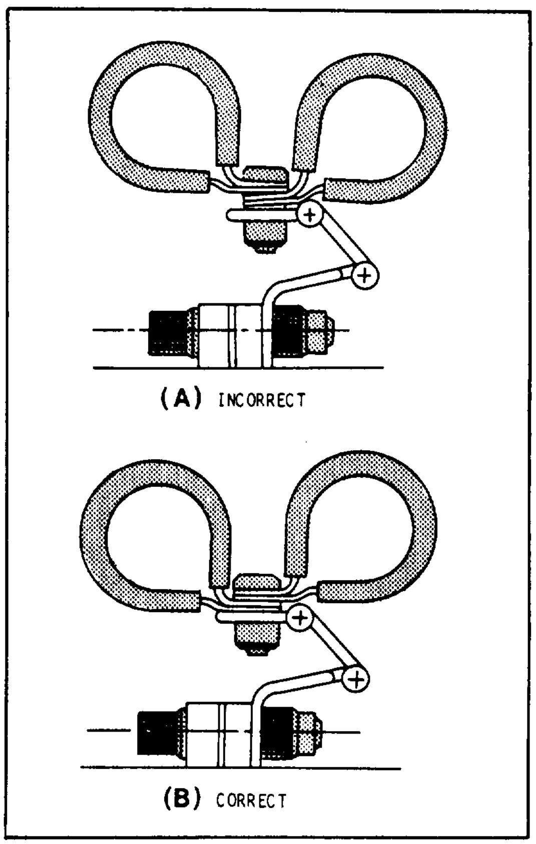


Figure 2-22.-Examples of (A) incorrect and (B) correct installation of Adell clamp.

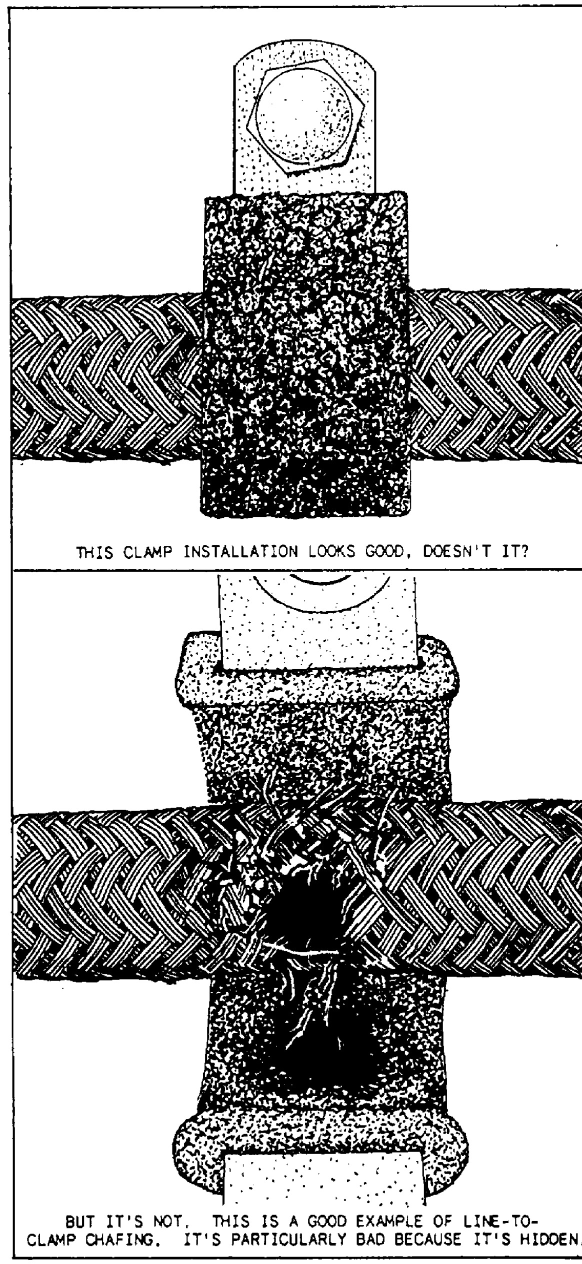


Figure 2-23.-Hidden damage from improperly installed clamp.

wire, cotter pins, lock washers, snap rings, and special nuts. Some of these nuts and washers have been described previously in this chapter. You should know how to use safety wire and cotter pins.

Safety Wiring

Safety wiring is the most positive and satisfactory method of safetying. It is a method of wiring together two or more units. Any tendency of one unit to loosen is counteracted by the tightening of the wire.

Nuts, bolts, and screws are safety wired by the single-wire double-twist method. This method is the most common method of safety wiring. A single-wire may be used on small screws in close spaces, closed electrical systems, and in places difficult to reach.

Figure 2-24 shows various methods commonly used in safety wiring nuts, bolts, and screws. Examples 1, 2, and 5 of figure 2-24 show proper methods of safety wiring bolts, screws, square-head plugs, and similar parts when wired in pairs. Examples 6 and 7 show a single-threaded component wired to a housing or lug. Example 3 shows several components wired in series. Example 4 shows the proper method of wiring castellated nuts and studs. Note that there is no loop around the nut. Example 8 shows several components in a closely spaced, closed geometrical pattern, using the single-wire method. Figure 2-25 shows safety wire techniques for T-bolt clamps.

When drilled-head bolts, screws, or other parts are grouped together, they are more conveniently

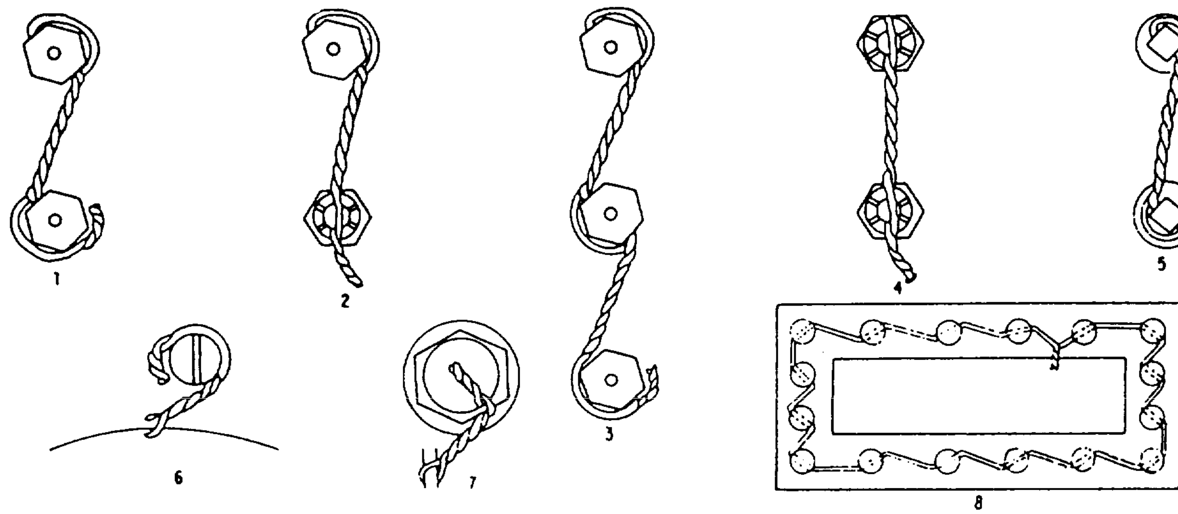


Figure 2-24.-Safety wiring methods.

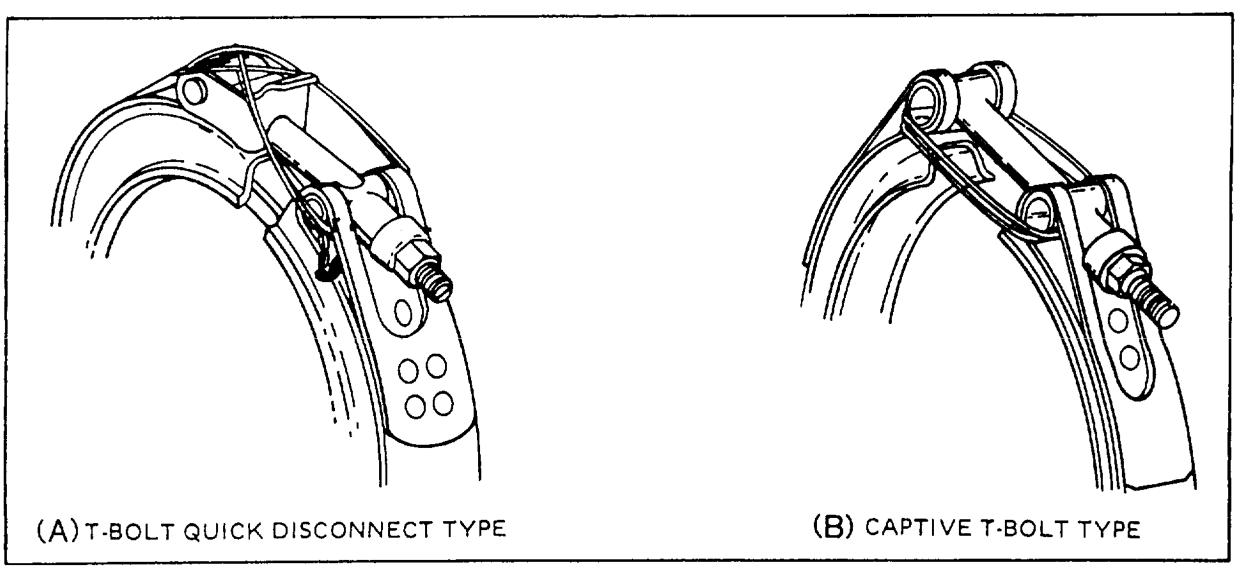


Figure 2-25.-V-band coupling safety wiring techniques.

safety wired to each other in a series rather than individually. The number of nuts, bolts, or screws that may be safety wired together depends on the application. For instance, when you are safety wiring widely spaced bolts by the double-twist method, a group of three should be the maximum number in a series.

When you are safety wiring closely spaced bolts, the number that can be safety wired by a 24-inch length of wire is the maximum in a series. The wire is arranged in such a manner that if the bolt or screw begins to loosen, the force applied to the wire is in the tightening direction.

When you use the safety wire method of safetying, follow these general rules:

1. Torque all parts to the recommended values, and align holes before you attempt to proceed with the safetying operation. Never over-torque or loosen a torqued nut to align safety wire holes.
2. The safety wire must be new upon each application.
3. When you secure castellated nuts with safety wire, tighten the nut to the low side of the selected torque range unless otherwise specified. If necessary, continue tightening until a slot aligns with the hole.
4. All safety wires must be tight after installation but not under such tension that normal handling or vibration will break the wire.
5. Apply the wire so that all pull exerted by the wire tends to tighten the nut.
6. Twists should be tight and even, and the wire between the nuts should be as taut as possible without being overtwisted.
7. A pigtail of 1/4 to 1/2 inch (three to six twists) should be made at the end of the wiring. This pigtail must be bent back or under to prevent it from becoming a snag.

Safety wire comes in different sizes and material. Use the size and material appropriate for the job. When using the single-wire method, you should use the largest size wire that the hole will accommodate. Different types of safety wire include Monel for normal use, Inconel for high temperatures (800- 1500 degrees), and alclad for nonmagnetic applications.

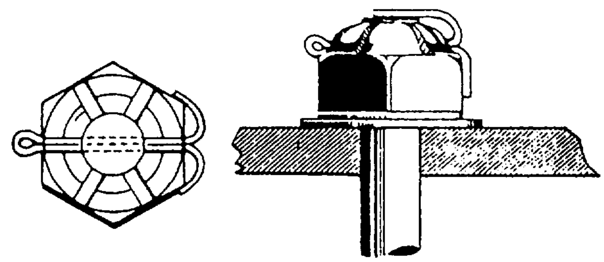


Figure 2-26.-Cotter pin installations.

Cotter Pins

Use cotter pins to secure bolts, screws, nuts, and pins. Some cotter pins are made of low-carbon steel, while others consist of stainless steel and thus are more resistant to corrosion. Use stainless steel cotter pins in locations where non-magnetic material is required. Regardless of shape or material, use all cotter pins for the same general purpose— safetying.

NOTE: Whenever uneven-prong cotter pins are used, the length measurement is to the end of the shorter prong.

Cotter pin installation is shown in figure 2-26. Use castellated nuts with bolts that have been drilled for cotter pins. Use stainless steel cotter pins. The cotter pin should fit neatly into the hole, with very little side-play. The following general rules apply to cotter-pin safetying:

- Do not bend the prong over the bolt end beyond the bolt diameter. (Cut it off if necessary.)
- Do not bend the prong down against the surface of the washer. (Again, cut it off if necessary.)
- Do not extend the prongs outward from the sides of the nut if you use the optional wraparound method.
- Bend all prongs over a reasonable radius. Sharp angled bends invite breakage. Tap the prongs lightly with a mallet to bend them.

CHAPTER 3

AVIATION SUPPORT EQUIPMENT

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Recognize the means to identify different types of support equipment.
- Identify the purpose, operation, and safety precautions in using both powered and non-powered support equipment.
- Identify the function of the Support Equipment Training and Licensing Program.

As naval aircraft have become more complex, the equipment used to support them has become more complex. The Aviation Machinist's Mate uses many different types of support equipment (SE) to maintain aircraft in top condition. Some support equipment such as tow tractors and power units are common to many different aircraft. There is also a long list of SE that applies only to a specific type or model of aircraft. Using SE correctly is a challenging, sometimes dangerous, but never routine operation. The support equipment manuals or the maintenance instruction manuals (MIMs) cover the proper operating procedures and safety precautions for the use of SE. Read the manuals, learn to use the equipment, and become qualified on it before you are required to use it.

Over the years safety procedures and precautions for operating SE have developed mainly from direct experience. Unfortunately, much of that experience was gained as a result of accidents. Each of us must be aware that accidents don't "just happen." People cause accidents. We are all capable of having an accident, for any number of reasons. Carelessness, complacency, haste, ignorance, shortcuts, fatigue, and stress are some of reasons given for SE accidents. It's amazing, and a little sad, that the same type of SE accidents happen over and over again each year. Each year the Navy spends millions of dollars to repair damaged SE and aircraft caused by the improper use of SE. Navy personnel are injured, maimed, or killed by improper use of SE because of failure to follow prescribed safety precautions. We must do something to eliminate these tragedies and costs.

This chapter discusses SE identification and the use of different types of SE. You will learn about the hazards, safety precautions, and proper procedures to follow when using both powered and nonpowered SE. Finally, you will learn about the SE Training and Licensing Program, as discussed in OPNAVINST 4790.2.

IDENTIFICATION OF SUPPORT EQUIPMENT

In previous years, identifying SE has been somewhat difficult. You learned the designations and applications of the equipment by association. You knew that an MD-3 was a tow tractor; so was a TA-18 and a JG-75. There were several more tow tractors, but there was nothing in their designations that showed that they had anything in common. Support equipment is now undergoing

CHART 1 - Equipment Indicators			
INSTALLATION (1st Indicator)	**TYPE OF EQUIPMENT** (2nd Indicator)	**PURPOSE** (3rd Indicator)	**Miscellaneous Identification**
A - Aircraft or Missile (Installed in or on vehicle, nonmission expendable) B - Aircraft or Missile (Transported, but not installed in or on vehicle, mission expendable) C - Combination (Ground and Airborne) E - Ground, Not Fixed F - Ground, Fixed M - Ground, Self-contained (Movable, includes vehicle but not self-propelled) N - Aircraft or Missile (Transported, but not installed in or on vehicle, nonmission expendable) P - Personal use (Held or worn by individual) S - Ground, Self-propelled (Includes vehicle) U - Multi-installation W - Water (Surface or Submerged)	22 - Apparel 23 - Chemical 24 - Electrical 25 - Explosive 26 - Gaseous 27 - Hydraulic 28 - Materials, Pliable (fabric, rubber, etc.) 29 - Materials, Rigid (metals, wood, etc.) 32 - Mechanical 33 - Nuclear 34 - Pneumatic 35 - Optical 36 - Optimechanical 37 - Electromechanical 38 - Invisible Light (Infrared) 39 - Inertial 42 - Electrohydraulic 43 - Manual 44 - Internal Combustion 45 - Biological 46 - Pneumatic-Hydraulic 47 - Electropneumatic 48 - Hydromechanical 49 - Gunnery 82 - Mobile Deployment (Bare Base) - Miscellaneous 83 - Mobile Deployment (Bare Base) - Medical including dental, surgical, x-ray, etc. 84 - Mobile Deployment (Bare Base) - Billeting/Administration 85 - Mobile Deployment (Bare Base) - Shop facilities - all types except electronics 86 - Mobile Deployment (Bare Base) - Food Serving including kitchen, dining, etc. 99 - Miscellaneous Note: Where more than one type number applies, use the one most applicable.	A - Aircraft or Missile B - Bombing or Fire Control or Both (Nonelectronic) C - Air Conditioning D - Detection E - Destruction G - Flight Control or Navigation or Both (Nonelectronic) H - Aircraft Loading and Cargo Handling J - Indicating K - Aerial Stores (Munitions) Handling L - Lubricating M - Maintenance, Aircraft P - Protection Q - Reconnaissance (Nonelectronic) R - Fueling S - Personnel Support T - Testing U - Special, Not Otherwise Covered, or Combination of Purposes V - Maintenance Automotive W - Graphic Arts X - Identification Y - Dissemination	T - Training (V) - Variable Configuration

Figure 3-1.-Equipment indicator code.

a change in designations to group them by application. Newly constructed and modified support equipment is now identified by MIL-STD-875A. This designation system for aeronautical and support equipment will be identical throughout the military services. Present SE with old designations remain the same until they undergo an alteration or modification; then they are redesignated.

Some time ago the tow tractor, known to the fleet as the MD-3, underwent the service life extension program (SLEP). It emerged fleet-ready and redesignated as the A/S32A-31. The new system is different from those you may be accustomed to, but it is a long-needed improvement. After you study the equipment indicators chart from MIL-STD-875A, you'll see it isn't so difficult after all. See figure 3-1. Figure 3-2 shows a breakdown of the A/S32A-31.

TYPES OF SUPPORT EQUIPMENT

Support equipment is all equipment required on the ground to make an aeronautical system, system command and control system, support system, subsystem, or end item of equipment operational in its intended environment. SE is primarily that equipment covered by the Aircraft Maintenance and Material Readiness List (AMMRL) Program.

Support equipment is categorized as common (general-purpose) and peculiar (special-purpose). SE is normally identified as either powered or nonpowered. SE types maybe further divided into the categories of avionic SE and nonavionic SE.

Avionic SE (common and peculiar) includes all equipment of an electronics nature used for, but not limited to, the testing, troubleshooting, alignment, or calibration of aircraft systems or components. Avionic SE include general-purpose electronic test equipment (GPETE) and automatic test equipment (ATE). Examples of this type of SE include multimeter, pressure testers, and fuel quantity indicator test sets.

Nonavionic SE (common and peculiar) includes all equipment that is nonelectric in nature and may be powered or nonpowered. Examples of powered equipment are mobile electric power plants (NC-10C), aircraft tow tractors (A/S32A-31), and mobile air-conditioners (A/M32C-17). Examples of nonpowered SE are engine stands (4000A) and maintenance workstands (B-4).

POWERED SUPPORT EQUIPMENT

The most common types of powered SE are the mobile electric power plants (MEPPs), the mobile motor-generator sets (MMGs), the mobile air-conditioners, the gas turbine compressors (GTCs), and the portable hydraulic power supplies/hydraulic test stands.

MOBILE ELECTRIC POWER PLANTS (MEPPs)

Mobile electric power plants supply regulated electrical power for aircraft servicing, starting, maintenance, and testing. There are various types of motor generator assemblies. Some supply dc power only, while others furnish both dc and ac power.

The MEPPs used today are designed for operation on shore stations and aboard aircraft carriers. On aircraft carriers, these units are usually mobile with minimum vehicular dimensions

Tow Tractor	A/	S	32	A	31
Item Name	Aero/ Support Equipment	Ground, Self-Propelled	Mechanical	Aircraft or Missile Support	The 31st equipment in the 32A category to which a type designation has been assigned

Figure 3-2.-Equipment type designation.

and weight. They are designed for the utmost maneuverability and mobility. On shore stations, these units may be mobile or they maybe mounted on trailers and require towing. There are many types of MEPPs in use. The type used depends upon the type of aircraft to be serviced.

MEPPs, especially the self-propelled type, are high on the list of SE involved in ground accidents with aircraft. In addition to the hazards of driving or towing MEPPs with cables still plugged into the aircraft, there is the possibility of damage to the aircraft's electrical or electronic systems due to improper electrical operation. High voltage is certainly a hazard in the use of all MEPPs. Although protective insulation and covers provide protection, malfunctions or improper operation can create electrical shock hazards.

NC-2A Power Plant

The NC-2A is a self-propelled MEPP. See figure 3-3. It is designed primarily for use aboard aircraft carriers. This unit is powered by a three-cylinder, two-cycle, series 53 Detroit diesel engine governed at 2,550 rpm. The NC-2A is front-wheel driven and steered by the rear wheels. The steering is similar to that of a forklift, and is highly maneuverable in congested areas. The unit has a turning radius of approximately 11 feet. The front wheels are driven by a variable-speed, reversible, 28-volt dc electric motor. It is capable of propelling the unit up to 14 mph on level terrain.

The diesel engine drives the generators through a speed-increasing transmission to produce a 115/200-volt, three-phase ac, and 28-volt dc power. The electrical power controls are located on two panels at the right side of the operator's compartment. The propulsion control and engine instruments are on the control panel forward of the steering wheel.

The power plant uses two electronic governors—the engine governor assembly and the drive-control module governor assembly. The engine governor assembly monitors the output frequency of the ac generator and controls the engine speed. Speed control is achieved by the governor-controlled torque motor, which adjusts the engine internal fuel control. The drive-control module governor assembly controls the torque motor by the position of the accelerator pedal when the START/DRIVE SERVICE POWER is in the START/DRIVE position. The accelerator pedal uses a variable resistor, not mechanical linkage.

One of the primary hazards of this MEPP is the unusual driving characteristic. The rear wheel steering puts the maneuvering part of the vehicle behind you. It takes lots of practice to become familiar with rear-wheel steering, and you should be totally familiar with it before maneuvering close to aircraft on the flight line.

NC-8A Power Plant

The NC-8A is a mobile, self-propelled unit used for servicing and starting rotary- and fixed-wing aircraft. See figure 3-4. This MEPP is used primarily aboard shore stations. It is powered by a four-cylinder, two-cycle, diesel engine controlled by an electrohydraulic governor.

This unit has one dual-purpose generator capable of supplying both ac and dc power simultaneously. It consists of a dc generator and a synchronous alternator enclosed in one housing.

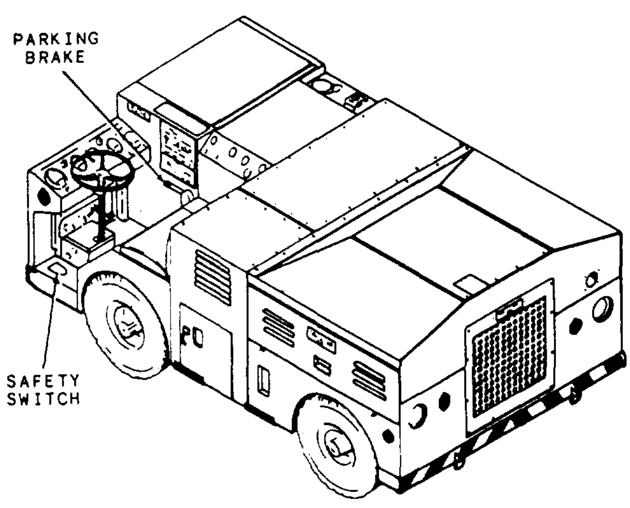


Figure 3.3.-NC-2A mobile electric power plant (MEPP).

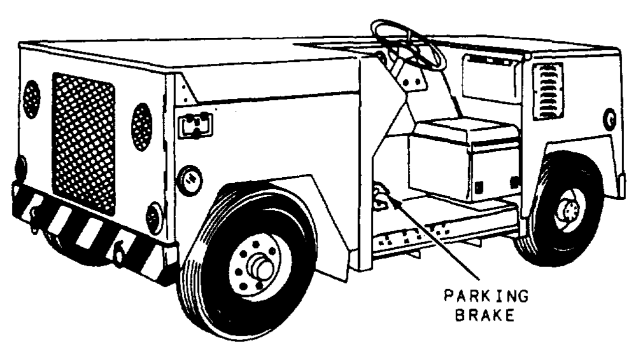


Figure 3-4.-NC-8A mobile electric power plant (MEPP).

The dc generator provides 28 volts, 500 amperes continuously, or 28 volts, 750 amperes intermittently. The ac generator provides 120/208 volts, three phases, 400 Hz, 60 kVA, and 68 amps at a .8 power factor when only the ac power is being used,

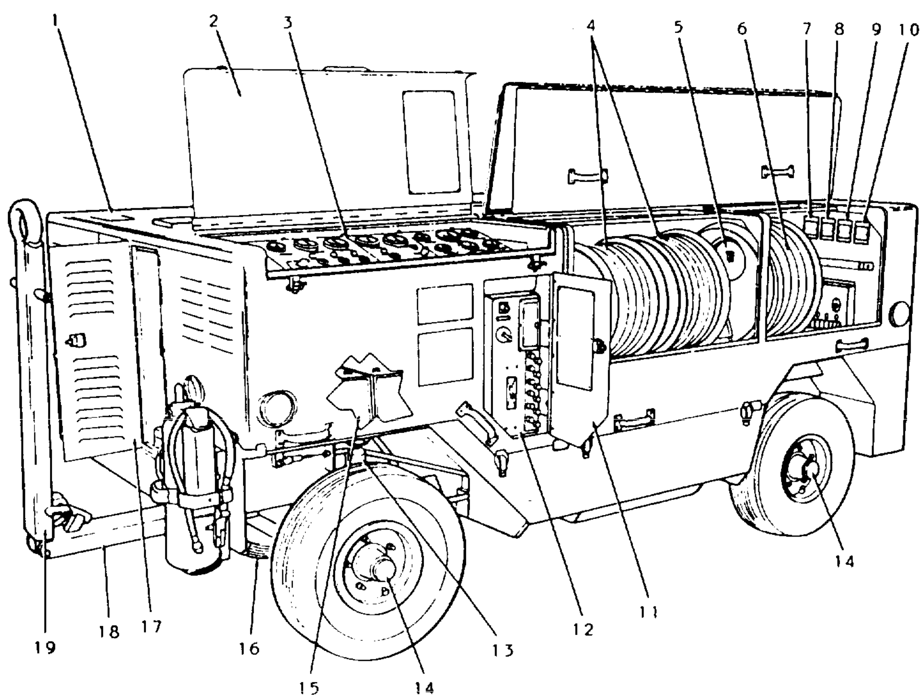
All engine controls and instruments are located directly in front of the operator. Controls and instruments for the generators are located to the operator's right.

Vehicle propulsion is provided by a 28-volt dc, reversible, variable-speed motor. The motor is connected to the rear wheels via an automotive-type differential. The speed is controlled by a variable resistor in the accelerator pedal. The direction of travel is controlled by a switch mounted on the engine instrument/control panel.

A primary hazard associated with the NC-8A is the tendency for the SE operator to drive off with the power cables still connected to the aircraft. Although a SE change (SEC) has been incorporated to prevent propulsion unless the power cables are properly stowed has decreased this hazard, this accident still occurs because of defective cable receptacles. Noxious gases, heat, and exhaust sparks from the diesel engine are hazardous. Noise from diesel engine SE is a serious hazard. Most operate above the 90 dBA level, so hearing protection is a must! Other hazards associated with the NC-8A include personnel with poor driving habits or inadvertent NC-8A movement while close to the aircraft.

NC-10C Power Plant

The NC-10C is designed for shore-based facilities. See figure 3-5. The unit will supply regulated electric power up to 90 kVA at .08 power factor, 120/208-volt, three-phase, 400-Hz ac for servicing, maintenance, and starting of helicopter and jet aircraft. The unit is powered by a Detroit diesel six-cylinder, two-cycle engine.



1. **Fuel fill access door**
2. **Control panel access door**
3. **Control panel**
4. **Cable reels and cables ac**
5. **Floodlight**
6. **Cable reel and cable dc**
7. **Overvoltage relay**
8. **Undervoltage relay**
9. **Overfrequency relay**
10. **Underfrequency relay**
11. **Fuse panel assembly access door**
12. **Fuse panel assembly**
13. **Shock absorber**
14. **Running gear**
15. **Battery**
16. **Leaf spring**
17. **Exhaust air doors**
18. **Steering arm**
19. **Drawbar**

Figure 3-5.-NC-10C mobile electric power plant (MEPP).

A portion of the generated ac power is rectified to supply 28-volt dc at 750 amperes continuously.

The unit is self-contained and requires no external electrical or mechanical sources of power. It may be towed at speeds up to 20 mph. The efficiency of the NC-10C is not affected on inclines up to 15 degrees maximum in any direction from horizontal. Climatic conditions of operation are from – 18°F to 120°F (– 22°C to 50°C) and under relative humidity up to 100 percent. It will operate efficiently at altitudes from sea level to 8,000 feet.

The general hazards of high voltage, hot cables, noise, noxious gases, and exhaust heat are all applicable to the NC-10C. There is also no lockout circuit to prevent moving the unit with the cables still plugged into the aircraft.

MOBILE MOTOR-GENERATOR SETS (MMGs)

Mobile motor-generator sets perform the same function as the mobile electric power plants, but they are not self-contained and require an external source of electrical power for operation. The MMG-1A and MMG-2 are primarily used in hangars on shore stations, or on the hangar decks of aircraft carriers where the running of an internal combustion engine would be objectionable and where external power (220-440/60 Hz) is readily available.

MMG-1A Motor Generator Set

The MMG-1A, shown in figure 3-6, is a small, compact, trailer-mounted, electric motor-driven generator set used to provide 115/200-volt, three-phase, 400-hertz ac, and 28-volt dc power for ground maintenance, calibration, and support for various types of aircraft systems and equipment. Operation of the unit requires a three-phase, 60-hertz, 220- or 440-volt ac external power source. It is used both aboard ship and ashore.

The unit is not self-propelled and must be towed or manually moved. The four-wheel trailer is equipped with tie-down rings, pneumatic tires, and a tow bar in front for towing or manual steering. A mechanically actuated hand brake, located on the front of the unit, is connected to drum/shoe type of brakes on the rear wheels. Maximum towing speed is restricted to 5 mph. The MMG-1A weighs 4,120 pounds. It is 7 feet 10 inches long, 4 feet 2 inches wide, and 3 feet 6 inches high.

Stowage compartments are located at the rear of the unit for 30-foot ac and dc output cables. The 30-foot input power cable is stowed in a compartment at the left front side of the unit. Control panels and a utility power connector panel are located under fold-open panels on the right front side of the unit. A portable floodlight, which can be attached to a mounting bracket atop the unit, is stored in a door compartment at the front of the unit.

MMG-2 Motor Generator Set

The MMG-2 is physically quite small and compact. See figure 3-7. It is a trailer-mounted, electric motor-driven generator set used to provide 120/208-volt, 400-Hz ac power, and 28-volt dc power for use in ground maintenance, calibration, and support for all fighter/interceptor types of aircraft equipment.

MOBILE AIR-CONDITIONERS

Mobile air-conditioners are designed to cool, ventilate, dehumidify, and filter the air used in aircraft cabins and compartments. Although mobile air-conditioners are usually associated

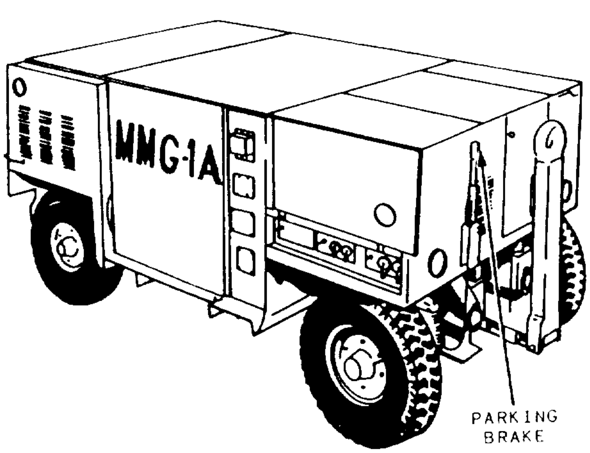


Figure 3-6.-MMG-1A.

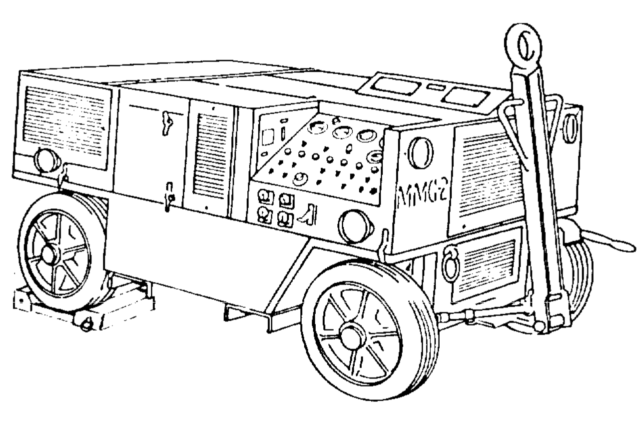


Figure 3-7.-MMG-2.

with them since you will be working around them.

Some of the hazards for air-conditioning units are the same as other diesel or electrical support equipment. These hazards include noise, high voltage, high-pressure fluids, and exhaust fumes. In addition, air-conditioners have large, whirling fans and blowers and refrigerant 22 in both the liquid and gaseous state.

Refrigerant 22 (R-22) is nonflammable, nontoxic, nonexplosive, and odorless. However, it can still be dangerous. It can cause serious "burns" in its liquid state. R-22 vapors displace oxygen in the air, and if enough is inhaled, it can cause asphyxiation.

A/M32C-17 Mobile Air-Conditioner

The A/M32C-17 mobile air-conditioner is a self-contained, trailer-mounted unit. See figure 3-8.

All the power-consuming components of the A/M32C-17 are driven by an industrial diesel

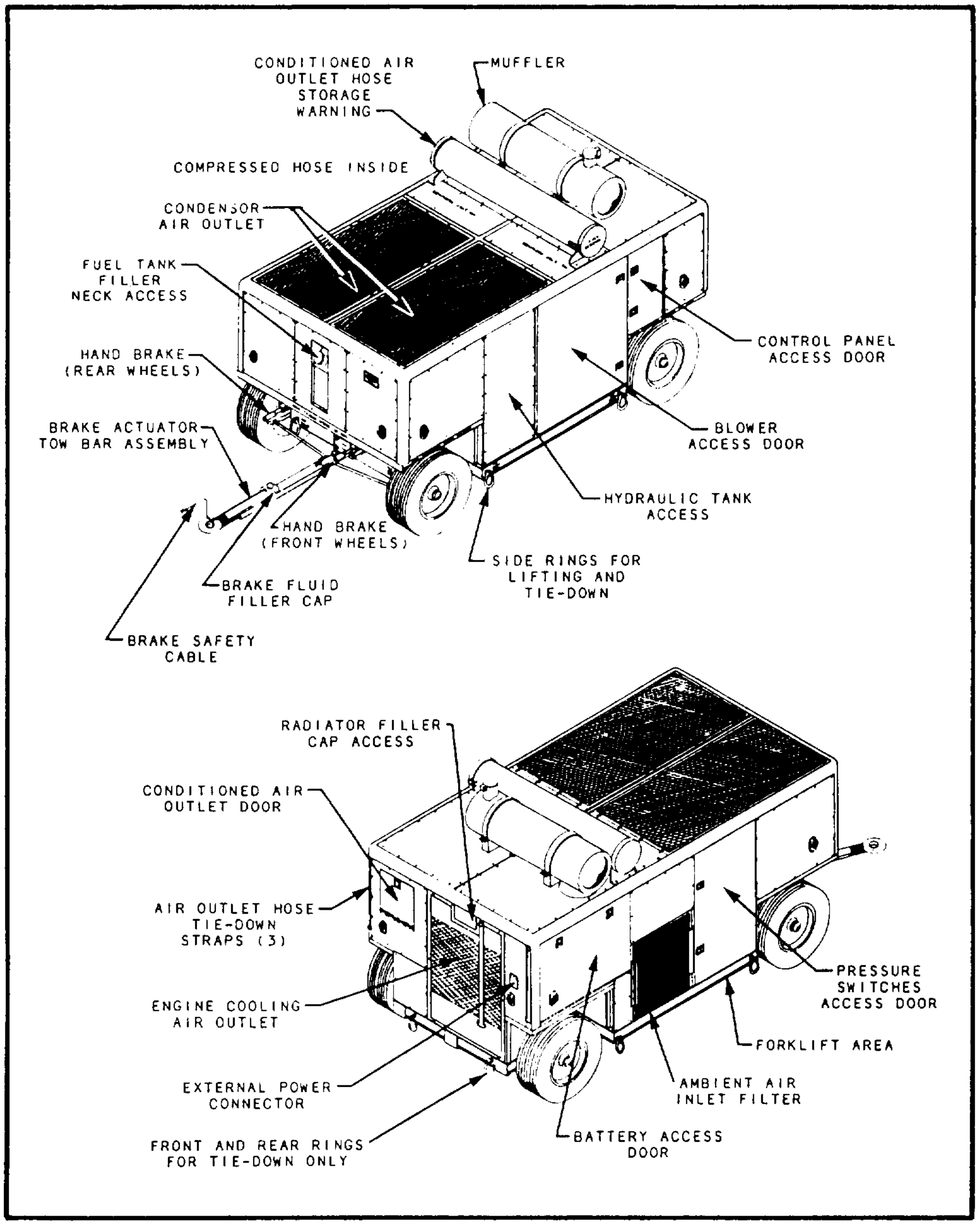
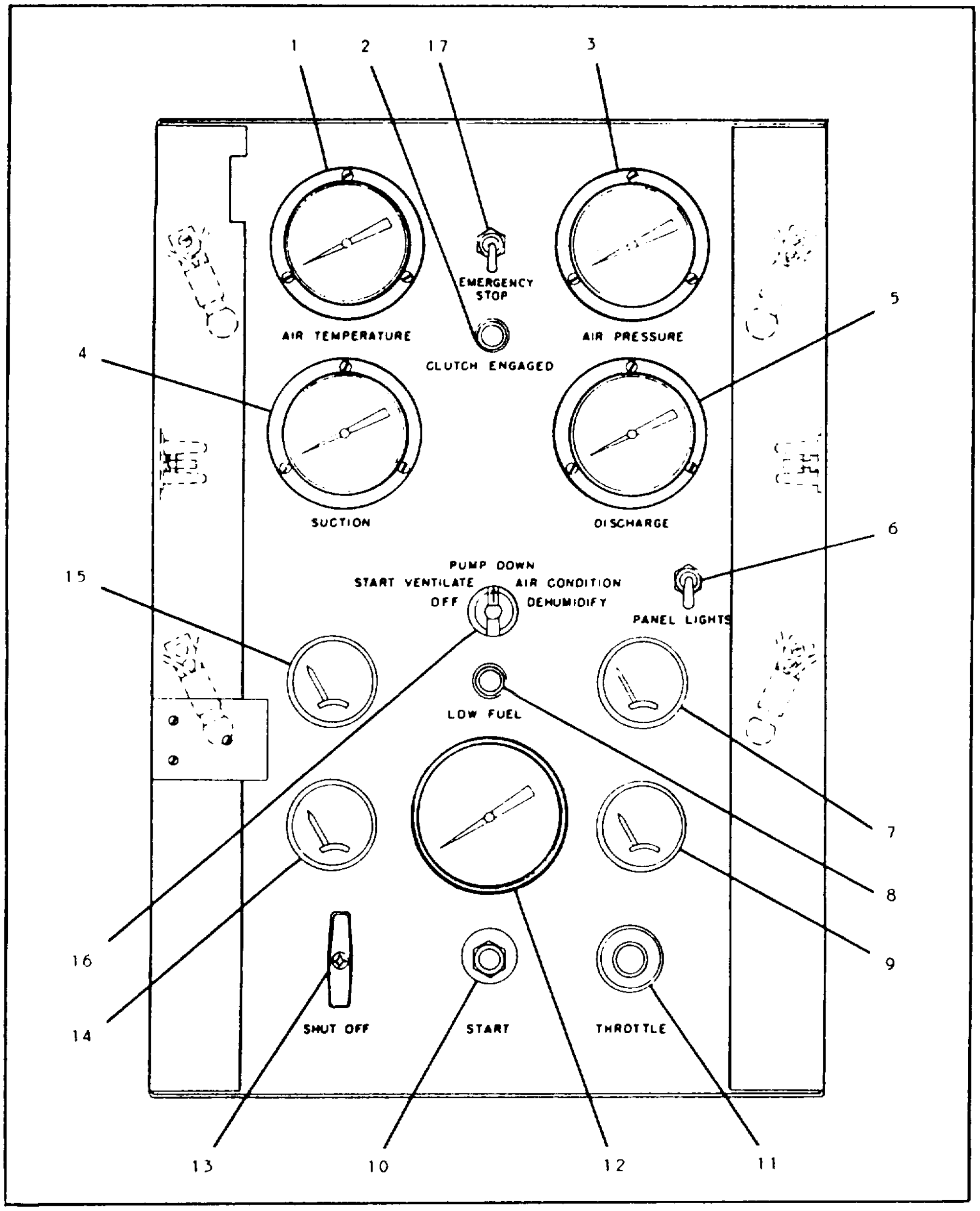


Figure 3-8.-A/M32C-17 mobile air-conditioning unit.

engine. The operating controls are mounted on the control panel located in a compartment above the left rear wheel of the trailer. See figure 3-9. Figure 3-10 describes the operation of each control on the control panel.

NR-5C Mobile Air-Conditioner

The NR-5C air-conditioner is a mobile, trailer-mounted unit. See figure 3-11. The NR-5C is electric powered. The compressor is powered by



1. Outlet air temperature gauge
2. Clutch indicator light
3. Outlet air pressure gauge
4. Compressor suction gauge
5. Compressor discharge pressure gauge
6. Panel light switch
7. Fuel level gauge (large rank)
8. Fuel warning light
9. Engine coolant temperature gauge
10. Starter switch
11. Engine speed throttle
12. Tachometer and operating-time meter
13. Fuel shutoff
14. Engine oil pressure gauge
15. Voltmeter
16. Selector switch
17. Emergency stop (not on units with HKQ serial numbers)

Figure 3-9.-A/M32C-17 operating control panel.

NOMENCLATURE	FUNCTION/INDICATION	NORMAL OPERATING RANGE
1. Outlet air temp.	Indicates outlet air temperature	As desired
2. Clutch indicator light	Light ON indicates clutch engaged	ON-OFF
3. Outlet air pressure	Indicates outlet air pressure	1 - 4.5 psig
4. Compressor suction pressure	Indicates compressor suction	48 - 65 psig
5. Compressor discharge pressure	Indicates compressor head pressure	100 - 365 psig
6. Panel light switch	Illuminates control panel	ON-OFF
7. Fuel level gauge	Indicates fuel level in large tank	FULL to EMPTY
8. Fuel warning light	Indicates large fuel tank is empty; small fuel tank is low	ON-OFF
9. Engine coolant temperature	Indicates engine coolant temperature	Approx 180°F (82°C)
10. Starter switch	Rotates engine to start	Momentary ON
11. Throttle	Controls engine speed (rpm)	(Refer to tachometer)
12. Tachometer and opersting-time meter	Indicates engine speed (rpm) and elapsed operating time	500 rpm (Idle) 2000 rpm (Normal)
13. Fuel shutoff	Cuts off fuel supply to engine	ON-OFF
14. Oil pressure gauge	Indicates engine oil pressure	30 - 60 psig
15. Voltmeter	Indicates operation of alternator and battery condition	Variable
16. Selector switch	Selects operating modes	As desired
17. Emergency stop switch (Not on units with HKQ serial numbers)	Stops unit in emergency situations without allowing for engine cooling or refrigeration pump down	Move up to stop unit

Figure 3-10.-A/M32C-17 control functions and ranges.

a 440-volt ac, three-phase, 60-cycle, 30-horsepower electric motor, which is an integral part of the compressor.

The NR-5C is mounted on four wheels. The two rear wheels are nonsteerable, shock absorbing on heavy-duty cushion tread tires. Two swivel shock-absorbing wheels incorporate parking brakes that are applied or released by a single manual control lever located at the front of the unit. Access doors and panels are provided for

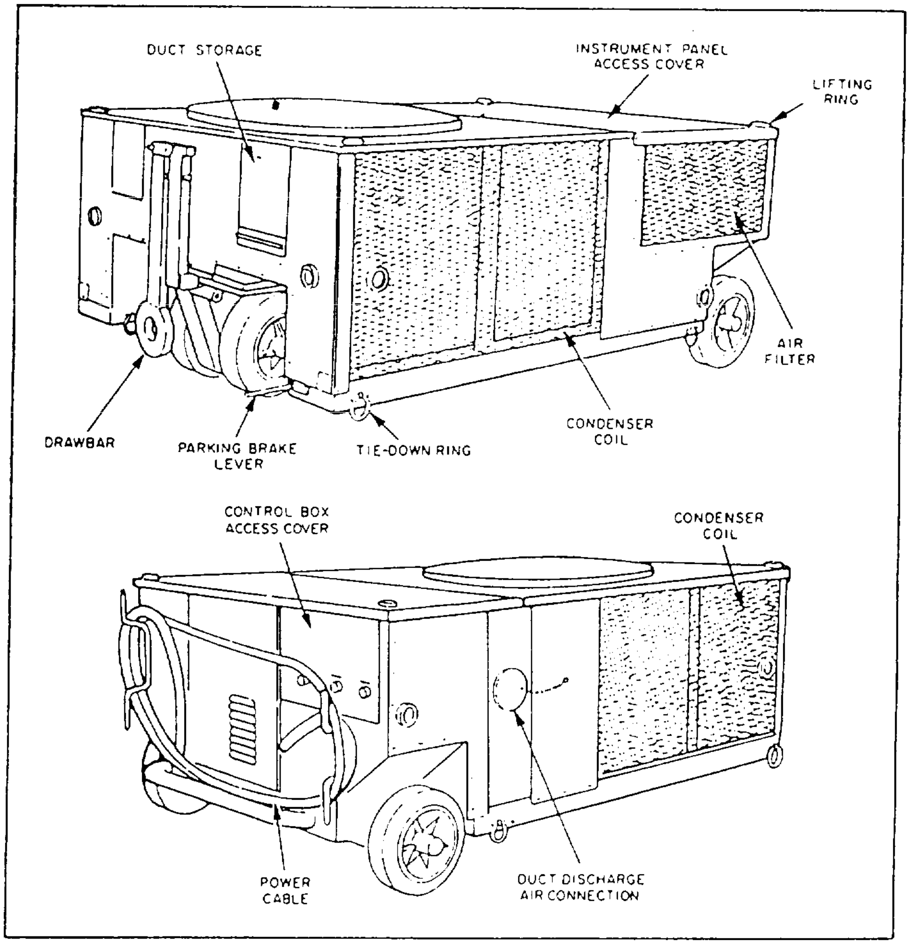


Figure 3-11.-NR-5C mobile air-conditioning unit.

full accessibility. Four lifting rings are mounted on the upper corners of the unit, and four tie-down rings are mounted on the bottom corners of the unit.

NR-10 Mobile Air-Conditioner

The NR-10 mobile air-conditioner is also a trailer-mounted, self-contained, air-conditioning unit. See figure 3-12. A six-cylinder, turbo-charged, diesel engine supplies all the power for the operation of the air-conditioner.

The engine is liquid cooled by means of a radiator. Airflow through the radiator is provided by the condenser fan. The trailer assembly consists of the tow bar and four independent suspension wheels. The tow bar assembly is designed so that when the front wheels attain their maximum angular position, a cam on the tow bar assembly is released, allowing the tow bar to continue following the motion of the towing vehicle. All four wheels are provided with a hydraulic braking system on the tow bar for towing, and all four wheels have parking brakes that are controlled by two parking brake handles mounted on the front of the vehicle.

GAS TURBINE COMPRESSORS (GTCs)

Gas turbine compressors supply compressed air for systems requiring large quantities (volume) of air at low pressure. The gas turbines you will be using are used to supply air for starting jet aircraft engines. Some of the units also include a power generating system.

Anytime you are around GTCs you must be aware of the dangers associated with them. A noise hazard exists anytime you are around GTCs. The exhaust gases of the GTC are also very hazardous. Hot, high-velocity gases can burn you or any part of the aircraft they hit. If the aircraft is loaded with external fuel tanks or weapons, the exhaust can be extremely dangerous. Another danger comes from the high-pressure air in the air start hoses. Disconnects or ruptures happen most often during the initial surge of air through the hose. A flailing hose end can severely injure personnel and damage the aircraft.

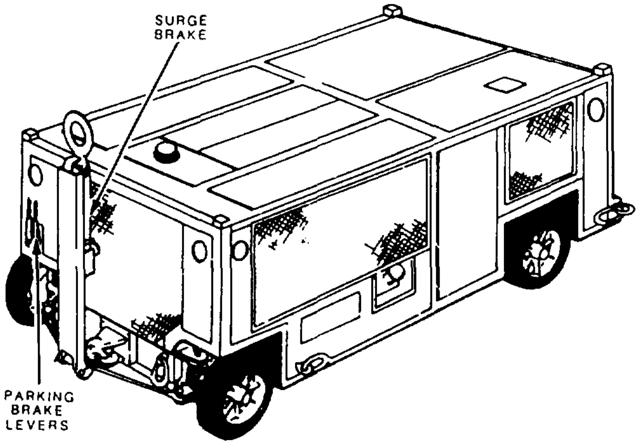


Figure 3-12.-NR-10 mobile air-conditioning unit.

GTC-85 Compressor

The GTC-85 gas turbine engine is basically a two-stage centrifugal compressor directly coupled to a radial inward-flow gas turbine. Compressed air is obtained as bleed air from the second stage of the compressor at a 3.6:1 pressure ratio. This pneumatic power (bleed air) is used for the operation of large pneumatic equipment, such as jet aircraft turbine starters.

NCPP-105 Compressor

The NCPP-105 is a complete, self-contained unit consisting of a flyaway assembly enclosed in a skid-mounted, weather-resistant enclosure. See figure 3-13. The top view of figure 3-13 shows the NCPP-105 as a skid-mounted unit. This unit

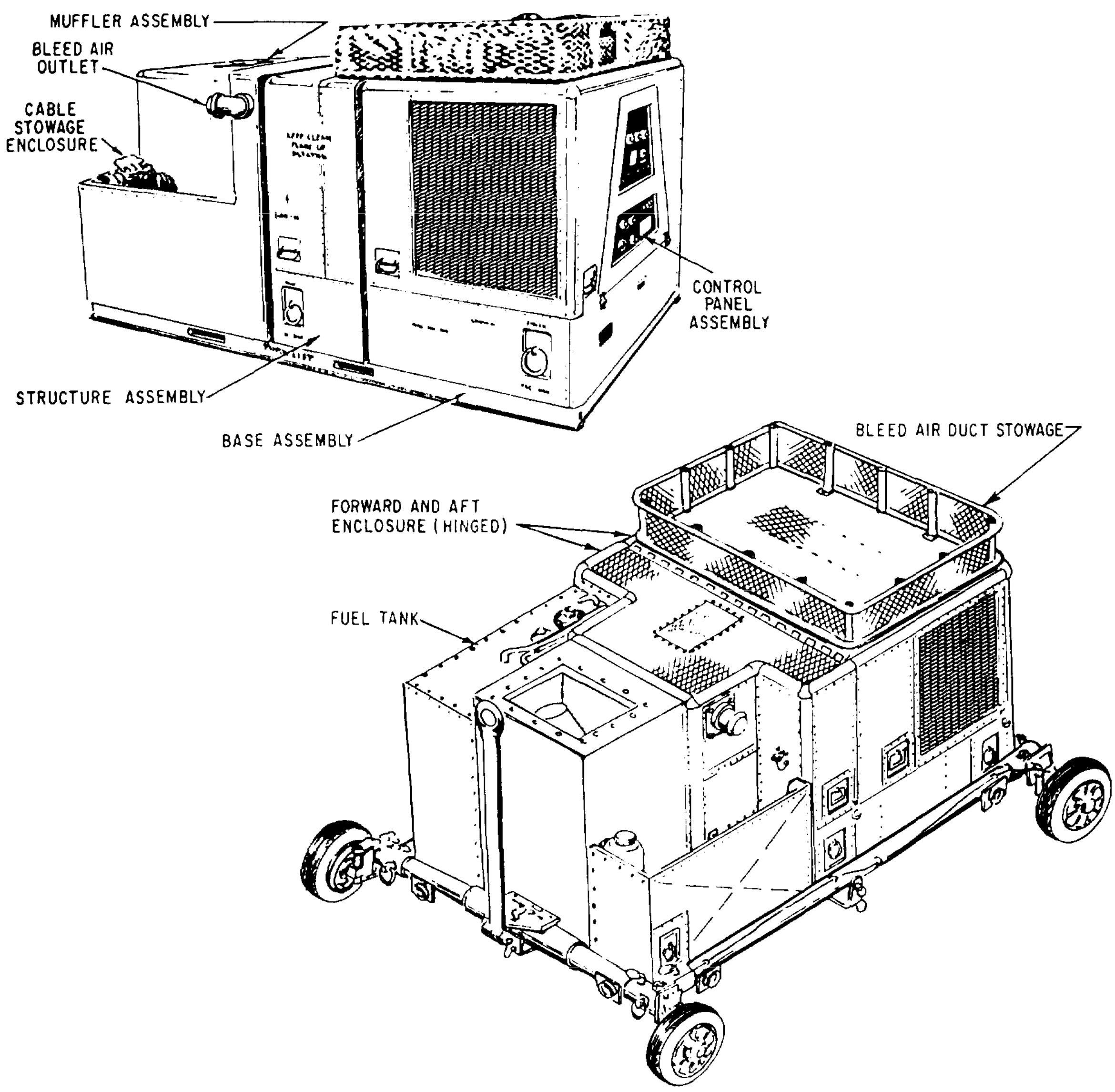


Figure 3-13.-Model NCPP-105 gas turbine compressor power unit.

can be installed on a trailer, as shown in the lower view of this figure. This permits ease of movement from aircraft to aircraft and from place to place.

The NCPP-105 supplies compressed air at two pressure ratios (5:1 and 3.6:1) for aircraft engine starting, and ac and dc electrical power for operation of aircraft ac and dc electrical components. It is equipped with an ac output cable, a dc output cable, and a bleed-air duct assembly.

The unit enclosure consists of a forward and aft enclosure (hinged together), a cable stowage compartment, a muffler assembly, a fuel tank structural assembly, and a base assembly.

The flyaway assembly is normally operated while in the NCPP-105 enclosure, with the dc power supply mounted in the forward enclosure. However, when it is required to transport the flyaway assembly by aircraft to a temporary location, the dc power supply is removed and relocated on the flyaway assembly structure. The fuel line and ac and dc electrical output cables are disconnected, the forward and aft enclosures are lifted off the structure assembly, and the flyaway assembly is then removed from the base assembly. The flyaway assembly, with its remote cable, ac and dc electrical output cables, and bleed-air duct assembly, upon arrival at its temporary location, can be operated by attaching it to a fuel supply.

The control panel is part of the flyaway, and is located on one end of the NCPP-105 unit, as shown in figure 3-13. The control panel contains the complete operating instructions for the operation of the unit.

HYDRAULIC POWER SUPPLIES/ HYDRAULIC TEST STAND

Portable hydraulic power supplies/test stands provide a means of simulating the aircraft's hydraulic pump. By connecting a hydraulic power supply/test stand to the aircraft's hydraulic system, the various actuating systems can be operated without turning up the aircraft engine. One of the systems that might be checked out this way is the aerial refueling store. The power supply is connected to the aircraft system at ground test couplings (quick disconnects) provided on the aircraft.

The A/M27T-5 portable hydraulic power supply is a single system hydraulic pumping unit. See figure 3-14. It is rated at 20 gpm at 3,000 psi and 10 gpm at 5,000 psi.

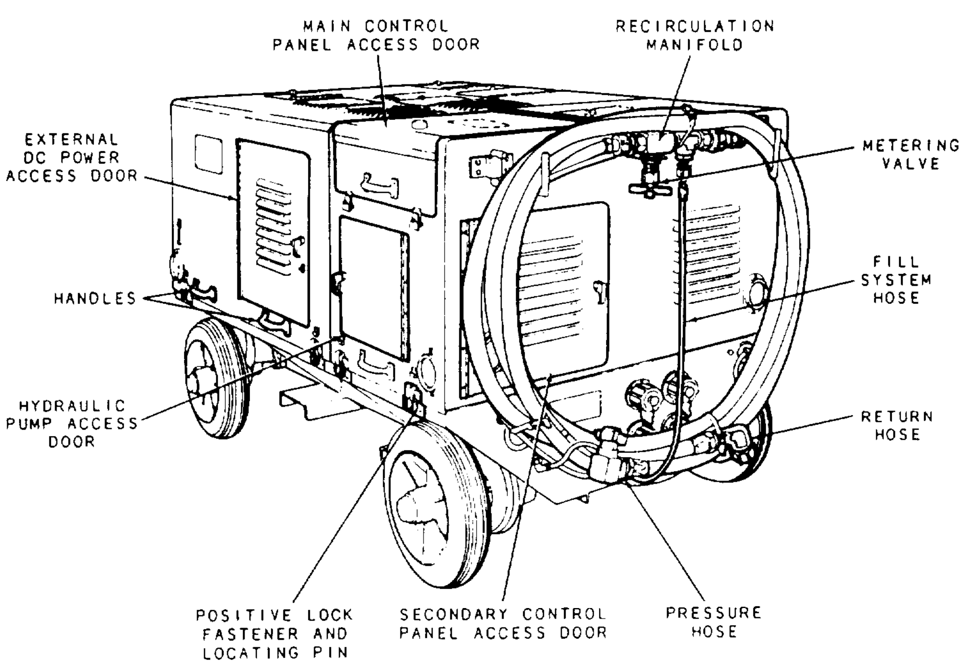


Figure 3-14.-A/M27T-5 portable hydraulic power supply.

The power supply is self-contained. It is designed to check the performance and characteristics of aircraft hydraulic systems. The A/M27T-5 is capable of performing the following functions:

1. Delivering hydraulic fluid at controlled pressures. This enables operation of the aircraft's hydraulic system without the need to start the aircraft's engines.
2. Testing the flow rate of aircraft hydraulic systems.
3. Testing the aircraft hydraulic system and components for leakage or malfunction.
4. Flushing and refilling aircraft hydraulic systems with MIL-H-83282 hydraulic fluid filtered to 3-micron absolute.

NONPOWERED SUPPORT EQUIPMENT

So far we have discussed only powered SE. This portion of the text will discuss nonpowered support equipment. Nonpowered SE is all the equipment that has no engine or motor installed to supply power for equipment operation.

MAINTENANCE PLATFORMS

Maintenance stands, platforms, or workstands (the names are commonly interchangeable) give us a means to reach parts of the aircraft we can't safely reach or work on from the ground. There are a large variety of types and models. Some of the stands are common SE used on almost any type of aircraft. Others are very large stands used only at shore activities or on one specific type of aircraft.

Most adjustable aircraft maintenance platforms are hydraulically operated. A platform and ladder assembly are mounted on a caster-equipped base. This enables maintenance personnel to safely work at heights from 3 feet to a maximum of 20 feet, depending on the stand selected. Since the design, use, safety precautions, and procedures are generally very similar, we will cover only a few of the more common stands.

Most maintenance workstands become defective through abuse and lack of care. Most small stands are designed to hold 500 pounds safely. Overloading the stand can cause some part of the platform structure to bend. That generally causes the lift structure, or steps to bind. That, in turn, puts abnormal pressure on the hydraulic cylinder, pump, and lines. Eventually the stand will fail, either jamming or collapsing.

B-2 Workstand

A type of workstand in common use is the B-2, shown in figure 3-15. The B-2 consists basically of a fixed height, 10-foot lower structure; a variable height upper structure; and a manual pump-actuated hydraulic system for raising and lowering the upper structure. The upper structure includes a work platform with guardrails and steps with handrails. The platform and steps, because of parallelogram linkage, stay horizontal throughout their upward or downward travel. The lower structure includes fixed steps and handrails, a tow bar, and four free-swivel caster wheels for mobility. Each caster is equipped with a safety locking device containing a spring-loaded pin, which snaps into notches on the caster pivot axle to lock the caster swivel. The lower structure also includes four immobilizing jacks with baseplates. The jack plates press against the ground and act as brakes, but not supports, for the structure. You may find some B-2 stands with the foot-lever brakes (like the B-4A and B-5A) instead of the jackscrews.

The height range for the B-2 work platform is from 13 feet to 20 feet. Overall height, including the 3 1/2-foot guardrails, is 16 1/2 feet lowered

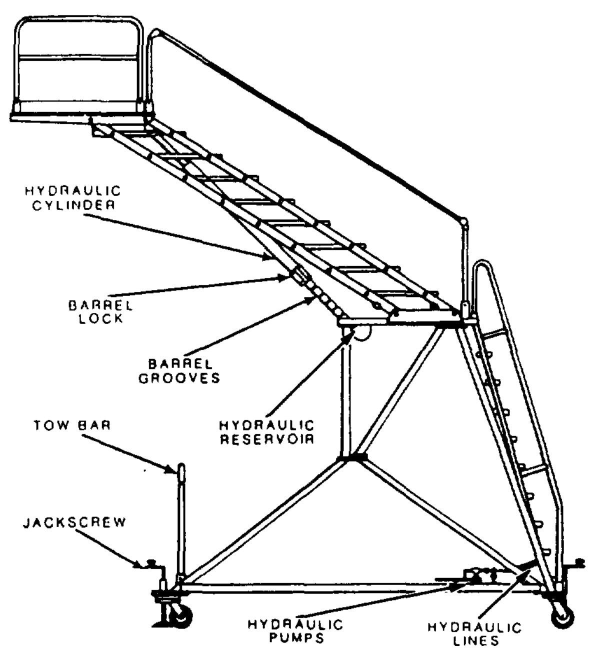


Figure 3-15.-B-2 maintenance platform.

and 23 1/2 feet raised. The base structure is 10 feet wide and 14 feet long; however, the upper work platform extends the length of the whole workstand to 21 feet when it's in the lowered position. The work platform space is 4 feet by 4 feet square. The complete workstand weighs 1,900 pounds.

The hydraulic system on the B-2 includes a hand pump, hydraulic lines, a reservoir, and a hydraulic lift cylinder with a safety lock. The pump is located on the left-hand angle iron of the platform. Hydraulic lines lead from the pump to the lift cylinder reservoir, which attaches to the scissor section and platform structure. The workstand is raised and lowered by using the pump and the release valve, the same as a jack.

When the B-2 work platform is raised, the inner barrel of the hydraulic cylinder is exposed. This inner barrel has spaced grooves around it to hold a safety barrel lock. Most of the models have a barrel lock consisting of a ring with four spring grips, which rides out on the piston. When the ring is rotated, cams force the grips out free of the barrel. When the ring is rotated farther, the cams allow the grips to press against the barrel and snap into one of the grooves. The lock then prevents the cylinder piston from collapsing in the event of hydraulic failure. You may run across some models that have a U-shaped bolt attached to the piston by a chain. This U-lock is inserted into a barrel groove to lock the piston up.

B-4A and B-5A Platforms

The two most common maintenance platforms are the B-4A and the B-5A, as shown in figures 3-16 and 3-17. Both workstands are movable, hydraulically operated, adjustable platforms with ladders. They are mounted on free-swivel caster wheel assemblies. Each wheel has a foot-lever actuated mechanical brake and a swivel lock assembly.

The steel-grated platforms are equipped with safety rails on three sides, and there are handrails on the ladder. Both stands are equipped with locking pins that, when inserted through the top of the platform frame, lock the scissors. This prevents the platform from collapsing in the event of hydraulic failure.

Both stands are raised by using a hydraulic pump, which is located on the platform to the left

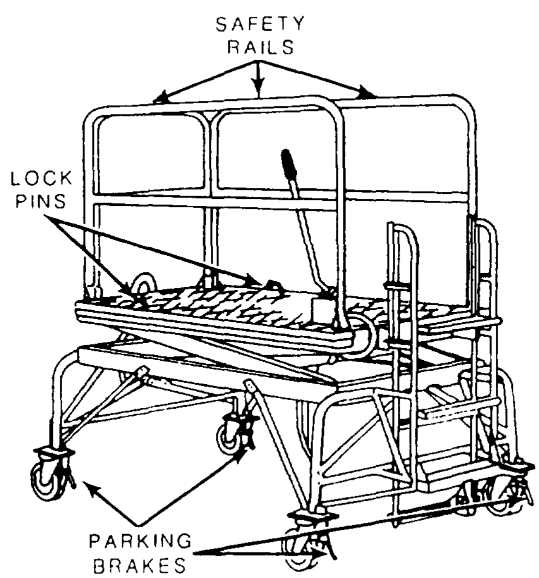


Figure 3-16.-B-4A maintenance platform.

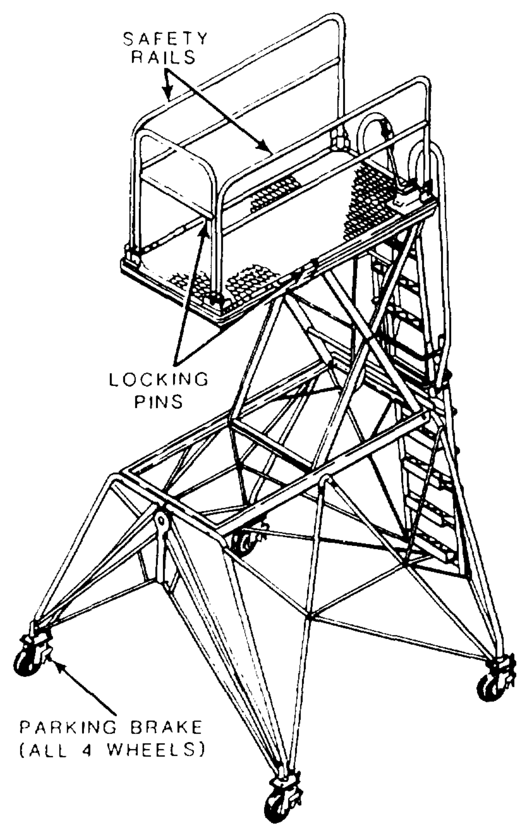


Figure 3-17.-B-5A maintenance platform.

of the ladder. The stands are lowered by using the hydraulic release valve on the pump.

The major difference between the B-4A and the B-5A stands is their size and height range. The B-4A extends for a working height of between 3 and 7 feet. The B-5A extends for a working height of between 7 and 12 feet. Both stands have a capacity of 500 pounds. The B-4A is 8 feet long, 3 feet wide, and weighs 460 pounds. The B-5A is 8 feet 4 inches long, 8 feet wide at the base, and weighs 860 pounds.

Other Maintenance Platforms

There are many more types of workstands available to you from both Navy and commercial sources—from foot-high work stools to step stools, stepladders, and phase platforms. These are generally designed for the specific jobs they are used for and incorporate the strength, ruggedness, and features required for safety. If used properly and with care they are safe.

What isn't safe is anything that wasn't designed as a ladder or workstand; such as folding steel chairs, swivel or even solid chairs, boxes, card tables, cans, barrels, drums, tractor hoods, or the top of any other SE. There are a hundred other things that people try to use every day instead of proper workstands. These substitutes are usually available and convenient, although they are NOT safe. They are dangerous and cause a tremendous number of falls and disabling injuries.

ENGINE TRAILERS AND WORKSTANDS

Since the days of the early axial flow turbojet engines, the Navy has moved toward universal engine installation, removal, and transportation trailers and workstands. These basic trailers and engine workstands are a matched rail ground-handling system that can be modified to handle different types of engines, installations, and aircraft by the use of various peculiar support equipment (PSE) adapters and, in some cases, hoisting equipment.

The equipment in common use today are the engine removal and positioning trailer, models 4000A and 4000B, and the engine transportation trailer, model 3000B. The removal and positioning (or installation/removal) trailer, as the name shows, is used to remove and install engines and move them for short distances. The transportation trailer is used for transporting engines over longer distances and to transfer engines from other pieces of the matched rail ground-handling system. Actual work on the engine is normally performed after it is transferred to the engine workstand. The workstand is usually in a fixed location in the hangar or shop.

3000B Trailer

Figure 3-18 shows the 3000B trailer. The unit is a four-wheel trailer incorporating a detachable, telescopic tow bar at the front and a tow coupling at the rear. The twin parallel rails are equipped with male and female quick-disconnect couplings and spring-loaded roller adapter stops on both ends of each rail. The rails can be mated to the model 4000A or B engine removal stand or the model 3110 engine workstand.

The main purpose of the 3000B trailer is to move or transport engines for short or long distances, such as hangar to hangar or from squadron to the aircraft intermediate maintenance department (AIMD). The trailer is one part of the universal matched rail ground-handling system.

The trailer weighs 600 pounds and has a load carrying capacity of 8,000 pounds. It is equipped with pneumatic tires inflated to 30 psi. The rails are 12 feet 8 inches long. The overall trailer is 2 feet 10 inches high and 6 feet wide.

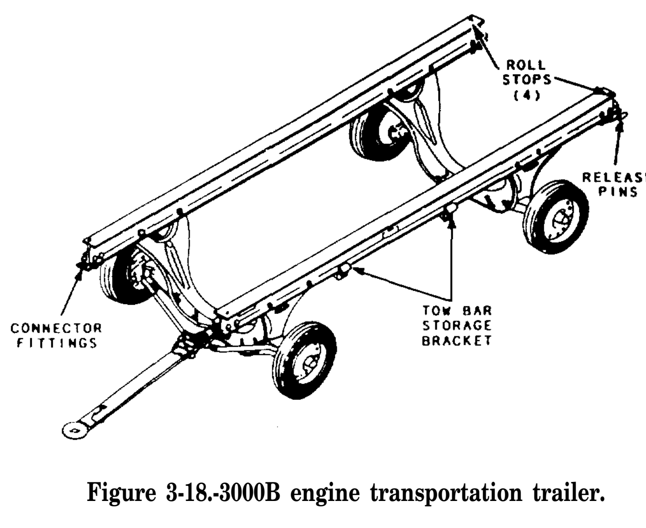


Figure 3-18.-3000B engine transportation trailer.

4000A and 4000B Trailers

These two models are very similar. Figure 3-19 shows the model 4000A. It is a four-wheel, mobile, hydraulically controlled, self-supporting unit. The trailer consists of a main frame supported by four wheels, a lift linkage system, an upper frame holding two cradle assemblies, and a tube and rail assembly. A detachable, telescopic tow bar provides a means of manually steering or towing the trailer. Some trailers may be equipped with a tow coupling on the rear.

The hydraulic system consists of the following:

- Four hydraulic frame lift rams that raise and lower the upper frame assembly (rails)
- Four (two on some models) wheel lift rams that raise and lower the main frame
- Two hand pumps with release valves that operate either the lift rams or the wheel rams
- A two-position selector valve labeled LIFT CYLINDER and WHEEL CYLINDER
- A hydraulic fluid reservoir (two on some models)
- Connecting lines and fittings

Foot-lever actuated drum/shoe types of parking brakes are located on the two rear wheels. Large foot assemblies, which can be manually lowered, are provided to give the stand maximum stability and support when required. The tie rods that hold the rear wheels fore and aft, and those that control tow bar steering of the front wheels, are configured so that they can easily be disconnected. This permits all four wheels to be manually positioned for maximum maneuverability in close quarters.

All four wheels are attached to the main frame by hydraulically controlled wheel support arms, operated by wheel lift rams. A ratchet and pawl system is provided on the rams to safely lock the rams, mechanically and automatically, as they extend. Pawl handles on each wheel lift cylinder must be actuated and held to permit the rams to retract.

The wheel lift rams permit raising or lowering the main (lower) trailer frame. The main frame can be lowered right to the deck, provided the four manual foot assemblies are all the way up. The main frame full up position gives maximum ground clearance and is used when towing or

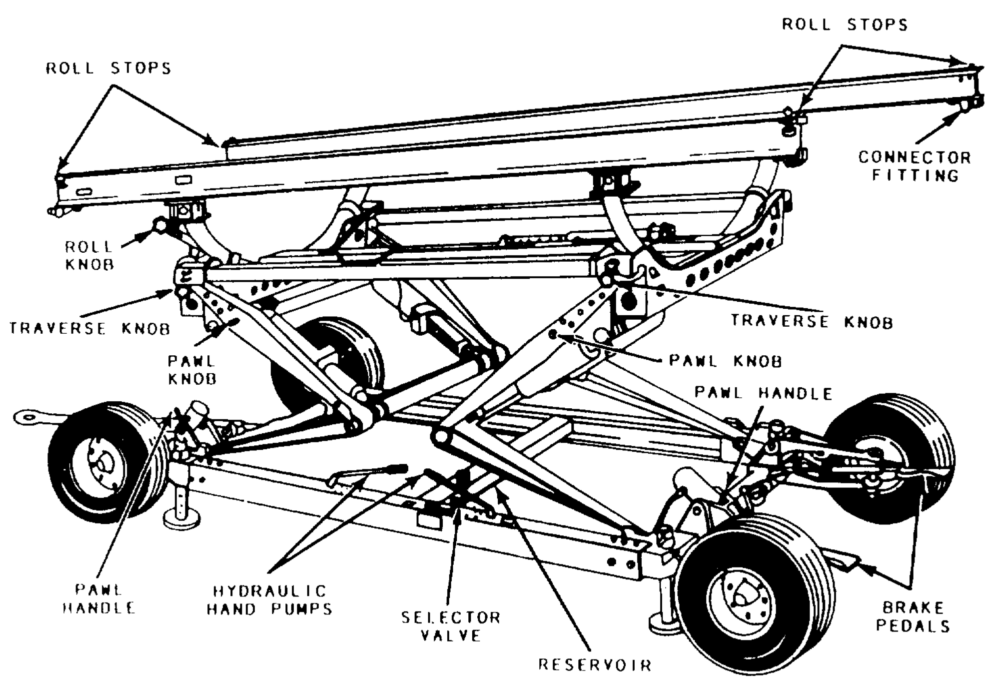


Figure 3-19.-4000A engine removal/installation trailer.

moving the trailer, particularly when loaded. The forward hydraulic pump and release valve raise and lower the front end of the main frame. The aft pump and release valve raise and lower the rear end of the main frame. Operated together, the pumps or release valves raise and lower the whole main frame at once.

The lift linkage consists of four upper and four lower links, centrally hinged in a jackknife position. The linkage system is raised and lowered by four frame lift rams. These lift rams are also equipped with a ratchet and pawl system to provide a safe mechanical lock in case of a hydraulic system leak or failure. Pawl knobs located on all four upper links must be actuated and held to permit the rams to retract.

The upper frame is attached to the lift linkage system and holds a cradle assembly at each end. Inside each cradle are two rollers upon which the semicircular support tubes, holding the two parallel rails, can roll (rock from side to side). A rotation adjustment knob, located on the left side of the forward support tube, permits ±10 degrees of roll adjustment of the rails. Two traverse adjustment knobs, located on the left side of each cradle assembly, permit ±3 inches of horizontal lateral (side) movement of the rails. Yaw adjustments up to ±2.25 degrees left or right of the center line of the rails can be made using just one of the traverse adjustment knobs, or both in different directions.

A mechanical winch assembly with a hand crank is provided on the unit for moving an engine onto the trailer when the rails are tilted. The ends of the two upper rails are equipped with male and female quick-disconnect couplings to permit mating and load transfer from one type of stand to another. Roller adapter assemblies are provided on the rails to hold the engine. The roller adapters can be locked in any position on the rail to center the load. The very ends of the rails are equipped with spring-loaded stop pins to prevent an engine, on unlocked roller adapters, from accidentally rolling off the rails.

The model 4000A stand has been in service for many years. During that time many modifications and changes have resulted in various configurations of stands in the fleet. The U.S. Air Force also uses this stand. Some stands have pneumatic tires, and some have solid rubber tires. Some hydraulic pumps have selector collars for heavy or light load. Some stands have two hydraulic reservoirs.

Some stands have only two, instead of four, wheel lift rams. The pumps on some stands are located on top of the left side main frame, whereas some pumps are inside the main frame member. The 4000A and 4000B trailers should never be used to transport engines, even for short distances.

3110 Workstand

The model 3110 workstand is a 49-gauge matching rail-type unit designed to mate with rail-type trailers for the roll transfer of the engine. Model 3110, usually located in the hanger or power plants work center, allows for the horizontal maintenance and storage of aircraft engines. These stands can be used on any hard surface, and are easily erected and maintained. See figure 3-20.

SPECIAL-PURPOSE SUPPORT EQUIPMENT

The Aviation Machinist's Mate has a requirement to use special support equipment to accomplish tasks such as engine removal and corrosion control purposes. The aero bomb hoist and the jet engine corrosion control carts are examples of this special-purpose gear.

Aero Bomb Hoists

Aero bomb hoists are used in conjunction with the air logistic trailer for aircraft engine removal

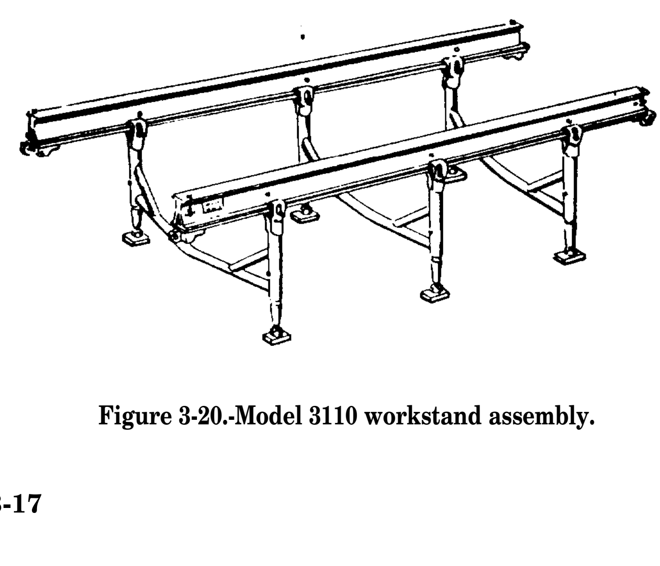


Figure 3-20.-Model 3110 workstand assembly.

and installation in some aircraft. See figure 3-21. Prior to using the bomb hoist, a PREOPERATIONAL inspection, which includes checking the cable for frayed or broken strands, must be conducted. Always be sure that the hoist load test date is current and that the cable is routed properly.

WARNING

Never leave an engine unattended while it is being supported by hoists. Never work or get under an engine while it is being supported by hoists. When lowering or raising an engine, do it slowly. Constantly check the engine clearance with the aircraft nacelle and controls to prevent damage or binding.

Jet Engine Corrosion Control Cart

The corrosion control cart provides freshwater rinsing or the application of preservation compound to the compressor section of an engine through a low-pressure spray. See figure 3-22.

The primary components of the unit are a large solution tank, two air cylinders, a work platform with guardrail, four spray applicator wand assemblies, and the trailer.

WARNING

A **drawbar at the front of the trailer provides towing and steering capabilities. It also incorporates a spring loaded "deadman" brake. If the drawbar is released from the horizontal towing position, it returns to the vertical position with considerable force. If a person is unaware of this feature when disengaging the tow bar from a tractor, there is the possibility of personnel injury.**

The 33-gallon solution tank is separated into two separate compartments. The forward section is a 7-gallon preservative tank. The rear section is a 26-gallon freshwater tank. Each tank has its own filler neck and cap. There is a 4-inch opening for water and a 2-inch opening for the preservative tank. Each tank has a pipe plug at the bottom for draining. The freshwater and preservative fluid systems each have a shutoff valve, a quick

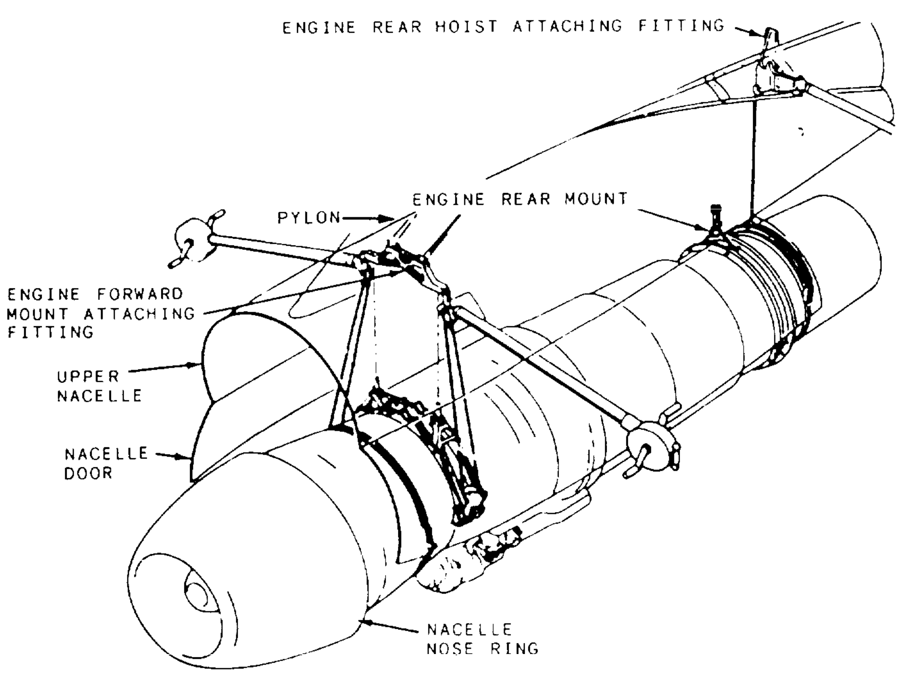


Figure 3-21.-Aero bomb hoist.

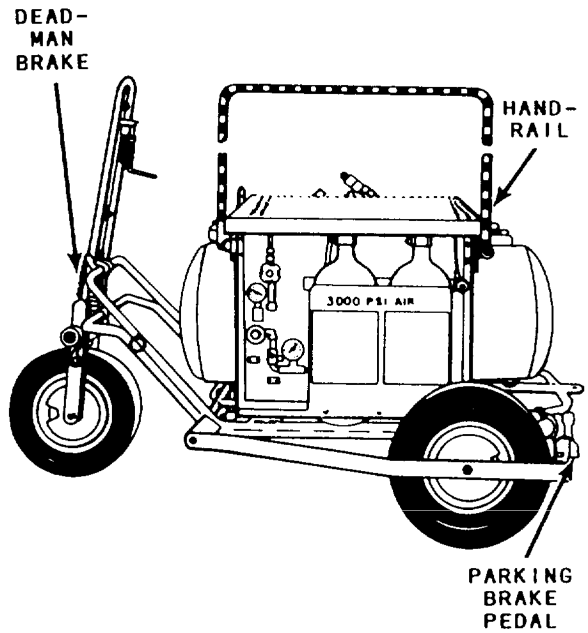


Figure 3-22.-Corrosion control cart.

acting lever valve, and an applicator wand on/off valve.

Two 500 cubic-inch, 3,000 psi, air cylinders mount on the left side of the unit to supply air pressure to pump freshwater or preservative from the storage tanks. Four applicator wands are stored on the right side of the unit. Each wand is about 6 feet long and attaches to the two 10-foot supply hoses off the storage tanks. A steel grate work platform on top of the unit provides a work platform to help operators reach the intakes of helo engines.

SE TRAINING AND LICENSING PROGRAM

The purpose of the SE Training and Licensing Program is to make sure you receive effective training in the safe and efficient operation of SE on specific types of aircraft. The improper use of SE has resulted in excessive ground accidents and repair and replacement costs amounting to millions of dollars each year. It also results in reduced operational readiness. The major reasons for improper use of SE are lack of effective training and lack of effective supervision.

Proper licensing of SE operators takes the coordinated effort of both the IMA SE division and the user activity. OPNAVINST 4790.2 (latest edition) lists the procedures and responsibilities required for the training and licensing of support equipment operators.

The SE Training and Licensing Program has two distinct parts. Part one, taught by the supporting IMA, covers the proper operation or use of the SE. Part two, taught by the user activity, consists of on-the-job training (OJT), practical exams, and written tests to operate the SE on a specific type/model/series of aircraft. Once this training is accomplished and documented, the division officer initiates an SE operator's license and forwards it for approval.

CHAPTER 4

JET AIRCRAFT FUEL AND FUEL SYSTEMS

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Identify the types of fuels used in aviation and recognize the operational properties required in aviation fuels.
- Identify the parts and recognize a typical airframe fuel system. Also recognize the safety precautions required in airframe fuel system operation.
- Identify the types and operation of engine fuel system parts.
- Identify procedures for troubleshooting malfunctions in airframe and engine fuel systems.
- Identify the major safety precautions, and recognize the basic procedures for fuel cell removal and installation.

INTRODUCTION

The purpose of the fuel system is to deliver a uniform flow of clean fuel under constant pressure to the engine under all operating conditions. To accomplish this task the fuel system must be properly maintained. The AD's responsibility to maintain and troubleshoot the fuel system include the following:

1. Knowing the different types of fuels and their characteristics.
2. Knowing the different types of aircraft and engine fuel systems and their parts.

In general, aircraft fuel systems are divided into two parts:

1. The airframe fuel system consisting of fuel tanks, float-operated transfer valves, selector and shutoff valves, and fuel tank boost pumps.
2. The engine fuel system includes some combination of different parts. These parts are filters, fuel control units, engine-driven fuel pumps, flow dividers, pressurizing valves, drain valves, afterburner fuel controls, and fuel nozzles or injectors.

The jet engine fuel system usually includes an emergency system to supply fuel to the engine in case of main system failure. In some cases, the emergency system is a duplicate of the main system. However, in others the emergency system is not fully automatic and must be controlled by the pilot. With the nonautomatic type of emergency system, the pilot must accelerate and decelerate slowly, or there will be danger of rich blowout, lean blowout, stall, or overheating of the combustion and turbine areas.

Both the airframe fuel system and engine fuel system, as well as the type, designation, and requirements of the aircraft fuels, are discussed in this chapter.

FUELS

For many years it was popularly believed that gas turbine engines could burn any type of fuel, from crude oil to aviation grade 115/145 gasoline. Of course, this is not true. Because of the wide range of operating conditions and high rate of fuel consumption, jet engines require specific fuels to operate efficiently and maintain a reasonable engine service life. Various grades of jet fuels were developed to meet specific operating or handling characteristics. A study of the basic characteristics of turbine fuels will help you understand the importance of delivering the proper fuel to the aircraft. Such a study is also valuable in understanding the need for safety and caution in handling these fuels. This section includes the basic characteristics of engine fuels.

CHARACTERISTICS

Aircraft engine fuels are petroleum products manufactured from crude oil by oil refineries. They are classified as inflammable liquids. Any material easily ignited that burns rapidly is inflammable. (NOTE: The terms *flammable* and *inflammable* mean the same.) Under proper conditions, fuel can explode with force similar to dynamite. Death can result if the vapors of fuel are inhaled in sufficient quantities. Serious skin irritation can result from contact with the fuel in the liquid state. In liquid form, aircraft fuels are lighter than water, and in vapor form they are heavier than air. Consequently, water in the fuel usually settles to the bottom of the container. And vapors of these fuels, when released in the air, tend to remain close to the ground, thus increasing the danger to personnel and property. From safety and health standpoints, aircraft engine fuels must be handled with caution.

In the selection of a fuel, several factors must be considered. Since one fuel cannot have all the requirements to the greatest degree, the fuel selected is a compromise of various factors. Specific properties of fuels are determined through testing. These tests determine the volatility, density, heating value, combustion, safety, and handling characteristics of the fuels. There are hundreds of test that determine the physical, chemical, and performance properties of fuel. We limit this discussion to the most common and important ones as follows:

1. Volatility (vapor pressure and distillation
2. Flash point and fire point
3. Heat energy content
4. Viscosity
5. Handling characteristics
6. Combustion products
7. Effects of additives and impurities
8. Freeze point

Volatility

Volatility measures the ability of a liquid to convert to a vaporous state. Fuel must vaporize and the vapor be mixed in a given percentage of air for it to burn or explode. Only fuel-air mixtures within the flammable range will burn (fig. 4-1). Volatility of a fuel effects starting, range, and safety. A highly volatile fuel starts easier (especially at low temperatures or under adverse conditions) and has less range (due to fuel evaporation in flight). The fuel has a higher tendency to vapor lock and is more susceptible to a fire during a crash. The volatility of a petroleum fuel is usually measured in terms of vapor pressure and distillation.

The vapor pressure shows the tendency to vaporize at specific temperatures. Vapor pressure is measured in a Reid Vapor Pressure Test Bomb. In the test, one volume of fuel and four volumes of air are contained in a sealed bomb fitted with a pressure gauge. The container and fuel are heated to 100°F, shaken, and then you read the pressure on the gauge. The pressure shown on the gauge is known as the Reid Vapor Pressure (RVP) and is expressed in pounds per square inch (psi). The higher the pressure the more volatile the fuel.

The distillation measurement for volatility measures the amount of fuel boiled off at specific temperatures. Since turbine fuels are a mixture of hydrocarbons (gasoline and kerosene), they have a wide range of boiling points. This test records the boiling ranges. The military

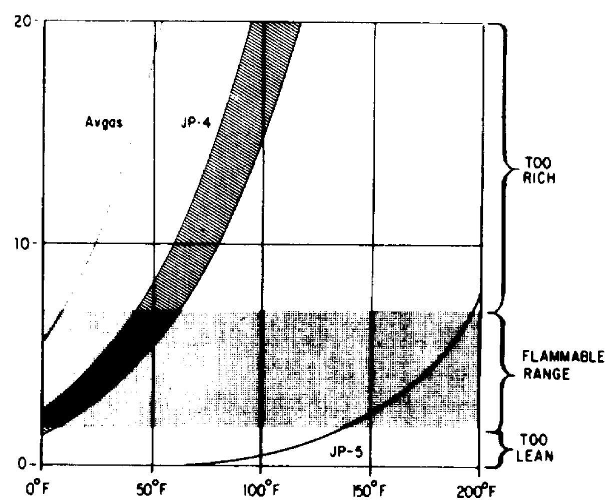


Figure 4-1.-Vaporization of aviation fuels at atmospheric pressure.

specification for fuels will give these temperatures and the percentages of the fuel allowed to boil off to meet the desired standards.

Flash Point and Fire Point

The flash point is the temperature at which the fuel vaporizes enough to ignite with an outside heat source. The flash point of a fuel is an index of its potential safety for handling and storage. Ships require at least a 140°F flash point for storage for safety reasons. The fire point is the temperature where the vapors continue to burn without an outside heat source.

Heat Energy Content

For aircraft engine use, it is important that the fuel contain as much heat energy (thermal value) as possible, both per unit weight and per unit volume. The thermal value is the amount of heat produced as a result of complete combustion and expressed in calorie or British thermal units (Btu).

NOTE: A calorie is the amount of heat needed to raise the temperature of 1 gram of water 1 degree Celsius. A Btu is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. One Btu equals 252 calories.

Thermal value per unit of weight increases as gravity increases. Energy content and density influence fuel selection when range or payload are the limiting factors. This is important to understand when the aircraft will be weight-limited rather than volume-limited.

Viscosity

Viscosity is the internal resistance of a liquid that tends to prevent it from flowing. Turbojet engine fuels should be able to flow through the fuel system and strainers under the lowest operating temperatures to which the engine will be subjected. Fuel viscosity and density also have considerable effect on nozzle performance, especially when varied over a wide range. The most important fuel property influencing nozzle performance is viscosity. It affects drop size, flow range, and spray angle. Changes in fuel density affect fuel flow.

Handling Characteristics

For a fuel to have satisfactory handling characteristics, it must be noncorrosive and should not clog fuel filters, even at very low temperatures. The fuel should not produce vapor lock in the fuel tanks or in the various fuel pumps or slugging out of the fuel tank vents. (Slugging is the process by which liquid fuel is carried along with vaporized fuel when the vapor escapes to the atmosphere.) As far as possible, the fuel should have enough of the properties of a lubricant to avoid significant wear of the fuel-metering pumps.

Combustion Products

Aircraft fuels must have a minimum tendency to form solids or carbon on combustion. A loss in the efficiency of the engine results when these deposits build up in the engine.

Additives, Impurities, and Their Effects

Only materials that will be effective when added in a maximum concentration of 5 percent are considered as liquid additives. Beyond this concentration, the material may be considered as a fuel.

Gum inhibitors used in military gas turbine fuels are the same as those used for military aviation gasolines. In aviation gasoline, gum is almost always completely soluble and becomes apparent only when the gasoline is evaporated. Both soluble and insoluble gum, especially the insoluble form, can be expected to have serious effects on the fuel system of the turbine engines. The fuel-metering pumps, fuel pumps, and fuel filters are likely to be seriously affected by insoluble gum. The soluble type can be expected to cause difficulty in the fuel system, at points where microscopic leakage occurs and exposes thin films of fuel to air, and thus to evaporation. The microscopic fuel leaks will usually appear at fuel valves.

Certain aircraft require a minimum concentration of fuel system icing inhibitors (FSII). This is put in the fuel to prevent icing in the airframe fuel system, engine filter, or engine fuel control. FSII materials are considered to be dangerous before their additions to fuel; therefore, shipboard injection is not approved.

Freeze Point

The freezing point of a fuel is the temperature at which solid particles begin to form in the fuel. These particles are waxy crystals normally held in suspension in the fuel. These particles can readily block the filters in an aircraft fuel system. The fuel almost always becomes cloudy before the solid particles form. This cloud is caused by dissolved water coming out of the solution and freezing.

TYPES OF JET FUEL

The U.S. Military grades of jet fuel are designated by the letters *JP* followed by a number. The grade number merely shows the approximate sequence the fuel specifications were accepted by the military. NATO codes show compatible fuel standards. When changing to a different fuel, it is usually not necessary to drain out the old fuel. Some aircraft prohibit fuel mixing or require different settings on some fuel components (fuel controls) when switching fuel grades.

JP-1. JP-1 was the original kerosene-type fuel used in turbine engines. Its characteristics were low vapor pressure and high energy content per volume of fuel.

JP-3. JP-3 was a mixture of 65 percent gasoline and 35 percent kerosene. Because of its high percentage of gasoline, its characteristics were similar to gasoline. This included low flash point (–40°F), easy cold weather starting, and poor lubricating qualities. There is also a high fuel loss due to evaporation and a tendency to vapor lock.

JP-4. JP-4 (NATO Code F-40) is an alternate fuel to JP-5 for USN jet aircraft used at shore stations only. It is never used on ships. Its low vapor pressure reduces fuel tank losses and vapor lock tendencies. Its fuel density is 6.5 pounds per gallon, and its flash point is below 0°F. When switching to JP-4 from JP-5, engine operating characteristics may change. Changes include easier starting, slower acceleration, lower operating temperature, and shorter range.

JP-5. JP-5 (NATO Code F-44) is now the Navy's primary jet fuel. It is relatively safe to store, thermally stable, and has a high heat content per gallon. JP-5 is a kerosene-type fuel with a vapor pressure close to 0 psi. Its high flash point makes it safe for shipboard handling. In fact, it is the only jet aircraft fuel used aboard ships. It has a lower tendency to vaporize than the more volatile grades. The vapor-air mixture in tanks or containers above its liquid surfaces will generally be too lean to be ignited until the surface of the liquid reaches a temperature of about 140°F.

JP-8. JP-8 (NATO Code F-34) is similar to JP-5 in most characteristics, except flash point and freeze point. JP-8 is now available only in Europe. JP-8 represents significant advantages over JP-4 in fuel handling and operational safety. Although, like JP-4, its flash point is lower than shipboard safety standards. The disadvantages of cost, availability y, and low temperature starting problems prevent it from replacing JP-4.

Commercial Fuels. Common commercial fuels used include types A, A-1, and B. Commercial fuels are authorized for use in military aircraft when JP fuel is not available. The characteristics of commercial fuel are similar to military fuels. A-1 is designated NATO code F-34, or equal to JP-8. Jet A is equal to JP-5, and Jet B is equal to JP-4.

FUEL CONTAMINATION

The complex fuel systems of modern aircraft do not function properly if the fuel is contaminated with dirt, rust, water, or other foreign matter. Very small quantities of water may form into ice at altitude affecting small fuel control orifices. Contaminated fuel has caused aircraft accidents with a tragic loss of life and valuable aircraft. This means clean fuel is a **LIFE-OR-DEATH** matter with aviation personnel.

Besides being deadly, contaminants are also sneaky. A certain type of emulsion resulting from water and rust particles can adhere to the sides of aircraft's fuel cells and go undetected, even with fuel sampling. It will continue to build up until parts of it wash off, blocking fuel filters, lines, or fuel control passages. Contamination causes unnecessary man-hours in troubleshooting and fixing fuel problems and possible engine failure.

In addition to causing extra maintenance and engine failure, fuel contamination causes serious delays in flight operations. Contaminated fuel must be tracked back to the source of contamination and the problem corrected. Until the cause of contamination is found and corrected, the contaminated system cannot be used. The fuel system may be a mobile refueler, air station hydrant refueling system, or the entire fuel system of an aircraft carrier. Contaminated fuel could affect one aircraft or the operation of an entire air wing.

Measuring Contamination

How do you determine how much contamination is too much? First, you have to understand the units of measurements used to identify contamination. The two units for measuring contamination are microns for solids and parts per million (ppm) for water.

There are about 25,400 microns in 1 inch. Figure 4-2 gives you a microscopic view of a human hair compared with small particle contaminants.

Part per million is the reference for water contamination. If you take a 32-ounce sample bottle and fill it 3 1/4 inches from the bottom, you have about 500 cubic centimeters (cc). Break the 500 cc down into one million little pieces. You now have 1ppm. Of course, you must use accurate surveillance equipment to perform measurements that small. Normally, the organizational maintenance level does not require this precise testing and inspection. Instead, the organizational level visually inspects fuel samples for contamination.

Types and Limits of Contamination

Acceptable fuel is *clean* and *bright* with no visually detected free water. The terms *clean* and *bright* have no relation to the natural color of the fuel. Jet fuels are not dyed and vary from clear, water white to straw-yellow in color. Clean means the absence of any cloud, emulsion, visible sediment, or free water. Bright means the fuel has a shiny, sparkling appearance. A cloud, haze, specks of particulate matter, or entrained water indicates contaminated fuel that cannot be used. Steps must be taken to find the source of

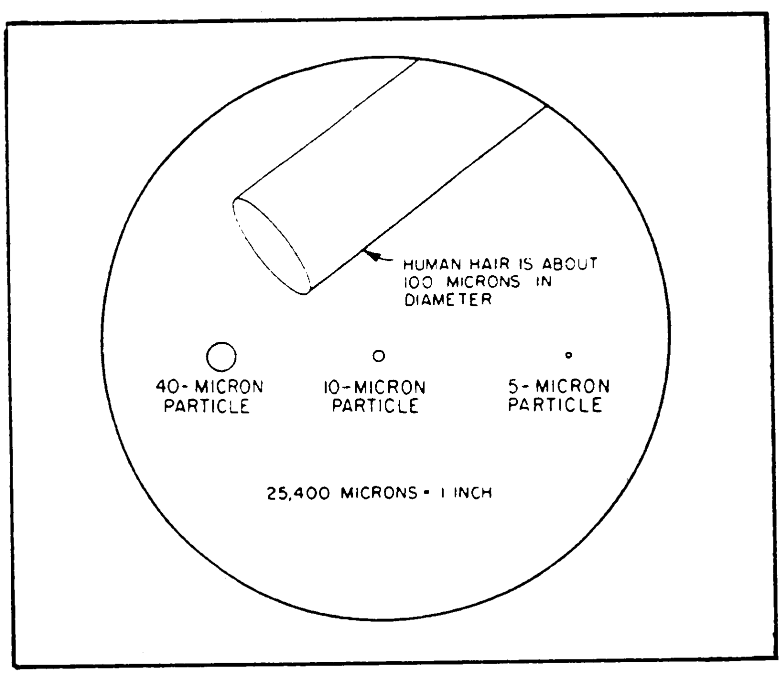


Figure 4-2.—Enlargement of small particles and comparison to human hair.

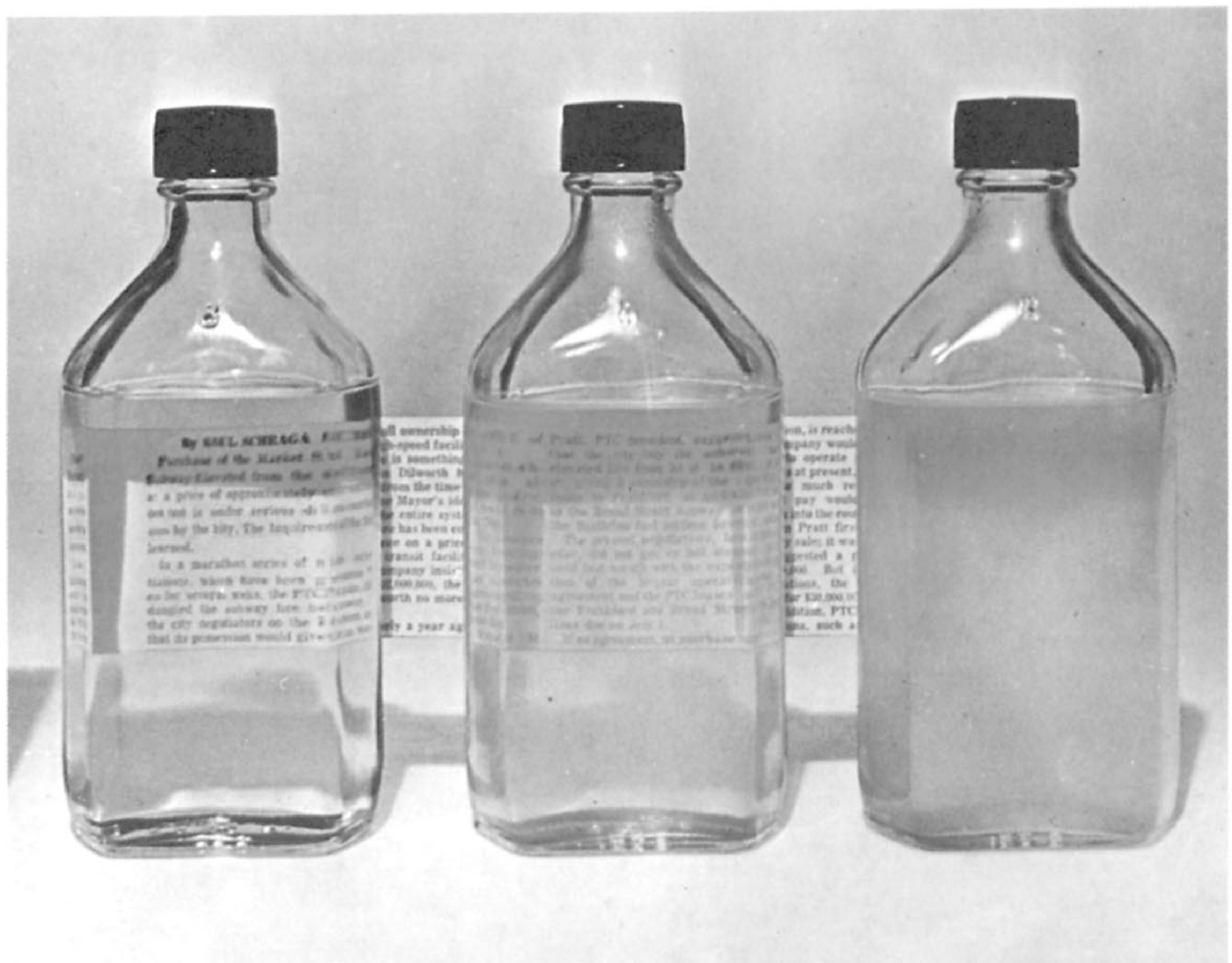


Figure 4-3.—Samples of JP-5 showing common visual contamination (air bubbles not contaminants—shown here for information).

contamination and correct it. Figure 4-3 shows an acceptable sample and common types of contamination usually detected visually.

WATER.— Water in fuels is either fresh or saline and present as dissolved or free water. Dissolved water is water in the fuel that is NOT visible. Free water is a cloud, emulsion, droplets, or gross amounts in the bottom of the container. Any form of free water could result in icing, corrosion, or malfunctioning of fuel system parts. Saline water will cause corrosion faster than fresh water.

SEDIMENT.— Sediment appears as dust, powder, fibrous material, grain, flakes, or stain. Specks or granules of sediment indicate particles in the visible size (fig. 4-2) of about 40 microns or larger. In a clean sample of fuel, sediment should not be visible except upon the most meticulous inspection. Sediment or solid contamination is either course or fine.

Course sediment is 10 microns or larger in size. Course particles can clog orifices and wedge in sliding valve clearances and shoulders, causing malfunction and excessive wear. They can also clog nozzle screens and other fine filter screens throughout the fuel system. Fine sediments are less than 10 microns and are not visible as distinct or separate particles. They appear as a dark shellac-like surface on sliding valves.

MICROBIOLOGICAL GROWTH.— Microbiological growth consists of living organisms that grow at a fuel/water interface. These organisms include protozoa, fungus, and bacteria. Fungus is the major constituent causing many of the problems associated with biological contamination of jet fuels. Fungus is a vegetable life that holds rust and water. It is also a stabilizing agent for fuel-water emulsion. Microbiological growth can develop wherever free water exists in the fuel tanks. Traces of metallic elements are also necessary, but water is the key ingredient. Remove free water and growth ceases. Microbiological growth is a brown, black, or gray color and has a stringy, fibrous-like appearance. It clings to glass and metal surfaces, causing problems such as severe corrosion or erratic operation of fuel system components. Microbiological growth causes erroneous readings in fuel quantity systems, sluggish fuel control operation, and clogging of filters. It is more prevalent in tropical and semitropical locations because of higher temperatures and humidity. Fuel suspected of microbiological contamination must not be defueled into a clean system.

Sampling Procedures

Fuel samples are taken from the fuel cell low-point drains as specified in the applicable Maintenance Requirement Card (MRC) deck.

NOTE: Obtain fuel samples prior to refueling. Only trained personnel shall take fuel samples; personnel taking samples must have clean hands. Improper containers and poorly drawn or mishandled samples result in meaningless or misleading results.

1. Ensure exterior of low-point drain is cleaned prior to sampling.
2. Drain off 1 pint from low-point drain, using a 1-quart, clear glass or polyethylene container.
3. Inspect sample for loose drops of water puddled under fuel.

NOTE: If dark stringy or fibrous material that tends to float in the fuel is noted in any sample, forward the sample(s) to the nearest Navy Petroleum Laboratory for microbiological growth determination.

4. If water is detected, discard sample and repeat steps 1 and 2 until no water is found.
5. Swirl the sample by briskly rotating the container.
6. If water is present under the swirling vortex, draw another sample and reinspect.
7. Inspect fuel sample for any discoloration, cloudiness, and loose sediment under the swirling vortex.
8. If small amounts of particulate material are noted, discard the sample, draw another sample, and reinspect.
9. If relatively large quantities of water or foreign matter are noted, or small amounts persist from one or more cell drains, perform the following:
   a. Keep the fuel sample.
   b. Immediately notify maintenance control, who will ground the aircraft and notify the quality assurance division to perform an investigation to determine the source of contamination.
   c. If the source of contamination is not isolated to the aircraft, notify the cognizant fuel handling activity. **The source of contamination must be identified.** See table 4-1 for types of contamination and limits.

Table 4-1.—Visual Contamination Table

TYPE CONTAMINANTS	APPEARANCE	CHARACTERISTICS	EFFECTS ON AIRCRAFT	ACCEPTABILITY LIMITS FOR DELIVERY TO AIRCRAFT
A. WATER				
(1) Dissolved water	Not visible.	Fresh water only. Precipitates out as cloud when fuel is cooled.	None unless precipitated out by cooling of fuel. Can then cause ice to form on low pressure fuel filters if fuel temperature is below freezing.	Any amount up to saturation.
(2) Free Water	Light cloud. Heavy cloud. Droplets adhering to sides of bottle. Gross amounts settled in bottom.	Free water may be saline water or fresh water. Cloud usually indicates water-in-fuel emulsion.	Icing of fuel system—usually low pressure fuel filters. Erratic fuel gage readings. Gross amounts of water can cause flame-outs. Salt water will cause corrosion of fuel system components.	Zero—Fuel must contain no visually detectable free water.
B. PARTICULATE MATTER				
(1) Rust	Red or black powder, rouge, or grains. May appear as dye-like material in fuel.	Red rust (Fe_2O_3)—nonmagnetic Black rust (Fe_3O_4)—magnetic rust generally comprises major constituent of particulate matter.	Will cause sticking, and sluggish or general malfunction of fuel controls, flow dividers, pumps, nozzles, etc.	*Refer to NOTE 1
(2) Sand or Dust	Crystalline, granular or glass-like.	Usually present and occasionally constitutes major constituent.	Will cause sticking, and sluggish or malfunction of fuel controls, flow dividers, pumps, nozzles, etc.	*Refer to NOTE 1
(3) Aluminum or Magnesium Compounds	White or gray powder or paste.	Sometimes very sticky or gelatinous when wet with water. Usually present and occasionally represents major constituent.	Will cause sticking, and sluggish or general malfunction of fuel controls, flow dividers, pumps, nozzles, etc.	*Refer to NOTE 1

*NOTE 1: Particles large enough to be visible should rarely be present. At the most, the total sediment should be a spot of silt. If any appreciable contamination is found, the test must be repeated.

Table 4-1.—Visual Contamination Table—Continued

TYPE CONTAMINANTS	APPEARANCE	CHARACTERISTICS	EFFECTS ON AIRCRAFT	ACCEPTABILITY LIMITS FOR DELIVERY TO AIRCRAFT
C. MICROBIOLOGICAL GROWTH	Brown, gray, or black. Stringy or fibrous.	Usually found with other contaminants in the fuel. Very light weight; floats or "swims" in fuel longer than water droplets or solid particles. Develops only when free water is present.	Fouls fuel quantity probes, sticks flow dividers, makes fuel controls sluggish.	Zero.
D. EMULSIONS				
(1) Water-in-fuel Emulsions	Light cloud. Heavy cloud.	Finely divided drops of water in fuel. Same as free water cloud. Will settle to bottom in minutes, hours, or weeks depending upon nature of emulsion.	Same as free water.	Zero—Fuel must contain no visually detectable free water.
(2) Fuel and water or "stabilized" Emulsions	Reddish, brownish, grayish or blackish. Sticky material variously described as gelatinous, gummy, like catsup, or like mayonnaise.	Finely divided drops of fuel in water. Contains rust or microbiological growth which stabilizes or "firms" the emulsion. Will adhere to many materials normally in contact with fuels. Usually present as "globules" or stringy, fibrous-like material in clear or cloudy fuel. Will stand from days to months without separating. This material contains half to three-fourths water, a small amount of fine rust or microbiological growth and is one third to one half fuel.	Same as free water and sediment, only more drastic. Will quickly cause filter plugging and erratic readings in fuel quantity probes.	Zero.
E. MISCELLANEOUS				
(1) Interface Material	Lacy bubbles or scum at interface between fuel and water. Sometimes resembles jellyfish.	Extremely complicated chemically. Occurs only when emulsion and free water is present.	Same as microbiological growth.	Zero—There should be no free water.
(2) Air Bubbles	Cloud in fuel.	Disperses upward within a few seconds.		Any amount.

AIRFRAME FUEL SYSTEM

Airframe fuel system maintenance is the responsibility of more than one work center. For instance, ADs remove and install bladder and self-sealing fuel cells. Personnel of the AM rating perform the repairs on integral tanks. Personnel from the AO rating usually help in the installation and removal of external tanks (drop tanks). To maintain the aircraft fuel system pertaining to the AD rating, you must be familiar with the aircraft fuel system as well as the engine fuel system.

To meet the particular needs of the various types of aircraft, fuel tanks vary in size, shape, construction, and location. Sometimes a fuel tank is an integral part of a wing. Most often fuel tanks are separate units, configured to the aircraft design and mission.

FUEL TANK CONSTRUCTION

The material selected for the construction of a particular fuel tank depends upon the type of aircraft and its mission. Fuel tanks and the fuel system in general are made of materials that will not react chemically with any fuels. Fuel tanks that are an integral part of the wing are of the same material as the wing. The tank's seams are sealed with fuelproof sealing compound. Other fuel tanks may be synthetic rubber, or self-sealing cells or bladder-type cells that fit into cavities in the wing or fuselage of the aircraft.

Fuel tanks must have facilities for the inspection and repair of the tank. This requirement is met by installing access panels in the fuselage and wings. Fuel tanks must be equipped with sump and drains to collect sediment and water. The construction of the tank must be such that any hazardous quantity of water in the tank will drain to the sump, so the water can be drained from the fuel tank. The AD should be familiar with the different types of fuel tank/cell construction as described in the following paragraphs.

Self-Sealing Fuel Cells

A self-sealing cell is a fuel container that automatically seals small holes or damage caused during combat operations. A self-sealing cell is not bulletproof, merely puncture sealing. As illustrated in figure 4-4, the bullet penetrates the outside wall of the cell, and the sticky, elastic sealing material surrounds the bullet. As the bullet passes through the cell wall into the cell, the sealant springs together quickly and closes the hole. Now some of the fuel in the tank comes in contact with the sealant and makes it swell, completing the seal. In this application, the natural stickiness of rubber and the basic qualities of rubber and petroleum seal the hole. This sealing action reduces the fire hazard brought about by leaking fuel. It keeps the aircraft's fuel intact so the aircraft may continue operating and return to its base.

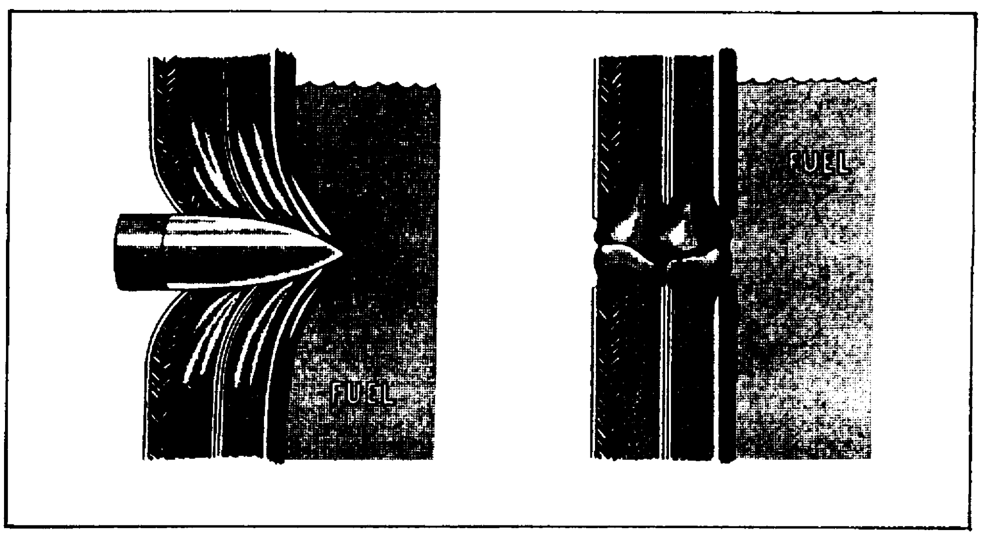


Figure 4-4.-Bullet sealing action.

The most commonly used types of self-sealing fuel cells are the standard construction type and the type that uses a bladder along with the self-sealing cell. Of the two, the standard construction cell is used the most. It is a semiflexible cell, made up of numerous plies of material.

The combination bladder and self-sealing cell is made up of two parts. One part is a bladder-type cell, and the other part is identical to the standard construction cell. It is designed to self-seal holes or damage in the bottom and the lower portions of the side areas. The bladder part of the cell (nonself-sealing) is usually restricted to the upper portion. This type of cell is also semi-flexible.

SELF-SEALING CELL (STANDARD CONSTRUCTION).— There are four primary layers of materials used in the construction of a self-sealing cell. These layers are the inner liner, nylon fuel barrier, sealant, and retainer. All self-sealing fuel cells now in service contain these four primary layers of materials. If additional plies are used in the construction of the cell, they will be related to one of the primary plies.

The inner liner material is the material used inside the cell. It is constructed of Buna N synthetic rubber. Its purpose is to contain the fuel and prevent it from coming in contact with the sealant. This will prevent premature swelling or deterioration of the sealant.

Buna rubber is an artificial substitute for crude or natural rubber. It is produced from butadiene and sodium and is made in two types, Buna S and Buns N. The Buna S is the most common type of synthetic rubber. It is unsuitable for use as inner liner material in fuel cells. It causes the petroleum fuels used in aircraft to swell and eventually dissolve. The Buna N is not affected by petroleum fuels, making it ideal for this application. However, the Buna N is slightly porous, making it necessary to use a nylon barrier to prevent the fuel from contacting the sealant.

The nylon fuel barrier is an unbroken film of nylon. The purpose of the nylon fuel barrier is to prevent the fuel from diffusing farther into the cell. The nylon is brushed, swabbed, or sprayed in three or four hot coats to the outer surface of the inner liner during construction.

The sealant material is the next material used in fuel cell construction. It remains dormant in the fuel cell until the cell is ruptured or penetrated by a projectile. It is the function of the sealant to seal the ruptured area. This will keep the fuel from flowing through to the exterior of the fuel cell (fig. 4-4.)

The mechanical reaction results because rubber, both natural and synthetic, will "give" under the shock of impact. This will limit damage to a small hole in the fuel cell. The fuel cell materials will allow the projectile to enter or leave the cell, and then the materials will return to their original position. This mechanical reaction is almost instantaneous.

The chemical reaction takes place as soon as fuel vapors penetrate through the inner liner material and reach the sealant. The sealant, upon contact with fuel vapors, will extend or swell to several times its normal size. This effectively closes the rupture and prevents the fuel from escaping. The sealant is made from natural gum rubber.

The retainer material is the next material used in fuel cell construction. The purpose of the retainer is to provide strength and support. It also increases the efficiency of the mechanical action by returning the fuel cell to its original shape when punctured. It is made of cotton or nylon cord fabric impregnated with Buna N rubber.

SELF-SEALING CELL (NONSTANDARD CONSTRUCTION).— One variation from the standard construction, self-sealing fuel cell previously discussed is shown in figure 4-5. It has four primary layers—an inner liner, a nylon fuel barrier, two sealant plies, and three retainer plies.

The cords in the first retainer ply run lengthwise of the cell. The cords in the second retainer run at a 45-degree angle to the first. The cords in the third retainer run at a 90-degree angle to the second. The outside is coated with

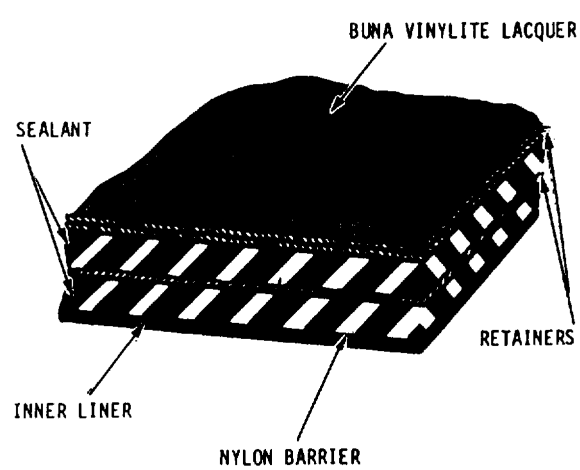


Figure 4-5.-Self-sealing fuel cell (standard construction).

Buna-Vinylite lacquer to protect the cell from spilled fuel and weathering.

Baffles and internal bulkheads are used inside the cell to help retain the shape of the cell and prevent sloshing of the fuel. They are constructed of square woven fabric impregnated with Buna N rubber.

Flapper valves are fitted to some baffles to control the direction of fuel flow between compartments or interconnecting cells. They are constructed of Micarta, Bakelite, or aluminum.

These plies, baffles, internal bulkheads, and flapper valves with the necessary fittings and combinations make up a typical self-sealing fuel cell.

Bladder-Type Fuel Cells

A nonself-sealing fuel cell is commonly called a bladder-type cell. It is a fuel container that does not self-seal holes or punctures. The advantage of using a bladder fuel cell results from the saving in weight. Some of the other advantages are the simplicity of repair techniques and the reduced procurement costs over self-sealing fuel cells.

Bladder-type cells are usually made of very thin material to give minimum possible weight. They require 100-percent support from a smooth cavity. The cell is made slightly larger than the cavity of the aircraft for better weight and distribution throughout the aircraft's fuel cavity structure.

The thinner wall construction increases the fuel capacity over the self-sealing cells, thus increasing the range of the aircraft. Many of our aircraft that were formerly equipped with self-sealing cells have been changed to bladder-type cells.

There are two types of bladder fuel cells—rubber type and nylon type.

RUBBER-TYPE BLADDER CELLS.— The rubber-type bladder cells are made in the same manner as self-sealing cells. They have a liner, nylon barrier, and a ret airier ply. The sealant layers are omitted. All three plies are placed on the building form as one material in this order—liner, barrier, and retainer. Figure 4-6 illustrates this type construction.

The inner liner may consist of Buna N rubber, Buna N coated square-woven fabric (cotton or nylon), or Buna N coated cord fabric. The purpose of the inner liner is to contain the fuel and provide protection for the nylon barrier.

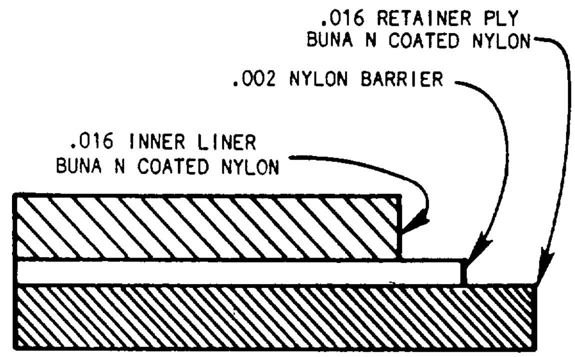


Figure 4-6.-Bladder cell construction.

The nylon barrier consists of three to four coats of nylon applied hot by brush, swab, or spray. The purpose of the nylon barrier is to keep fuel from diffusing through the cell wall.

The retainer consists of Buna N coated square-woven fabric (cotton or nylon) or cord fabric. The purpose of the retainer ply or plies is to lend strength to the fuel cell and provide protection for the nylon fuel barrier.

NYLON-TYPE BLADDER CELL (PLIOCEL).— Nylon bladder cells differ in construction and material from the Buna N rubber cells. This type of cell may be identified by the trade name "Pliocel" stenciled on the outside of the cell. The Pliocel construction consists of two layers of nylon woven fabric laminated with three layers of transparent nylon film.

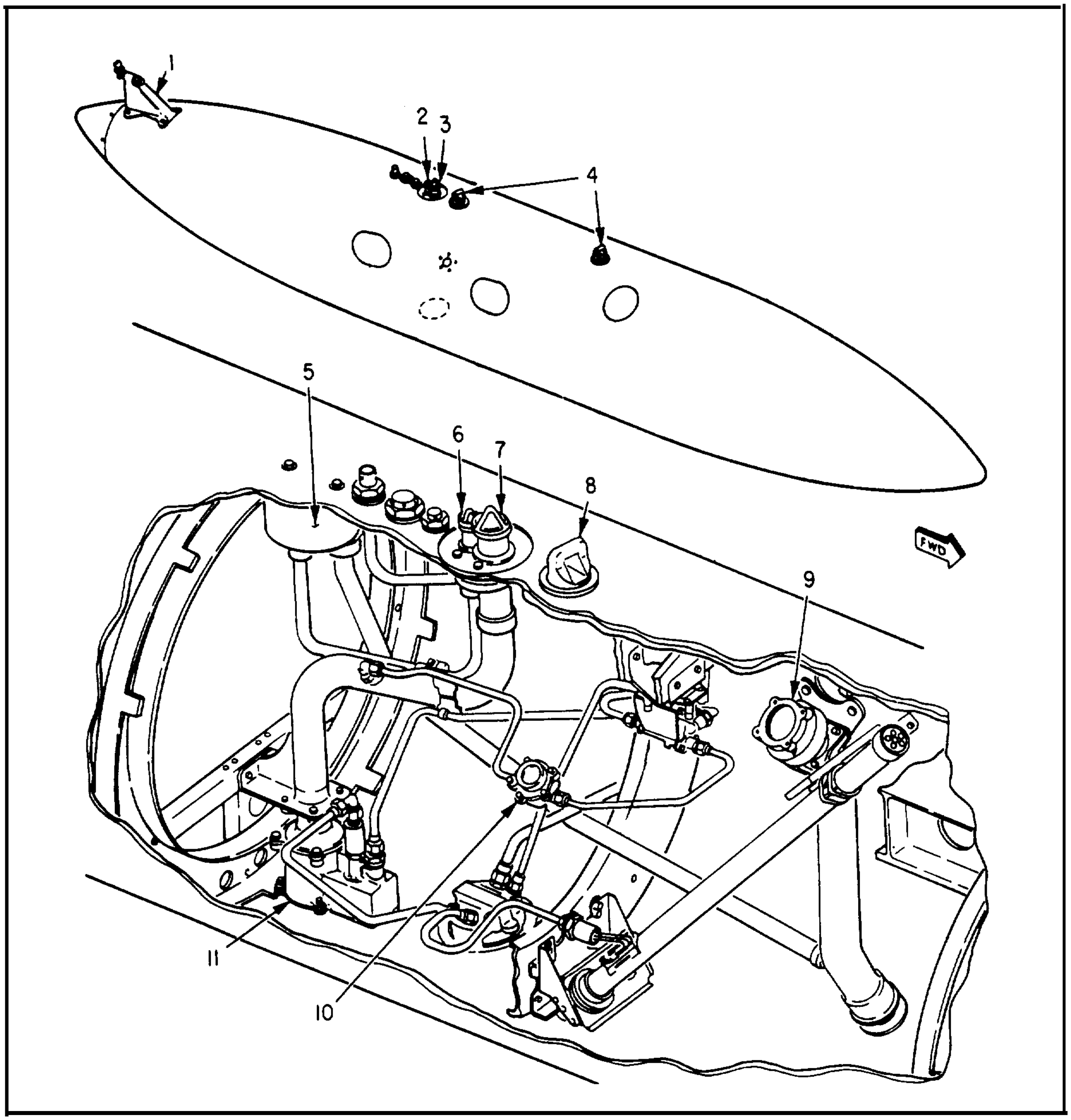
The repair of this type of cell must be accomplished by entirely different methods and with different materials. The adhesive and Buna N rubber used to repair the rubber-type bladder cell cannot be used on the nylon-type cell.

EXTERNAL FUEL TANK SYSTEM DESCRIPTION

External fuel systems increase range or mission by providing additional fuel for increased range or tanking. The external fuel system consists of the fuel (drop) tanks, a transfer system and jettison system.

Drop Tanks

The 150- and 300-U.S. gallon Aero 1C and the 300-U.S. gallon Aero 1 D external fuel tanks are droppable, streamlined, metal containers (fig. 4-7). These are carried under the wing to



1. Jettison pivot
2. Pylon air probe
3. Pylon fuel probe
4. Suspension lugs
5. Pressurization and vent valve
6. Pylon air probe
7. Pylon fuel probe
8. Suspension lug
9. Pressure relief valve
10. Manual precheck valve
11. Refuel/transfer shutoff valve

Figure 4-7.-External fuel tank (with cutway view).

supplement the internal fuel supply for extended range.

Threaded bosses and threaded inserts are provided on the top of the tank to accommodate the installation of adapter fittings. These are used to connect the fuel tank to the aircraft fuel system and the fuel tank air pressurization system. The tank is equipped with a pressure-fueling float switch and an air pressure and vent shutoff valve. The pressure-fueling float switch is a float-operated device that accomplishes the shutoff of fuel flow when the external fuel tank is filled to capacity. This is an electrical connector provided on the top of the tank for connecting the float switch electrical wiring to the aircraft wiring. The air pressure and vent shutoff valve vents the tank to the atmosphere during the pressure fueling procedure. However, the valve is also used with the external fuel tank air pressurization system. This valve uses engine bleed air as a means of pressurizing the tank and forcing fuel into the wing tank, or tanker store. A gravity filler port is provided to accomplish gravity fueling when pressure fueling equipment is not available.

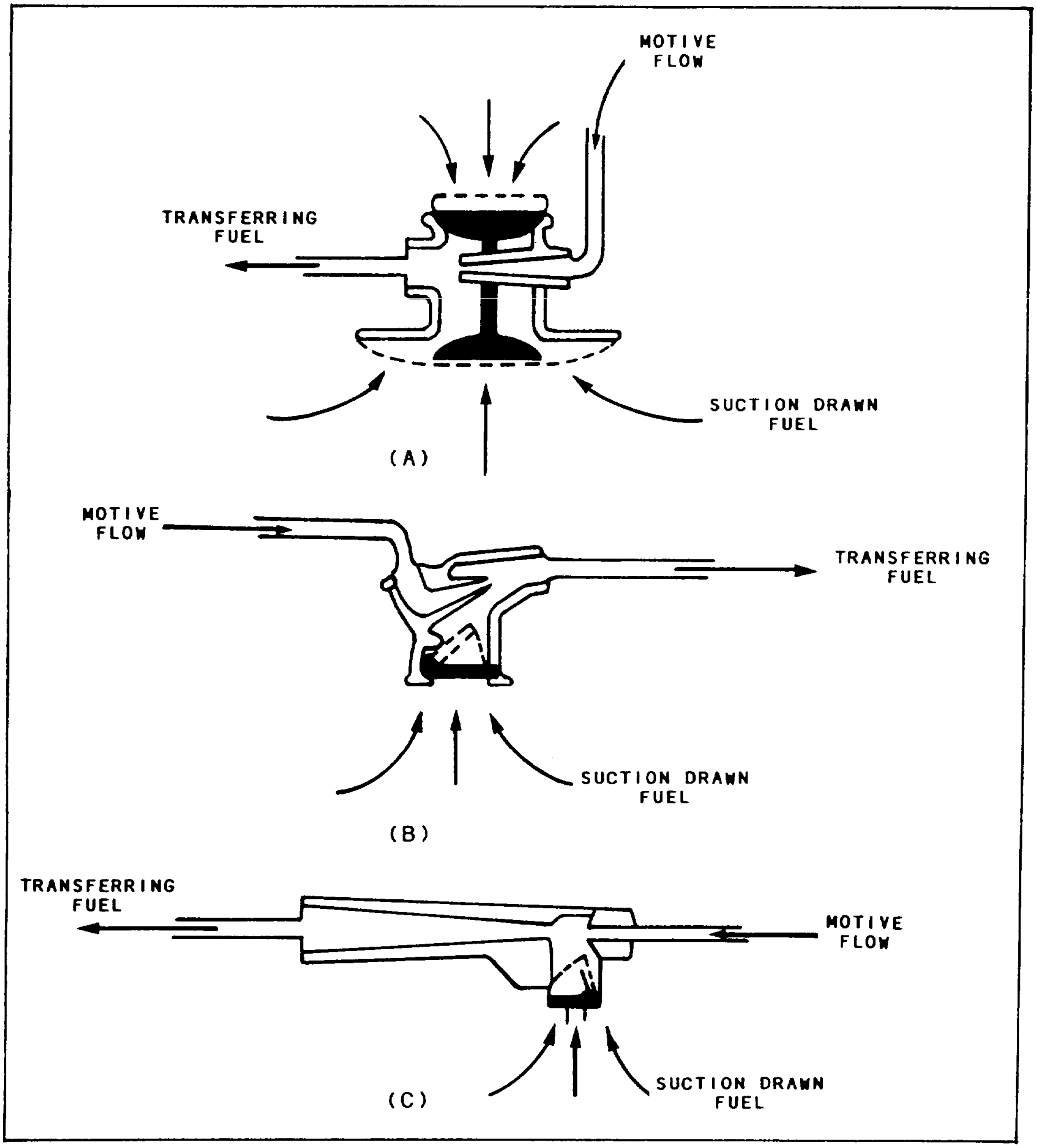


Figure 4-8.-Ejector pumps. (A) Dual seat; (B) single seat; (C) wing transfer.

External Fuel Transfer

External fuel tank pressurization and transfer is accomplished with regulated engine bleed air. An external tank pressure regulator maintains 15 to 18 psi air pressure to each of the external tanks. Once the tank is pressurized, fuel then transfers through the refuel/transfer shutoff valve into the refueling manifold. External fuel is then transferred to any of the fuel tanks that will accept the fuel. The refuel/transfer valve will close automatically when the external tank is empty.

The external tank air pressure regulator closes when there is weight on the wheels or when the in-flight refueling probe is extended. This will prevent the tanks from being pressurized while the aircraft is on the ground, during an arrested landing, or during in-flight refueling.

External Fuel Tank Jettison

The external fuel tanks can be selectively jettisoned or all jettisoned at one time, such as during an emergency situation. The external tank to pylon fuel/air coupling valves will automatically close the fuel transfer and air pressurization tubes once the tanks are jettisoned.

Fuel Tank Components

Common fuel tank parts include pumps, strainers, fuel quantity indicators, valves to control fuel level or routing, and vents and drains. These parts provide capabilities for fueling, defueling, and fuel system management.

PUMPS.— The airframe fuel system uses transfer pumps and boost pumps to deliver a continuous supply of fuel to the engine(s) under all operating conditions.

Transfer Pumps.— Fuel transfer pumps are installed in the fuel system to pump fuel from the various tanks of the aircraft to the main or sump tank. There are several different types of transfer pumps; common ones are electrically driven or an ejector-type motive-flow pump. See figure 4-8. Since the type of pump may differ from one aircraft model to another, the applicable maintenance instruction manual should be consulted for proper identification and maintenance.

Boost Pumps.— All Navy fixed-wing aircraft use pressure feed fuel systems. The basic source for this pressure is the engine-driven pump. Auxiliary fuel pumps or booster pumps are required in every pressure feed system. They are needed to supply fuel pressure for starting the engine and to supply fuel to the primer system. They are also used as an emergency pump in case of failure of the engine-driven unit.

The submerged boost pump is essentially an integral unit composed of a centrifugal pump and an electric motor. A screen is provided to protect the pump from foreign matter. A submerged boost pump is shown in figure 4-9.

Strainers.— Strainers are installed in the tank outlets and frequently in the tank filler necks. These strainers are of fairly coarse mesh and prevent only the larger particles from entering the fuel system. Other strainers are provided in the fuel inlets and in the fuel lines themselves. The latter are fine-mesh strainers.

FUEL QUANTITY INDICATORS.— Quantity-indicating units will vary. A fuel counter or indicator, mounted on the instrument panel, is electrically connected to a flowmeter installed in the fuel line to the engine. The fuel counter is similar in appearance to an automobile speedometer. When the aircraft is serviced with fuel, the counter is automatically set to the total number of pounds of fuel in all tanks. As fuel passes through the measuring element of the flowmeter, it sends electrical impulses to the fuel counter. These impulses actuate the fuel counter mechanism in such a way that the number of

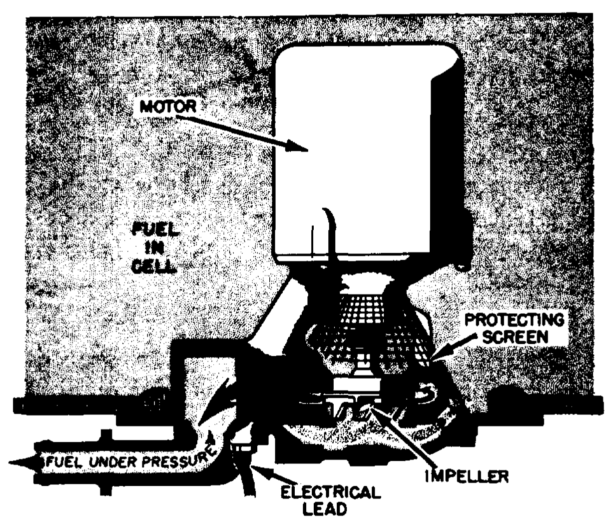


Figure 4-9.-Submerged boost pump.

pounds passing to the engine is subtracted from the original reading. Thus, the fuel counter continually shows the total quantity of fuel (in pounds) remaining in the aircraft. However, there are certain conditions that cause the fuel counter indication to be inaccurate. Any fuel remaining in the droppable tanks when they are jettisoned is indicated on the fuel counter as fuel still available for use. Any fuel that leaks from a tank or a fuel line upstream of the flowmeter is not counted. Any fuel supplied to the engine by the emergency pump is not counted.

Some continuous-flow fuel systems have a fuel quantity gauge for each tank or group of interconnected tanks. If the system has a main tank with auxiliary tanks feeding into it, a fuel quantity gauge is normally for the main tank. In this type of system, the pilot relies on the indication of the fuel counter (flowmeter). All fuel in the auxiliary tanks is transferred to the main tank and fed to the engine. When all fuel except that in the main tank has been consumed, the fuel quantity gauge provides a more reliable indication of the fuel still available. The accuracy of its indication is not affected by the conditions listed in the preceding paragraph; that is, leakage and emergency system supply.

The fuel quantity gauge normally used in aircraft is an electronic (capacitor) type for measuring fuel in aircraft in pounds. Normally, the capacitor-type fuel gauge is used without a flowmeter, although most engines have provisions for installing one if it is required,

A low-level switch is incorporated in the fuel-level transmitter. This switch turns on an indicator light in the cockpit when the fuel in the tank drops to a specific low level. This signal informs the pilot that the fuel supply is almost exhausted.

AIRCRAFT FUEL VALVES.— Valves are used to regulate and control the flow of fuel in the airframe and engine fuel systems. Some of these valves are discussed in the following paragraphs.

Shutoff Valves.— Shutoff valves are two-position (open and closed) valves. The manually operated type is installed to shut off the fuel while a unit in the system is being removed or replaced. Electrically operated shutoff valves control flow during fuel transfer and when fuel is being bypassed because of a defective or damaged unit. Figure 4-10 shows a motor-operated shutoff valve, commonly referred to as a gate valve.

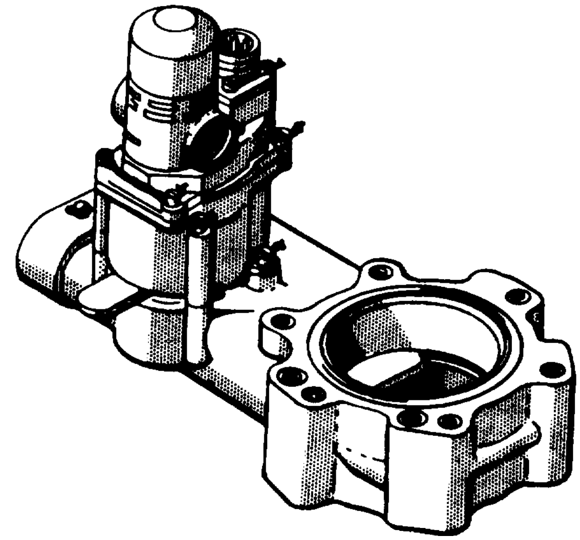


Figure 4-10.-Motor-operated shutoff valve (gate valve).

Fuel Level Control Valves.— Fuel level control valves control fuel levels in a tank during ground fueling or fuel transfer to the main tank. There is one fuel level control valve for each tank, auxiliary tank, or group of interconnected tanks. When used for fuel transfer, the valves are located at different levels in the main tank. Fuel is then transferred from the auxiliary tanks in the order designed by the manufacturer. During normal operation of the fuel system, the boost pumps for all the tanks are turned on before the engine is started. Each auxiliary tank boost pump continues to operate until the tank is emptied; then the fuel pressure warning light comes on and the boost pump is turned off by the pilot. Thus, fuel is delivered under boost pump pressure to each fuel level control valve. The fuel then remains in the tank or group of tanks to which it is connected.

In the sectional views of the valve in figure 4-11, note how the float rises and lowers with the fuel level. When the fuel level in the main tank is high, the float is raised. This closes the pilot valve and lifts the ball check from its seat. Fuel, under boost pump pressure, then passes through the main valve stem into the valve body. Note how the fuel pressure exerted against the bottom surface of the synthetic rubber diaphragm holds the main valve closed. This prevents fuel from entering the main tank from the transfer line.

When the fuel level in the main tank drops, the float moves downward. Note in figure 4-11 how this action allows the ball check to seat in

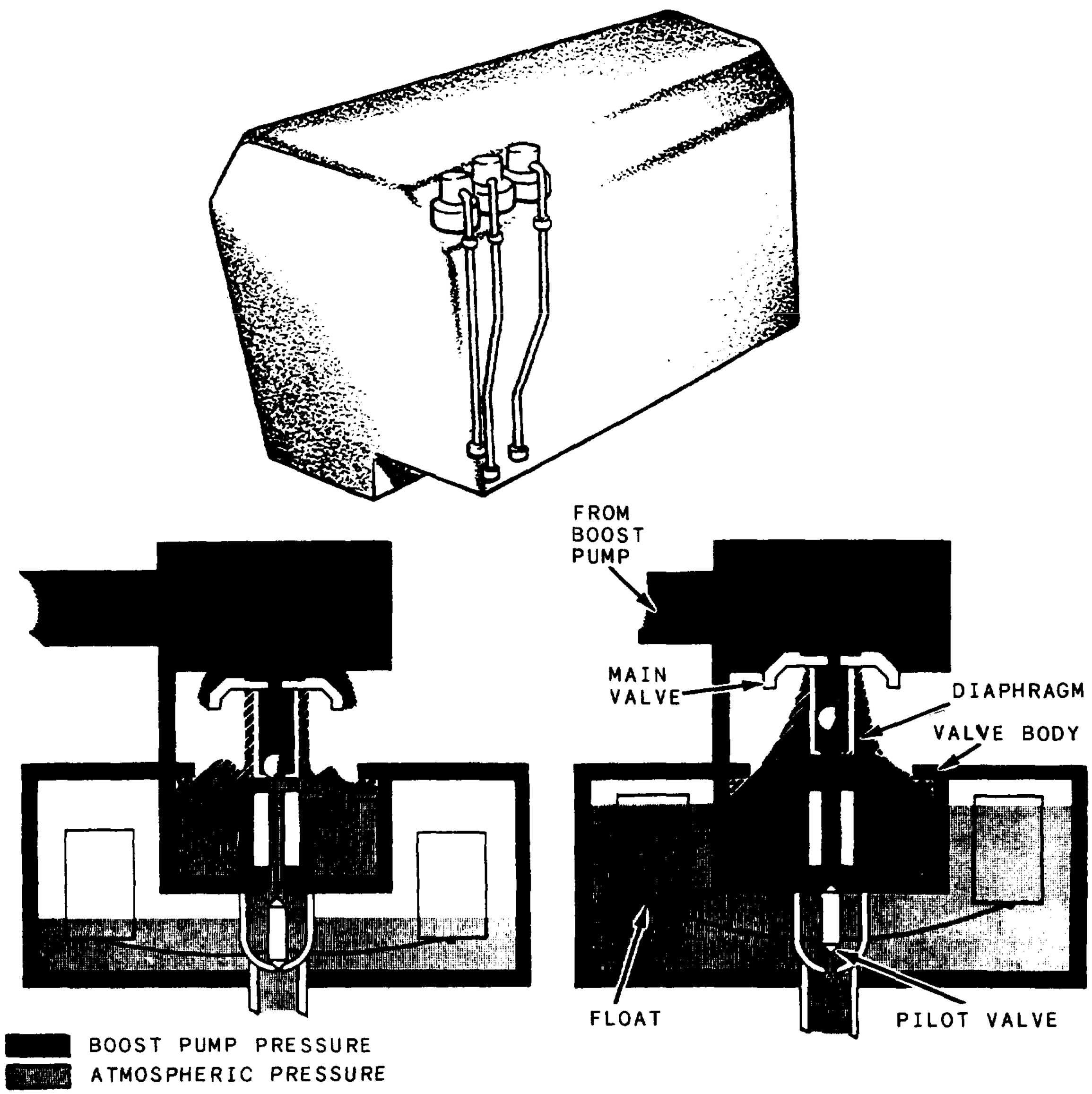


Figure 4-11.-Fuel level control valve.

the main valve stem. It then shuts off the fuel pressure in the bottom side of the diaphragm. The pilot valve opens and permits fuel to drain from the main valve body. As the pressure on the under surface of the diaphragm is relieved, the main valve opens to admit fuel from the auxiliary tank.

Check Valves.— Check valves are installed in the fuel system wherever fuel flow in one direction is required. Fuel pressure in the direction of flow-indicated by an arrow on the valve-forces the valve open against spring pressure. Spring force and reversal of fuel flow close the valve. This is a one-direction valve, It is important that the valve be installed so that the arrow points in the desired direction of flow.

In some turbojet engine fuel systems, there is a check valve between the fuel control and the fuel dump valve. The check valve remains closed until a certain pressure is reached in the fuel line. A bypass to the top of the dump valve transmits this bypass pressure. Then, upon engine starting, the controlled fuel pressure builds up. The dump valve is then actuated to close the drain port and open the flow into the fuel manifolds. The check valve remains fully open during engine operation.

Selector Valves.— In the continuous-flow system, selector valves are not used for tank-to-engine selection during normal operation. However, in many installations there are selector valves to enable the pilot or mechanic to control the fuel flow for special purposes. This includes fuel integrity checks, shutting off fuel to the engine, bypassing fuel components to allow manual operations in emergency conditions, and cross-feeding fuel to different tanks or engines to prevent an unbalanced fuel load.

FUEL LINES AND FITTINGS.— The fuel lines between the various tanks and between the tanks and the engine-driven pump are of the conventional type. They consist of metal tubing or flexible hose. There are drain cocks at low points in the lines so that any water that collects at these locations may be drained. A quick-disconnect fitting is often installed in the main fuel line to the engine. This fitting permits quick disconnection of the main fuel line when an engine change is performed.

The line connecting the various fuel system units installed on the engine are made of either metal tubing or flexible hose. Since these lines and fittings must withstand the high pressures encountered on the discharge side of the engine-driven fuel pump, special types are used.

Lightweight Hose Assemblies.— The lightweight engine hose assembly is designed for continuous operating temperatures of –40° to +300°F. The inner tube is seamless and is of a specially formulated synthetic compound. The reinforcement and cover are of stainless steel wire braid and consist of a partial inner braid and a full-coverage outer braid. This hose can be identified by the bright wire braid outer cover with red markings. These markings are repeated 6 inches apart.

This hose is designed for aircraft power plant and airframe fuel and oil lines. It is widely used in jet engines. It is flexible, lightweight, and has the ability to withstand high operating temperatures where maximum fire resistance is a prime consideration. This hose may be used in submerged applications.

The fitting on this type of hose uses a lip-seal principle, instead of compression, to effect a fluid seal. This lip-seal is formed during assembly by a sharp knifelike spur, which cuts an annular flap in the hose inner tube. Fitting retention against blowoff is affected by the cutting action of the spur. This separates the wire braid, which is then gripped between the nipple and the socket. These fittings must be marked with a painted stripe to detect hose pushout after assembly or proof test.

Rigid Tubing.— The majority of rigid tubing used in naval aircraft is manufactured from aluminum. However, exposed lines and lines subject to abrasion or intense heat are made of stainless steel. Therefore, you will be concerned more with stainless steel lines. Whenever an engine fuel line requires replacement, the normal procedure is to obtain from supply a preformed line with fittings attached. If a line must be manufactured locally and installed on an engine or component, the original line must be duplicated as exact as possible.

Figures 4-12 and 4-13 show a few of the correct and incorrect methods of installing metal tubing and flexible hose.

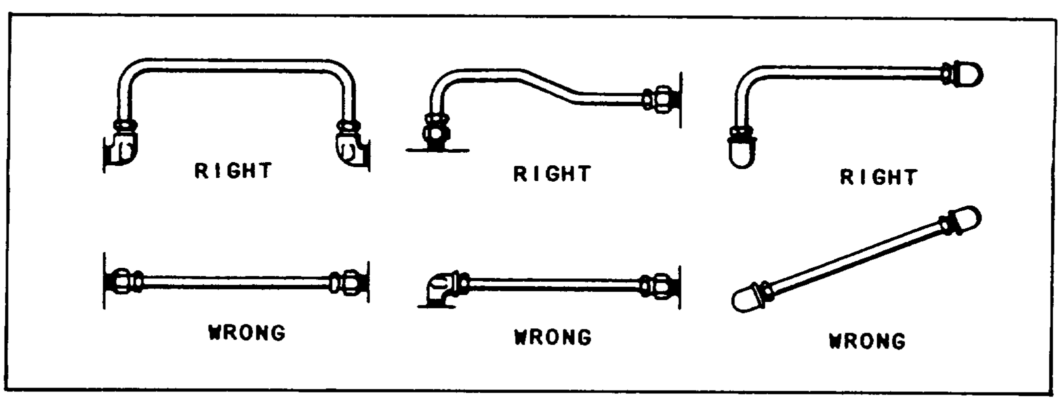


Figure 4-12.-Correct and incorrect methods of installing tubing.

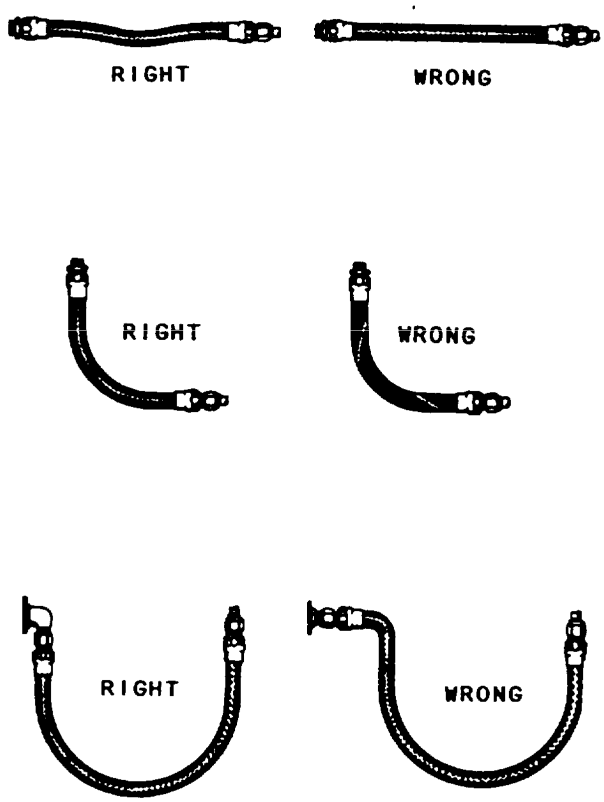


Figure 4-13.-Correct and incorrect installation of flexible hose.

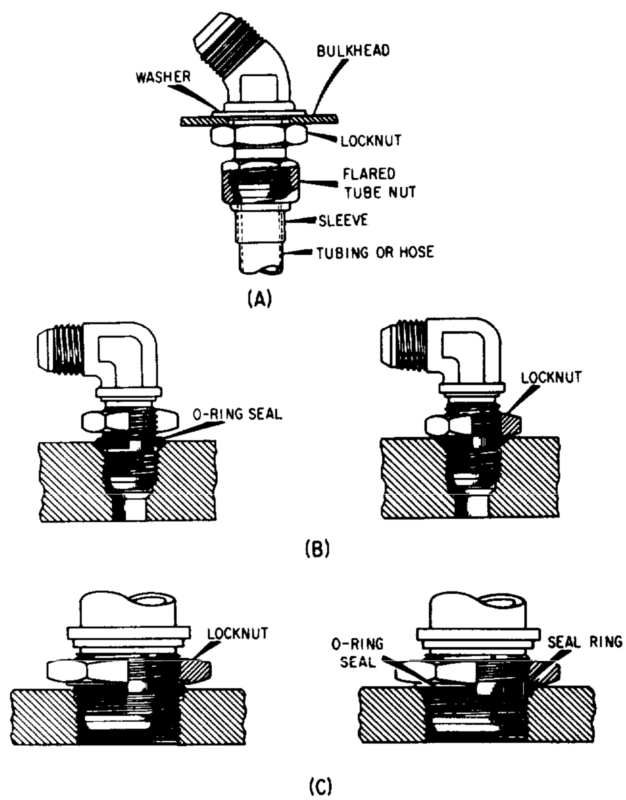


Figure 4-14.-Fuel line fittings. (A) bulkhead fitting; (B) universal fitting; (C) universal fitting with O-ring seal and seal ring.

Bulkhead Fitting.— Bulkhead fittings must be properly installed. To ensure proper installation of the fitting shown in figure 4-14, view A, the mechanic must check to see that the bulkhead has the required thickness for which the fitting was designed.

Fitting With O-Ring Seal.— The nut should be assembled on the fitting end until the washer face of the nut lines up with the upper corner of the seal groove. The O-ring seal should be lubricated sparingly with petrolatum and placed on the fitting groove so it contacts the nut. Then screw the fitting (and nut simultaneously) into the boss until the seal contacts the boss chamfer and the nut contacts the boss. Before tightening the locknut, position the fitting direction by turning it three-fourths turn or turning it out one-fourth turn. Assemble the fluid line to the fitting end. Holding the fitting stationary in the selected position, tighten the locknut. See figure 4-14, view B.

Fitting With O-Ring Seal and Seal Ring.— The threads of the fitting, the O-ring seal, and the seal ring should be coated sparingly with petrolatum or hydraulic fluid. Work the seal ring, with the smooth (hair) side toward the O-ring seal, into the counterbores of the nut. You then turn the nut down until the O-ring seal is pushed firmly against the lower threaded section of the fitting. Install the fitting into the boss. You then keep the nut turning with the fitting until the O-ring contacts the boss. This point can be determined by a sudden increase in torque. With the fitting in this position, put a wrench on the nut to prevent its turning; then turn the fitting in 1 1/2 turns. Then position the fitting by turning in not more than one additional turn. Hold the fitting and turn the nut down tight against the boss. Slight extrusion of the ring is not considered detrimental. See figure 4-14, view C.

FUEL DRAINS.— So the moisture content can be checked and moisture drained from the fuel system, the drain valve(s) is/are installed in the low point (or points) in the system (or units).

Figure 4-15, views A through G, shows seven different types of fuel drain valves used on aircraft.

The valve shown in view A is usually located in the boost pump or in the low-point drain. This fitting needs to be pushed up and held to have it in the OPEN position. To close the valve, you should release the plunger.

The valve shown in view B is usually found in the main fuel filter drain. To open this type of drain, you should rotate the bar counterclockwise to lock it in the OPEN position. To close the drain, rotate the bar in the clockwise direction.

The valve shown in view C is usually located in the inboard or outboard compartment low-point drain. To open and lock it in the open position, insert a screwdriver in the slot and turn it clockwise (about 90°). To close this valve, turn the screwdriver counterclockwise.

The fuel drain valve shown in view D can be opened by inserting a screwdriver in the slot, pushing in, and holding it, which will allow fuel to flow. It can be closed by releasing the screwdriver.

The fuel drain shown in view E is for the aft boost pump drain. It can be opened and locked in the OPEN position by rotating it in the counterclockwise direction. Rotating it in the clockwise direction will close the valve.

The valve shown in view F is usually found in the low-point drain and in the main vent line of the low-point drain. The valve is automatically actuated open at 1.0 psi minimum and closes at 3.0 psi maximum.

The valve shown in view G is usually found in the low-point drain, forward sump cell, and is opened by pushing and holding. It is closed by releasing the plunger.

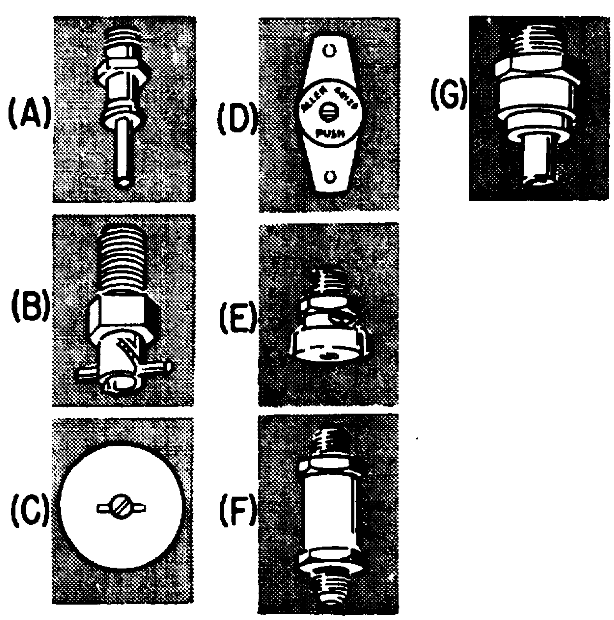


Figure 4-15.-Fuel drain valves.

ENGINE FUEL SYSTEM

Fuel from the airframe fuel system is supplied to the engine-driven fuel pump through the engine fuel supply hose. The engine fuel supply hose is the last link between the airframe fuel system and the engine fuel system. Fuel from the engine-driven fuel pump is directed to the fuel control. Then it is regulated and distributed to the combustion chambers. Components of the engine fuel system are discussed in the following paragraphs, along with operation.

FUEL CONTROL (JFC 25-3) OPERATION

The JFC 25-3 hydromechanical fuel control, shown in figure 4-16, is a lightweight, high-capacity, fuel-flow-metering unit. It is designed to permit selection of a desired engine jet thrust level. It also provides automatic compensation through the full range of thrust for the ambient operating conditions encountered during flight. Engine thrust during ground operation and under various flight conditions is controlled by a single power lever. It also regulates fuel for engine starting and shutdown. The variables sensed by the fuel control are power lever angle, burner pressure **(P_B)**, high-pressure compressor speed **(N_2)**, and compressor inlet temperature **(T_{T2})**. By using these variables, the fuel control accurately governs the engine's steady-state. It is selected through a speed-governing system of the proportional or droop type. The fuel control also uses these same variables to control fuel flow for acceleration and deceleration.

The fuel control consists of a fuel-metering system and a computing system. The metering system regulates fuel supplied to the engine by the engine-driven fuel pump to provide the engine thrust demanded by the pilot. Fuel regulation is also controlled by engine operating limitations, as sensed and scheduled by the fuel control computing system. The computing system senses and combines various operational parameters to govern the output of the metering system of the fuel control under all engine operating conditions.

High-pressure fuel is supplied to the control inlet from the engine-driven pump. At the inlet

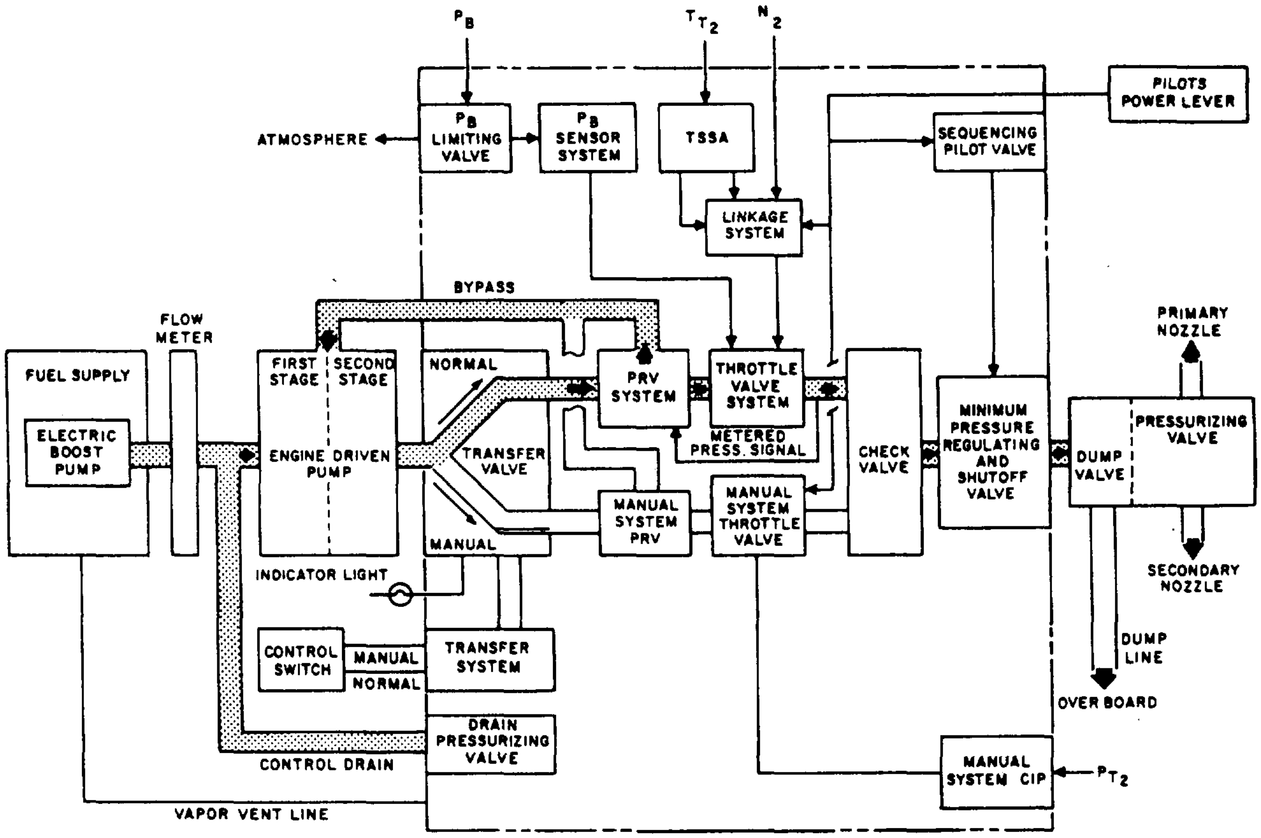


Figure 4-16.-Fuel control (JFC 25-3).

of the control, the fuel is filtered by a coarse (80-mesh) screen and a fine (40-micron) screen. The coarse screen protects the metering system from large particles of fuel contaminants. If this screen becomes clogged, a filter relief valve will open, permitting continued operation with unstrained fuel. The fine screen protects the computing system against solid contaminants. This screen is self-cleaning. It traps particles by removing the high-velocity of the fuel flowing past the screen into the metering section.

Next, the fuel encounters the pressure-regulating valve, which is designed to maintain a constant pressure differential across the throttle valve. All high-pressure fuel in excess of that required to maintain this pressure differential is bypassed to the pump interstage by the pressure-regulating valve. This valve is servo controlled. The actual pressure drops across the throttle valve orifice and is compared, by the sensor, with a selected pressure drop, and any error is hydraulically amplified. The amplified error positions the pressure-regulating-valve spring, altering the force balance of this valve so that sufficient high-pressure fuel is bypassed to maintain the selected pressure drop. The pressure-regulating-valve sensor also incorporates a bimetallic disc to compensate for any variation in the specific gravity of the fuel, which results from fuel temperature change.

The high-pressure fuel, as regulated by the pressure-regulating valve, then passes through the throttle valve. This valve consists of a contoured plunger that is positioned by the computing system of the control within a sharp-edged orifice. By virtue of the constant pressure drop maintained across the throttle valve, fuel flow is a function of the plunger position. An adjustable stop limits the motion of this plunger in the decrease fuel direction to permit minimum fuel flow.

The final part to act upon the metered flow prior to its exit from the control is the minimum pressure and shutoff valve. This valve is designed to shut off the flow of metered fuel to the engine when the power lever is in the OFF position. This causes the power-lever-operated sequencing valve to transmit a high-pressure signal to the spring side of the shutoff valve. This forces the latter against the seat, thus shutting off the flow of fuel to the engine. When the power lever is moved out of the OFF position, the high-pressure signal is replaced by pump interstage pressure. Then metered fuel pressure is increased sufficiently to overcome the spring force, the valve opens, and fuel flows to the engine. Thereafter, the valve will provide a minimum operating pressure within the fuel control. This ensures that adequate pressure is always available for operation of the servos and valves at minimum flow conditions.

The power-lever-operated sequencing valve also incorporates a windmill bypass feature, which functions when the shutoff valve is closed. This feature bleeds throttle valve discharge flow to the fuel pump interstage to increase the throttle valve pressure drop and opens the pressure-regulating valve. Damage to the fuel pump from excessive pressure is thus prevented during engine windmilling. The sequencing valve functions in both the normal and manual operating systems.

The following designators are used in the description of the computing system of the JFC 25-3 fuel control. These designators should be referred to during study of the fuel control.

N_2 .... High-pressure compressor rotor speed (RPM)

T_{T2} .... Compressor inlet temperature

P_B .... Burner can pressure

W_F/P_B .... Ratio of metered fuel flow to burner can pressure

The computing system positions the throttle valve to control steady-state engine speed, acceleration, and deceleration. This is accomplished by using the ratio W_F/P_B (the ratio of metered fuel flow to engine burner pressure) as a control parameter. Throttle valve positioning of this parameter is achieved through a multiplying system whereby the W_F/P_B signal is used for acceleration or deceleration. The steady-state speed control is multiplied by a signal proportional to P_B to provide the required fuel flow.

P_B is sensed in the following manner: A motor bellows is internally exposed to P_B and the resulting force is increased by the force of an evacuated bellows of equal size. It is directly connected to the motor bellows. The net force, absolute burner pressure, is transmitted through a lever system to a set of rollers having a position proportional to W_F/P_B. These rollers ride between the bellows-actuated lever and a multiplying lever. The force proportional to P_B is thus transmitted through the rollers to the multiplying lever. Any change in the roller position (W_F/P_B) or the P_B signals upsets the equilibrium of this lever. This changes the position of a flapper-type servo valve, which is supplied with regulated high-pressure fuel through a fried bleed orifice. The resulting change in servo pressure between the two orifices is controlled by the position of a piston attached to the throttle valve plunger. The motion of this piston compresses or relaxes a spring that will return the multiplying lever to its equilibrium position. An adjustable minimum-ratio stop on the W_F/P_B signal controls engine deceleration. This arrangement provides a linear relationship between decreasing W_F and P_B, which results in blowout-free decelerations.

An adjustable maximum-ratio stop on the W_F/P_B signal controls engine acceleration. This stop is positioned by an acceleration-limiting cam. It is rotated by a speed-sensing servo system and translated by a compressor inlet temperature (T_{T2}) sensing servo system. The cam is so contoured as to define a schedule of W_F/P_B versus engine speed for each value of T_{T2} that will permit engine accelerations. This avoids engine overtemperature and surge limits without compromising engine acceleration time.

A burner pressure limiter incorporated in the fuel control senses burner pressure with respect to ambient pressure. When this differential exceeds a preset maximum, the pressure signal to the burner pressure motor bellows. This reduces bleeding through the limiter valve to ambient pressure. This causes a limitation on fuel flow, which prevents burner pressure from exceeding a maximum, safe value.

A flyweight-type, engine-driven, speed-sensing governor controls movement of the speed servo piston through a pilot valve. When N_2 speed changes, the flyweight force varies and the pilot valve is positioned to meter either low- or high-pressure fuel to the speed servo piston. The motion of the piston repositions the pilot valve until the speed-sensing system returns to equilibrium. The piston incorporates a rack that meshes with a gear segment on the three-dimensional acceleration cam to provide the speed signal for acceleration limiting. This piston position is also used to indicate actual engine speed, and it is connected by a droop lever to a droop cam.

The temperature-sensing bellows and servo assembly are connected through a lever and yoke assembly to the acceleration-limiting cam. The position of this servo piston is indicative of compressor inlet temperature (T_{T2}) and is used to translate the acceleration cam. It integrates the temperature and speed signals. The position of the speed-set cam is also translated by the servo piston by means of a cross-link to the acceleration cam. Engine steady-state condition is a function of high compressor (N_2) speed, compressor inlet temperature (T_{T2}), burner pressure (P_B), and power lever position.

In the event that the primary control system malfunctions, the manual system may be engaged by operating a switch in the cockpit. It then energizes the manual transfer solenoid to close the flapper valve. The flapper valve will remain in the closed position because of residual magnetism, regardless of whether or not the solenoid is continuously energized. Servo action positions the shuttle valve to direct pump discharge pressure to the spring side of the manual and normal systems transfer valve. This pressure, combined with spring pressure, positions the valve to close off the primary operating system and direct high-pressure fuel to the manual system.

FUEL VALVES

Fuel valves in the engine fuel system aid in starting, stopping, and as safety factors. Valves may differ slightly from engine to engine, and they may be called by different nomenclature, although they perform identical functions. Some of these valves and their functions are discussed in the following paragraphs.

Fuel-pressurizing Valve

The fuel-pressurizing valve is usually required on jet engines. It incorporates a duplex-type fuel nozzles to divide the flow into primary and secondary (main) manifolds. At the low fuel flows required for starting and altitude idling, all the fuel passes through the primary line. As the fuel flow increases, the valve begins to open the main line. At maximum flow, the main line is passing about 90 percent of the fuel.

Fuel-pressurizing valves will usually, through incorporation of spring-loaded inlet check valves, trap fuel forward of the manifold, giving a positive cutoff. This cutoff prevents fuel from leaking into the manifold and through the fuel nozzles. This eliminates afterfires and carbonization of the fuel nozzles. Carbonization occurs when low combustion chamber temperatures cause incomplete burning of the fuel.

An example of this arrangement is the fuel-pressurizing and dump valve. This valve performs two major functions, as indicated by its name. During engine operation, it divides metered fuel flow into two properly pressurized portions, primary and secondary. During engine shutdown, it provides a dump system that connects the fuel manifolds to an overboard drain. The features of the fuel-pressurizing and dump valve are shown in figure 4-17.

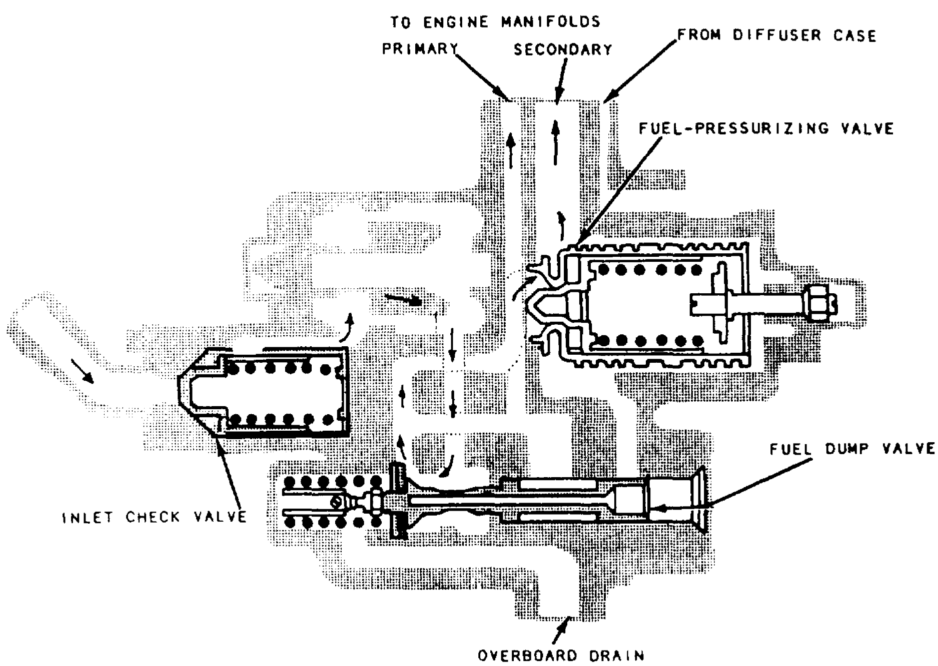


Figure 4-17.-Fuel-pressurizing and dump valve.

The fuel-pressurizing and dump valve is connected to the fuel manifold. It is composed of an inlet check valve, a 200-mesh fuel inlet screen, a pressurizing or flow-dividing valve, and a manifold dump or drain valve.

Flow Divider

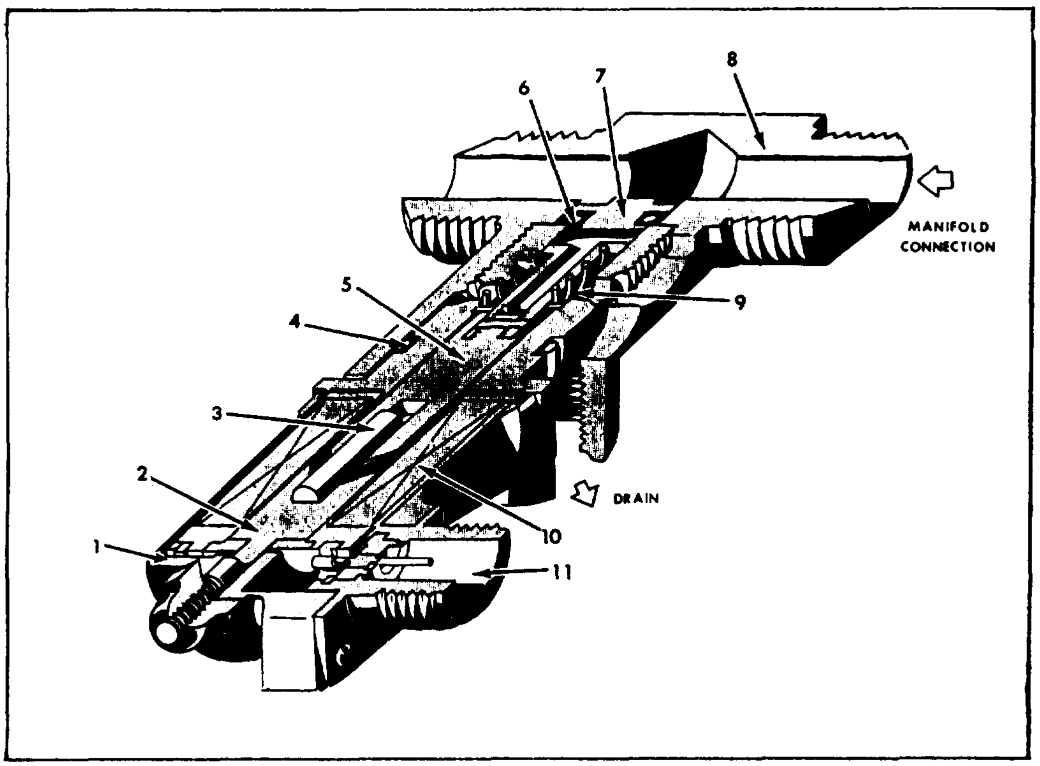
A flow divider performs essentially the same function as a pressurizing valve. It is used, as the name implies, to divide flow to the duplex fuel nozzles. It is not unusual for units performing the same functions to be called different names on different engines or by different manufacturers.

Drain Valves

Drain valves drain residual fuel from the various parts of jet engines where accumulated fuel is most likely to present operating problems The chance of a fire hazard exits in a combustion chamber if fuel accumulation occurs during shutdown. Residual lead and gum deposits from evaporated fuel cause problems in fuel manifolds and fuel nozzles.

In some instances, the function of draining fuel manifolds is accomplished by an individual unit known as a drip or dump valve. This type of valve may operate by pressure differential, or it may be solenoid operated. See figure 4-18.

The combustion chamber drain valve drains raw fuel that accumulates in the combustion chamber. It drains after each shutdown when the engine fire has gone out, and it drains fuel that collects during a false start. The can type combustion chambers drain fuel, by gravity, down through the flame tubes or interconnector tubes until it gathers in the lower chambers. It is fitted with drain lines to the drain valve. In the basket annular type combustion chamber, the fuel drains through the airholes in the liner and collects in a trap in the bottom of the chamber housing. A



1. Solenoid cover assembly
2. Solenoid core
3. Guide pin
4. Packing
5. Plunger
6. Packing
7. Valve
8. Body
9. Spring
10. Solenoid spool and wire assembly
11. Electrical disconnect

Figure 4-18.-Solenoid-operated drip (dump) valve.

typical combustion chamber drain valve is shown in figure 4-17.

When the fuel collects in the drain lines, the drain valve allows the fuel to drain when pressure in the combustion chamber manifold is reduced to near atmospheric pressure. As shown in figure 4-17, the drain valve is spring-loaded in an open position. It is closed as pressure within the manifold and lines to the burners increases above that of the spring tension trying to keep the valve open. It is imperative this valve be in good working condition to drain accumulated fuel after each shutdown. Otherwise, a HOT START during the next starting attempt or an AFTERFIRE after shutdown may occur.

Fuel Spray Nozzles and Fuel Manifolds

In jet engines, the fuel spray nozzles function is to inject fuel into the combustion area in a highly atomized, precisely patterned spray. It then burns evenly and in the shortest possible space and time. It is very important that the fuel be evenly distributed by the spray to prevent the formation of any hot spots in the combustion chambers. It is of particular value for this reason that the spray be well centered in the flame area of the liners.

Fuel nozzle types vary between engines; mostly fuel is sprayed into the combustion area under pressure through small orifices in the nozzles. The nozzles generally used are of the vaporizing orifice type and include the simplex and the duplex configurations. The duplex nozzle usually requires a dual manifold and a pressurizing valve or flow divider. This is to divide primary and secondary (main) fuel flow, while the simplex nozzle requires only a single manifold for proper fuel delivery.

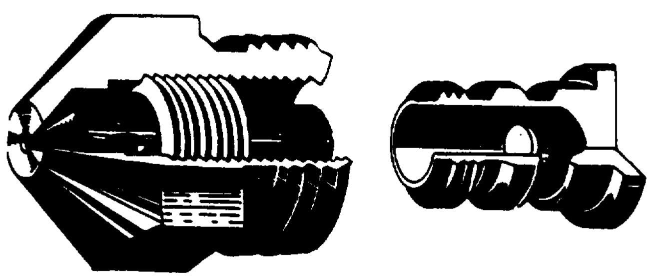


Figure 4-19.-Simplex fuel nozzle.

SIMPLEX FUEL NOZZLE.— The simplex fuel nozzle was the first type of nozzle used in turbojet engines, but it was replaced in most installations with the duplex nozzle, which gives better atomization at starting and idling speeds. The simplex nozzle is still being used to a limited degree. A simplex nozzle is shown in figure 4-19. Each of the nozzles of the simplex type consists of a nozzle tip, an insert, and a strainer made of a fine-mesh screen and a support.

DUPLEX FUEL NOZZLE.— The duplex fuel nozzle is the type nozzle most widely used in present-day engines. Its use requires a flow divider, which gives a desirable pattern of spray for combustion over a wide range of operating pressures. A nozzle of this type is shown in figure 4-20.

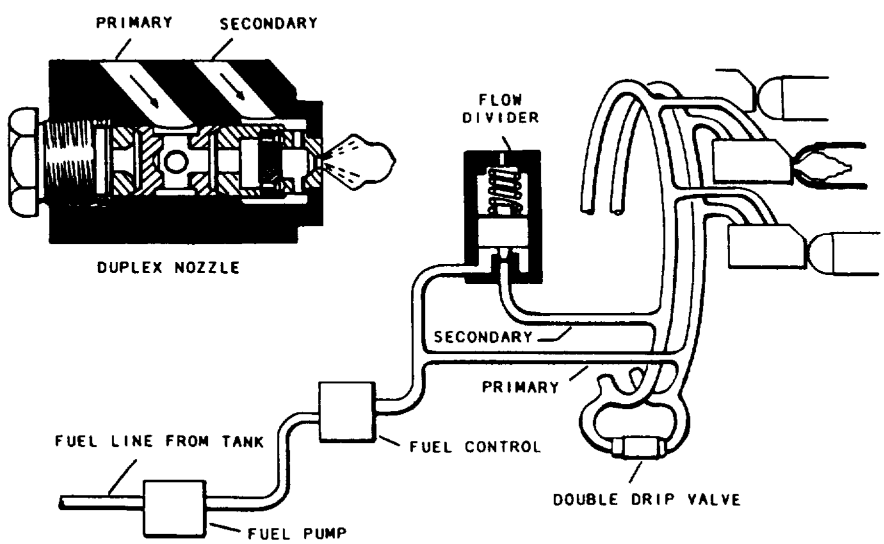


Figure 4-20.-Duplex fuel nozzle.

The primary fuel entry line (manifold) of the duplex nozzle is smaller than the secondary entry line. This feature permits fuel within the primary line to reach a comparatively high degree of pressure and atomization during starting and altitude idling conditions. The secondary fuel entry line also starts supplying fuel when engine rpm raises fuel pressure to a predetermined level—usually after engine rpm is stabilized after a start.

The single manifold of the simplex nozzle does not have the above-mentioned feature and must supply fuel under all operating conditions. So duplex nozzles provide better low-speed performance then simplex-type nozzles.

At sufficient pump outlet pressure, the pressurizing valve or flow divider allows fuel to enter the main or secondary line. The spray orifice will increase its spray angle because of the increased fuel flow and pressure. Figure 4-20 shows the spray angle of a typical duplex nozzle.

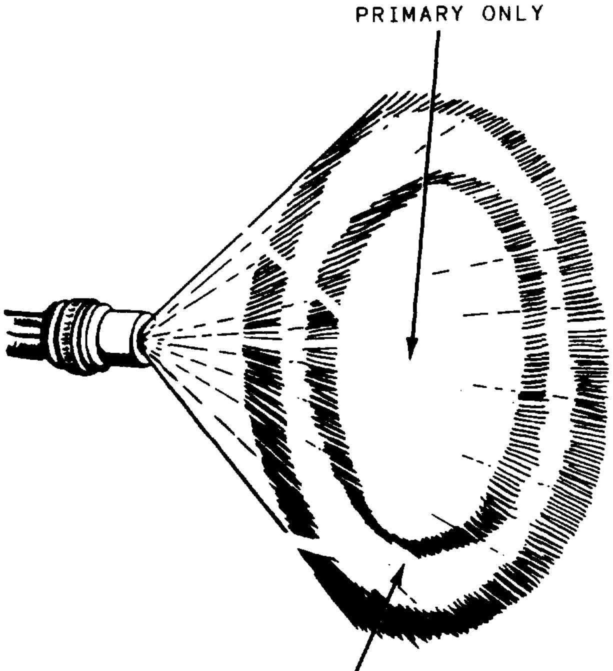


Figure 4-21.-Duplex nozzle spray pattern.

The duplex nozzle may be represented in many configurations, depending upon the type of combustion chamber installation. Therefore, the nozzle parts will vary between duplex nozzles of various engines. Figure 4-21 shows a duplex nozzle for use in a can-annular combustion chamber.

FUEL SELECTORS

Valves covered in this section are designed to control the flow of fuel in all aircraft fuel systems. Construction and flow control are similar for most valves used in modern aircraft. The construction of the selector is basically a ported body housing a rotor. Controlling these valves can be manual or electrical. Graphite sealing discs are so arranged on the rotor that the ports are sealed or opened in sequence by rotation of the rotor. The ends of the rotor bores in the body are closed by top and bottom caps with O-rings. The rotor stem extends through the top cap with an O-ring seal to prevent leakage. This stem is rotated by an electrical actuator assembly or by either a handle or a yoke for manual actuation. Where manual actuation is used, the top cap incorporates a spring-loaded ball and a stop pin to index the various rotor positions. Figure 4-22 shows a selector valve.

The motor-operated gate valve provides a means of controlling the flow of fuel to various

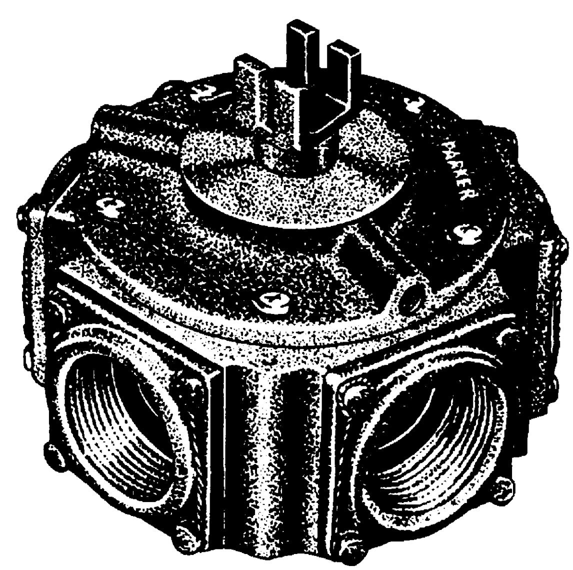


Figure 4-22.-Selector valve.

parts of the fuel system. It is designed as an open-and-closed valve and is motor-operated. The gate or sliding portion of the valve slides between O-rings or other suitable sealing devices in the body of the valve. On some models, an indicator is attached to the gate to show the position of the valve while installed in the system. Some of these valves have a cable and drum between the motor and valve mechanism to provide for manual override. This mechanism may be used if the electrical motor is defective. Figure 4-23 shows a motor-operated gate valve with a manual-override mechanism. The installation and rigging of motor-operated gate valves are similar to those of the fuel selector valves. However, the motor-operated gate valves that have no manual override require no adjustment on installation.

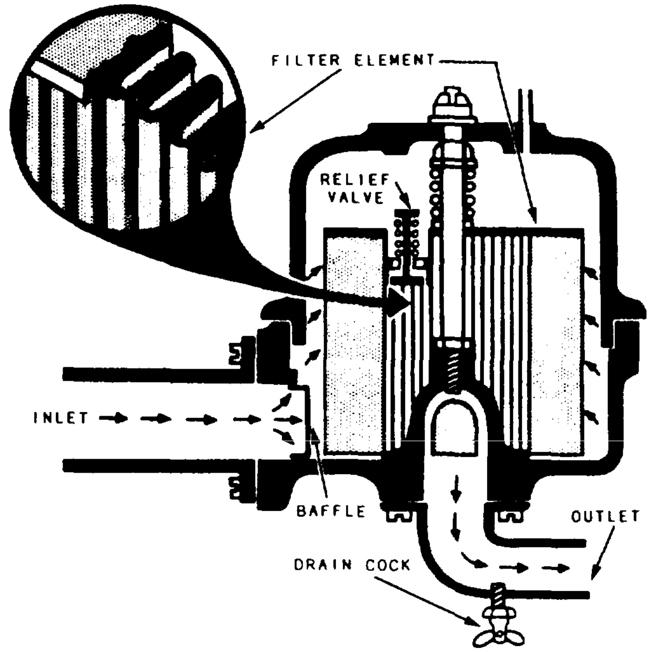


Figure 4-24.-Aircraft fuel filter (microfilter).

FILTERS

The three most common types of filters in use are the microfilter, the wafer screen filter, and the plain screen mesh filter. The individual use of each of these filters is dictated by the filtering treatment required at a particular location.

Microfilter

The microfilter, shown in figure 4-24, has the greatest filtering action of any present-day filter, and it is rated in microns. (A micron is a thousandth part of 1 millimeter.) The porous cellulose material, frequently used in the construction of filter cartridges, removes foreign matter measuring 10 to 25 microns. The minute openings make this type of filter susceptible to clogging; therefore, a bypass valve is a necessary safety factor.

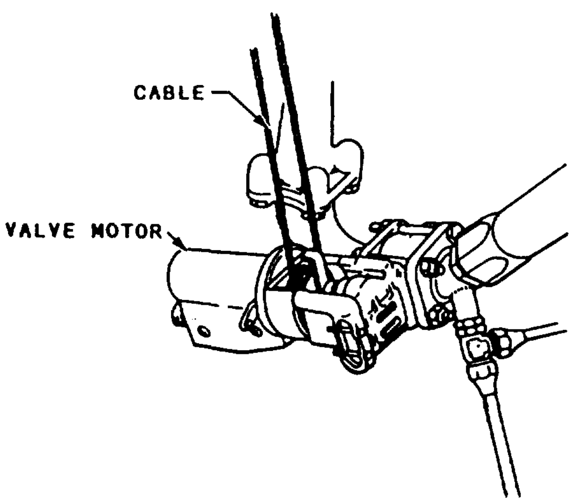


Figure 4-23.-Motor-operated gate valve and override mechanism.

Since the microfilter does such a thorough job of removing foreign matter, it is especially valuable between the fuel tank and engine. The cellulose material also absorbs water, preventing it from passing through the pumps. If water does seep through the filter-and this happens occasionally when filter elements become saturated with water—the water can and does quickly cause damage to the working elements of the fuel pump and control units. These elements depend solely on the service fuel for their lubrication. To reduce water damage to pumps and control units, periodic servicing and replacement of filter elements are imperative.

The most widely used filters are the 200-mesh and the 35-micron filters. They are used in fuel pumps, fuel controls, and between the fuel pump and fuel control where removal of microscopic particles is needed. These filters, usually made of a fine-mesh steel wire, are a series of layers of wire. This type of filter replaces the wafer screen described in-the next paragraph.

Wafer Screen Filter

The wafer screen filter, shown in figure 4-25, has a replacement element made of layers of screen discs of bronze, brass, and steel. This type of filter can remove minute particles. It also has the strength to withstand high pressure.

Plain Screen Mesh Filter

The plain screen mesh filter is the most common type. It has long been used in internal-combustion engines of all types for fuel and oil strainers. In present-day turbojet engines, it is used in units where filtering action is not so critical, such as in fuel lines before the high-pressure pump filters. The mesh size of this type of filter varies greatly according to the purpose for which it is used.

ENGINE-DRIVEN PUMPS

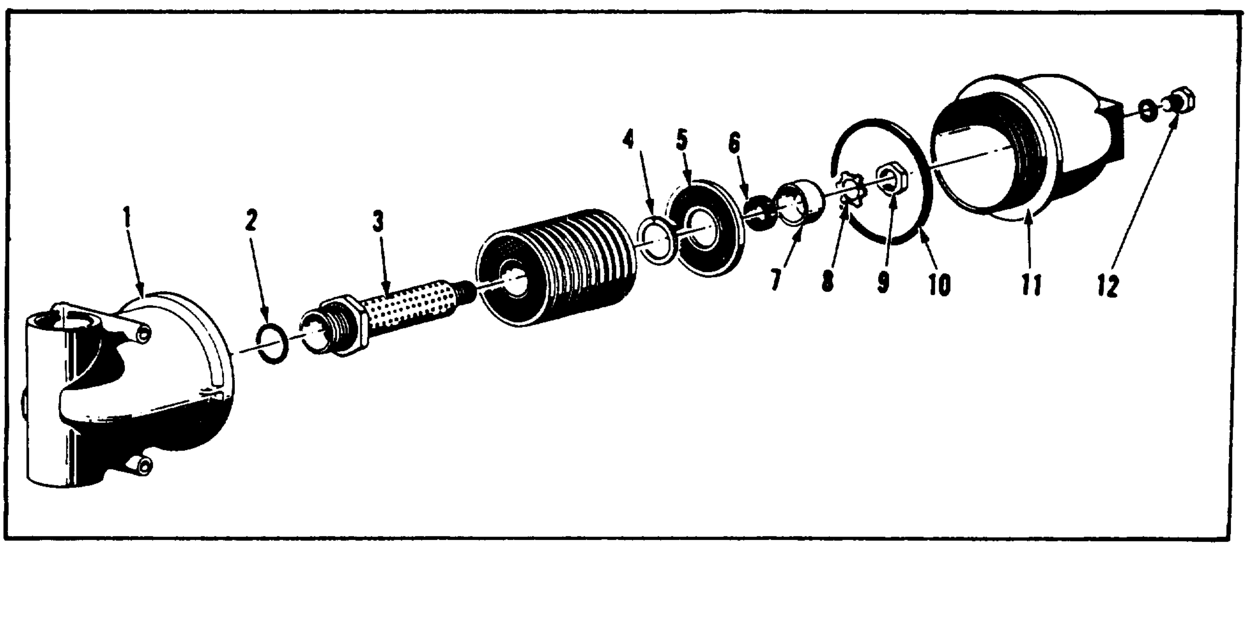
Engine-driven fuel pumps deliver a continuous supply of fuel at the proper pressure during operation of the aircraft engine. The engine-driven fuel pumps must be capable of delivering the maximum needed flow at high pressure to obtain satisfactory nozzle spray and accurate fuel regulation.

Fuel pumps for engines are generally positive displacement gear, piston, or rotary vane types. The term *positive displacement* means that the pump will supply a fixed quantity of fuel to the engine.

These pump types may be divided into two groups—constant displacement and variable displacement. Their use depends on the fuel control system used to regulate the flow of fuel to the fuel controls.

Gear-Type Pumps

Gear-type pumps have straight-line flow characteristics. However, fuel requirements vary with flight or ambient air conditions. Hence, a pump of adequate capacity at all engine operating conditions will have excess capacity over most of



1. Filter head	**5. Filter disc**	**9. Tube nut**
2. O-ring	**6. Packing ring**	**10. O-ring**
3. Tube	**7. Retainer cup**	**11. Filter sump**
4. Spacer	**8. Lock washer**	**12. Plug**

Figure 4-25.-Wafer screen filter.

the range of operation. This characteristic requires the use of a pressure relief valve for disposing of excess fuel. A constant-displacement gear-type pump is illustrated in figure 4-26.

Variable-Displacement Pump

The variable-displacement pump system differs from the constant-displacement pump system. Pump displacement is changed to meet varying fuel flow requirements; that is, the amount of fuel that is discharged from the pump can be made to vary at any one speed. With a pump of variable flow, the applicable fuel control unit can automatically and accurately regulate the pump pressure and delivery to the engine.

Where variable-displacement pumps are installed, two similar pumps are provided, connected in parallel. Either pump can carry the load if the other fails during normal parallel operations. At times, one pump is not enough to meet power requirements. Pump duplication increases safety in operation, especially in takeoffs and landings.

The positive-displacement, variable-stroke type of pump incorporates a rotor, a piston, a maximum speed governor, and a relief valve

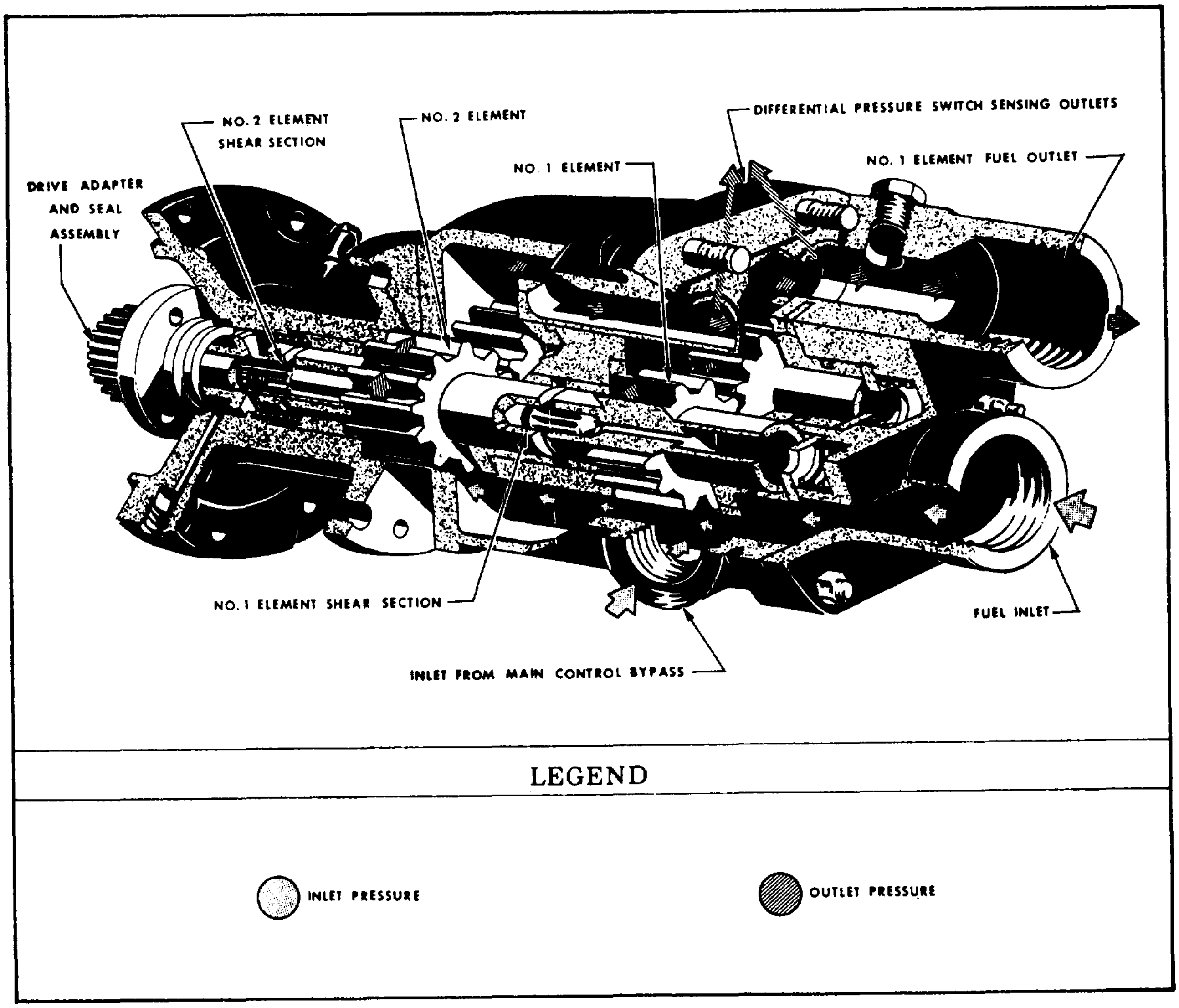
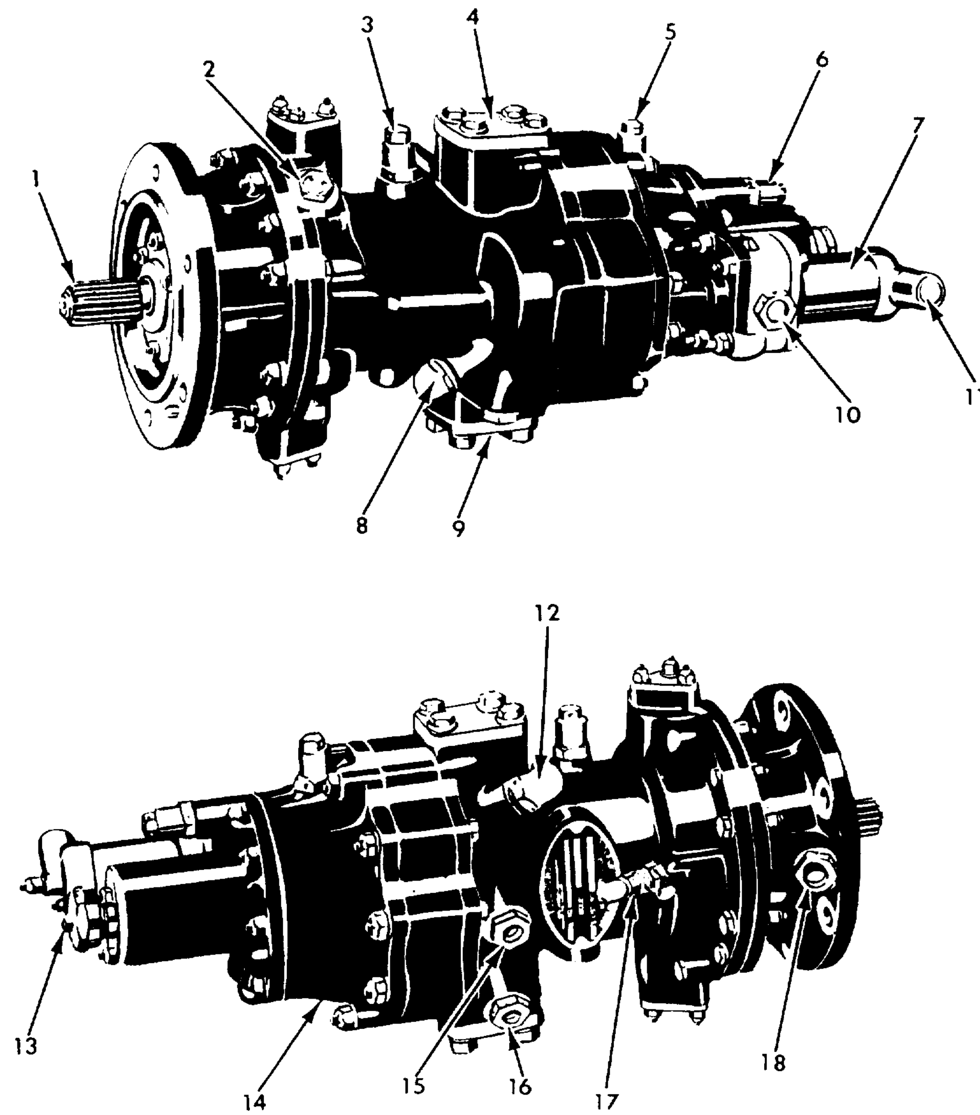


Figure 4-26.-Cutaway view of a dual-element gear-type pump.



1. Pump drive shaft
2. Auxiliary vapor vent plug
3. Air bleed valve
4. Fuel delivery port
5. Air bleed valve
6. Air drive valve
7. Solenoid-operated isolating valve
8. Location of pump control bleed
9. Fuel inlet port
10. Isolating valve servo line connection
11. Isolating valve electrical connection
12. Centrifugal force bleed
13. Governor adjustments
14. Control chamber circulating fuel outlet connection
15. Fuel outlet pressure gauge connection
16. Fuel inlet pressure gauge connection
17. Maximum flow stop adjusting screw
18. Drive shaft weep drain port

Figure 4-27.-Variable-stroke fuel pump.

mechanism. A variable-stroke pump is shown in figure 4-27.

An engine-driven rotary-vane type of pump and a diagram showing the operation of the unit are shown in figure 4-28.

The engine-driven fuel pump is turned by a gear train in the accessory section of the engine. Constant pressure is maintained by a spring-loaded pressure relief valve. Figure 4-28 shows the pressure relief valve in operation, bypassing excess fuel back to the inlet side of the pump.

Fuel is bypassed before the engine is started, when the engine-driven fuel pump is not turning. An auxiliary fuel booster pump delivers fuel under pressure. Fuel pumped by the booster pump will pass through the stationary engine-driven pump; it is necessary to incorporate a bypass valve in the engine-driven pump. Both the fuel pressure relief valve and the bypass valve may be contained in the same mechanism.

Refer to *Fluid Power,* NAVEDTRA 12964, for a detailed description of the principles of operation of the various types of pumps.

FUEL SYSTEM MAINTENANCE

The most important consideration in working with any fuel system maintenance task is the safety of personnel. Aircraft fuels are extremely hazardous because of the explosive and toxic dangers that are always present. The health hazards associated with aviation fuels (breathing of vapors, spillage on skin or in the eyes, or swallowing) must be avoided. It is not possible to describe all the potential problems or dangers that may arise in the performance of any type of fuel system maintenance. As an AD, it is your responsibility to be thoroughly aware of all the safety practices and procedures that must be strictly followed.

Fuel vapors are very harmful when they are inhaled. It takes only a very small percentage of these vapors to cause very serious effects on personnel. Fuel vapors are heavier than air and will collect in the lower areas of the fuel tank/cell. Unless these vapors are removed by the use of forced-air ventilation, they can present a hazard for an indefinite period. Personnel should avoid the inhalation of these vapors, and always be alert

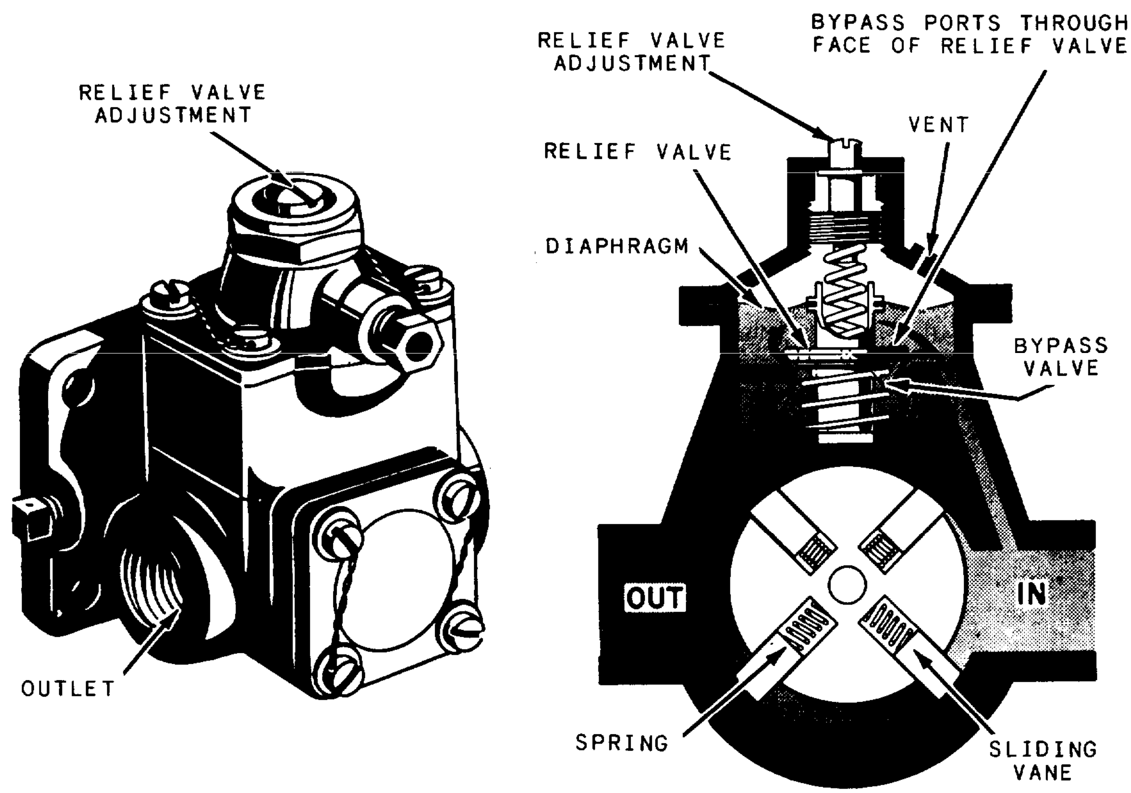


Figure 4-28.-Engine-driven, rotary-vane type of pump.

to recognize the first signs of the toxic effect of breathing these vapors. The symptoms of inhalation include nausea, dizziness, and headaches. If a person should experience these symptoms during fuel system maintenance, immediately stop and move the individual to a source of fresh air. If the individual appears to be completely overcome by the vapors, get prompt medical attention. When working with any type of aviation fuel, personnel should always avoid prolonged contact with the fuel. If a person's clothing becomes saturated, they should remove them as soon as possible and wash off the affected areas with soap and water. It is essential to know the location of approved eyewash stations and how they are used.

FUEL LEAK ANALYSIS

In modern aircraft, the fuel systems are designed to operate satisfactorily under all conditions, such as acceleration and deceleration, temperature, pressure and flight attitudes. However, no matter how good the design, the fuel system will not function as designed if it is not maintained properly. A significant number of fuel leaks can be attributed to incorrect maintenance procedures used in installing fuel tanks/cells, components, lines, and fittings. By referring to the applicable aircraft maintenance manual and learning the general procedures discussed in this section, you will have little difficulty in locating the source of an aircraft fuel leak.

LOCATION OF LEAKS

Leak source analysis is the process of using the aircraft maintenance manual, fuel system schematic diagrams, installation diagrams, and troubleshooting charts. The most common method of analysis is the methodical process of elimination to isolate the source of a fuel leak. In addition, you should first screen the aircraft discrepancy book (ADB) to possibly save many man-hours looking for a leak. The review of a prior fuel system discrepancy may reveal that spilled fuel was not properly cleaned or components were improperly installed. Never assume that the first leak you find is the only leak in the system. Completely check and test the entire fuel system as directed by the applicable maintenance manual.

Severe leaks in the tank/cell drain system are caused by a rupture, loose interconnecting fittings, or cut or distorted O-rings. These leaks can usually be detected immediately after refueling the tank/cell. Dripping leaks are usually found at fuel system plumbing connections. Leaks are caused by undertorquing or overtorquing lines, hoses, or fittings. Never assume that the leaks can usually be detected by operating the fuel transfer pump/boost pump to pressurize the fuel system. Intermittent leaks are most often caused by loose cell fittings or connections. Fuel quantity probes that are mounted on the high side of the tank/cell usually leak when the aircraft is in a climb or descent. In some cases, servicing the fuel tank/cell to capacity may aid in locating these types of leaks.

Fuel Dye to Locate Leaks

The use of colored dye to detect hidden fuel leaks is a practical means you can use in fuel system leak source analysis. The dyed fuel will leave a stain that can be traced back to the source of the fuel leak. (The use of dyed fuel is particularly useful in checking for leakage. This is especially true near the engine's hot section where high temperatures prevent the fuel from leaving a wet spot.) When using a dye to aid in the troubleshooting of fuel leaks, a logbook entry in the miscellaneous history section of the aircraft logbook should be made. The fuel color, resulting from the use of dye, can be disregarded in fuel sample analysis. Additionally, a similar entry should be made for aircraft serviced with dyed fuel. You should always select a dye color that will provide the highest visibility in the area where the leaking fuel is suspected. The use of 2 ounces of dye for each 100 gallons of fuel in the cell or tank is required. The appropriate information for ordering the dye can be found in Appendix A of NA 01-1A-35. The addition of unmixed dye to empty fuel systems should always be avoided because it can cause deterioration of the cell lining. The dye should always be added to the fuel, rather than fuel added to the dye. For information and correct procedures for the use of dyes in fuel system leak detection, refer to the proper maintenance manual.

A liquid red or yellow dye that can be added directly to the aircraft fuel tank is available. Before the dye is used to determine the source of fuel leaks, any visible fuel leaks in the tanks and plumbing must be eliminated. If you must use dye to locate a hidden leak, test only one questionable tank at a time. Add the liquid dye to the suspected tank when it is one-third full, using a full 2-ounce can of dye for each 100 gallons of tank capacity.

NOTE: Never use more than one 2-ounce can of dye to each 100 gallons of fuel.

A very small leak may require an hour or more for color to appear. If no coloration appears after a reasonable waiting period, fill the tank to the two-third level. Add another 2-ounces of dye for each 100 gallons of fuel added. Wait as before. Again, if no coloration appears after a reasonable waiting period, repeat the process at full tank capacity. The dye will leave a stain, which can be traced to the source of the leak even after the tank unit has been emptied.

NOTE: Do not return the colored fuel to bulk tanks or trucks, as there is sufficient dye in a 2-ounce can to color 10,000 gallons of fuel.

The colored fuel is suitable for use in aircraft engines since the dye does not have a harmful effect on the usefulness of the fuel. If you do not empty the aircraft fuel tank to repair the leak, the dyed fuel can be burned in the engine. Fuel from tanks tested with dye will remain colored until the tanks have been filled and emptied several times. Stains on the aircraft structure or clothing can be removed with aircraft fuel or an approved dry-cleaning solvent.

Preparation for Fuel Cell Maintenance

Before any maintenance is performed on a fuel tank/cell, a check of the applicable aircraft maintenance manual is required. If the aircraft maintenance manual is not specific enough to cover the type of maintenance that is required, refer to the *Aircraft Fuel Cell and Internal/External Tank* manual, NA 01-1A-35, for additional information. If you find conflicting information between the specific fuel system portion of the aircraft maintenance manual and the NA 01-1A-35, the procedures in the NA 01-1A-35 manual take precedence.

To protect personnel from the health hazards associated with aviation fuels, protective clothing and equipment are required and should be the first priority before starting any fuel cell maintenance. Specific items such as respirators, coveralls, proper shoes, and safety goggles are usually available for use by personnel. All of these are required to work with aviation fuels cell or tanks. Appendix B of NA 01-1A-35 contains specific information on all of the required safety equipment.

DEFUELING, DEPUDDLING, PURGING

Prior to an inspection, entry of personnel, or repair of any fuel tank/cell, specific functions must be accomplished. These functions are discussed in the following paragraphs. A definition of each function is provided to allow you to become familiar with it.

1. Defueling. Defueling is the process of removing fuel from the aircraft tank/cell.
2. Depuddling. Depuddling is the process of removing residual fuel from cells/tanks after defueling and low-point draining. Depuddling is a necessary step prior to air purging when a nontoxic and noncombustible atmospheric state is required in a fuel cell or tank.
3. Purging. Purging is the process for removing fuel vapors capable of producing a combustible or toxic atmosphere.

Before you perform any defueling, depuddling, or purging on an aircraft, you park it in an area specifically authorized for such operations. You must be familiar with the safety precautions and procedures listed in the maintenance instruction manuals and NAVAIR wing and squadron instructions.

Defueling

General defueling precautions of aircraft include the following:

1. Position the aircraft at least 100 feet from any building or smoking area or in the designated defueling area.
2. Fire extinguishers must be inspected for serviceability and manned at all times.
3. The defueler must be parked as far from the aircraft as possible. It should be parked heading away from the aircraft in case it becomes necessary to move the defueler in an emergency.

WARNING

All the required grounding and bonding cables must be attached before the aircraft or defueler tanks are opened. Bonding and grounding wires must be attached to clean, unpainted, conductive surfaces to be effective.

4. You should always ground the aircraft to an approved grounding point. The aircraft must be bonded to the defueler. The grounding cable for the nozzle must be grounded to a metal part remote from the tank/cell. This minimizes static electricity y between the nozzle and the aircraft. Then you attach the bonding cable from the nozzle to the aircraft.

5. Personnel requirements are one person to man each fire extinguisher, one to operate the defueler, and one person to operate the aircraft defueling panel. You also need one person to operate the fuel system control panel inside the aircraft, if applicable.

WARNING

Do not defuel aircraft in the vicinity of an electrical storm. No maintenance of any type will be allowed on the aircraft during defueling.

6. Once defueling is complete, drain remaining fuel from low-point drains into an approved safety container.

Depuddling

Depuddling of the aircraft fuel tank/cell is a hazardous operation because it requires the entry or partial entry of personnel into an aircraft tank/cell. They remove any residual fuel that was not removed from the tank/cell during defueling. In an effort to minimize the hazards associated in depuddling, all maintenance personnel are required to work in pairs. One person should remain outside the tank/cell to act as a safety observer while the other actually enters the tank/cell to do the depuddling. The following general safety precautions apply to depuddling: The aircraft battery connector and aircraft power receptacle should always be tagged with an appropriate warning placard. This is to indicate power is NOT to be applied to the aircraft under any circumstances. Before you perform any depuddling, refer to the aircraft maintenance manual and NA 01-1A-35 for the proper support equipment that must be used.

When you purge a tank/cell, attach an approved air blower to the tank/cell and ensure that all personnel remain clear of the removed access panel. After allowing approximately 30 minutes for the blower to remove the toxic vapors, you should stop the air blower and have the tank/cell tested by a gas-free engineer to ensure the tank/cell is safe for personnel to initiate depuddling. If after this time a "safe" condition is not reached, reinstall the air blower for at least an additional 15 minutes and have the test repeated. Continue the venting and testing, if necessary, until the tank/cell can be certified safe for personnel. The air inside the tank/cell has to be certified and documented as safe. The outside safety observer and the individual who is going to enter the tank/cell should obtain all the necessary protective clothing and equipment and proceed with the depuddling.

NOTE: The two individuals should always be connected by a safety line in case of an emergency.

The next step in depuddling is to remove all the necessary access panels and covers required. Then, immediately after entering the tank/cell, the individual must cap or seal all openings leading from other possible sources of fuel or fuel vapors. Depuddling can be accomplished by using an approved explosionproof vacuum cleaner. You can also use a cellulose sponge or cheesecloth to remove the residual fuel from the tank/cell.

Purging

When you perform maintenance on a fuel tank/cell, the next step is purging. There are now four approved methods you may use to purge the aircraft fuel tank/cell. They are the air blow, air exhaust, oil purge methods, and JP-5 method.

The air blow purging method uses an air blower and ducting to force fresh outside air into the tank/cell. The air exhaust purge method uses an air blower and ducting to draw fresh outside air through the tank/cell. The oil purge method uses lubricating oil, MIL-L-6081, grade 1010, to dilute the fuel vapors in the defueled tank/cell. The oil purge method is the most desirable of the three methods. It is necessary to perform extensive repairs to the aircraft other than maintenance solely related to the fuel system. The oil purge method will normally keep the tank/cell safe for personnel for approximately 10 to 15 days. The JP-5 method uses JP-5 fuel to dilute and help remove all residues from low flash point fuels including JP-4 or AVGAS.

NOTE: In all methods of purging, it is mandatory that the tank/cell be certified. This is done by a gas-free engineer and documented as being safe for personnel or safe for hotwork.

FUEL CELL REMOVAL AND INSTALLATION

General fuel cell removal and installation procedures are discussed in the following paragraphs. These procedures are applicable to the removal and installation of all fuel cells. However, the latest technical publications must be used for actual removal and installation of fuel cells on any naval aircraft.

Removal

After the aircraft is defueled, depuddled, and purged, the following steps should be accomplished for the removal of the cell:

1. Remove required access covers.
2. Remove all interior parts, lines, clamps, fittings and plates from cell.

NOTE: Clean dust covers must be installed on all open tubes, ports, and disconnected electrical plugs and receptacles.

3. Cap or plug all lines, fittings, and parts removed from the cell to prevent contamination.
4. Place removed items in a separate container for each cell, and identify with cell number and aircraft bureau number.
5. If possible, locate and mark with yellow crayon (SS-C-635) any damaged areas showing evidence of leakage.
6. Disconnect cell fittings and interconnects.

CAUTION

Fuel cells are easily damaged. Use caution when cutting nylon lacing cords.

7. Untie and remove lacing cords. If the cord is cut during removal, retain old cord to determine length of replacement cord.
8. Remove the screws or hangers that secure the cell to the cavity. Install lifting device if necessary.

The cell must be handled very carefully to prevent abrasions, cuts, and punctures. Tape should be applied to sharp edges of all cavity openings to eliminate chafing of the cell upon removal.

If necessary, the cell may be collapsed and strapped in a folded position. Bends should not occur at any of the fittings.

Carefully remove the cell, observing the following precautions:

1. Do not pull the cell by its fittings.
2. Carefully guide the protruding fittings past all obstructions.
3. If the cell binds while removing it, do not force it. Stop to determine the cause of the trouble and remedy it before continuing. Sprinkle the cell with talc or other suitable powder if it becomes necessary to squeeze the cell around or between structural members.
4. Do not pry on rubber fittings or on the cell with sharp instruments; use large wooden paddles.

When removal of the cell is necessary because of major repairs or other reasons, it should be inspected. You then reinstall it, provided it is fit for further service in the aircraft. Fuel cells should be removed when signs of leakage appear. These signs are rubber particles in the strainer, loose seams, loose or cracked fittings, or if swollen sealants are found. If the cell is considered to be repairable beyond organizational level, it should be crated and sent to the nearest fuel cell repair activity.

When a fuel cell remains empty for more than 72 hours, a thin coat of oil, Specification MIL-L-6081, Grade 1010, is applied to the inner liner. This should be accomplished whether the cell is installed or removed from the aircraft for storage. The oil will act as a temporary plasticizer, and it will prevent the inner liner from drying out and cracking.

Fuel cells that are to be returned to storage until repairs can be accomplished at a later date should have a coating of oil, Specification MIL-L-6082, Grade 1065. It is applied to the interior of the cell. The heavier type of oil will act as a preservative over a sustained period. Oil should not be applied to the interior of self-sealing cells that have exposed sealant. It is applied when the exposed area has been covered with an oil-resistant tape. Although complete coverage of the cell interior is necessary, preservative oil should not be allowed to puddle in the bottom of the cell.

Handling Procedures

Always carry or haul fuel cells carefully. The purpose of carrying or handling fuel cells is to protect the outside (retainer ply) wall. It serves to support the shape of the cell and protect the self-sealing (sealant) layer underneath it from fuel spillage. The cord construction and lacquer coating must be cautiously safeguarded.

To avoid any undue damage to the cell during handling, follow the following instructions:

1. Always transport the cell by a well-padded truck or dolly, or by hand carrying.
2. Never use any of the cell fittings for handholds while carrying the cell.
3. Never allow the cell to be dragged or rolled on the deck.
4. Before placing the cell on the deck, you should spread an appropriate barrier material on the area where the cell will be placed.
5. Never place the cell on a bench, pallet, or table where parts of the cell are allowed to overhang.
6. If the cell was removed during cold weather, you should warm the cell to at least 60°F (16°C) before collapsing or folding.
7. Never use unnecessary force or pressure to compress a collapsed cell into a small package. The undue pressure will produce sharp folds that cause damage to the cell.
8. Never allow the cell to be folded across or beside any of the cell fittings.
9. Never leave a self-sealing cell in a collapsed condition for a period longer than 1 hour. Bladder-type fuel cells may be left collapsed for a longer period of time, providing the cell is not walked on, severely creased, or abused.
10. Always install protective caps on the cell hanger receptacles while the cell is removed from the aircraft.

When a fuel cell remains empty for more than 72 hours, a thin coat of oil, MIL-L-6081, Grade 1010, should be applied to the inner liner. This process should be accomplished when the cell is installed, or when it is removed from the aircraft for storage. The oil will act as a temporary plasticizer, and it will prevent the inner liner from drying out and cracking. To get a uniform coat on the entire inner lining, you should use an oil-soaked cheesecloth to apply the preservative oil. Inaccessibility is a problem with some fuel cells and the only way to properly protect the cell is to apply the preservative by spraying. Pliocel-type bladder cells do not require internal preservation except when they are folded and stored for a period in excess of 2 weeks. If it becomes necessary to preserve this particular type of cell, the inner. lining must be coated with equal parts of glycerin, MIL-G-491, and water. A cheesecloth soaked with this solution should be used to apply the preservative. Fuel cells that are returned to storage until repairs can be accomplished should have a coating of oil, MIL-L-6082, Grade 1065, applied to the interior of the cell. The heavier type of oil will act as a preservative during the sustained period. Although complete coverage of the cell interior is necessary, the preservative oil should not be allowed to puddle in the bottom of the cell.

When uncrating a fuel cell, you must always follow the opening instructions on the crate or shipping container. These instructions are provided for your use to prevent possible damage to the cell and to preserve the crate/shipping container for future use. Before removing the cell from the container, you should be sure that a clean, smooth surface, larger than the cell itself, has been cleared and protected with an appropriate barrier material before unfolding the cell. Fuel cells that have been stored for a long time can shrink or become distorted. Cells in this condition will be difficult for you to install, and they often cause misalignment of the cell fittings with the aircraft fittings. To restore a shrunken or distorted fuel cell to its original condition, you should soak the cell in water. The length of time required for soaking will normally depend on the condition of the cell. Normally, 72 hours is enough, as long as the water temperature remains at least 70°F (21°C). Soaking time can be reduced by placing the cell in an air-circulating oven at a maximum temperature of 120°F (49°C) for about 4 hours. It must also be maintained at high humidity.

NOTE: Bladder-type fuel cells and nylon Pliocels are much more delicate than self-sealing cells and require extremely careful handling. However, the handling precautions are the same as for self-sealing cells.

Installation

The steps outlined below are generally followed when installing a fuel cell in an aircraft.

Check the cell to make certain that it is the proper one for the cavity. Tape all cell openings. Inspect the fuel cell cavity for cleanliness and loose bolts, nuts, etc.; and make certain there are no sharp metal or protruding edges that may damage the cell during or after the installation of the fuel cell. Tape or otherwise protect the edges of the fuel cell if necessary.

Apply talc or other suitable powder to the outer surface of the cell and the cell cavity to make it easier to move the cell into position.

If necessary, collapse or fold the cell as required, and secure it with webbed straps. The cell should be warmed to room temperature. When applying straps, place them and the buckles so they are easily accessible after the cell is installed.

Guide the fuel cell into the cavity, making sure it is installed in the right direction. Wooden paddles with rounded edges may be used to guide the cell into the cavity; never use tools with sharp edges or points. If any binding occurs, determine the trouble and remedy it before damage is caused to the fuel cell. Be very careful that protruding fittings are not damaged.

Remove straps if cell was collapsed; then check the interior of the cell to make certain that no tools or foreign materials were left inside.

Install all fittings and components. New seals and gaskets must be used.

NOTE: The use of any sealing compounds on rubber fuel cell fittings is prohibited. Sealing compounds may be used only on connections when the adjoining surfaces are metal.

Torquing Requirements

One of the main causes of fuel leaks is improper torquing of bolts used to secure fuel cell access covers, access plates, and cell fittings. Over-torquing or improper torquing sequence causes excessive rubber cold flow, warps fitting plates, and, in some cases, breaks the metal insert in fuel cell fittings. It is important that torquing be performed properly.

Before the bolts are installed, threads should be inspected for burrs or other defects that could damage cell fitting inserts or give incorrect torque readings. Threaded cell fittings should be inspected to ensure that they are not filled with rust-preventive compound or dirt. Presence of such foreign material will result in incorrect torque values.

All bolts should be fully installed fingertight before they are torqued. Bolts should be of proper length. A bolt that is short will not safely engage the mated part; one that is too long will bottom out, giving incorrect torque values and causing leaks.

Each work package (WP) that requires removal and installation of a fuel cell access cover specifies required torque values and refers to the applicable bolt torque sequence for securing the part.

Testing

When a new or repaired fuel cell is installed in an aircraft, it should be tested for possible leaks before it is filled with fuel. The air pressure test is the best method of determining if any leaks exist. This test consists of applying air pressure to a sealed cell and checking for the existence of leaks with a mercury manometer. Further details on this type of testing can be found in the specific aircraft MIM.

FUEL SYSTEM PART MAINTENANCE

The maintenance of the aircraft and engine fuel system is primarily the responsibility of the AD rating. Besides fuel cell repairs, some of these maintenance tasks that are the responsibility of the AD are discussed in the following paragraphs. These tasks include inspecting, cleaning, replacing fuel parts, and the rigging and adjusting of various fuel system controls.

Fuel System Component Inspection

Periodically, the entire fuel system must be inspected for wear, damage, and leaks. Fuel system parts must be inspected for security of mounting, leaks, and loose connections. Maintenance should be limited to such items as the tightening of connections to eliminate leaks and the replacement of defective units. Repairs involving the disassembly of units are made at overhaul activities.

The entire system should be checked for wear, damage, and leaks. All units must be securely mounted and all connections tight and properly safetied. Boost pumps should be used to buildup pressure to check for leaks.

Pumps

The boost pump should be checked periodically for proper operation and correct pressure output. The pump assemblies must be checked for leaks, the condition of the fuel, and the condition of the electrical connections. The drain lines must be free of traps, bends, and restrictions.

Main-Line Strainer

The main-line strainer must be drained at each preflight inspection to eliminate any water and/or sediment. The screen must be removed and cleaned at the intervals specified in the applicable technical publications. The sediment removed from the housing should be examined thoroughly. Particles of rubber are often early warnings of deterioration of hose or self-sealing tanks. The strainer must be checked for leaks and damaged gaskets.

Fuel Lines and Fittings

The lines must be inspected to see that they are properly supported and that the nuts and clamps are securely tightened. A hose-clamp torque wrench should be used to tighten hose clamps to the proper torque. If this wrench is not available, the clamp should be tightened finger-tight plus the number of turns specified for the hose and clamp. Clamps should be tightened only when the engine is cold. If the clamps do not give a seal at the specified torque, the clamp, the hose, or both should be replaced. After a new hose has been installed, the hose clamps should be checked daily and tightened if necessary. When this daily check shows that cold flow (the flowing of the rubber from the clamping area) has ceased, the clamps should be inspected at the less frequent periods specified for hose clamps throughout the system. The hose should be replaced if the plies have separated, if there is excessive cold flow, if there are signs of chafing, or if the hose is hard and inflexible. Permanent impressions from the clamps in the tube or cover stock indicate excessive cold flow. Hose that has collapsed at the bends as a result of misaligned fittings or lines should be replaced. Some hose tends to flare at the ends beyond the clamps. This is not an unsatisfactory condition and does not indicate leakage. At each engine change, all hose connections forward of the firewall should be inspected and defective hose replaced.

Selector Valves

Selector valves should be rotated and checked for free operation, excessive backlash, and accurate pointer indicators. If the backlash is excessive, the entire operating mechanism should be checked for worn joints, loose pins, and broken drive lugs. Defective parts in the operating mechanism must be replaced. The cable control systems should be inspected for worn or frayed cables, damaged pulleys, and worn pulley bearings.

High-Pressure Fuel Lines

Since the fuel lines installed on the discharge side of the engine-driven fuel pump are subjected to high pressures. You should take special care when inspecting for leaks and damage. The lines must be properly connected; otherwise, units such as the governor and barometric control will not function correctly and may be seriously damaged.

Combustion Chamber Drain Valve

The engine will have to be turned up to check the operation of the drain valve. If fuel does not run from the overboard drain after shutdown, the cause should be determined.

High-pressure Filter

The high-pressure filter must be inspected for security of mounting, leaks, and proper safetying. The filter element must be removed, cleaned, and inspected at regular intervals. Regardless of their condition, filter elements must be discarded at the period(s) specified in authorized maintenance instructions. Whenever the element is removed, the housing should be cleaned and the seals should be replaced.

Fuel Nozzles

Periodically, the fuel nozzles and screens must be removed and inspected. The screens should be cleaned and defective nozzles replaced. The inner surface of the exhaust cone must be inspected for heavy streaks—discoloration of the metal due to overheating. These inspections are rough checks for a combustion chamber in which the fuel nozzle is not functioning properly.

Ram Air Turbine, Hose, and Reel Inspection

One of the inspections that is of importance to you as an AD is the ram air turbine, hose, and reel inspection. It is performed every 10 hours of reel operation on the model D-704 air refueling store. The inspection is accomplished as follows:

WARNING

Be sure that the hose jettison cartridge is removed before performing any maintenance on the store.

1. Remove the filler cap and side access doors and inspect the interior for corrosion, contaminants, and security of components. Reinstall cap and doors.

2. Inspect the ram air turbine for the following:

a. Axial blade freedom. No looseness is permitted.

b. Angular blade freedom. A maximum of 10 degrees is permitted.

WARNING

Be sure that your hands remain away from the turbine blades' plane of rotation when performing step c.

c. With the power OFF, rotate the turbine counterclockwise (viewed from front) until blades are fully feathered. Hold the spinner stationary and turn the power ON. The blades should snap to the unfeathered position.

d. With the power ON, grasp any two opposite blades and twist toward the feathered and unfeathered position. Check for binding of internal mechanism. Turn the power OFF.

e. With the power OFF, attach a 1-inch C-clamp on the end of the blade 12 inches from the center of the spinner. Rotate the turbine counterclockwise (viewed from front) until the blades are fully feathered. Then rotate the turbine for at least two more revolutions. To measure brake slippage, place the hook end of a fishscale (0-15 pounds) at the C-clamp opening and continue to rotate the turbine. The force should be 3 to 5 1/2 pounds.

3. Extend the hose fully in accordance with the applicable maintenance instruction manual (MIM) and inspect as follows:

a. Hose and fittings for slippage.

b. Hose for cuts, abrasion, and soft spots.

c. Drogue assembly for torn canopy, bent struts, and frayed cables.

d. Reception coupling for binding of swivel joint.

e. Direct a rearward stream of air (shop air at 90 psi) across the generator blades and check the lighting circuit for proper operation.

f. Shroud and shoe assembly for damage.

g. T5 switch arm for damage.

WARNING

Ensure that the hose reel snubber valve is installed prior to performing step 4.

4. Operate the reel for three cycles of extension and retraction in accordance with the MIM and check for the following:

a. Presence of hose tension (response) at fully extended position.

b. Proper operation of tail cone lights and control panel.

c. Lockpin engagement in reel for stowed position.

5. Perform the fuel flow test as follows:

a. Fuel the store to 50 gallons minimum.

b. Extend the hose at least 25 feet in accordance with the MIM.

c. Remove the reception coupling and insert the hose end in the filler cap opening.

WARNING

Be sure that the hose is held firmly in the tank filler opening when performing step d.

d. Place the control panel TRANS-OFF switch in TRANS and check fuel flow. Minimum flow as observed on the store control panel should be 40 gallons in 15 seconds (160 GPM) if JP-5 fuel is used and 37.5 gallons in 15 seconds (150 GPM) if MIL-L-6081C (1010) oil is used.

Fuel Part Removal/Installation

The most important item for you to remember when removing or installing any engine part is to follow the procedures set forth in the applicable MIMs. The following basics should prove helpful.

1. Make sure all special and required tools are available.

2. Have a new O-ring kit available for component installation.

3. Have all of the appropriate caps and plugs available to prevent the contamination of open fuel lines during component replacement.

4. Have parts bags and tags available to keep all removed nuts, bolts, and washers in one location, and be sure to tag all fuel lines before removal. This makes reinstallation much easier and less confusing.

5. If the removed component is to be turned into supply, make sure it is purged and filled with an approved preservative before turn-in.

RIGGING AND ADJUSTING

This section covers some of the basic inspections and procedures to be used in the rigging and adjusting of fuel controls, fuel selectors, and fuel shutoff valves. Inspect all bell cranks and rod bearings for looseness, cracks, and corrosion. Particular attention should be given to the rod and bell cranks where the bearing is staked. This area is subject to stress cracking and corrosion. The adjustable rod ends should be inspected for damaged threads and the number of threads remaining after final adjustment. The drums should be inspected for wear, and the cable guards should be checked for proper positioning. If the cables have been loosened, the tension should be set.

While rigging the fuel selector, power control, and shutoff valve linkages, you should follow the step-by-step procedures for the particular aircraft model being rigged. The cables should be rigged with the proper tension with the rigging pins installed. The pins should be removed without any binding; if they are hard to remove, the cables are not rigged properly and should be rechecked. The power lever should have the proper cushion at the IDLE and FULL POWER positions. The pointers or indicators on the fuel control should be within limits. You must take all of these things into consideration while rigging or adjusting the parts of the fuel system. Also, the fuel selectors must be rigged so that they have the proper travel and will not restrict the fuel flow to the engines.

Rigging the fuel control of a turbojet engine is an exacting job. The power lever assembly and its related linkage provide manual control of the engine thrust. The power lever assembly is located in the cockpit, and its related mechanical linkage connects it with the fuel control unit of the engine. Positioning the power lever at any selected setting mechanically actuates the linkage to the fuel control unit, resulting in the desired engine thrust.

Modern jet aircraft use various power lever control systems. One of the common types is the cable and rod system. In this system, you will find bell cranks, push-pull rods, drums, fairleads,

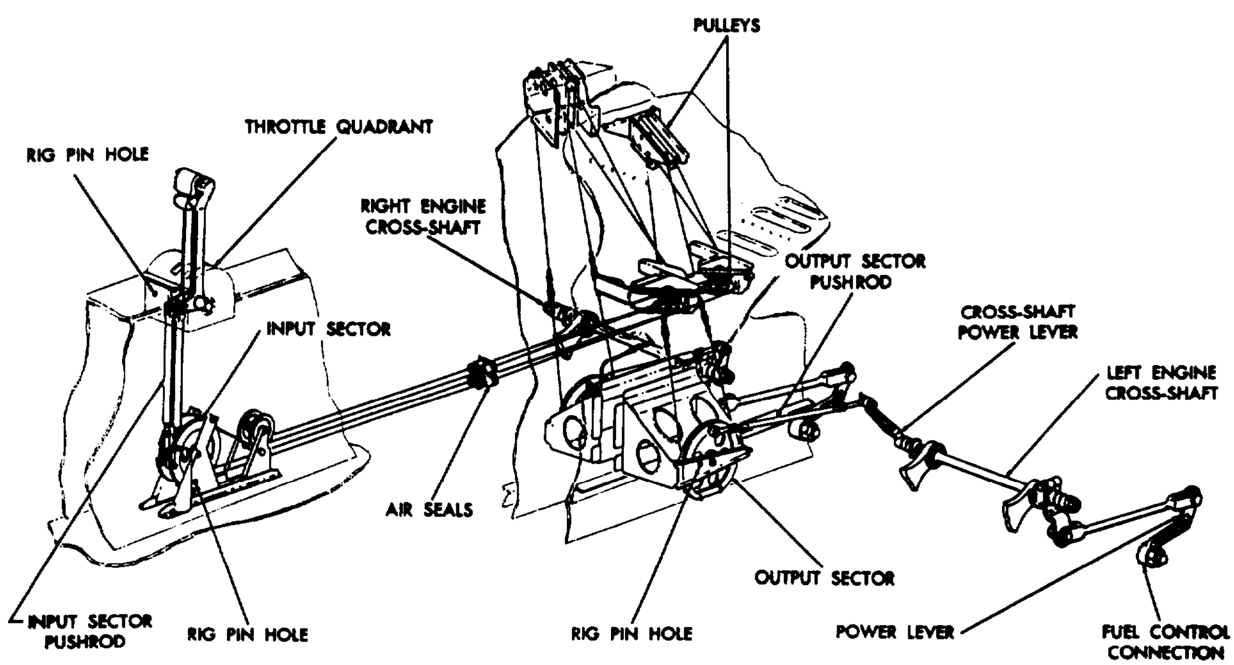


Figure 4-29.-Engine power control system rigging.

flexible cables, and sheaves. All of these parts make up the control system and must be adjusted or rigged from time to time. On single-engine aircraft, the rigging of the power lever controls is not very difficult. The basic requirement is to have the desired travel on the power lever and correct travel at the fuel control. However, on multi-engined jet aircraft, the power levers must be together or married at all power settings.

The rigging of the proper control cables and push-pull rods is usually accomplished at the factory, and no rigging is required except when a part has been changed. The control system you would be most concerned with is at the fuel control and throttle quadrant. See figure 4-29.

Before starting the adjustment of the power controls at the engine, you should make sure that the power lever is free from binding. Use a tensionometer to ensure correct cable tension. If the power controls do not have full throw or are binding, the entire system should be checked and the discrepancies repaired before adjusting the power control system. Low cable tension may cause sluggishness or insufficient travel of the control. High cable tension may result in damaged pulleys, bell cranks and cables, or vibrations in the controls.

CHAPTER 5

JET AIRCRAFT ENGINE LUBRICATION SYSTEMS

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Identify the types, characteristics, and requirements of lubricants in aircraft engines; and recognize sources and procedures for the prevention of oil contamination.
- Recognize the two main types and major parts of lubrication systems.
- Identify maintenance procedures of oil systems and system parts, including oil pressure adjustments; oil filter removal, inspection, and installation; and metal particle identification.
- Recognize the goals and requirements of the Navy Oil Analysis Program (NOAP) to include proper oil sampling techniques, required NOAP forms and recommended action, and required logbook entries for NOAP.

The increased complexity of aircraft engines has added to the requirements for proper lubrication. Jet engines require lubrication to prevent friction from reducing the engines' efficiency. Oil is the lifeblood of the aircraft engine. If the oil supply to the bearings stops, the lubricating films break down and cause scoring, seizing, and burning between moving parts. Fortunately, the engine oil pump and oil system are dependable. Like the heart and circulatory system of the human body, they quietly perform their function so well we forget their importance.

LUBRICANTS

The primary purpose of any lubricant is to reduce friction caused by metal-to-metal contact. Lubricating oils provide a film that permits surfaces to glide over one another with less friction. Therefore, lubrication is essential to prevent wear in mechanical devices where surfaces rub together.

The Navy uses many different types of lubricants. The selection of the proper lubricant depends on the design of the equipment and the operating conditions. Maintenance instruction manuals (MIMs) or maintenance requirements cards (MRCs) list the type of lubricant required for specific aircraft maintenance tasks. With an understanding of the different types of lubricates, their characteristics, and purposes, you will know why we must use the proper lubricant. Using the wrong type of lubricant, mixing different types, or improper lubrication can cause extra maintenance man-hours, part failures, and accidents.

TYPES OF LUBRICANTS

Lubricants are classified according to their source—animal, vegetable, petroleum, mineral, or synthetic. Animal oils are not suitable lubricants for internal-combustion engines. They form fatty acids, which cause corrosion when exposed to high temperatures. Vegetable oils have good lubricating qualities, but break down (they change in chemical structure) after long periods of operation in internal-combustion engines. Mineral-base lubricants are usually divided into three groups—solids, semisolids, and liquids. Petroleum-based oils (for example, MIL-L-6081 grade) were used in early jet engines. This oil was distributed in two grades—1010 for normal use and 1005 for extremely low temperatures. MIL-L-6081 grade 1010 is still used as a preservation oil in fuel systems.

The types of lubricants used in the engines of today are different from the lubricants used years ago. As the power output of jet engines increased, aircraft were able to fly higher. The result of jet engines operating at these higher, colder altitudes and higher engine temperatures created greater demands on lubricating oils. This, in turn, required the development of synthetic lubricants that could withstand these higher bearing temperatures.

MIL-L-7808 was the first synthetic oil developed to meet these demands. Today, most jet engines use another synthetic-based oil, MIL-L-23699. These two oils are completely compatible and may be mixed when necessary. However, certain 23699 characteristics are downgraded in proportion to the quantity of 7808 oil, if mixed. Synthetic oils are based on acids and other chemicals; therefore, they are not compatible with the mineral- or petroleum-based oils.

NOTE: You should consult the applicable technical instructions for the grade number or MILSPEC of oil recommended for use in an engine. Reciprocating engines use MIL-L-228S1, W-120, or E-120 oil, which is not compatible with the turbojet engine.

FUNCTIONS OF JET ENGINE OILS

Lubricating oils must perform three basic functions in a jet engine: (1) lubrication, (2) cooling, and (3) cleaning.

1. Lubrication. Oils should have the following characteristics to lubricate properly:

a. It must be of low enough viscosity to flow readily between closely fitted, rapidly moving parts. It must also have a high enough viscosity to prevent metal-to-metal wear.

b. It must not break down under high temperatures and pressures.

c. It must have a low enough pour point to flow readily when starting under extremely low temperatures.

d. It must have a high enough flash and fire point so it doesn't burn or vaporize under high heat.

e. It should not form and deposit excessive amounts of carbon, varnish, or gum deposits.

2. Cooling. Lubricating oil must cool moving parts by carrying heat away from gears and bearings. This is an important function considering the many parts located next to burners or turbine wheels, where temperatures are over 1700°F.

Liquid lubricants cool by pumping or spraying oil on or around bearings or gears. The oil absorbs the heat and later dissipates it through oil coolers.

3. Cleaning. Another major function of a lubricating oil is cleaning. Oil carries dirt, small carbon and metal particles, and gum and varnish to filters. This has become increasingly important with the higher compression ratios, engine speeds, operating temperatures, and closer tolerances between parts in newer engines.

DESIGNATIONS OF LUBRICATING OILS

All lubricating oils used by the Navy have a classification number, which shows the grade and intended use of the oil. Aircraft engine lubricating oils are given a four-digit grade number, such as 1065. The Navy and the Air Force use the Saybolt scale for designating the viscosity of oil. The designation consists of four digits. The first digit designates the use of the oil; the 1 indicates aviation engine lubrication. The last three digits give the viscosity using the Saybolt scale.

NOTE: You are probably more familiar with the Society of Automotive Engineers (SAE) numbers for grading viscosity. If you want a comparison between the two systems, take the 3 numbers for the Saybolt system, divide by 2, and round to the nearest multiple of 10. For example, 1065 has an SAE rating of 30.

Synthetic oils use military specification numbers for references. See table 5-1.

CONTAMINATION OF LUBRICATING OILS

Contaminated fuel in the lubricating system of an engine can be disastrous to engine operation. Lubricating oils can be contaminated through operational conditions (dusty or sandy places, high operating temperatures), faulty maintenance practices, and part failures.

An example of operational contamination is carbon. Carbon forms when oil evaporates,

Table 5-1.-Classification of Lubricating Oils

NATO number	MILSPEC & grade	Use
O-133	MIL-O-6081 Gr. 1010	Early turbine engine lube oil. (Fuel system preservative and oil.)
O-123	MIL-L-22851 Type III Gr. 1100	Ashless dispersant piston engine oil. (Used principally by the Army for small aircraft engines.)
O-128	MIL-L-22851 Type II Gr. 1100	Ashless dispersant piston engine oil.
O-148	MIL-L-7808	Three centistoke turbine engine synthetic lubricating oil.
O-156	MIL-L-23699	Five centistoke turbine engine and gearbox oil.

especially where heat is concentrated; for example, in the bearing compartments near hot turbine sections. This carbon eventually breaks off and circulates through the engine lubricating system. The pieces of carbon are usually not hard enough or large enough to cause failure of the pumps. However, they may be large enough to clog small filters or nozzles. The presence of sand, dirt, and metallic particles in the lube system is another source of operational contamination.

Faulty maintenance practices that contaminate lubricating systems include using the wrong type, or mixing oils, and improper servicing. The lube system parts of an engine are made of materials based upon the type of oil that is to be used. Synthetic oils attack the common rubber materials used in the O-ring, seals, and gaskets of lubrication systems that use mineral-based oil. This attack causes the material to soften, swell, and lose its ability to seal properly. This condition causes the oil to leak from the system.

The contamination of oil by rust maybe due to water in the oil system. There is also contamination from storage containers or servicing equipment. Over time, rust in the lube system will eventually discolor the bearings. Ordinary rust will leave a red discoloration on the bearing elements, and black iron oxides will leave a black indication. These rust particles are not large enough to cause pump failure.

The contamination of oil by engine fuel can result from a ruptured fuel-oil cooler. Since the fuel system operates at a higher pressure than the lube system, the flow will be into the oil supply. The presence of fuel in the oil will cause oil dilution. It also changes the oil properties so the oil cannot cool and lubricate the bearings properly.

Another serious type of contamination is the oil itself. Synthetic oil will cloud or form other contaminants if stored too long. This is why there is a shelf life for all synthetic oils. Never use overaged oil. Follow the applicable instruction for shelf life of synthetic oil (it is usually 6 months) to prevent problems.

LUBRICATING GREASES AND THEIR PROPERTIES

Another type of lubricant ADs should be familiar with is grease. Grease is used on bearings, outside the engine lubricating system, control arms and linkages, and actuators, The most important requirements of greases are as follows:

1. Stability. It must be free from bleeding (separation of oils), oxidation, and changes in consistency during periods of storage and use.
2. Noncorrosiveness. The lubricant must not chemically attack the various metals and other material it comes in contact with.

3. Water resistance. In some cases, a grease that is insoluble in water is required. In other cases, the grease must be resistant only to weathering or during washing.

4. Satisfactory performance in use. The grease must perform satisfactorily in the equipment and under the conditions it was intended.

Properties of greases vary with the type of soap used in manufacturing. Military specifications specify the operating conditions or applications. Table 5-2 contains information on some of the most frequently used greases.

LUBRICATION SYSTEMS

Oil systems used in jet engines are relatively simple in design and operation, but their function is important. The principal purposes of the oil system are the same as those covered under lubricating oils—to provide an adequate supply of clean oil to bearings and gears at the right pressure and temperature, to remove heat from the engine, and to remove contaminants from the system and deposit them in the filters.

The ability of the oil to lubricate correctly depends upon its temperature and pressure. If the oil is too hot, it will not have enough viscosity. If it is too cold, the oil will resist movement between the parts and flow too slowly for proper lubrication. If the oil pressure is too low, it will not supply enough oil to the bearing for proper cooling. If the pressure is too high, it may cause high-speed antifriction bearings to skid and not roll properly.

It would be impossible to cover all the different parts of every type of engine oil system in use today. Therefore, this text presents a representative sample of various parts common to different types of oil systems.

TYPES OF LUBRICATION SYSTEMS

Engines use a wet-sump, dry-sump, or a combination of both as lubricating systems. Wet-sump engines store the lubricating oil in the engine or gearbox. Dry-sump engines use an external tank mounted on the engine or somewhere in the aircraft structure near the engine. Under the dry-sump lubrication system is another type called the hot tank system. You should know the similarity and operation of these systems.

Wet-sump System

Engines needing a limited supply of oil and cooling can use a wet-sump type (fig. 5-1). The

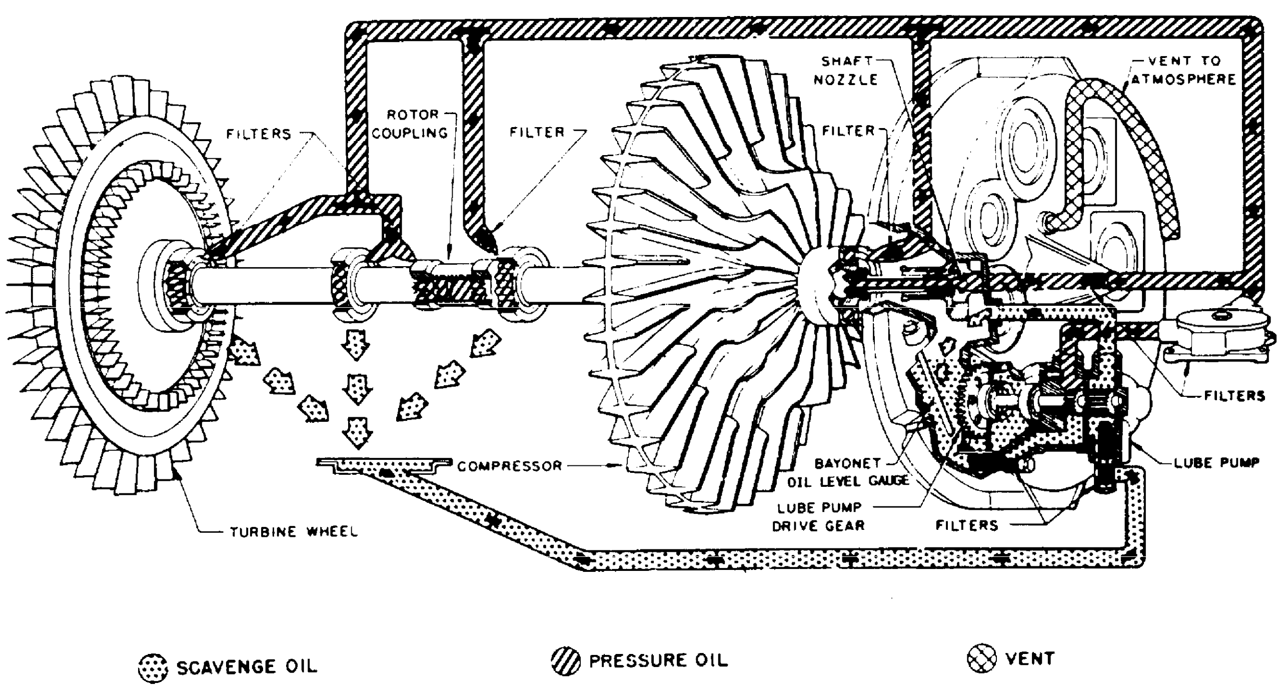


Figure 5-1.-Wet-sump lubrication system.

Table 5-2.-Common Military Lubricants and Their Uses

TITLE AND SPECIFICATION	RECOMMENDED TEMPERATURE RANGE	GENERAL COMPOSITION	INTENDED USE
MIL-G-23827 [Grease, Aircraft, Synthetic, Extreme Pressure]	−100° to 250°F (−73° to 121°C)	Thickening agent, low-temperature synthetic oils, or mixtures EP additive	Actuator screws, gears, controls, rolling-element bearings, general instrument use
MIL-G-21164 [Grease, Aircraft, Synthetic, Molybdenum Disulfide]	−100° to 250°F (−73° to 121°C)	Similar to MIL-G-23827 plus molybdenum disulfide	Sliding steel on steel heavily loaded hinges, rolling element bearing where specified
MIL-G-81322 [Grease, Aircraft, General Purpose, Wide Temperature Range]	−65° to 350°F (−54° to 177°C)	Thickening agent and synthetic hydrocarbon. Has cleanliness requirements	O-rings, certain splines, ball and roller bearing assemblies, primarily wheel bearings in internal brake assemblies and where compatibility with rubber is required
MIL-G-4343 [Grease, Pneumatic System]	−65° to 200°F (−54° to 93°C)	Thickening agent and blend of silicone and diester	Rubber to metal lubrication: pneumatic and oxygen systems
MIL-G-25537 [Grease, Helicopter Oscillating Bearing]	−65° to 160°F (−54° to 71°C)	Thickening agent and mineral oil	Lubrication of bearings having oscillating motion of small amplitude
MIL-G-6032 [Grease, Plug Valve, Gasoline and Oil Resistant]	32° to 200°F (0° to 93°C)	Thickening agent, vegetable oils, glycerols, and/or polyesters	Pump bearings, valves and fittings where specified for fuel resistance
MIL-G-27617 [Grease, Aircraft Fuel and Oil Resistant]	−30° to 400°F (−34° to 204°C)	Thickening agent and fluorocarbon or fluorosilicone	Tapered plug and oxygen system valves; certain fuel system components; antiseize
MIL-G-25013 [Grease, Ball and Roller Bearing, Extreme High Temp.]	−100° to 450°F (−73° to 232°C)	Thickening agent and silicone fluid	Ball and roller bearing lubrication

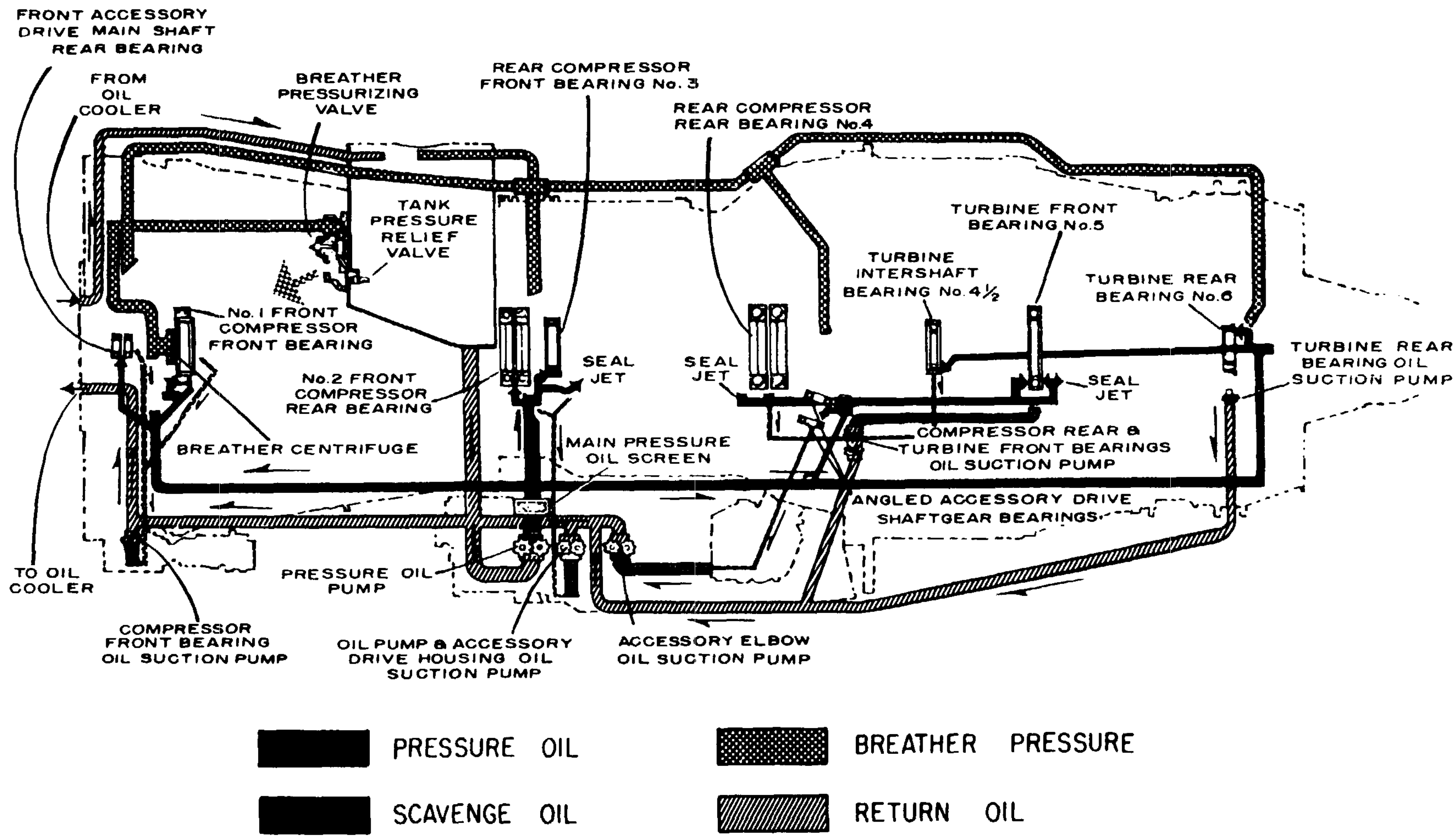


Figure 5-2.—Dry-sump oil system.

reservoir for the wet-sump system is either the accessory gear case or a sump mounted to the bottom of the accessory gear case. This system is similar to your car's engine. In the wet-sump oil system, the gearbox provides space for foaming and heat expansion because the oil level only partly fills the casing. Deaerators, in the gearbox, remove oil from the air and vent the air outside.

The main disadvantages of a wet-sump system are as follows:

1. The oil supply is limited by the sump capacity.
2. It is hard to cool the oil. Oil temperatures are higher because the oil is continuously subjected to the engine temperature.
3. The system is not adaptable to unusual flight altitudes, since the oil supply would flood the engine.

Dry-sump System

The dry-sump system is the most common. In the dry-sump lubrication system, a tank located in the airframe or mounted on the engine holds the oil. This type of system carries a larger oil supply, and an oil cooler is usually included to control temperature. The lubrication design of the engine may use either an air-oil or a fuel-oil cooler. The axial-flow engines keep their comparatively small diameter through a streamlined design of the oil tank and oil cooler. A dry-sump oil system is shown in figure 5-2.

The hot tank system stores oil in the tank before it is cooled. The oil tank is an integral part of the accessory drive case. The other parts include the main oil pump, pump pressure-regulating valve, and main oil filter (fig. 5-3).

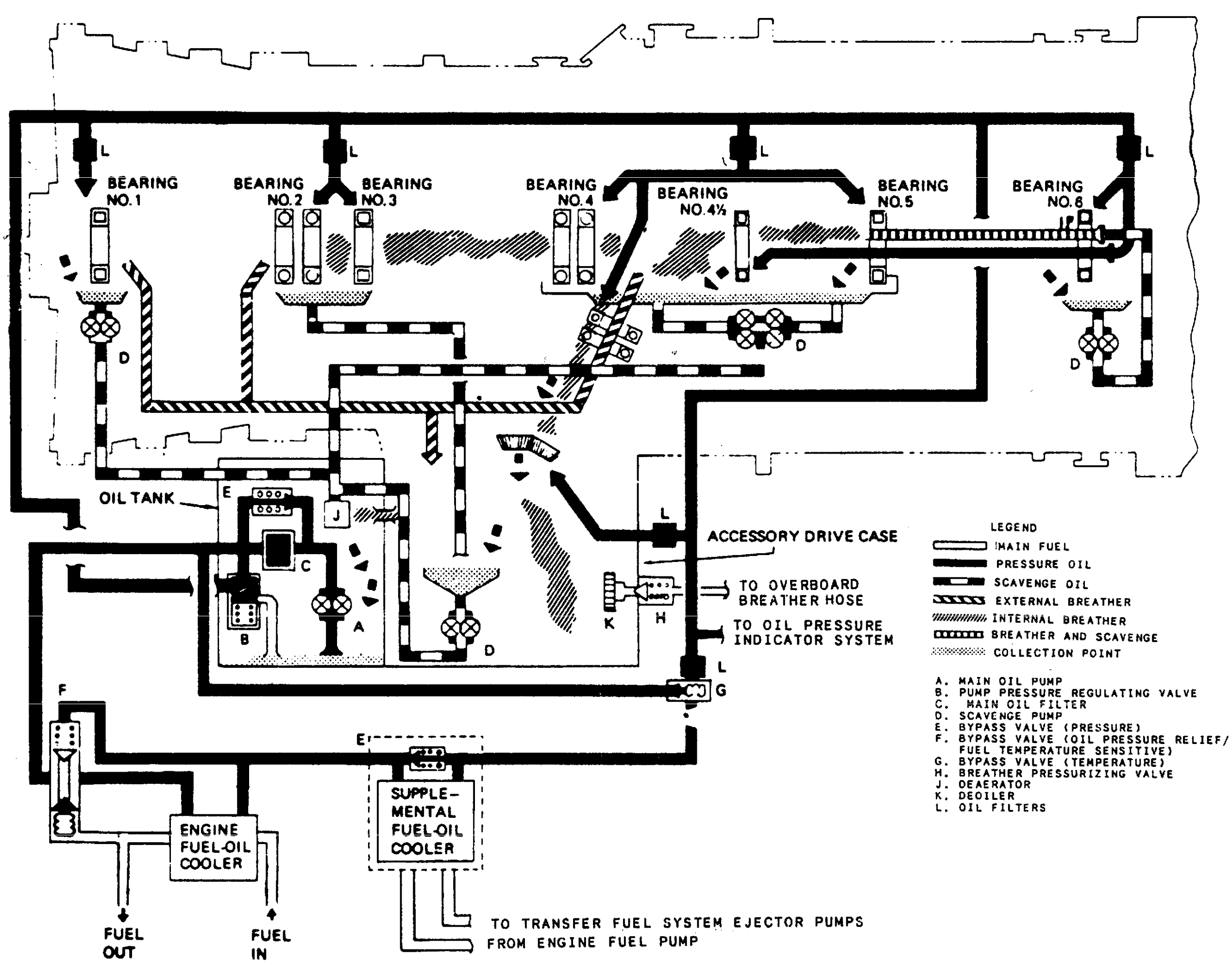


Figure 5-3.—Hot tank oil system.

OIL SYSTEM COMPONENTS

As we just discussed, there are two primary types of oil systems. Some of these parts are unique to one type of system, while other parts are used in both systems. The following paragraphs cover oil system parts regardless of type unless otherwise noted. The main parts of a typical oil system include an oil tank, oil pumps, valves, filters, and chip detectors. Other parts are oil coolers, oil jets, gauge connectors, vents, and oil system seals.

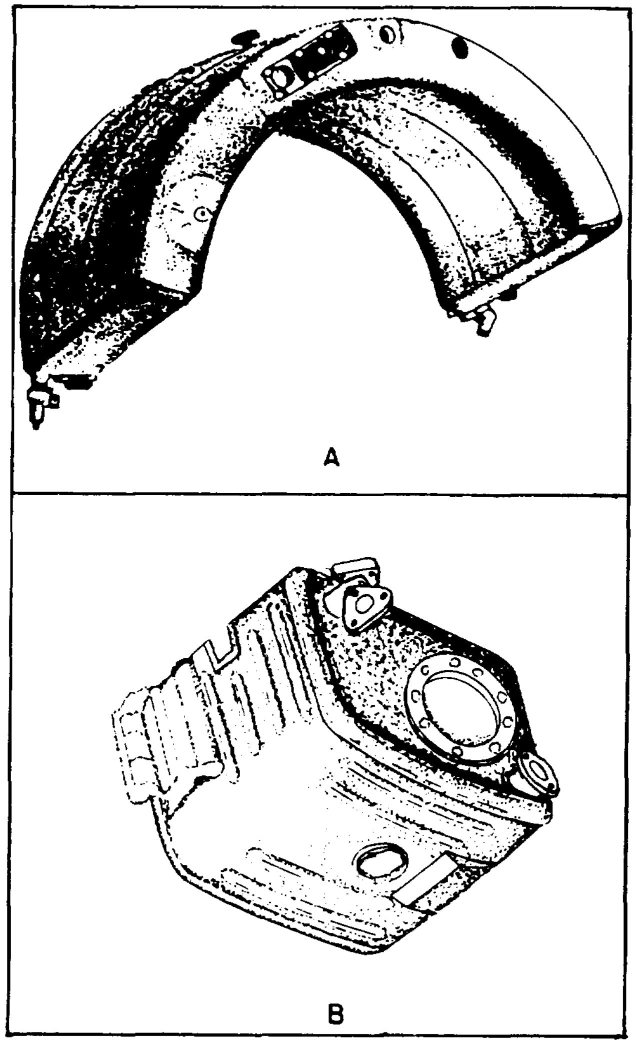


Figure 5-4.-Dry-sump oil tanks; (A) engine mounted; (B) engine or airframe mounted.

Oil Tanks

The oil tank stores the system oil supply. An oil tank may be a simple sealed container (similar to a car's fuel tank) where oil is gravity fed to the engine. Older low-performance aircraft engines could use this simple tank design. Today's high-performance aircraft require a more complicated pressurized type of oil tank; this assures positive lubrication during all flight conditions.

The dry-sump oil system uses an oil tank located either in the airframe or mounted on the engine. See figure 5-4. Oil tanks mounted on the airframe are normally located within or near the engine compartment. Additionally, designers place it high to gain as much advantage as possible from gravity flow to the oil pump inlet.

A view of a representative oil tank is shown in figure 5-5. It shows a welded aluminum tank with an oil capacity of 3.25 gallons and a 0.50-gallon foaming space. The tank is designed to furnish a constant supply of oil to the engine in any attitude, and during negative g loading or forces. This is done by a swivel outlet assembly mounted inside the tank, a horizontal baffle mounted in the center of the tank, two flapper check valves mounted on the baffle, and a positive vent system.

The swivel outlet fitting is controlled by a weighted end, which is free to swing below the baffle. The flapper valves in the baffle are normally open. They close only when the oil in the bottom of the tank tends to rush to the top of the tank. This happens during decelerations and inverted flight. Oil trapped in the bottom of the tank is picked up by the swivel fitting without any interruption in the flow of oil.

All oil tanks provide an expansion space. This allows for oil expansion from heat and oil foaming. Some tanks also have a deaerator tray for separating air from the oil. Usually these deaerators are of the can type, with oil entering at a tangent. The air released is carried out through the vent system in the top of the tank. The vent system inside the tank is so arranged that the airspace is always vented. This includes times when the aircraft is decelerating and oil is forced to the top of the tank. However, most oil tanks have a pressurized oil tank to assure a positive flow of oil to the oil pump inlet. The tank is pressurized by running the vent line through an adjustable check relief valve.

Other features common in oil tanks area sump with drain and shutoff valves in the bottom of the tank. The drain valve permits oil to be drained for oil changes. An oil shutoff valve is a motor-operated, gate-type valve attached to the oil sump. This valve can be operated electrically or manually

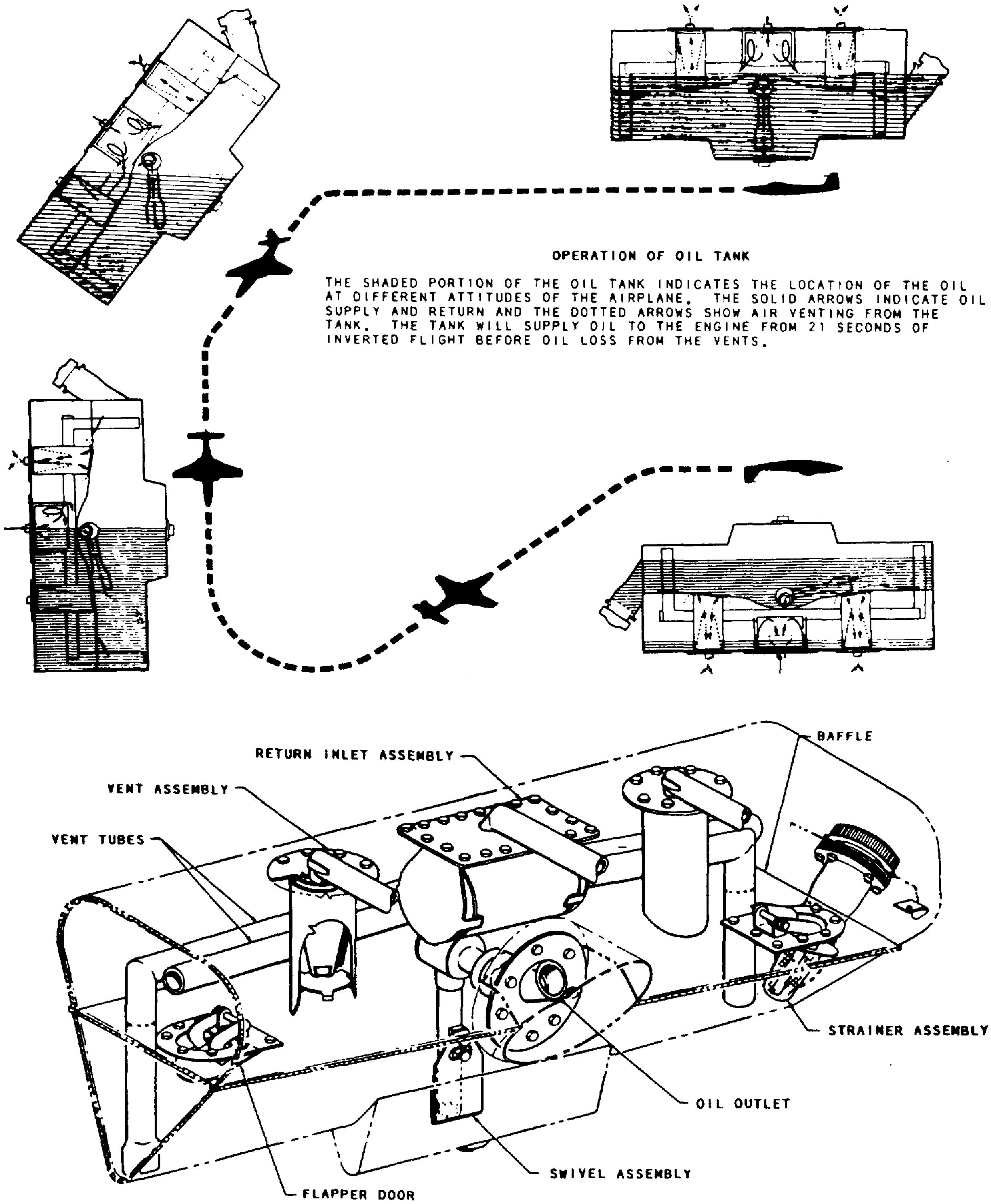


Figure 5-5.-Representative oil tank.

to shut off the oil supply to the engine in emergency conditions.

Some oil tanks include an oil temperature bulb in the outlet line. These bulbs send the temperature of the oil to indicators in the instrument panel. Oil quantity units or sight gauges are also located on the oil tank. A sight gauge gives a visual indication of oil level. A quantity indicator connects electrically to a gauge in the instrument panel. A quantity indicator uses a float-type unit located in the tank and an electrical transmitter on the outside of the tank.

Oil Pumps

The oil pump supplies oil under pressure to engine points that require lubrication. Most lubrication pumps have both a pressure supply element and a scavenge element. However, some oil pumps serve a single function; they either supply or scavenge the oil. The number of pumping elements, both pressure and scavenge, depends largely on the type and model of the engine. For instance, the axial-flow engines have a long rotor shaft and use more bearings than a centrifugal-flow engine. Therefore, the oil pump elements for both supply and scavenging must be of larger capacity or more of them.

It is common to use small individual scavenge pumps in the remote sections of an engine. This assures proper scavenging of the lubricating oil. In all types of pumps, the scavenge elements have a greater pumping capacity than the pressure element. This is to prevent oil from collecting in the bearing sumps.

The pumps may be one of several types, each type having certain advantages and limitations. The three most common oil pumps are gear, gerotor, and piston types. The first being the most used and the last the least used. Each of these pump types have several different designs. This makes it impractical to try to completely cover each type. However, a pump representative of each of the three types is discussed.

GEAR-TYPE OIL PUMP.— The gear-type oil pump shown in figure 5-6 has only two elements (one for pressure oil and one for scavenge). However, this type of pump could have several elements.

Notice in figure 5-6 a relief valve in the discharge side of the pump. This valve limits the

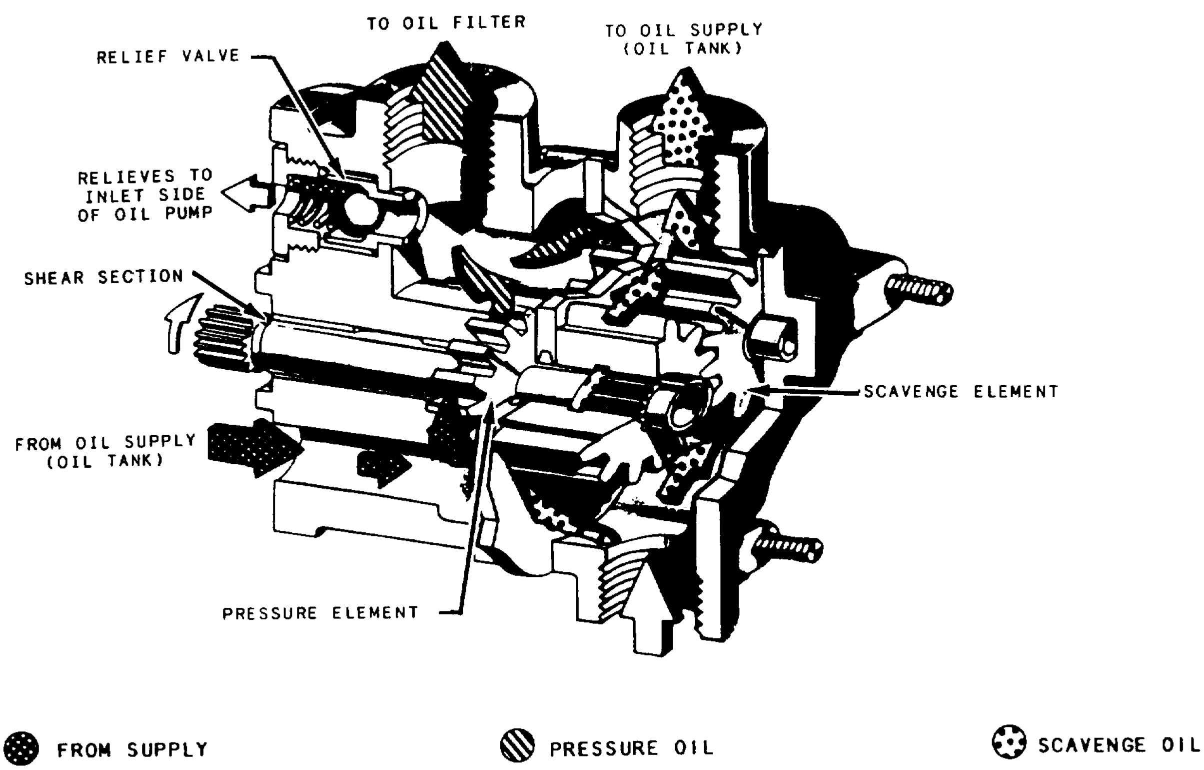


Figure 5-6.-Cutaway view of gear-type oil pump.

output pressure of the pump by bypassing oil back to the pump inlet. Also notice the location of the shaft shear section, which will allow the shaft to shear if the gears should seize.

GEROTOR OIL PUMP.— The gerotor pump usually has a single element for oil feed and several elements for scavenging oil. Each of the elements, pressure and scavenge, is almost identical in shape. However, the capacity of the elements is controlled by varying the size of the gerotor elements. The pressure element has a pumping capacity of 3.1 gpm (gallons per minute) compared to a 4.25-gpm capacity for the scavenge elements. So the pressure element must be smaller since the elements are all driven by a common shaft. Engine rpm determines oil pressure, with a minimum pressure at idling speed and maximum pressure at maximum engine speed.

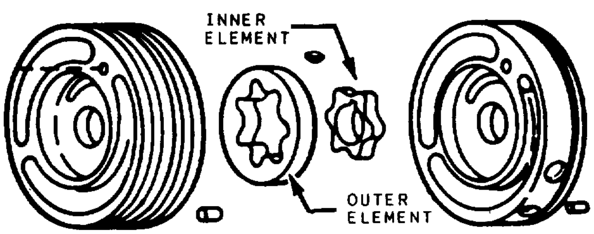


Figure 5-7.-Gerotor pumping element.

A set of gerotor pumping elements is shown in figure 5-7. Each set of gerotors is separated by a steel plate, making each set an individual pumping unit. Each set consists of an inner element and an outer element. The small star-shaped inner element has external lobes fitting within and matching with the outer element, which has internal lobes. The small element pinned to the pump shaft acts as a drive for the outer free-turning element. The outer element fits within its steel plate, having an eccentric (not having the same center) bore. In some engine models, the oil pump has four elements, one for oil feed and three for scavenging. In other models, pumps have six elements, one for feed and five for scavenge. In each case, the oil flows as long as the engine shaft is turning.

PISTON OIL PUMP.— The piston lubrication pump is always a multiplunger type. Output of each piston supplies a separate jet. Oil drained from the points of lubrication is scavenged by a separate pump element. The piston-type pump (fig. 5-8) is used less than either of the other types.

Valves

Valves control the pressure and flow of oil in the lubrication system. There are three types of valves common to oil systems that are discussed in this text. They are relief valves, check valves. and bypass valves.

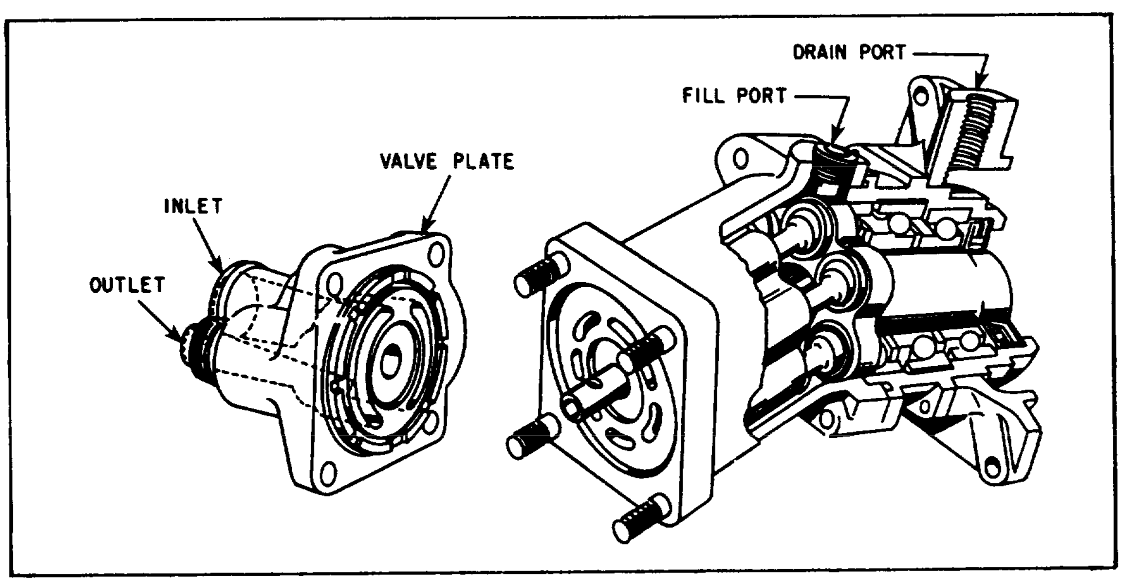


Figure 5-8.-Axial piston pump.

OIL PRESSURE RELIEF VALVE.— An oil pressure relief valve limits the maximum pressure within the system. The relief valve is preset to relieve pressure and return the oil to the inlet side of the lube pump. This valve is important if the system has an oil cooler, since the cooler's thin walls rupture easily.

CHECK VALVES.— Check valves installed in the oil supply lines or filter housings prevent oil in the reservoir from seeping (by gravity) into the engine after shutdown. Check valves prevent accumulations of undue amounts of oil in the accessory gearbox, rear of the compressor housing, and combustion chamber. Such accumulations could cause excessive loading of accessory drive gears during starts, contamination of the cockpit pressurization air, internal oil fires, and hot starts.

The check valves are usually of the spring-loaded ball-and-socket type, constructed for free flow of pressure oil. The pressure required to open these valves will vary. Most valves require from 2 to 5 psi to permit oil to flow to the bearings.

THERMOSTATIC BYPASS VALVES.— Thermostatic bypass valves are included in oil systems using an oil cooler. Their purpose is to maintain proper oil temperature by varying the proportion of the total oil flow passing through the oil cooler. A cutaway view of a thermostatic bypass valve is shown in figure 5-9. This valve consists of a valve body (having two inlet ports and one outlet port) and a spring-loaded thermostatic element valve.

The valve is spring-loaded so the valve will open (bypassing the cooler) if the pressure through the oil cooler drops too much because of denting or clogging of the cooler tubing.

Filters

The filters are an important part of the lubrication system, since they remove most foreign particles in the oil. Without some type of filter in the oil system, dirt or metal particles suspended in the oil could damage bearings, clog passages, and cause engine failure.

The filter bypass valve allows oil to flow around the filter element if it becomes clogged. The bypass valve opens whenever a certain pressure differential is reached because the filter became clogged. When this occurs, the filtering action is lost, allowing unfiltered oil to be pumped to the bearings. This is a dangerous situation; however, unfiltered oil is better than no oil.

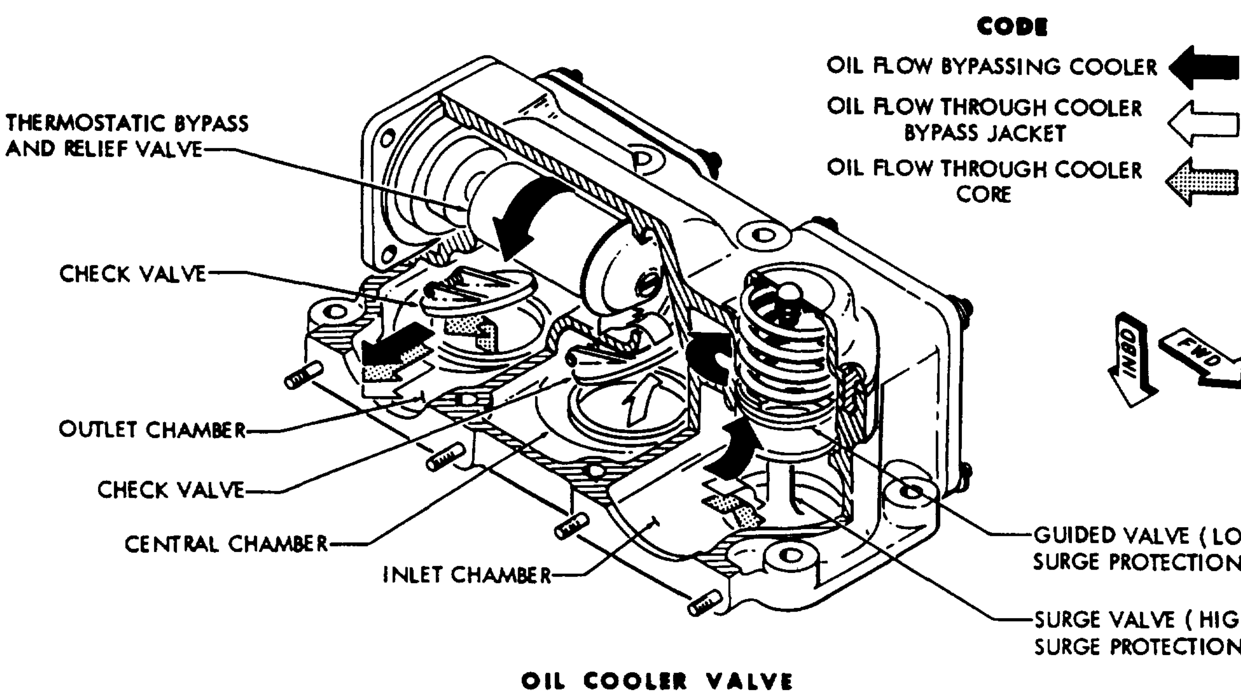


Figure 5-9.-Thermostatic bypass valve.

There are several types of filters used for filtering the lubricating oil. The filtering elements come in a variety of configurations. The parts of a main oil filter-include a-housing, which has an internal relief valve and a filtering element.

DISK-TYPE FILTER.— The disk filter (fig, 5-10) consists of a series of spacers and screens. The screens and spacers are stacked alternately in the housing. The spacers direct oil through the screens as it flows through the assembly. The screen mesh (usually measured in microns) determines the size of foreign matter allowed to pass through the filter.

MICRONIC-TYPE FILTER.— The micronic filter is similar to the cartridge filter used on a car's oil filter, as shown in figure 5-11. It uses either a paper or metal cartridge type of oil filter. The paper filtering element is removed and replaced, while the metal type is cleaned and reused.

Each of the oil filter types mentioned in the preceding paragraphs has certain advantages. The filter types just discussed are generally used as main oil filters. These filters strain the oil as it leaves the oil pump. In addition to main oil filters, there are also secondary filters throughout the system. For instance, there may be a finger screen filter to trap large metal pieces before the magnetic drain plug. Also, there are the fine mesh screens (last-chance filters) for straining the oil just before it passes through the spray nozzles onto the bearing surfaces.

Chip Detectors

The magnetic-chip detector is a metal plug with magnetized contacts, and is placed in the

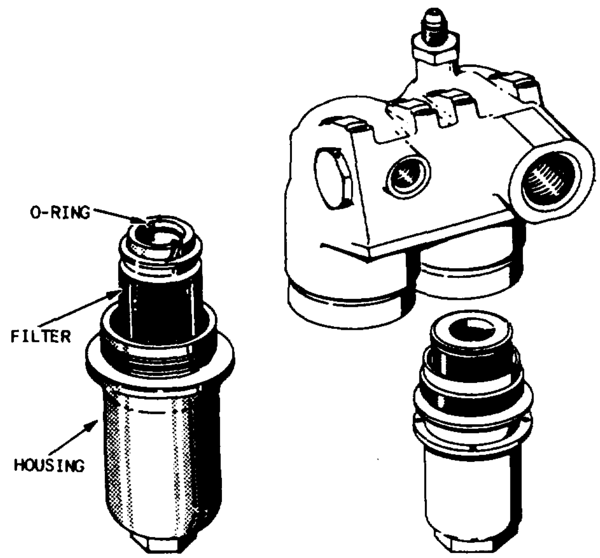


Figure 5-11.-Filtering assembly.

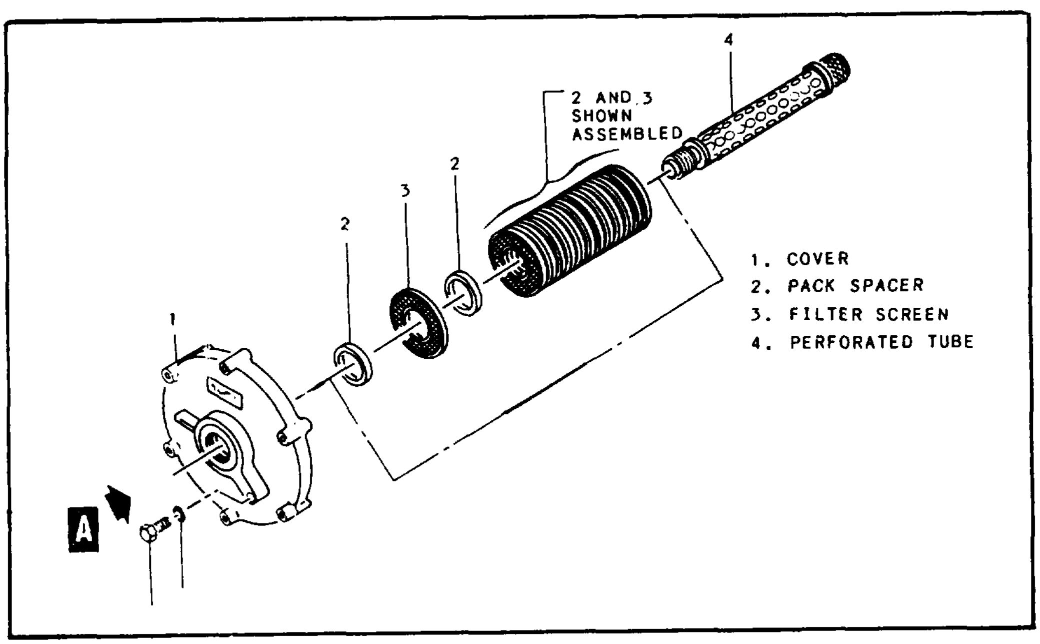


Figure 5-10.-Spacers-and-screens oil filter.

scavenged oil path. There are two types. Both types have magnetized contact points to collect metal particles. When enough metal particles collect on the magnetized contacts, one type completes a circuit between the contacts. This illuminates a warning light in the cockpit, advising the pilot of metal contamination. This indicates that one of the engine gears, bearings, or other metal parts might have failed. The other chip detector gives no cockpit indication. It is removed and inspected at regular intervals for metal particles.

Oil Coolers

Oil coolers reduce the temperature of the oil through either an air-oil or a fuel-oil type cooler. These coolers keep the temperature of the oil within the proper range.

AIR-OIL COOLER.— The air-oil type cooler (fig. 5-12) is installed at the entry end of the engine as an integral part of the engine. This type of cooler is usually an aircraft part conforming to the inlet duct design of the airframe. This cooler is made of rectangular-sectioned aluminum tubing, spirally wound between two end flanges and formed, by welding, into a cylinder. Two bosses, located on the horizontal center plane, are provided for oil inlet and outlet connections. This type of cooler acts as an inlet air duct; therefore, a cooling effect occurs when the engine is operating. The cooling capacity of each of the oil cooler assemblies also depends upon the amount of air allowed to pass through the cooler. Some aircraft use a controllable oil cooler door, which restricts the opening of the oil cooler exit duct.

FUEL-OIL COOLERS.— The fuel-oil cooler or heat exchanger (fig. 5-13) cools the hot oil and preheats the fuel for combustion. Fuel flow to the engine must pass through the heat exchanger. However, a thermostatic valve controls the oil flow, so the oil may bypass the cooler if no cooling is needed. The fuel-oil heat exchanger consists of a series of joined tubes with an inlet and an outlet port. The oil enters the inlet port, moves around the fuel tubes, and goes out the oil outlet port.

The heat-exchanger type of cooler has the advantage of allowing the engine to keep its small frontal area. Since the cooler is flat and mounted on the bottom side of the engine, it offers little drag. This type of cooler is an engine part.

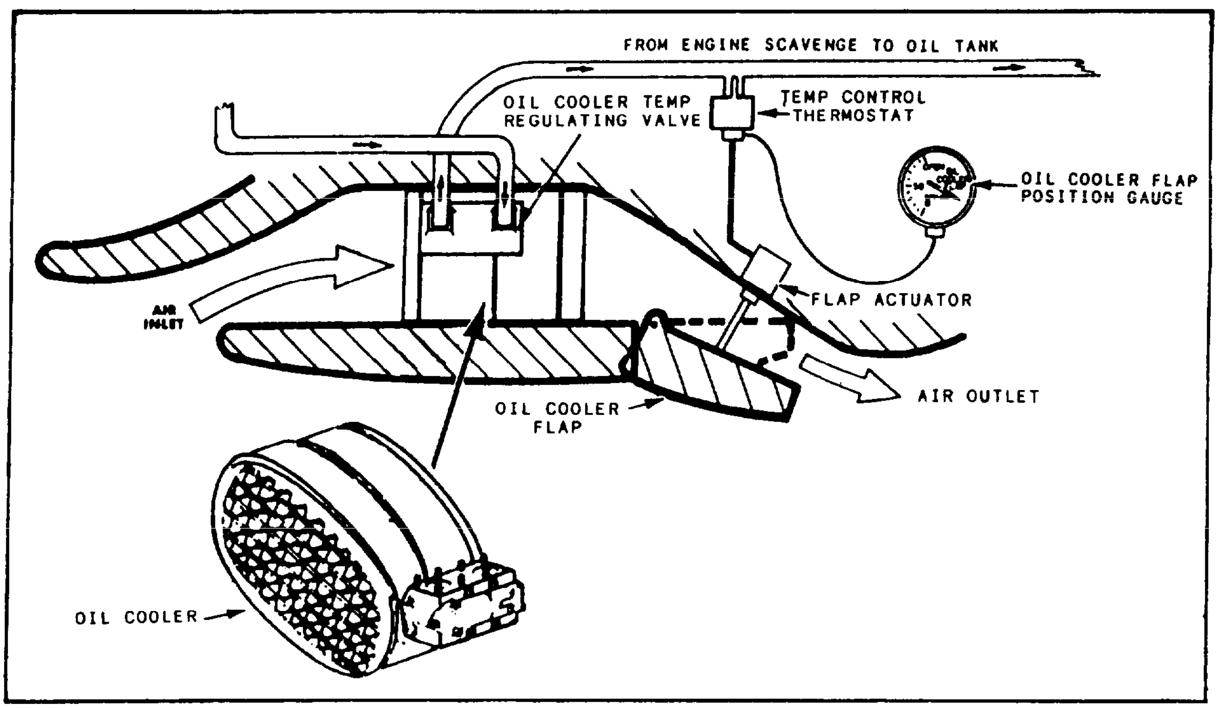


Figure 5-12.-Air-oil type of oil cooler.

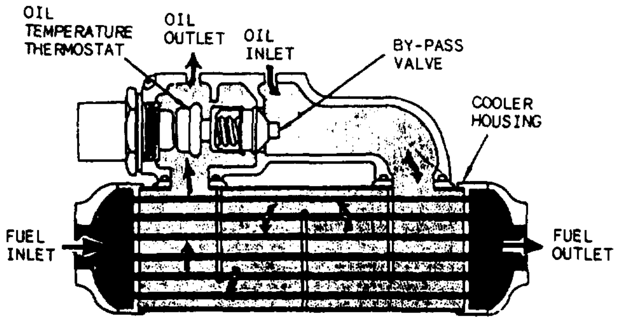


Figure 5-13.-Fuel-oil heat-exchanger type of cooler.

Oil Jets

The oil jets (or nozzles) are located in the pressure lines next to or within the bearing compartments and rotor shaft couplings. The oil from these nozzles is delivered as an atomized spray. Some engines use an air-oil mist type of nozzle spray. This air-oil mist is produced by tapping high-pressure bleed air from the compressor and mixing it with the oil. This method is adequate for ball and roller type of bearings; however, the solid oil spray method is better.

Some engines have "expendable oil" jets to lubricate the bearings supporting the turbine rotor shaft. The air-oil mist from such jets is not returned to the tank, but is discharged overboard.

Gauge Connections

Gauge connections are used in the oil system for oil pressure and oil temperature. The oil pressure gauge is usually a necessity in all systems to measure the pressure of the lubricant. This is done as it leaves the pump on its way to the oil jets. Since oil pressure is the best indication that the system is operating properly, the oil pressure gauge is vital.

The oil pressure gauge connection is always located in the pressure line between the pump and the various points of lubrication. The oil temperature gauge connection may be located in either the pressure or the scavenge line. However, the scavenge line is preferred, since this location permits a more accurate indication of the actual bearing temperatures, as the temperature of the oil is shown shortly after it leaves the bearings.

The most common methods of oil temperature indicators are a thermocouple-type fitting or an oil temperature bulb.

Vents

Vents are lines or openings to the atmosphere in the oil tanks or accessory cases of the engine. The purpose of the vent in an oil tank is to keep the pressure within the tank from rising above or falling below that of the outside atmosphere. However, the vent may be routed through a pressure relief valve that keeps pressure on the oil system to assure positive flow.

In the accessory case, the vent (or breather) is a screen-protected opening that allows accumulated air pressure to escape. The scavenged oil carries air into the accessory case, and this air must be vented. Otherwise, the pressure buildup within the accessory case would stop the flow of oil draining from the No. 1 bearing. This oil would be forced past the rear bearing oil seal and into the compressor housing. Oil leakage could cause any of several problems, including high oil consumption, cockpit air contamination, or a fire. An oil leakage around the combustion area or turbine area could cause burning and engine failure.

The screened breathers are usually located in the front center of the accessory case to prevent oil leakage through the breather. Some breathers have a baffle to prevent oil leakage during flight maneuvers.

A vent that leads directly to the No. 1 bearing compartment may be used in some engines. This vent equalizes pressure around the front bearing surface. Then the lower pressure at the first compressor stage will not force oil past the No. 1 bearing rear carbon oil seal and into the compressor.

Oil System Seals

Any system containing fluids need some type of seal to prevent fluid loss. **The importance of oil seals cannot be overemphasized!** An improperly installed or leaking seal in the oil system could cause bearing failure, fire, or cockpit fumes. This could result in loss of aircraft or LIFE. There are three types of seals used in jet engine oil systems—synthetic, carbon, and labyrinth.

SYNTHETIC SEALS.— Seals, packings, and O-rings are used where metal-to-metal contact prevents proper sealing. These seals come in many different shapes and sizes and are not reusable. It is important to use the proper seal (identified by correct part number) for the specific installation. NEVER use a seal, packing, or O-ring because they look alike. A seal designed to have excellent sealing characteristics in one environment could be hazardous when used in another. Some seals swell when contacted with MIL-L-7808 oil, while others deteriorate completely.

CARBON SEALS.— Carbon seals are used to contain the oil in the bearing areas. Carbon seals form a sealing surface by having a smooth carbon seal rub against a smooth steel surface (faceplate). All carbon seals are preloaded. Preloading means the carbon seal is held against the steel surface. Three common methods of preloading carbon seals are spring tension, centrifugal force, and air pressure.

LABYRINTH SEALS.— Labyrinth seals contains series of knifelike, soft metal edges that ride very close to a steel surface. A certain amount of air, taken from the compressor, forced between the steel surface and soft metal edges prevent oil leakage between sections. These seals were used as main bearing seals in earlier engines. These seals are made of very soft metal and used at main bearing areas. Small nicks in the seal can cause major oil leaks and premature engine changes.

ENGINE OIL SYSTEM DESCRIPTION

The engine oil system shown in figure 5-14 is a representative engine of a self-contained, pressurized, recirculating, dry-sump system. It consists of the following systems and parts:

1. Tank
2. Oil pressure and scavenge pump

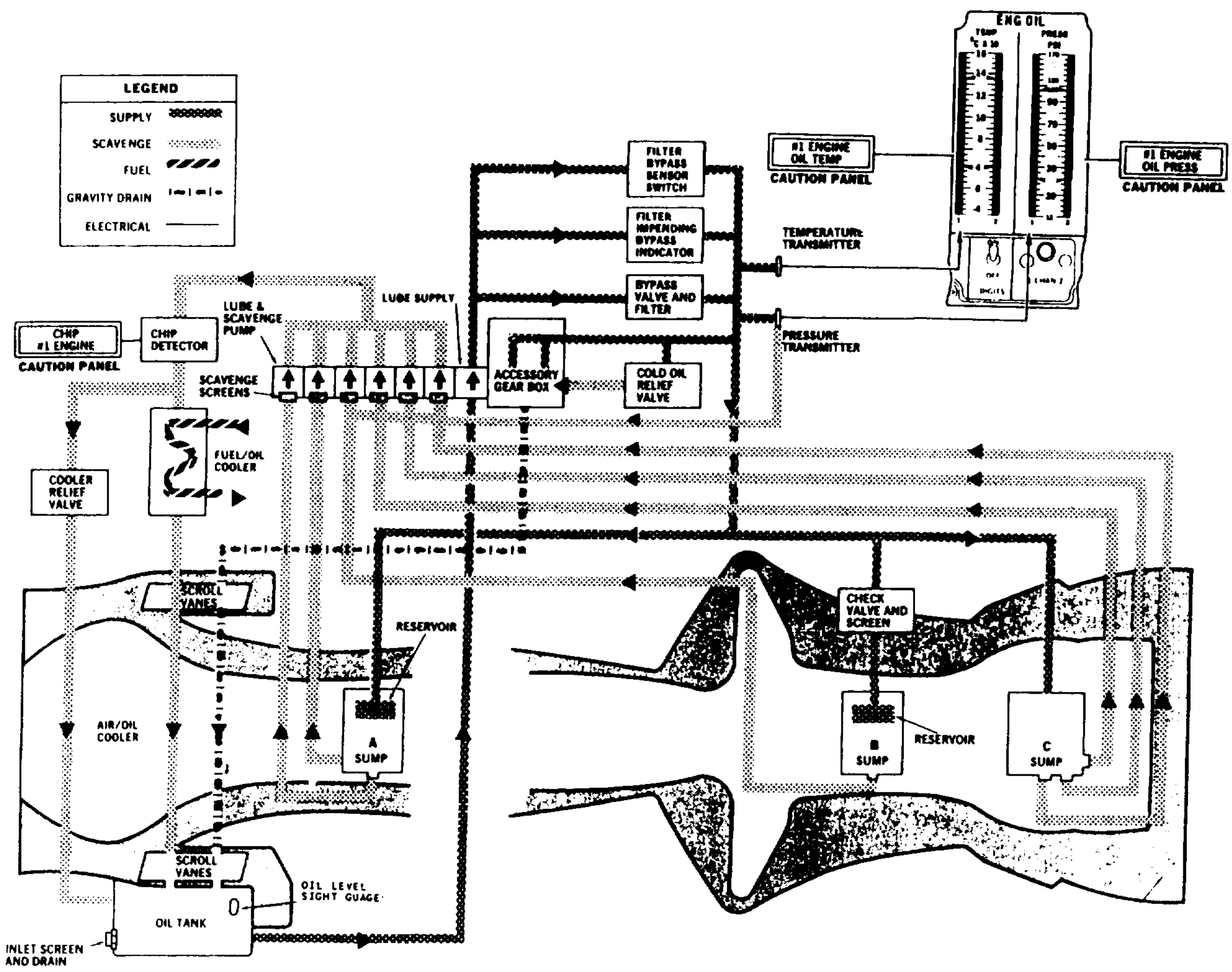


Figure 5-14.-Engine oil system schematic.

3. Oil filter and condition monitoring system
4. Oil coolers
5. Chip detector

Oil Tank

The oil tank and air/oil cooler are integral parts of an aluminum casting. Tank capacity is 7.6 U.S. quarts. The filler port is on the right side of the engine, and the filler design make it impossible to overservice the tank. Oil flows to the oil pump through a screen. The oil level is shown by a sight gauge on each side of the tank. The scavenge pump returns oil from the sumps and accessory gearbox to the oil tank through six scavenge screens.

Oil Pressure System

Oil suctioned through the pressure element of the pump is pressurized and flows through the oil filter. The oil then flows into passages in the accessory gearbox and to the six main bearings in the sumps. A cold-start relief valve downstream of the filter protects the system by dumping any extra oil into the accessory gearbox case. Air jets blow across the oil jets to provide continuous oil-mist lubrication. The engine has two sets of oil jets to provide each main bearing with oil for cooling and lubrication. Scavenge to the scavenge elements of the pump flows through screens at the pump inlet, and then through the electrical chip detector. The oil then flows through the oil cooler, main frame, scroll vanes, and into the oil tank. If the oil pressure drops below 24 psi, the appropriate ENGINE OIL PRESS caution light lights in the cockpit.

Oil Filter

Oil discharged from the oil pump is routed to a disposable element. The element is a 3-micron filter located on the forward, left-hand side of the AGB. As the pressure differential across the filter increases, the first indication will be a popped impending bypass button. As the pressure increases, the OIL FLTR BYPASS caution light will illuminate at the same time the filter bypass occurs.

Oil Coolers

Scavenge oil is cooled before it returns to the tank by a fuel/oil cooler. After passing through the oil cooler, oil enters the top of the main frame. At this location it flows through the scroll vanes that function as an air/oil cooler. This further cools the oil and heats the vanes for full-time anti-icing. The vanes discharge oil into the oil tank. If the oil cooler pressure becomes too high, a relief valve will open to dump scavenge oil directly into the oil tank.

Engine Chip Detector

The chip detector is on the forward side of the accessory gearbox. It consists of a housing with an integral magnet and electrical connector, with a removable screen surrounding the magnet. If there are chips, the completed circuit illuminates the appropriate number engine CHIP light.

MAINTENANCE

Maintenance of the oil system is an item of major importance to the Aviation Machinist's Mate. It consists mainly of adjusting, removing, cleaning, and replacing various parts. To troubleshoot and repair oil systems effectively, you should be thoroughly familiar with both the external and internal oil systems.

LOCATION OF LEAKS AND DEFECTS

The immediate location of any leak or defect within the oil system of any aircraft engine is important. The life of the engine is in its oil supply. Whenever a leak develops or the oil flow is restricted, a part failure or loss of the engine may result.

Locating leaks in the external oil system is easy. Often a visual inspection shows a loose line or leaking gasket. Although, you should never assume that an obvious corrective action is all that is needed.

REPLACEMENT OF GASKETS, SEALS, AND PACKINGS

A large portion of the maintenance involved is the replacement of parts and repair of various oil leaks. Much of this maintenance requires the use of new gaskets, seals, and packings.

New seals are packaged to prevent damage. These packages are identified from technical information printed on the package. This information identifies the use and qualifications

1 → KZ5330-00-833-7491
2 → PACKING PREFORMED SYN. RUBBER
3 → 1 EACH (MS28778-5)
4 → DISC-38329
5 → A5/66
6 → SR 810-8-90
7 → MFD. DATE 4-77 CURE DATE 2Q77
8 → STILLMAN RUBBER CO. (MFGR./CONTR.)
9 → MIL-G-5510A

1. STOCK NUMBER
2. NOMENCLATURE
3. PART NUMBER
4. DISC-38329
5. PRESERVATION
6. RUBBER COMPOSITION NUMBER
7. DATE OF MANUFACTURE AND CURE DATE
8. MANUFACTURER
9. MILITARY SPECIFICATION NUMBER

Figure 5-15.-Seal packing information.

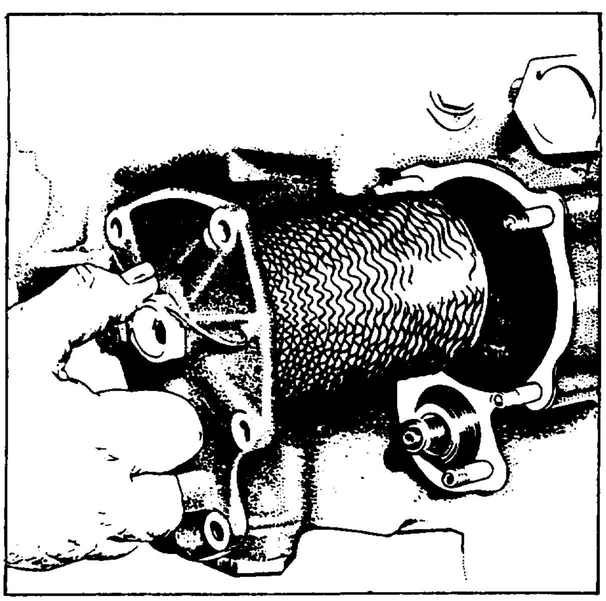


Figure 5-16.-Removing the oil filter assembly.

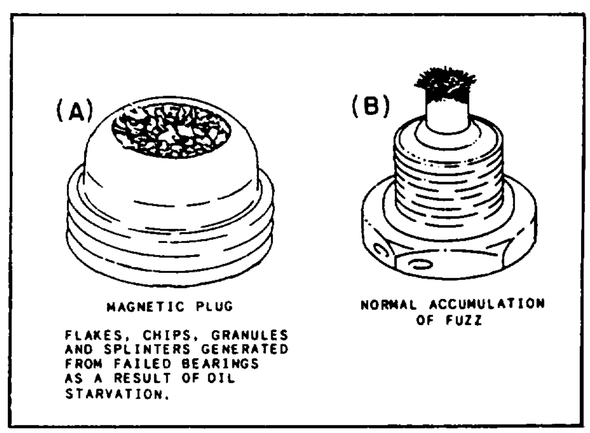


Figure 5-17.-Two types of magnetic drain plugs (A) Flakes from a failed bearing; (B) normal fuzz accumulation.

of the packing (fig. 5-15). Beside the part number, the manufacturers cure date is one of the most important items listed on the package. Refer to NAVSUP Publication 4105 for shelf life of preformed packings. Most synthetic rubbers are not damaged by several years of storage under ideal conditions. However, they deteriorate quickly when exposed to heat, light, moisture, and various other conditions. This is why it is important to keep them in their original envelopes. Damage also occurs to packings when improperly stored, such as flattening or creasing from storage under heavy parts. Before using the parts, inspect new seals for damage (nicks, scratches, flattening, overage). Do not use overaged, damaged or nonidentifiable seals (seals removed from original envelopes).

The difficulty encountered whenever a gasket, seal, or packing is being replaced is in proper installation. Always check that the mating surfaces are clean, and that the new gasket, seal, or packing is correctly installed. Seals or O-rings are comparatively soft, so you should use care to prevent nicks and scratches. Do not use sharp instruments during installation; they could nick the seals. Always refer to the applicable maintenance instructions manual for the correct procedures, tools, and lubricants used during installation.

ADJUSTMENT OF OIL PRESSURES

Before making any oil pressure adjustments, you should first check the oil pressure with a direct reading gauge. Record the oil pressure when running the engine at the recommended oil temperature and engine rpm. Oil pressure adjustments are made with the adjusting screw on the oil pressure relief valve of the oil pump. Turn the adjusting screw clockwise to increase and counter clockwise to decrease oil pressure.

WARNING

Some engines prohibit decreasing oil pressure; the oil pump must be changed instead. High oil pressure could indicate blocked oil passages and lowering the oil pressure could result in an inadequate oil supply to some bearings.

Oil pressure adjustments vary between different pumps or on pumps with worn parts. One full turn of the adjusting screw equals about 3 psi, but consult your specific engine MIMs before making adjustments.

After any adjustments, you must recheck the pressure with a direct reading gauge at the recommended oil temperature and engine rpm.

To identify defects in the oil system that are attributable to either high or low oil pressure, refer to table 5-3.

REMOVAL AND REPLACEMENT OF OIL FILTERS

The following procedures are general procedures. You should refer to the correct maintenance information manuals before you remove or replace oil filters on your engine. Oil filters are removed and inspected at regular intervals. They are also inspected when the cockpit indicator (chip light) for the magnetic drain plug warns of possible failure.

1. Provide a suitable container for collecting oil and remove the filter (fig. 5-16).

2. Inspect the filter for metal contamination.

NOTE: The screen and spacer-type filters require a special holding fixture for removing filter elements to prevent stacked screens and spacers from flying off assembly.

3. After inspection, clean the filters. Most filters are routed to AIMD for ultrasonic cleaning.
4. Install clean or new filters on the oil filter assembly.

NOTE: The screen and spacer-type filters require a special holding fixture for replacing (buildup) the filter elements. Be sure the screen and spacers are the correct number and in proper order.

5. Install the filter assembly using new O-rings and gaskets. Torque nuts to recommended values.

REMOVAL AND REPLACEMENT OF MAGNETIC DRAIN PLUGS

Magnetic drain plugs are usually removed and inspected at the same time as the main oil filters. Remove magnetic drain plugs carefully so contaminants will not be disturbed until inspected. Figure 5-17 shows two types of magnetic drain

Table 5-3.-Oil Pressure Troubleshooting Chart

Trouble	Probable Cause	Corrective Action
High oil pressure. **NOTE** Indicator accuracy must be confirmed using direct reading oil pressure gauge.	Low oil temperature. Improper setting of relief valve. Defective pressure indicator.	Check temperature indicator. Check grade of oil. Reset pressure relief valve. Replace with new or serviceable indicator.
Low oil pressure. **NOTE** Indicator accuracy must be confirmed using direct reading oil pressure gauge.	High oil temperature. Clogged oil filter. Improper setting of relief valve. Defective pressure pump. Defective pressure indicator. Low oil level. Viscosity of oil is too light. Air leak in the supply line.	Check temperature indicator. Remove and clean oil filter. Reset pressure relief valve. Repair or replace pump. Replace with new or serviceable indicator. Fill oil tank to the proper level. Drain system; refill with correct grade of oil. Locate and eliminate air leak.
Reduction gear oil pressure out of limits. **NOTE** The reduction gear has a fixed orifice oil system. The problems described are often caused by a change in the effective orifice or the pump output. Reduction gear and pump pressure may only be adjusted to increase pressure. Indicator accuracy must be confirmed using direct reading oil pressure gauge.	Reduction gear oil pump assembly pressure element deteriorated (low pressure), check valve stuck or restricted (low pressure). Reduction gear oil pump drive train bearing or gear failure (low pressure). Reduction gear internal oil passages blocked (high pressure) or ruptured (low pressure), worn transfer tubes (low pressure). Oil system air lock. Reduction gear pressure relief valve stuck open (low pressure).	Repair/replace as required. Replace engine. Replace engine. Prime reduction gear pump assembly. Clean/replace as required.

plugs indicating (A) engine bearing failure and (B) normal buildup of fuzz.

NOTE: Fuzz consists of fine, hairlike particles resulting from normal wear. Fuzz accumulation may be more noticeable on new engines during the first. 100 hours of operation. Always refer to your specific aircraft and engine MIM for contamination and serviceability limits. Rejection criteria for one engine may be only an oil flush and oil component replacement on another type engine.

METAL PARTICLE IDENTIFICATION

Metal particles found on the oil strainer screens and mag plugs indicate a possible failed part or impending engine failure. The presence of metal particles on the oil screen or on the mag plug does not mean that the engine must be replaced. The type (steel, bronze), shape (flakes, chunks), and quantity determine the source and dictate whether or not an engine is serviceable. The metals usually found are steel, tin, aluminum, silver, copper (bronze), chromium, nickel, and tin cadmium combinations. With some experience you can make a visual inspection as to color and hardness, and it will help you to identify the metal particles. The particles of metal found in an engine may be a granular, flake, or chunk.

When a visual inspection does not positively identify the metal, the kind of metal may be determined by a few simple tests. These tests are performed with a permanent magnet and an electric soldering iron. You also need about 2 ounces each of concentrated hydrochloric (muriatic) acid, concentrated nitric acid, chromic acid, and sodium or potassium hydroxide.

CAUTION

Always use the appropriate protective clothing and equipment, and use extreme care when handling acids.

The following test procedures help determine different types of metal particles:

1. Iron (Fe) and nickel (Ni). Use a permanent magnet to isolate these metal particles.
2. Tin (Sn). Tin particles can be distinguished by their low melting point. Use a clean soldering iron, heated to 500°F (250°C) and tinned with a 50-50 solder (50-percent tin and 50-percent lead). A tin particle dropped on the soldering iron will melt and fuse with the solder.
3. Aluminum (Al). Aluminum particles can be determined by their reaction with hydrochloric acid. When a particle of aluminum is dropped into the hydrochloric (muriatic) acid, it will fizz, and the particle will gradually disintegrate. Aluminum particles will also dissolve rapidly and form a white cloud in a strong caustic solution (sodium or potassium hydroxide). Silver and copper (bronze) do not noticeably react with hydrochloric acid.
4. Silver (Ag) and copper (Cu). Silver and copper (bronze because of its high copper contents) may be differentiated by their respective reactions in nitric acid. When a silver particle is dropped into nitric acid, it will react with the acid, slowly producing a whitish fog in the acid. When a particle of copper (bronze) is dropped into the nitric acid, it will react rapidly with the acid. This reaction produces a bright, bluish-green cloud in the acid.
5. Chromium (Cr). These particles may be determined by their reaction to hydrochloric acid. When a chromium particle is dropped into concentrated hydrochloric acid, the acid will develop a greenish cloud.
6. Cadmium (Cd). Cadmium particles will dissolve rapidly when dropped into a 5-percent solution of chromic acid.
7. Tin cadmium. These particles will dissolve rapidly when dropped into a 5-percent solution of chromic acid. The tin content will cause a clouding of the solution.

Make sure the metal particles found in the oil are of an acceptable quantity for the engine to remain in service. Always refer to the applicable maintenance instruction manual for the limits of metal particles for each particular engine.

NAVY OIL ANALYSIS PROGRAM (NOAP)

The Navy Oil Analysis Program (NOAP) provides a diagnostic technique to monitor and diagnose equipment or oil condition. This is done without the removal or extensive disassembly of the equipment. It is mandatory for all activities operating aeronautical equipment to participate in this program. Type commanders or the cognizant field activity (CFA) are the only ones to relieve you from this requirement. The CFA provides information on the sampling points, techniques, and intervals for all Navy equipment. The CFA also establishes and maintains sampling information for the maintenance requirements cards (MRCs). It also maintains maintenance instruction manuals (MIMs) for the respective equipment or weapon systems.

Spectrometric oil analysis is a diagnostic maintenance tool used to determine the type and amount of wear metals in lubricating fluid samples. Engines, gearboxes, and hydraulic systems are the types of equipment most frequently monitored. The presence of unusual concentrations of an element in the fluid sample indicates some abnormal wear of the equipment. Once the abnormal wear is verified and pinpointed, the equipment may be repaired or removed from service. This is done before a major failure of the fluid-covered part occurs. This philosophy enhances personnel safety and material readiness at a minimum cost, and serves as a decisive tool in preventive maintenance action. Thus, worn parts may be replaced prior to a catastrophic failure.

Wear Metals

Wear metals are generated by the motion between metallic parts, even though lubricated. For normally operating equipment, the wear metal is produced at a constant rate. This rate is similar for all normally operating equipment of the same model. Any condition that changes the normal relationship will accelerate the rate of wear and increase the quantity of wear metal particles produced. If the condition is not corrected, the deterioration will increase and cause secondary damage to other parts of the assembly. This can result in the final failure of the entire assembly and loss of the equipment. New or newly overhauled assemblies tend to produce wear metal in high concentrations during the initial break-in period.

Identification of Wear Metals

The wear metals produced in fluid lubricated mechanical assemblies can be separately measured. This is done in extremely low concentrations, by spectrometric analysis of fluid samples taken from the assembly. Two methods of spectrometric oil analysis are currently used to measure the quantity of various metals.

1. Atomic Emission—The emission spectrometer is an optical instrument used to determine the concentration of wear metals in the lubricating fluid. This analysis is accomplished by subjecting the sample of fluid to a high-voltage spark. This energizes the atomic structure of the metal elements and causes the emission of light. The emitted light is then focused into the optical path of the spectrometer and separated by wavelength. It is then converted to electrical energy, and measured. The emitted light for any element is proportional to the concentration of wear metal suspended in the lubricating fluid.

2. Atomic Absorption—The atomic absorption spectrometer is an optical instrument. It is also used in determining the concentration of wear metals in the lubricating fluid. The fluid sample is drawn into a flame and vaporized. The atomic structure of the elements present become sufficiently energized by the high temperature of the flame to absorb light energy. Light energy having the same characteristic wavelength as the element being analyzed is radiated through the flame. The resultant light is converted to electrical energy and measured electronically. The amount of light energy absorbed by the elements in the flame is proportional to the concentration of wear metals.

NOTE: The spectrometric fluid analysis method is effective only for those failures that are characterized by an abnormal increase in the wear metal content of the lubricating fluid. This is particularly true of failures that proceed at a rate slow enough to permit corrective action. This is done after receipt of notice from the laboratory.

The value of a spectrometric analysis is based on the assumption that the oil sample is representative of the system from which it is taken. Occasionally, samples from one part may be substituted for another, resulting in a false appearance of a developing wear condition. A sudden increase of wear metal in one part and a decrease in another should be considered as a problem related to sample error; for example, misidentifying a sample as an engine sample when it was actually a transmission sample.

Oil Sampling Techniques

Sampling' intervals should be as close as possible to specified times without interfering with scheduled operations. Generally, the sampling intervals should not vary more than ±10 percent of that time specified. This requirement must be considered when equipment is scheduled for detachments or missions away from the home base. Oil samples will still be due while away. The customer (squadron or detachment) is responsible for coordinating oil analysis support at mission or transit site(s).

NOTE: Refer to the applicable scheduled maintenance or periodic inspection document for the specific routine sampling interval. Also look for specific sampling instructions for each type/model/series of equipment being sampled.

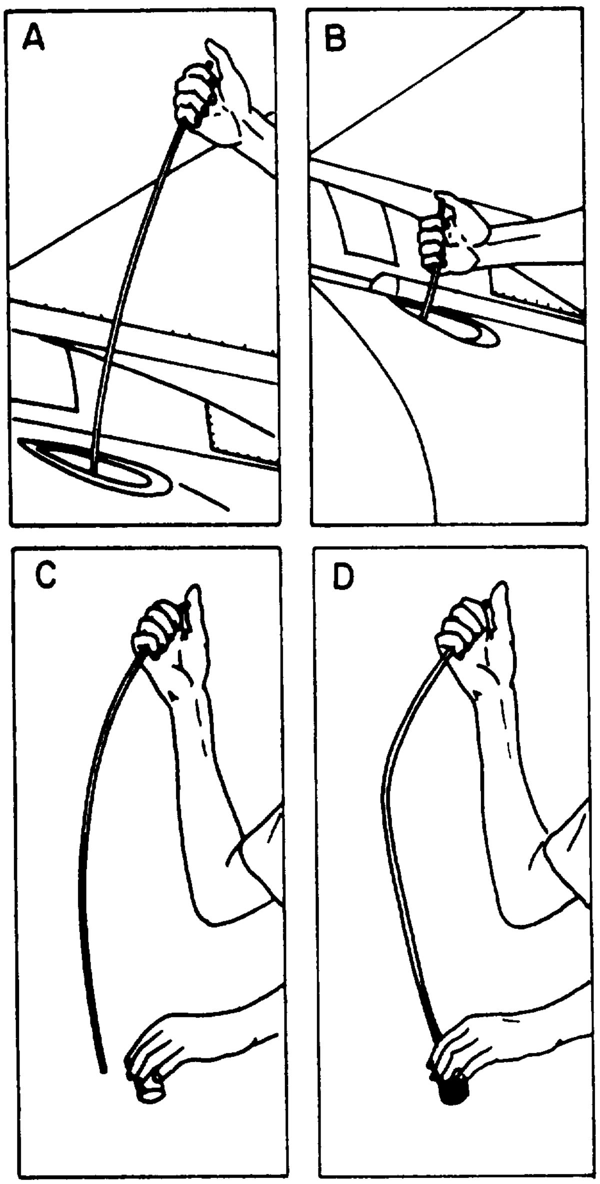


Figure 5-18.-Dip tube oil sampling.

Each operating activity participating in the NOAP must take routine samples properly and at the prescribed intervals. In addition to the routine samples, each operating activity is required to submit special samples under the following conditions:

1. When samples are requested by the CFA or by the laboratory.

2. When the activity is so directed by the unit maintenance officer to check out suspected deficiencies.

3. When abnormal conditions exist, such as malfunction of the oil lubricated part, damage to the oil lubricating system, excessive engine oil loss, or zero oil pressure.

4. Before and after the replacement of major oil lubricating system parts.

5. During and at the completion of a test cell run. If the repaired or suspect unit is operated on oil previously used in the test cell system, a sample must be taken. This is done before and after the completion of the test cell run.

6. After the final test on an aircraft that is undergoing rework or scheduled depot-level maintenance or after installations of new/overhauled engines or engines repaired by AIMD.

7. Following all accidents, regardless of cause and resulting damage. These samples must be taken by any means possible to get a representative sample.

There are two basic methods of taking a fluid sample: (1) the dip tube technique, and (2) the drain technique.

DIP TUBE SAMPLING.— The following procedures should be followed when using the dip tube method for getting a fluid sample:

1. Remove the filler cap from the oil tank and open the sample bottle.

2. Use a sampling tube of the correct length. Hold the tube at one end and lower it into the tank through the filler neck until only the upper end protrudes. (See fig. 5-18, views A and B.)

3. Allow the lower end of the tube to fill with oil, then close the upper end with your thumb or finger. Withdraw the tube and drain the trapped oil into the sample bottle. (See fig. 5-18, views C and D.) Repeat this operation until the bottle

has been filled to about one-half inch from the top.

WARNING

Do not use mouth suction to fill the sampling tube. Many oils and fluids are highly toxic and may cause paralysis or death.

4. Replace the bottle cap and tighten it to prevent leakage of the sample. Replace the cap on the tank and discard the sampling tube.
5. Reduce the chance of misidentifying samples by marking all oil samples with equipment/system identification as soon as possible after sampling.

DRAIN SAMPLING.— When using the drain sampling method for getting a fluid sample, you should use the following procedures:

1. Open the sample bottle.
2. Open the drain outlet in the bottom of the tank, sump, case, or drain port, and allow enough oil to flow through. This washes out accumulated sediment. (See fig. 5-19, view A.)
3. Hold the sample bottle under the drain and fill to about one-half inch from the top. (See fig. 5-19, views B and C.) Close the drain outlet.
4. Replace the bottle cap and tighten it enough to prevent leakage.
5. Reduce the chance of misidentifying samples by marking all oil samples with equipment/system identification as soon as possible after sampling.

NOAP Forms and Logbook Entries

Activities are also responsible for completing appropriate forms and making entries in the equipment logbook.

Proper completion of the Oil Analysis Request (DD Form 2026) is vital (fig. 5-20). Maintenance actions or recommendations (table 5-4) are based on information provided by this form and the oil sample. Incomplete information (oil added since last sample, hours since overhaul, etc.) could result in an invalid oil analysis and recommendations. The operating activity must also provide special reports or feedback information requested by the oil analysis laboratory or the CFA.

Logbook entries are necessary when starting, stopping, or changing the monitoring laboratory for oil analysis. A specific notation is also made

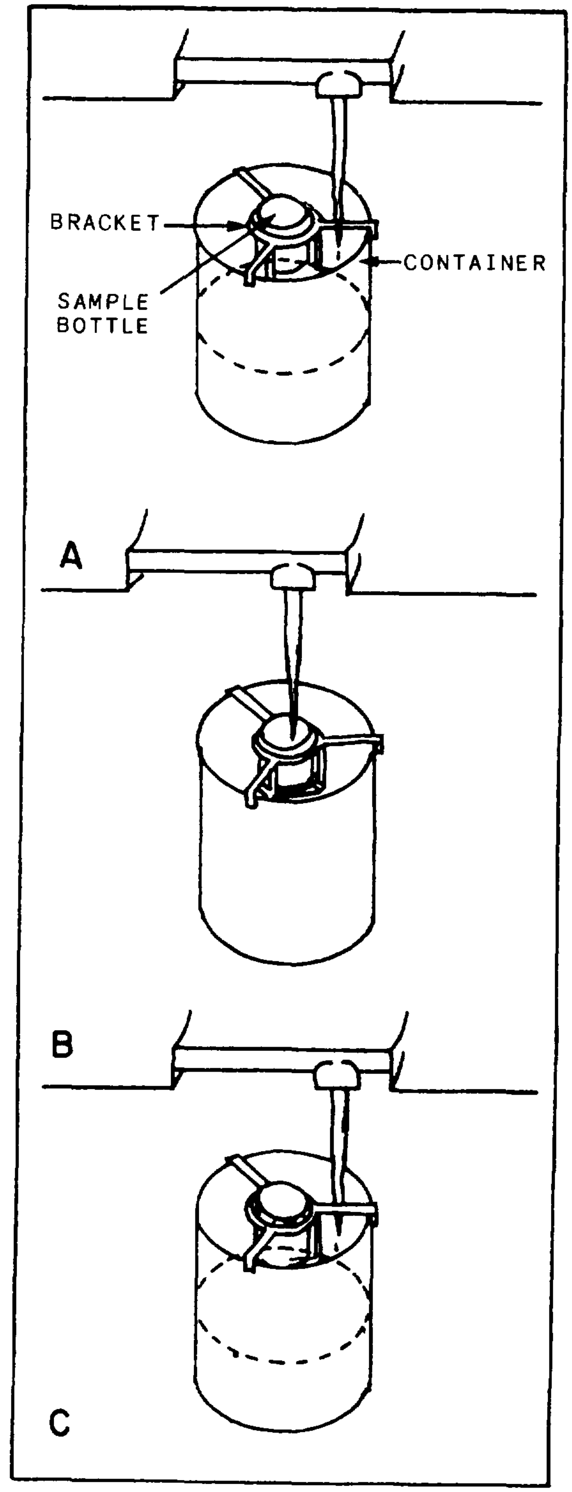
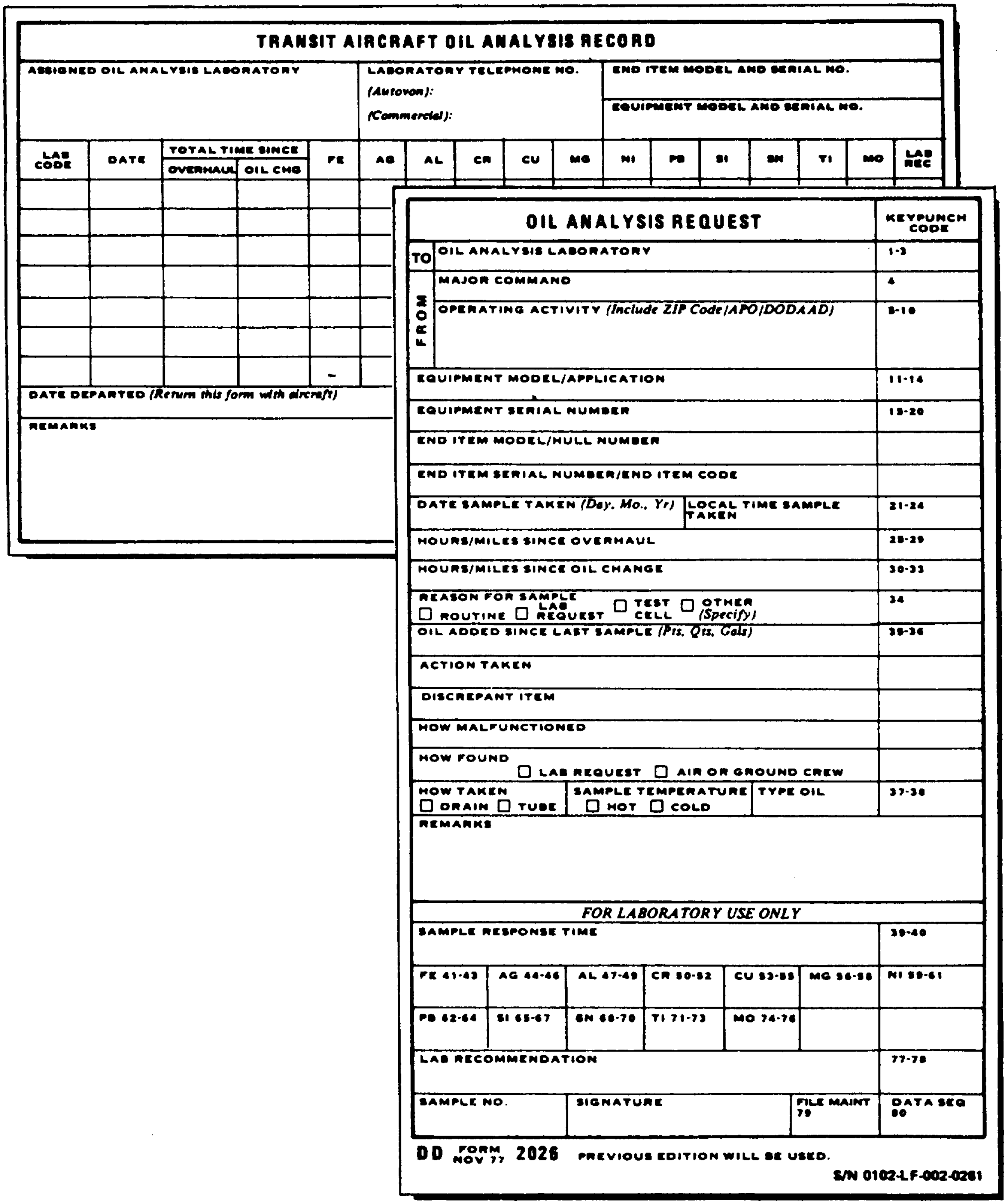


Figure 5-19.-Oil drain sample technique.



TRANSIT AIRCRAFT OIL ANALYSIS RECORD

ASSIGNED OIL ANALYSIS LABORATORY	LABORATORY TELEPHONE NO. (Autovon): (Commercial):	END ITEM MODEL AND SERIAL NO. / EQUIPMENT MODEL AND SERIAL NO.

LAB CODE	DATE	TOTAL TIME SINCE OVERHAUL	TOTAL TIME SINCE OIL CHG	FE	AG	AL	CR	CU	MG	NI	PB	SI	SN	TI	MO	LAB REC

DATE DEPARTED *(Return this form with aircraft)*

REMARKS

OIL ANALYSIS REQUEST

		KEYPUNCH CODE
TO	OIL ANALYSIS LABORATORY	1-3
FROM	MAJOR COMMAND	4
FROM	OPERATING ACTIVITY *(Include ZIP Code/APO/DODAAD)*	5-10
	EQUIPMENT MODEL/APPLICATION	11-14
	EQUIPMENT SERIAL NUMBER	15-20
	END ITEM MODEL/HULL NUMBER	
	END ITEM SERIAL NUMBER/END ITEM CODE	
	DATE SAMPLE TAKEN *(Day, Mo., Yr)* / LOCAL TIME SAMPLE TAKEN	21-24
	HOURS/MILES SINCE OVERHAUL	25-29
	HOURS/MILES SINCE OIL CHANGE	30-33
	REASON FOR SAMPLE ☐ ROUTINE ☐ LAB REQUEST ☐ TEST CELL ☐ OTHER *(Specify)*	34
	OIL ADDED SINCE LAST SAMPLE *(Pts, Qts, Gals)*	35-36
	ACTION TAKEN	
	DISCREPANT ITEM	
	HOW MALFUNCTIONED	
	HOW FOUND ☐ LAB REQUEST ☐ AIR OR GROUND CREW	
	HOW TAKEN ☐ DRAIN ☐ TUBE / SAMPLE TEMPERATURE ☐ HOT ☐ COLD / TYPE OIL	37-38
	REMARKS	

FOR LABORATORY USE ONLY

SAMPLE RESPONSE TIME						39-40
FE 41-43	AG 44-46	AL 47-49	CR 50-52	CU 53-55	MG 56-58	NI 59-61
PB 62-64	SI 65-67	SN 68-70	TI 71-73	MO 74-76		
LAB RECOMMENDATION						77-78
SAMPLE NO.	SIGNATURE				FILE MAINT 79	DATA SEQ 80

DD FORM NOV 77 2026 PREVIOUS EDITION WILL BE USED.

S/N 0102-LF-002-0261

Figure 5-20.-Oil Analysis Request (DD Form 2026).

Table 5-4.-NOAP Lab Recommendations

STANDARD LAB RECOMMENDATION CODES— AERONAUTICAL FOR SPECTROMETRIC ANALYSIS	
CODE	GENERAL LAB RECOMMENDATIONS
A	Sample results normal; continue routine sampling.
Z	Previous recommendation still applies.
	INSPECTION RECOMMENDATIONS (Requires Feedback)
H**	Inspect unit and advise lab of finding. Abnormal wear indicated by *** PPM (element).
R**	Do not fly or operate; inspect filters, screens, chip detector and sumps; advise laboratory of results.
T**	Do not fly or operate. Examine for discrepancy and advise laboratory of results and disposition. If discrepancy found and corrected, continue operation and submit resample after *** hours of operation. If discrepancy is not found, recommend remove component from service and send to maintenance.
	OIL CHANGE RECOMMENDATIONS (Requires Resample)
J	Contamination confirmed. Change oil, sample after *** minute run-up and after *** operating hours.
W	Contamination suspected. Change oil; run for *** additional hours, take samples hourly. (This code for Air Force ALC Depot use only.)
	LAB REQUESTED RESAMPLES (Requires Resample)
B*	Resample as soon as possible; do not change oil.
C*	Resample after *** hours; do not change oil.
E*	Do not change oil. Restrict operations to local flights or reduced load operation, maintain close surveillance and submit check samples after each flight or *** operating hours until further notice.
F*	Do not change oil. Submit resample after ground or test run. Do not operate until after receipt of laboratory result of advice.
G*	Contamination suspected; resample unit and submit sample from new oil servicing this unit.
P*	Do not fly or operate; do not change oil; submit resample as soon as possible.
NOTES:	*Resample (red cap) required **Maintenance feedback required; advise laboratory of findings ***Laboratory will specify time limit

of the NOAP analytical status when transferring equipment. For complete information concerning the NOAP, refer to NAVMATINST 4731.1 series. The *Joint Oil Analysis Program Laboratory Manual,* NAVAIR 17-15-50, provides instructions for oil sampling and filling out the sample request form (DD Form 2026). These instructions include procedures for submitting samples to the assigned supporting laboratory, evaluation criteria, and for getting special technical help.

CHAPTER 6

ENGINE AND AIRFRAME RELATED SYSTEMS

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Recognize the operating principles of hydraulic systems.
- Identify the sources and prevention of contamination.
- Recognize systems using fuel for hydraulic control.
- Recognize aircraft power plant electrical systems and their relationship to other aircraft systems.
- Recognize the different types of ignition systems.
- Identify the types and operation of jet engine starters, and recognize the procedures for safe operation of aircraft starting equipment.
- Recognize the purpose of the bleed-air systems.
- Recognize the use of the auxiliary power unit (APU).

ADs deal with a large variety of aircraft systems. You need a knowledge of hydraulics and electricity because of these different systems. You must be familiar with such systems as ignition, start, bleed-air, and auxiliary power unit systems. This chapter introduces you to basic hydraulics, electricity, and the related systems that the Aviation Machinist's Mate regularly maintains.

BASIC HYDRAULICS

Hydraulics is the science of liquid pressure and flow. In its application to aircraft, hydraulics is the action of liquids under pressure used to operate various mechanisms. All modern naval aircraft use hydraulic systems and hydraulic components.

The word *hydraulics* is from the Greek word for water. Hydraulics originally meant the study of physical behavior of water at rest and in motion. Today the meaning includes the physical behavior of all liquids. A liquid is any fluid whose particles have freedom of movement among themselves but remain separate. In aviation, hydraulics usually means the "red fluid" used to operate landing gear and flight control or propeller systems. Hydraulics apply to fuel and oils systems too, so a knowledgeable AD must be familiar with hydraulic principles.

Pascal's law states that "any force applied to a confined liquid transmits undiminished in all directions." This pressure acts at right angles to the walls of the container and exerts equal forces on equal areas. A 100-pound force will result from 5 pounds per square inch of pressure exerted against a 20-square-inch area. Figure 6-1 shows a simple hydraulic mechanism that demonstrates these principles in operation.

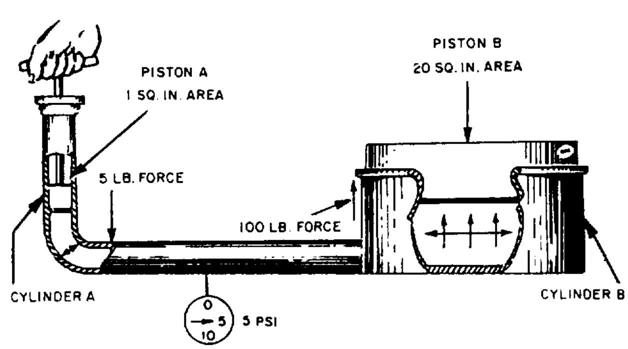


Figure 6-1.-Simple hydraulic mechanism.

A liquid has a definite volume but no definite shape. If you put a liquid into a container, it assumes the shape of that container. Since liquids are almost incompressible, they transmit pressure well. Although the application of large forces will cause a small decrease in the volume, this decrease is negligible. For more detailed information on the principles of hydraulics, study the training manual *Fluid Power,* NAVEDTRA 12964.

HYDRAULIC FLUIDS

Petroleum-based liquids are the most widely used fluids in hydraulic systems. Refined hydraulic fluid is clear in color. Red dyes are added to this fluid so that hydraulic system leaks are easier to find and identify. Special petroleum-based fluids are used for certain applications. For example, MIL-H-83282B is the hydraulic fluid approved for use in, and in the servicing of, Navy aircraft hydraulic systems. MIL-H-6083C is the approved hydraulic fluid for the preservation, packaging, and use in hydraulic test benches.

CONTAMINATION

Experience has shown that trouble in a hydraulic system occurs whenever the hydraulic fluid becomes contaminated. The nature of the trouble—whether a simple malfunction or the complete destruction of a component—depends to some extent on the type of contaminant.

Two general classes of contaminants are abrasives and nonabrasives. Abrasives include core sand, weld splatter, machining chips, and rust. Nonabrasives are contaminants resulting from oil oxidation and the soft particles that are worn or shredded from seals and other organic components. Oil-oxidation products, usually called sludge, have no abrasive properties. Nevertheless, sludge may prevent proper operation of a hydraulic system by clogging the valves, orifices, and filters.

The mechanics of the destructive action by abrasive contaminants is clear. When the size of the particles circulating in the hydraulic system is greater than the clearance between moving parts, the clearance openings act as filters. Hydraulic pressure pushes these particles into the softer materials. This results in blocked passages or scratches on finely finished surfaces from movement between parts. These scratches result in internal component leakage and decreased efficiency.

Abrasive particles contained in the system are not flushed out. New particles are continually created as friction sludge acts as an effective catalyst to speed up oxidation of the fresh fluid. A catalyst is a substance that, when added to another substance, speeds up or slows down chemical reaction. The catalyst itself is not changed or consumed at the end of the reaction.

Origin of Contaminants

The contaminants in hydraulic systems can be traced to four major sources.

1. Particles originally contained in the system. These particles originate during fabrication of welded-system components, especially reservoirs and pipe assemblies. Proper design and cleaning reduce the presence of these particles. For example, parts designed using seam-welded, overlapping joints reduce contamination. Parts designed using arc welding of open sections increase contamination. Parts designed with hidden passages, beyond the reach of sand-blasting, are the main source of core sand contamination.
2. Particles introduced from outside forces. Particles enter hydraulic systems at points where the liquid or working parts of the system are in temporary contact with the atmosphere. Struts and piston rods are constantly exposed to the atmosphere. The most common danger areas are at the refill and breather openings and at cylinder rod packings. Contamination results from carelessness during servicing and cleaning. Particles of lint from cleaning rags can cause abrasive damage in hydraulic systems, especially to closely fitted moving parts. Rust or corrosion present in a hydraulic system usually can be traced to improper storage of materials or parts. Proper preservation of stored parts helps to reduce corrosion.
3. Particles created within the system during operation. Contaminants created during system operation are of two general types—mechanical and chemical. Mechanical particles are formed by the wearing of parts in frictional contact, such as pumps, cylinders, and packing gland parts. These worn particles can vary from large chunks of packings to steel shavings of microscopic size, which system screens cannot filter.

The chief source of chemical contaminants in hydraulic fluids is oxidation. Chemical contamination forms as a result of the high pressure and temperatures acting with the catalytic action of water, air, and copper or iron oxides. Oil-oxidation products appear first as organic acids, asphaltenes, gums, and varnishes. These products combine with dust particles and appear as sludge. Oxidation products that dissolve in liquid increase a liquid's resistance to flow. Products that do not dissolve in liquid form sediments and precipitates, especially on colder elements such as heat exchanger coils. A precipitate is a solid substance that was chemically separated from a solution.

Liquids containing antioxidants have little tendency to form gums under normal operating conditions. However, as the temperature increases, resistance to oxidation diminishes. Hydraulic fluids that are subjected to high temperatures (above 250°F) will break down, leaving particles of asphaltene suspended in the liquid. The red fluid changes to brown, and is referred to as decomposed liquid. This explains the importance of keeping the hydraulic fluid temperature below specified levels.

The second chemical reaction that can produce impurities in hydraulic systems allows liquids to react with certain types of rubber. This reaction causes the structure of the rubber to change, turning it brittle, and causing the rubber to fall apart. Make sure that system fluids are compatible with the seals and hoses, and that those parts are appropriate for the system.

4. Particles introduced by foreign liquids. Water is the most common foreign fluid contaminant, especially in petroleum-based hydraulic fluid. Water enters through condensation of atmospheric moisture and normally settles at the bottom of the reservoir. Fluid movement in the reservoir disperses the water into fine droplets. These water droplets form an oil-water-air emulsion because of the mixing action created in the pumps and passages. This emulsion normally separates during the rest period in the system reservoir.

Contamination Control

Filters provide adequate control of the contamination problem during all normal hydraulic system operations. Contamination control from outside sources are the responsibility of maintenance personnel. Therefore, take all precautions to be sure contamination is held to a minimum during service and maintenance. Do not reuse fluid drained from hydraulic systems or equipment. Do not use hydraulic fluid stored in open containers. Hydraulic fluid absorbs dust and grit from the air, resulting in contamination problems. Keep hydraulic parts and servicing equipment clean. Should the system become contaminated, minimize damage by taking prompt maintenance action.

HYDRAULIC SYSTEM MAINTENANCE

Hydraulic system maintenance consists of inspecting for leaks, contamination, and replacing parts. External leaks, where fluid is escaping from a cylinder, valve, or fitting, are usually easy to find.

WARNING

A pinhole leak in a 3,000-psi hydraulic system can force fluid through your skin. Do not use your hand to feel for a leak.

Inspect the area around the leak, A leak may not be directly above the accumulation of fluid. Fluids often follow the structure or tubing to a lower point before dropping off. When you notice leaks, trace them to the source, and then repair or replace the bad unit or part.

Internal leaks are caused by fluid under pressure slipping past an unseated valve or worn packing ring. Normally, fluids flow into the return line back to the reservoir. The signs of internal leakage are sluggish operation of an actuating system or a drop-off in system pressure. A drop in gauge pressure or an indication of insufficient pressure on the gauge may be caused by an internal leak. When internal leakage is suspected or known to be in the hydraulic system, the symptoms should be noted to aid in locating the leak. Follow the aircraft technical instruction for specific troubleshooting and maintenance procedures. For more information on hydraulic maintenance procedures, consult the Aviation *Hydraulics Manual,* NAVAIR 01-1A-17.

FUEL AS A HYDRAULIC FLUID

Fuel, and the means to regulate fuel pressure, is readily available within the aircraft. It is an ideal fluid to use for hydraulic control of systems. Especially those systems controlling certain engine functions, such as compressor guide vane variable geometry actuation, and operation of the afterburner variable nozzles.

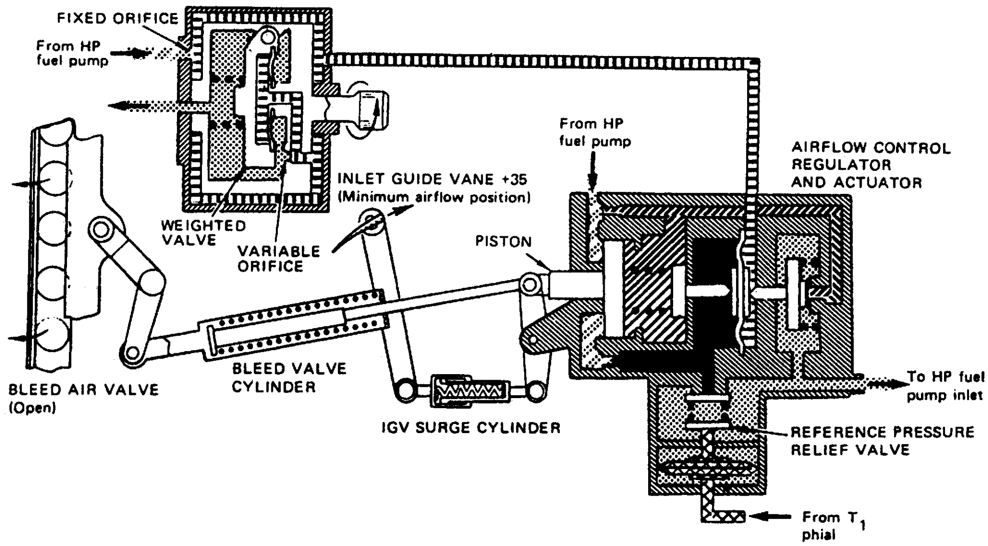


Figure 6-2.—Bleed-air and vane control system.

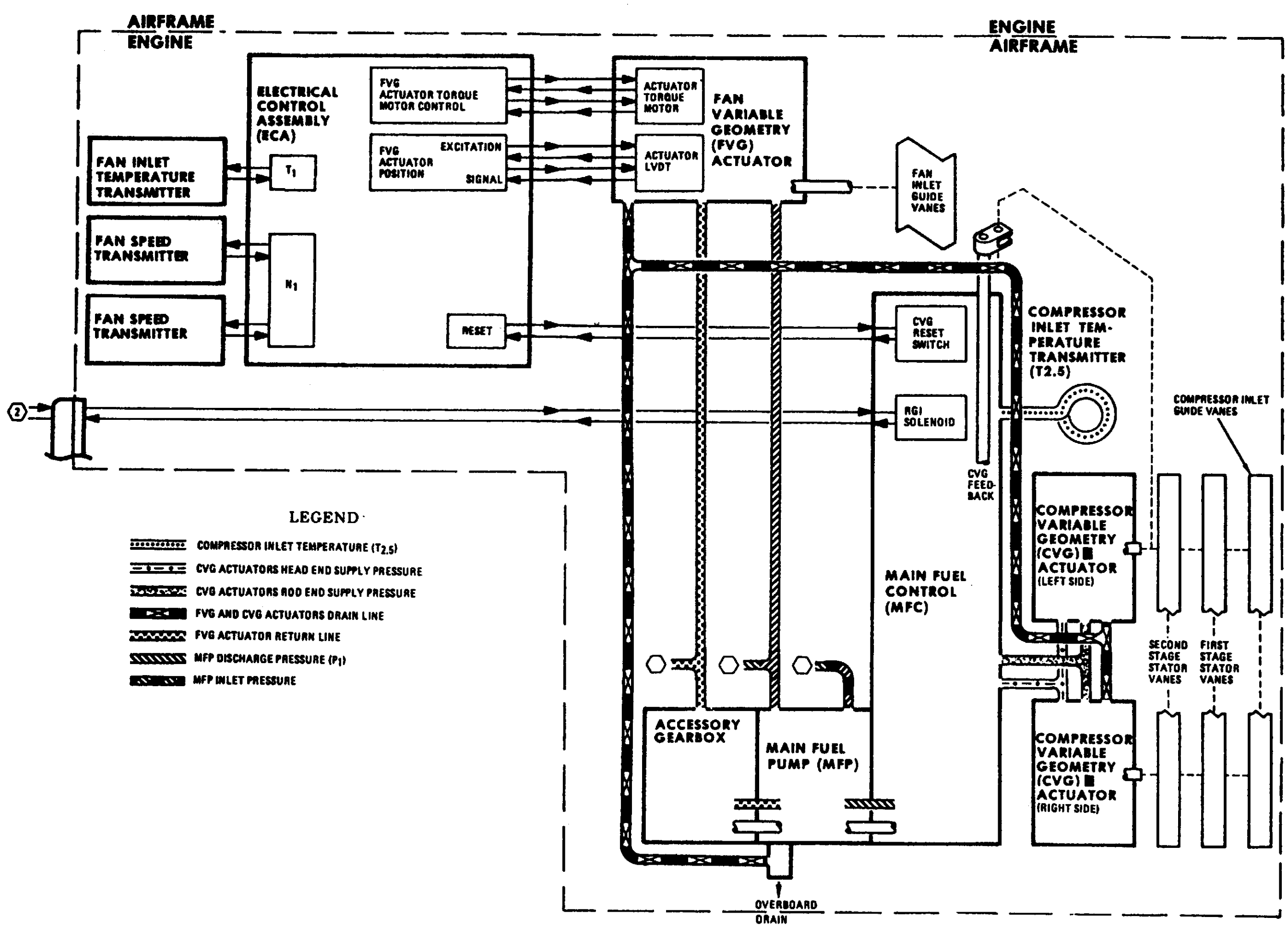


Figure 6-3.—Fan and compressor variable geometry systems.

Combination Inlet Guide Vane and Bleed Valve System

The TF41 engine is a good example of a system that uses fuel as a hydraulic fluid. Fuel pressure hydraulically operates the inlet guide vanes (IGVs) and the bleed valve ring. The vane control and the bleed-air system prevent compressor surges during low rpm range operation. The system uses engine fuel pressure as control and hydraulic force to vary the angle of the high-pressure compressor variable IGVs. Fuel pressure is used to operate the high-pressure compressor bleed air valve. See figure 6-2. This action decreases the airflow through the rear stages of the compressor. Compressor surge and choking caused by increased air velocity is prevented.

Variable Inlet Guide Vanes and Stators

The F404-GE-400, installed in the F/A-18 aircraft, uses two different systems to operate the variable IGVs and variable stators. These systems are the fan variable geometry (FVG) system and the compressor variable geometry (CVG) system. Compressor IGV and stator angle are changed by setting the CVG pilot valve to direct fuel pressure to two CVG actuators. A torque motor in the single FVG actuator sets the CVG pilot valve. See figure 6-3.

Variable-Area Exhaust Nozzles

The convergent-divergent geometry of the variable-area exhaust nozzle provides the optimum exhaust throat area. The action of the variable-area nozzle is achieved by close tolerance overlapping seals, which bridge adjacent leaf segments to provide a relatively smooth surface contour. The TF30-P-414/414A installed in the F-14 aircraft uses the hydraulic action of fuel to position the nozzles. See figure 6-4.

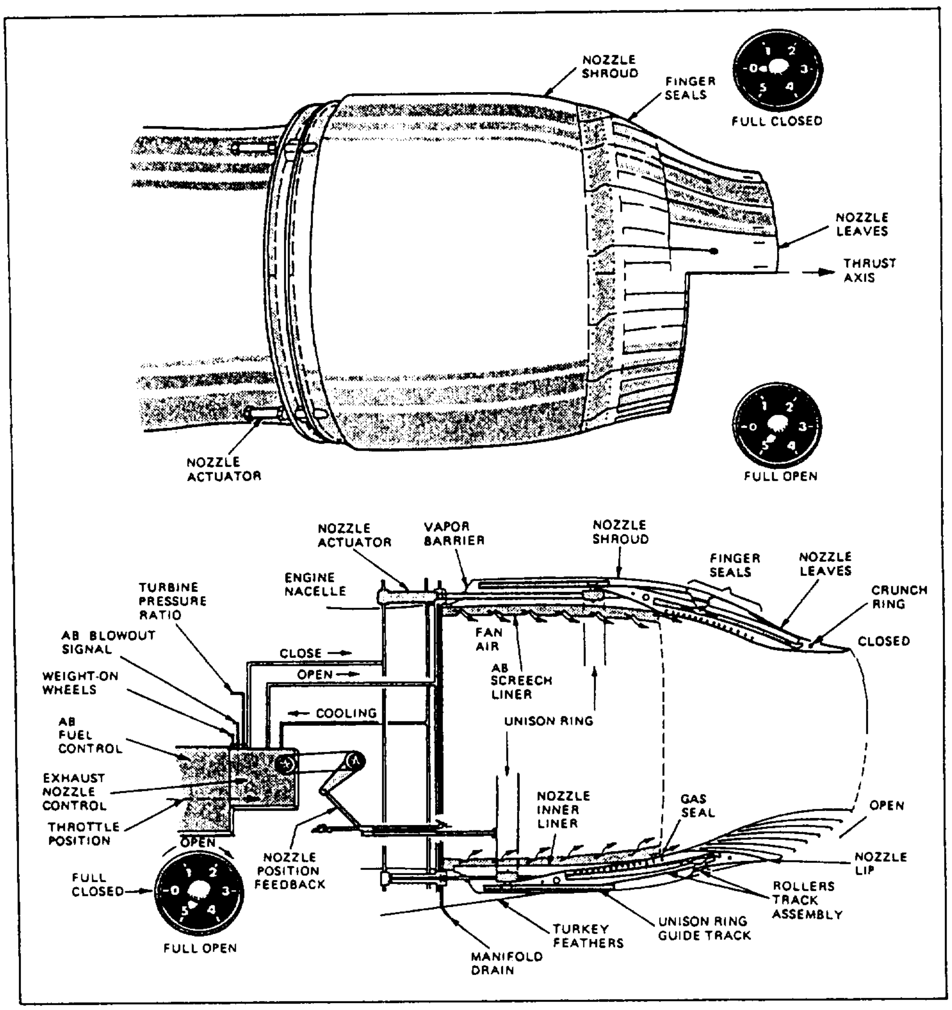


Figure 6-4.-Variable area exhaust nozzle actuation.

BASIC ELECTRICITY

You should be familiar with the aircraft electrical system in general. You must become familiar with the different engine electrical systems and components that support your type of engine. Some of the electrical systems that ADs maintain include ignition, starting, thermocouple, temperature control, and constant-speed drive (CSD) systems. To understand the operation of these systems, you must understand basic electricity. The following paragraphs cover some of the basic facts and laws that will be helpful in understanding electrical principles.

Electricity is a form of energy. Energy is the ability of a body to do work. It does not occupy space, but it can be measured. There are two forms of electricity-–static and dynamic. Static electricity is electricity at rest. It is produced by friction, which causes one body to give up electrons to another. The body that lost the electrons will have a positive charge. The body that gained the electrons will have a negative charge. As a result, the positively charged body will try to gain electrons. The negatively charged body will try to cast off its surplus electrons to an oppositely charged body or a neutrally charged body. Lightning is an example of static electricity during the discharge of electrons. Dynamic electricity is electricity y in motion. This is the most useful form of electricity, and it is produced, controlled, and measured with relative ease. It is called electricity in motion because it will flow along a definite path, called a circuit. Static electricity will remain in the body containing it until discharged.

There are three methods of producing electricity. These methods are heat, chemical, and mechanical means. When two dissimilar metals in contact with each other are heated, an electron flow takes place between them. Thermocouples are a good example of this flow. The storage battery is a good example of converting chemical energy into electrical energy. The mechanical means of producing electricity will be of the most interest to you. The generator and magneto are two methods used to mechanically produce electricity.

There are three types of current that these mechanical devices produce. They are direct, pulsating direct, and alternating current. Direct current is current that always flows in the same direction. Pulsating direct current is direct current that is interrupted by a set of breaker points. The current will flow in one direction when the circuit closes. When the circuit is open, the current cannot flow and its value, or voltage, drops to zero until the circuit closes again.

Alternating current is current that changes direction in the circuit, flowing first in one direction and then in the other. A cycle is two complete alternations within a period of time. The hertz (Hz) indicates one cycle per second. For example, one cycle per second is 1 hertz. The standard unit of electricity used in the United States is 60 Hz ac.

The electromotive force is the force that causes electrons to flow from atom to atom in a conductor. Electrons flow from atoms with an excess of electrons to atoms with less electrons.

The practical electrical units are the volt, the ampere, and the ohm. The volt is the unit of electromotive force necessary to cause electrons to flow in a circuit. The ampere is the rate of flow of these electrons in a conductor. The ohm is called the unit of electrical resistance. This resistance varies according to the kind of material used as a conductor, the length of the conductor, and the cross-sectional area of the conductor. Resistance also varies with temperature. Other factors being equal, the resistance increases if the length of the conductor is increased, and decreases if the cross-sectional area of the conductor is increased. Resistance increases as the temperature increases.

IGNITION, STARTING, BLEED AIR, AND AUXILIARY POWER UNIT SYSTEMS

As an Aviation Machinist's Mate, your primary responsibility is to maintain power plants and related systems. You should know that engine systems support the entire aircraft. Engine systems support more than just the engine. This means that the maintenance of these systems are the responsibility of more then one work center. Electrical or pneumatic systems that other work centers help maintain include ignition, starting, bleed-air, and auxiliary power units (APU).

AIRCRAFT IGNITION SYSTEMS

Jet engine ignition systems are simple compared to automobile ignition system. They are simple because jet engine ignition systems require no ignition timing. Since jet engine combustion is a self-sustaining process, a spark is needed only during the start cycle. After combustion starts, the ignition system may be turned off. However, some aircraft use continuously operating ignition systems to ensure an immediate relight in case of flame-out. Pressure switches or mechanical linkages that automatically reactivate the ignition system are also used in some aircraft for the same reason.

The ignition systems on all jet engines are basically the same, but terminology varies between engine manufacturers. The part that goes in the combustion chamber to supply spark is called a spark plug, an igniter plug, or a spark igniter. They may look a little different and maybe called by different names, but they all do basically the same job. Modern jet engines require an ignition system with a high voltage and high heat spark.

The high-energy, capacitor-discharge ignition system is the most widely used ignition system. It provides a high-tension spark capable of blasting carbon deposits and vaporizing large amounts of fuel. This high-energy system makes starts with carbon-fouled igniter plugs possible, and it also helps in air restarts at high altitude. High-energy, capacitor-discharge systems are classified as ac or dc systems, and they use either a high- or low-voltage capacitor.

High-Energy, Capacitor-Discharge Dc Ignition System

The ignition exciter gets its input from the low-voltage dc supply of the aircraft electrical system. See figure 6-5. The ignition system has three major components. The system consists of one ignition exciter and two lead assemblies. The exciter unit is hermetically sealed to protect internal components from moisture, foreign matter, pressure changes, and adverse operating conditions. This type of construction eliminates the possibility of flashover at high altitude due to pressure change and ensures positive radio noise shielding. The complete system, including leads and connectors, is built to ensure adequate shielding against leakage of high-frequency voltage. High-frequency leakage would interfere with radio reception of the aircraft. The system's primary purpose is to supply energy to two spark igniters.

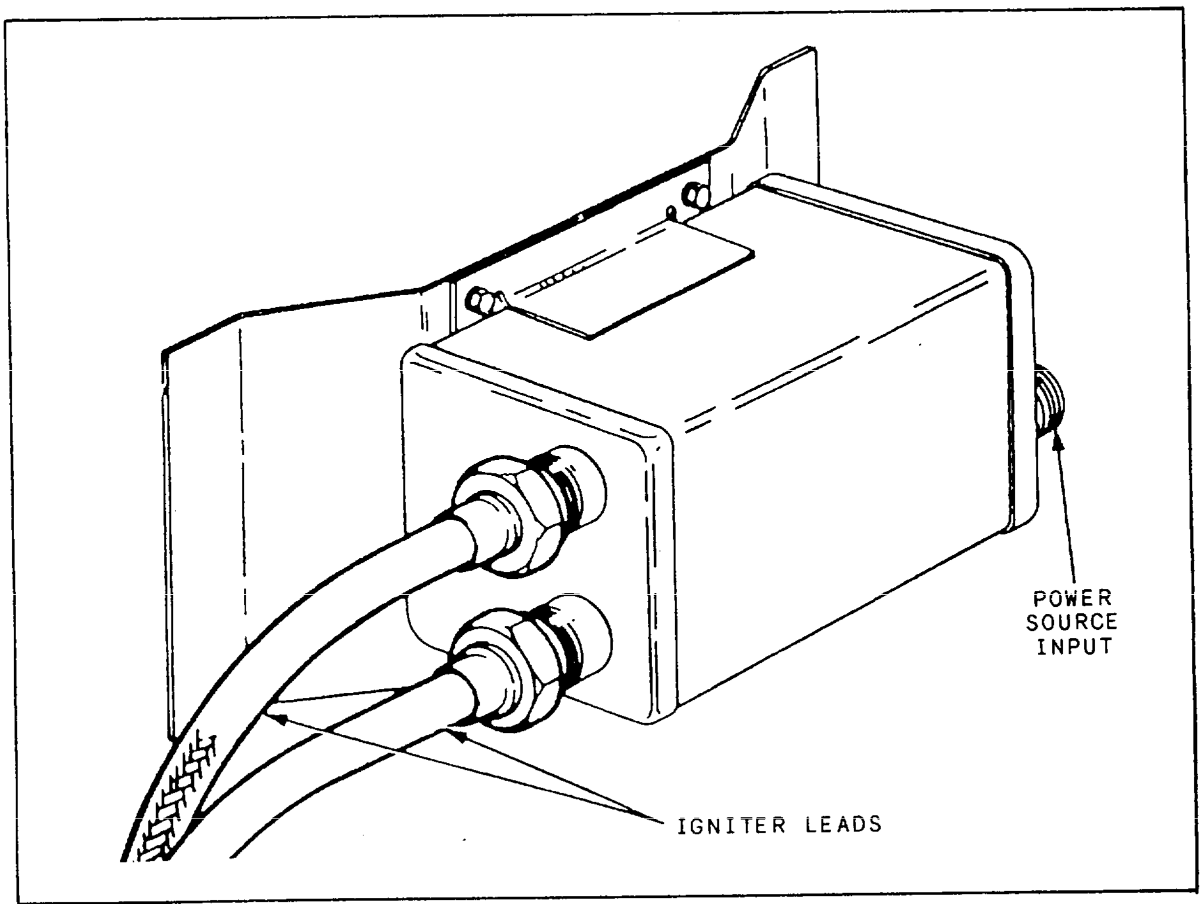


Figure 6-5.-Typical sealed ignition exciter box.

Figure 6-6 is a functional schematic of the system. You should refer to this figure when studying the theory of operation of a capacitor-discharge system. This schematic shows a cam-operated breaker point. Most modern systems have had all mechanical parts replaced with electronic solid-state devices. System operation is discussed in the following paragraphs.

A 24-volt dc input voltage is sent to the input receptacle of the exciter. The voltage first goes through a noise filter. This filter blocks conducted noise voltage from feeding back into the aircraft electrical system. This input voltage operates a dc motor, which drives one 16-lobe and one 1-lobe cam. The input voltage is also sent to two breakers actuated by the 16-lobe cam.

From the breakers, a rapidly interrupted current is sent to the autotransformer. When the breaker closes, the flow of current through the primary winding of the transformer generates a magnetic field. When the breaker opens, the flow of current stops. The collapse of the field induces a voltage in the secondary windings. This voltage causes a pulse of current to flow into the storage capacitor through a rectifier. This rectifier limits the flow to a single direction. With repeated pulses, the storage capacitor thus assumes a charge, up to a maximum of approximately 4 joules. One joule per second equals 1 watt of power.

The storage capacitor connects to the spark igniter through the triggering transformer and through a normally open contactor. When the charge on the capacitor has built up, the contactor closes by the mechanical action of the single-lobe cam. A portion of the charge flows through the primary of the triggering transformer and the capacitor connected in series with it.

This current induces a high voltage in the secondary, which ionizes the gap at the spark igniter. Thus, when the spark igniter conducts, the storage capacitor discharges the remainder of its accumulated energy through it. Energy also comes from the charge from the capacitor that

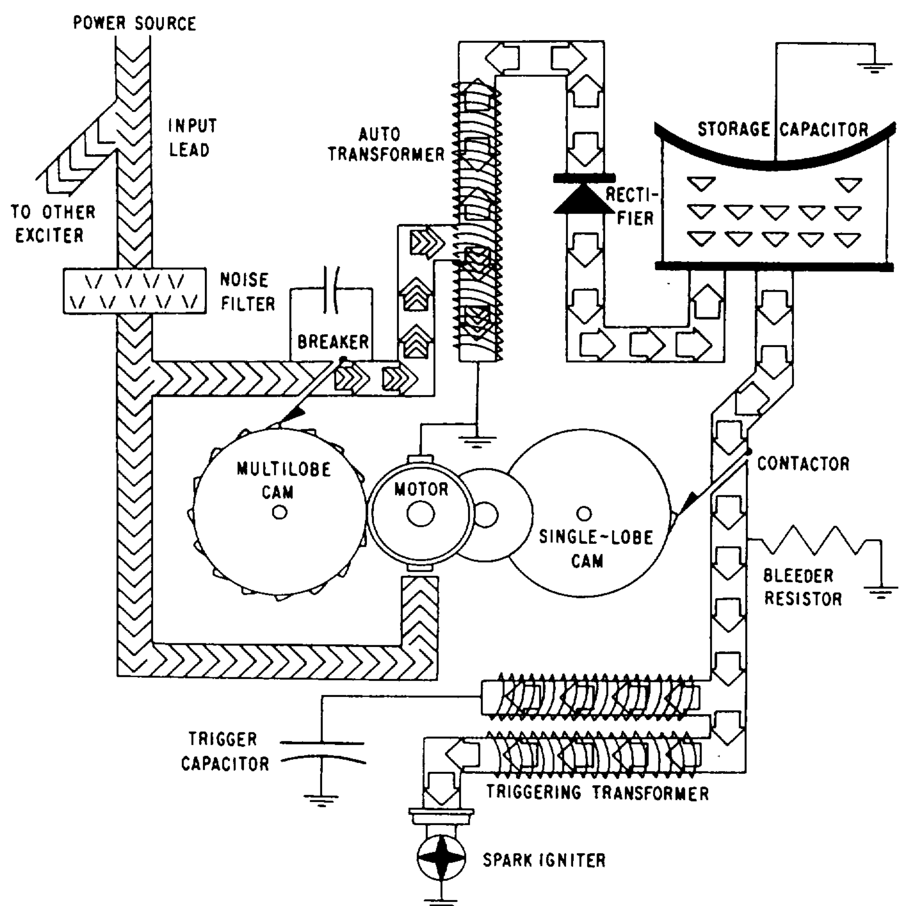


Figure 6-6.-Functional schematic diagram of a capacitor discharge ignition system.

is in series with the primary of the triggering transformer.

The spark rate at the spark igniter varies in proportion to the voltage of the dc power supply. This varying voltage affects the rpm of the motor. Since both cams are geared to the same shaft, the storage capacitor always accumulates its store of energy from the same number of pulses before discharge.

The use of the high-frequency triggering transformer, with a low-reactance secondary winding, holds the discharge time duration to a minimum. This concentration of maximum energy in minimum time achieves an ideal spark for ignition. This spark is capable of blasting carbon deposits and vaporizing globules of fuel.

The capacitor, constructed integrally with the exciter unit, is sealed separately in its own case. All high voltage in the triggering circuits is isolated from the primary circuits. The complete exciter is sealed against the escape or entry of air. This type of construction protects all parts from adverse operating conditions and eliminates flashover at altitude. This design also shields against leakage of high-frequency voltage that could interfere with radio reception in the aircraft.

High-Energy, Capacitor-Discharge Ac Ignition System

The ignition system is an automatic, intermittent duty, at-powered, electronic capacitor discharge system. See figure 6-7. It is used for

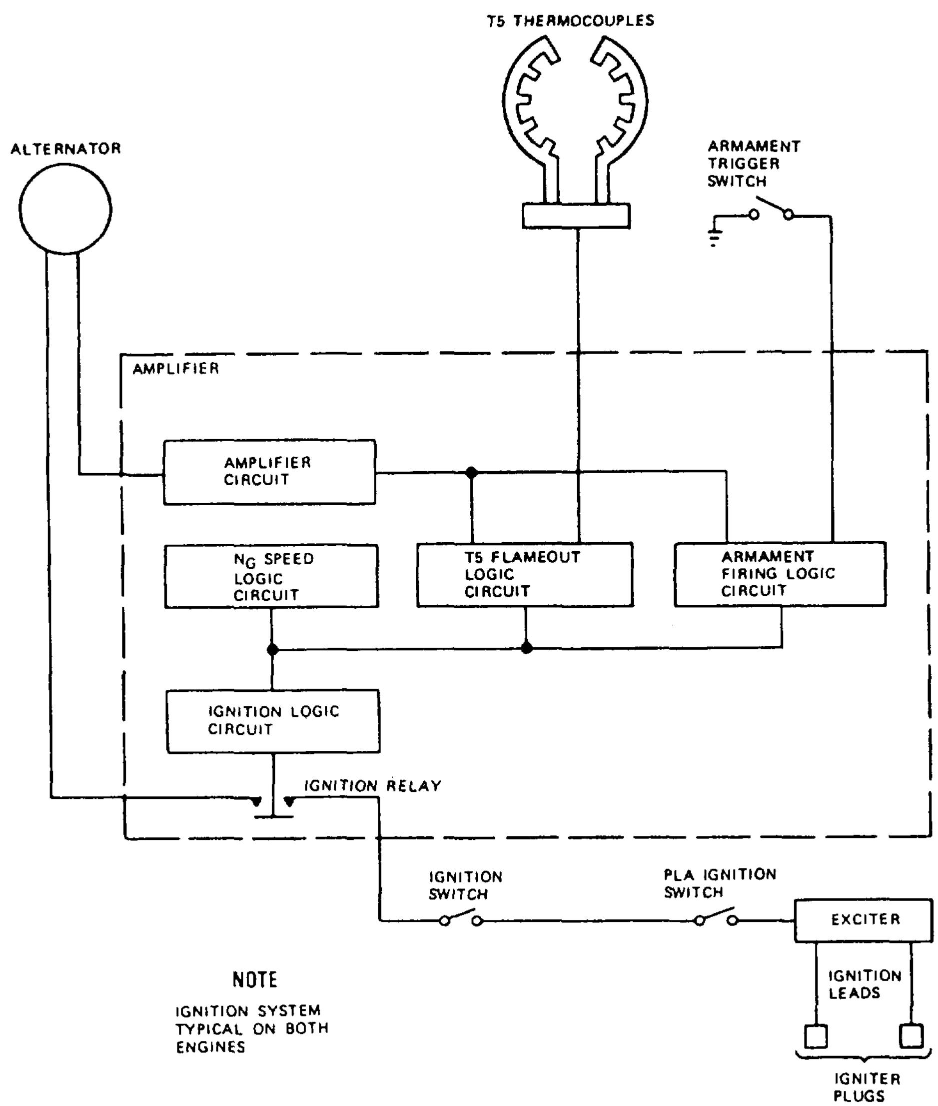


Figure 6-7.-Jet engine electronic ignition system.

initiating engine combustion during aircraft armament firing, during starting, and for automatic reignition in case of engine flameout. The ac ignition system consists of an ignition exciter, a control amplifier, leads and ignition plugs, and an alternator stator.

ENGINE IGNITION EXCITER.— The exciter is a dual-circuit and dual-output unit that supplies a high-voltage, high-energy electrical current for ignition. The exciter consists of a radio frequency interference filter. The exciter also contains power, rectifier, storage, and output elements. The exciter is on the forward part of the compressor section of the engine.

ENGINE CONTROL AMPLIFIER.— The amplifier is the electronic control center of the engine. It controls the function of the ignition system as well as other engine functions. The amplifier is on the compressor section aft of the engine front frame.

ENGINE IGNITION LEADS AND IGNITER PLUGS.— The ignition leads are high-tension cables that "transmit electrical current from the exciter to the igniter plugs. The igniter plugs are located in the combustion chamber housing.

ENGINE ALTERNATOR STATOR.— The alternator is an engine-driven, single-phase, ac electrical-output unit on the engine accessory gearbox. It supplies the engine with electrical power independent of the aircraft electrical system. It contains three sets of windings. Two windings supply electrical power to the ignition exciter, and the third winding supplies electrical power to the control amplifier.

Ignition Operation

The operation of an ignition system is explained in the following paragraphs. Refer to figure 6-7.

Starting procedures call for the ignition switch ON, the engine cranking for starting, and the throttle advanced to the 10-degree power lever angle (PLA) position. At that time, current flows from the alternator stator to power the control amplifier. Simultaneously, the PLA ignition switch in the fuel control closes. The gas generator speed (Ng) logic circuit will close the ignition relay to provide ignition whenever the Ng is within the 10 to 48 percent Ng range. With the relay closed, a circuit is completed from the alternator stator ignition windings, through the ignition exciter, to the igniter plugs. Current flows from the alternator, through the control amplifier, to the ignition exciter. At the ignition exciter, current increases and discharges as a high-voltage output, which is conducted through the igniter cables to the igniters. Current crossing the gaps in the igniters produces a continuous high-intensity spark to ignite the fuel mixture in the combustion chamber. When engine speed reaches 8,500 rpm Ng and interturbine temperature (ITT) reaches operating range, a T5 signal is generated. This signal goes from the T5 temperature detectors through the T5 circuit, and to the control amplifier ignition logic circuit. The control amplifier ignition relay opens and ignition stops. Combustion then continues as a self-sustaining process.

Ignition is automatically reactivated when either a flameout occurs or when aircraft armament is fired. When T5 temperature drops in excess of 800°F (427°C) from T5 selected by PLA, a signal transmitted from the T5 detectors causes the control amplifier T5 flameout logic to close the amplifier ignition relay. This activates ignition system operation. Ignition continues until engine operating temperature is again attained and the 800 "F temperature error signal is canceled. This action causes the control amplifier to end ignition operation.

An armament-firing protection circuit prevents flameout from armament gas ingested by the engine. When the aircraft armament is fired, the armament-firing logic circuit is activated by a signal from the armament trigger switch. The amplifier logic then causes ignition operation to be activated. Ignition operation ends after a 1-second time delay in the amplifier logic following release of the armament firing trigger.

Ignition System Maintenance

The only maintenance performed at the organizational level is cleaning and replacement of ignition parts. Ignition parts are sealed units and must be replaced as complete assemblies.

Degrease spark igniters and clean the outer shell with a wire brush. If deposits exist on the ceramic tip and on the center and ground electrodes, remove them by light abrasive blasting. However, this abrasive blast should not be used on the ceramic barrel surface. Clean the ceramic barrel of the igniter with a soft swab and a suitable solvent. Dry the igniter with compressed air. Visually inspect the barrel and shell threads. If necessary, clean the barrel and shell threads with a die. Visually inspect the exposed ceramic section. Any cracks are cause for rejection.

The functional testing of the capacitor discharge ignition system is a simple operation.

WARNING

You should exercise caution while performing this test. Do not come into contact with the igniter plugs or leads while the power is on in the ignition system. Some systems have voltages up to 28,000 volts or more. These high voltages could cause serious injury or death. Prevent fuel or fuel fumes from gathering under the engine while the igniter plugs are being ground tested.

Perform a dry run of the engine (operate the ignition system). Listen at the tailpipe. You can determine if the unit is working by listening for the spark. Another way is to remove the spark igniters, leave them hanging on the high-tension leads, and operate the ignition system. The spark can be seen at the plug if the unit is working. The spark should be brilliant and accompanied by a sharp report.

STARTING SYSTEMS

Starting a jet engine requires rotating the compressor fast enough to begin the engine combustion cycle. Starting systems must be capable of providing both high starting torque and high speed. High starting torque is required to overcome the large amount of weight of the engine rotor. High speed is required to increase rotor rpm until the rotor is self-sustaining. There are several ways to accomplish these objectives. The following paragraphs describe four methods. They are the air turbine starter, the direct turbine impingement starter, the electrical starter, or the hydraulic starter.

Air Turbine Starter

The air turbine starter is a lightweight unit for starting engines with compressed air. The starter is a turbine air motor equipped with a radial inward-flow turbine wheel assembly, reduction gearing, splined output shaft, and a quick-detaching coupling assembly. See figure 6-8.

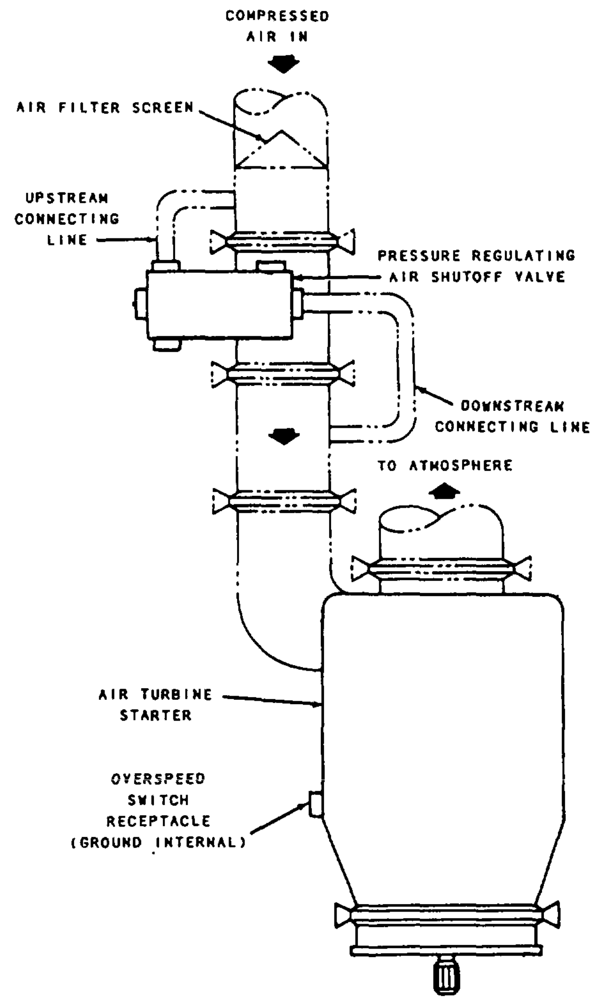


Figure 6-8.-Air turbine starting system.

Compressed air, supplied to the scroll inlet, is sent to the turbine wheel by the nozzle in the scroll assembly. The reduction gear system transforms the high speed and low torque of the turbine wheel to low speed and high torque at the output shaft. An overspeed switch mechanism is used to limit maximum rotational speed. When the desired starter rotational speed is reached, the fly weights in the governor assembly will open the limit switch. This section sends a signal that shuts off the supply of air. At a higher, predetermined rotational speed, the overrunning clutch assembly disengages the output shaft from the rotating assembly.

Turbine Impingement Starter

Some naval aircraft are started by means of low-pressure air directed onto the turbine or compressor blades. This little used method is called impingement starting. The number of air outlets and the air pressure required for impingement starts vary with the size, weight, and design parameters of the engine to be started. Refer to figures 6-9 and 6-10.

Starting air is supplied by an external starting unit, and is controlled by an air shutoff valve in the external air supply unit. The shutoff valve is electrically controlled by the applicable engine starter switch through the start relay. The starting air is delivered through a flexible hose to the starting manifold connection. The air is then ducted through the impingement manifold and directed onto the second-stage turbine blades.

A check valve in the starting manifold prevents loss of gases after the engine is started. The external starting unit electrical connector must be plugged into the receptacle corresponding to the engine being started. In addition to the air supply, external electrical power must be applied to the aircraft before the engines can be started. The function of the turbine impingement starting system is to start and sustain engine rotation at a speed at which the fuel-air mixture is satisfactory for light-off. The system must also assist the engine to increase rpm until it is self-sustaining.

Electrical Starters

Electrical starters are 28-volt dc series wound motors, designed to provide high starting torque. Their use is limited to small engines because of the high current drain on the electrical source and their heavy weight. Electrical starters develop a lot of heat while cranking. Starter damage from heat is prevented by observing maximum cranking time and time intervals between start attempts.

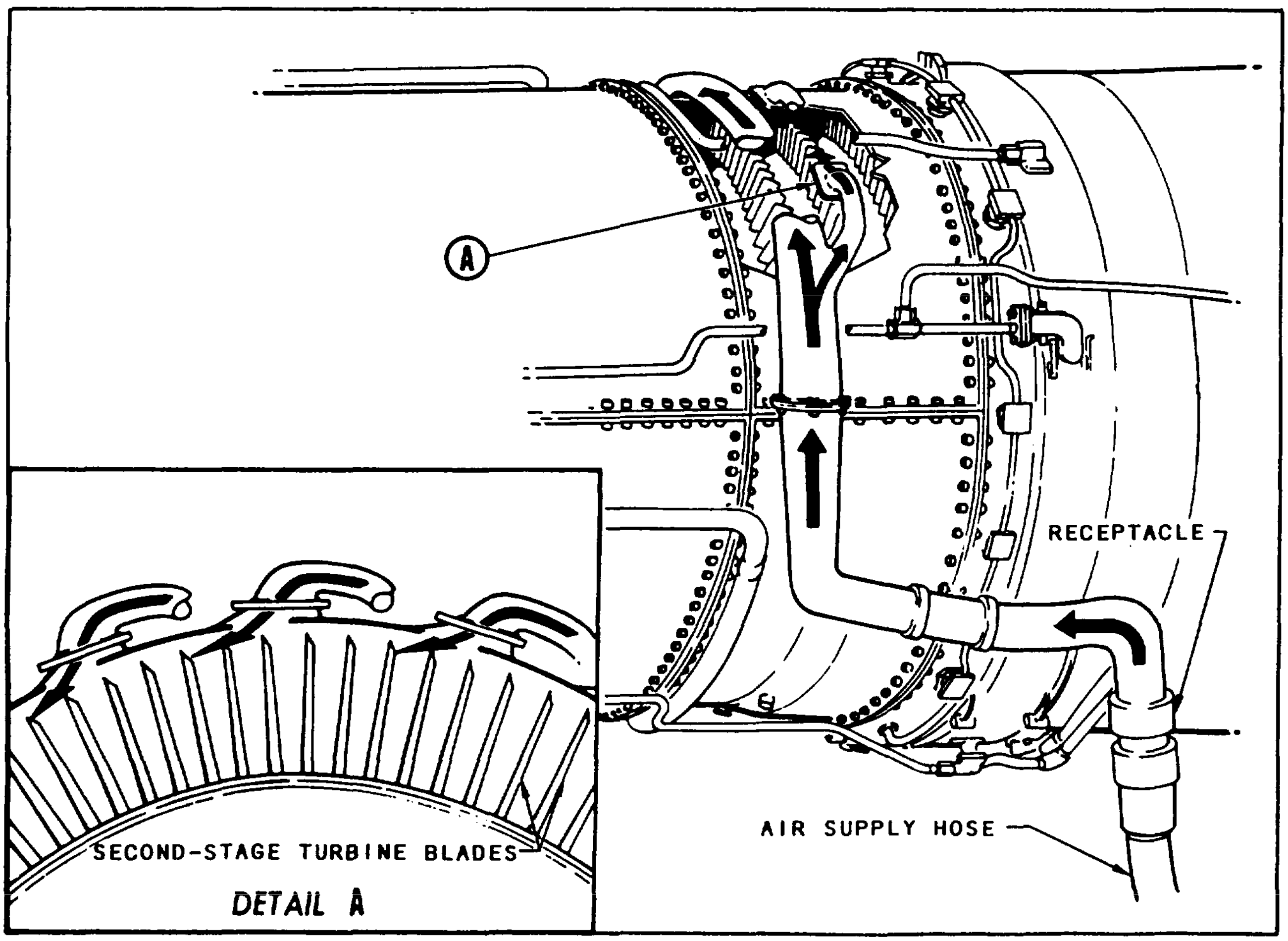


Figure 6-9.-Turbine impingement starting.

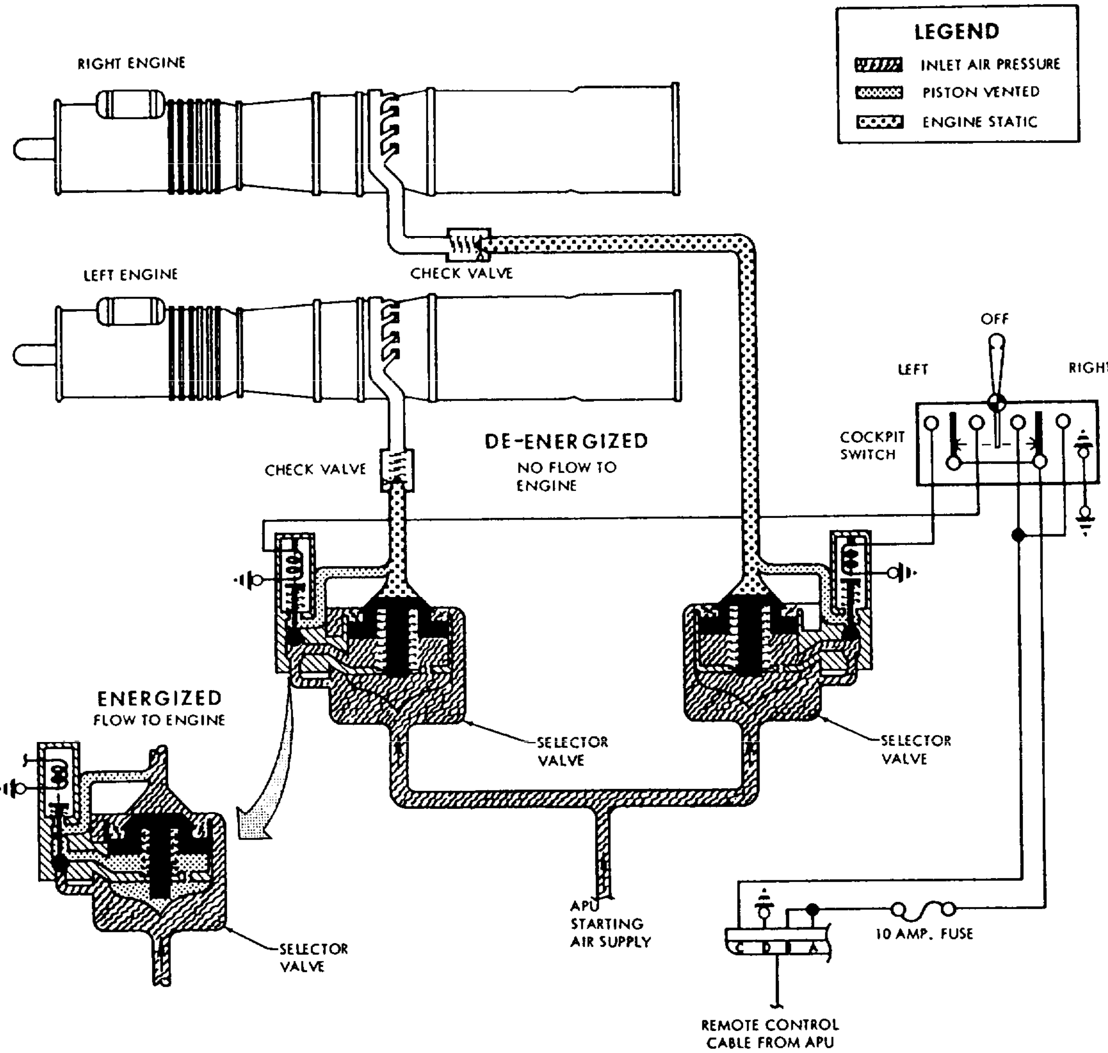


Figure 6-10.-Turbine impingement starting system flow schematic.

Hydraulic Starters

Hydraulic starters, like electrical starters, are energy-limited starting systems. Energy-limited starting systems are designed to start the engine in a short time period, and are limited to small engines. They make ideal starters for auxiliary power units (APUs).

Components include a high-pressure accumulator and a variable displacement motor. The variable displacement motor permits high torque to be applied without exceeding cut-off speed limits. A small electric motor or hand pump charges the accumulator. The accumulator then supplies power to the starter.

BLEED-AIR SYSTEMS (ENGINE)

It is important to understand what is meant by bleed air and where bleed air comes from. Bleed air is tapped off of pressurized air from the engine compressor section. On some engine configurations, the air is bled from more than one area of the compressor. This design gives a source for high- and low-pressure air to suit whatever requirements a particular system may have. Other engines have only one source of bleed air available from each engine. That source is often tapped from the last stage of compression on each engine.

The engine has a number of different uses for the air pressure it generates while operating.

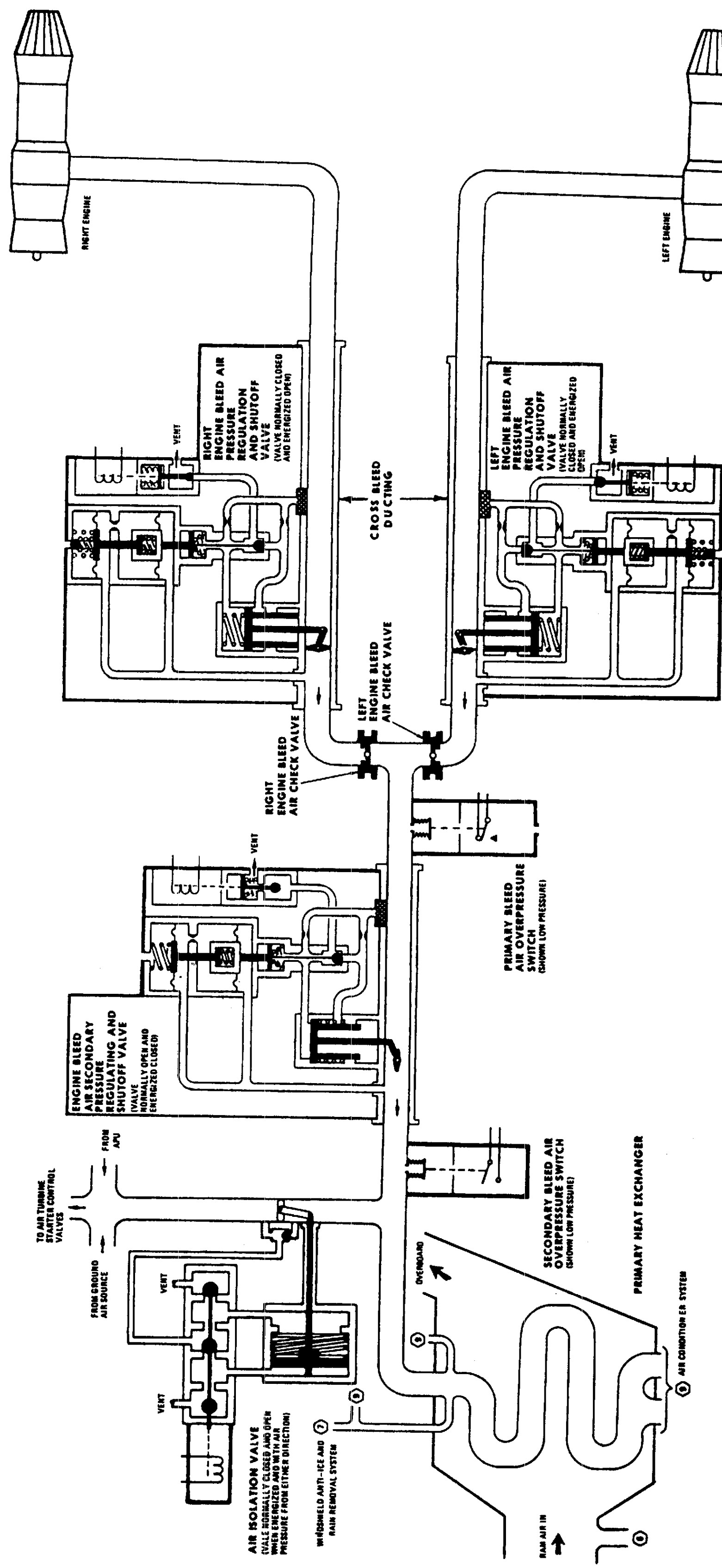


Figure 6-11.—Bleed-air system.

Besides thrust, bleed air can be used for engine starting, seal pressurization, and anti-icing.

Cross-bleed Air Engine Starting System

Most aircraft in the fleet using two or more engines employ a cross-bleed starting system. See figure 6-11. This system provides regulated air pressure from one engine to start the remaining engine(s). The first engine must be started by an external source of air pressure. External sources may be auxiliary power units or ground support equipment. Subsequent engines can then be started using bleed air from the running engine. Opening the cross-bleed air valves allows regulated bleed air from the running engine to supply air to the other engines' starter.

Compressor bleed-air valves reduce the load on the compressor, making it easier for the starter to turn the compressor. During starts, air is bled from the compressor through ports on the compressor housing. The bleed valves are held open by compressor air pressure until the engine starts. After starting, the speed-sensitive valve directs compressor discharges air to close the bleed valves.

Oil and Seal Pressurization System

Air pressure, bled from the compressor, controls oil leakage on nonrubbing labyrinth or clearance-type bearing seals. These bearings use the differential in sump pressures to keep oil loss to a minimum. The sump scavenge pump capacity is greater than that of the oil system pressure pump. Not only does the sump scavenge pump scavenge all the oil in the sump area, it also scavenges air in the sump, creating a lower air pressure than that of the area surrounding the bearing sump. This action allows the compressor bleed air external from the sump to flow from outside the sump area across the bearing seal, preventing oil leakage in the opposite direction. The airflow also helps cool the bearings. See figure 6-12.

Anti-icing System

The guide vanes of a turbine-powered engine are used to direct the flow of inlet air into the compressor section. The air is coldest at this point, and is subject to icing. The biggest problem resulting from ice forming at this point is the blockage of inlet air, which causes air starvation, and thus engine failure. Another problem is the

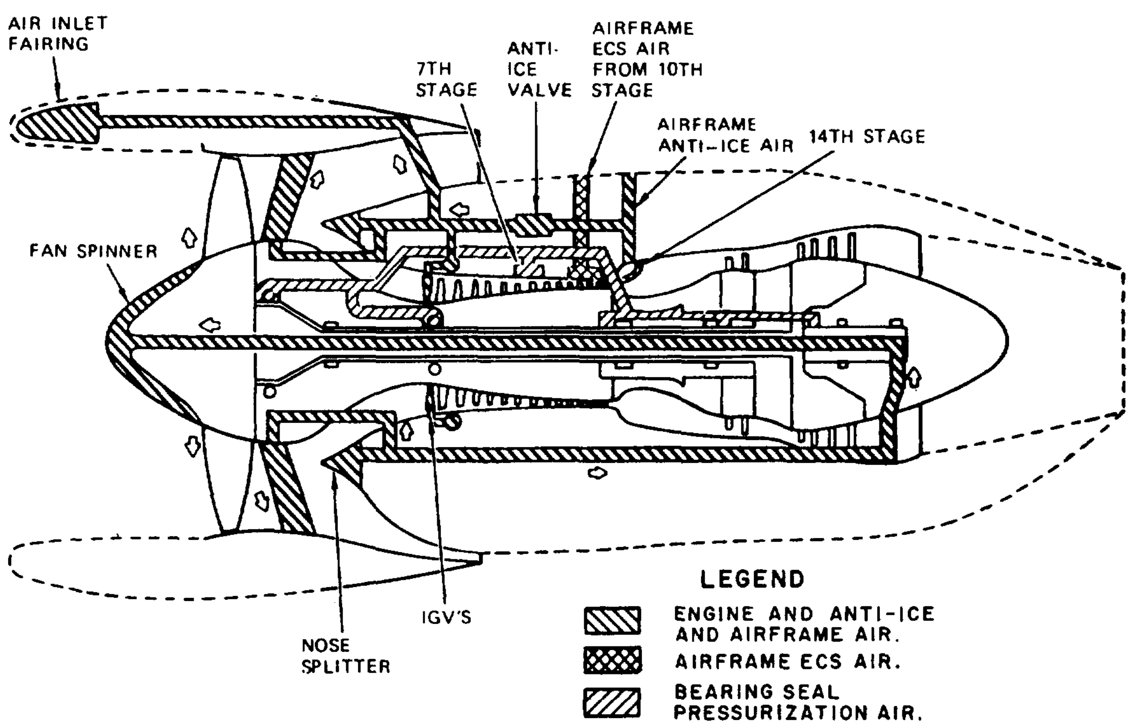


Figure 6-12.-Engine bleed-air distribution.

possibility of inducting chunks of ice into the engine. Engine anti-icing systems prevent these problems if turned on prior to entering an icing condition. Icing will not normally occur in supersonic flight because heat caused by the friction of the aircraft passing through the air is sufficient to prevent ice from forming.

Many types of anti-icing systems are in use today. All systems use bleed air from the engine to perform the anti-icing function. The use of bleed air causes engine power loss. Anti-icing will be used only when absolutely necessary. Some aircraft use a reversible electric motor to open and close an air valve to supply the needed air. Other aircraft use an electrical solenoid to control a pneumatic anti-icing valve. See figure 6-13.

When the aircraft routinely flys in adverse weather conditions, a fail-safe system may be used in the system. The solenoid-actuated air valve is electrically actuated closed. If the switch is turned on, or if electrical power is lost, the valve is spring loaded to the open position. Some systems anti-ice the complete inlet duct, while in other systems only the guide vanes are anti-iced.

BLEED-AIR SYSTEMS (AIRFRAME)

There are a several airframe systems that rely on engine bleed air to operate. See figure 6-14.

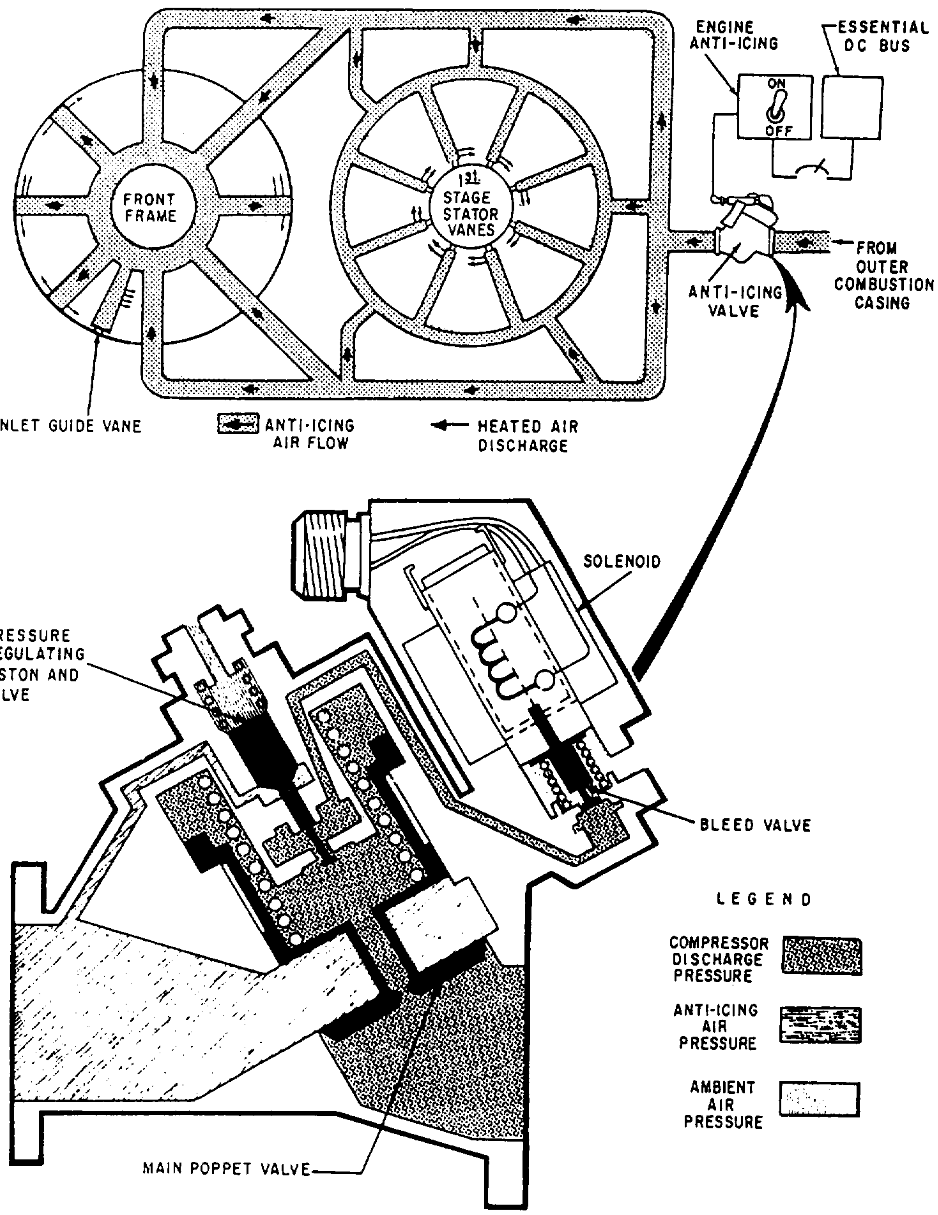


Figure 6-13.-Inlet guide vane anti-icing system.

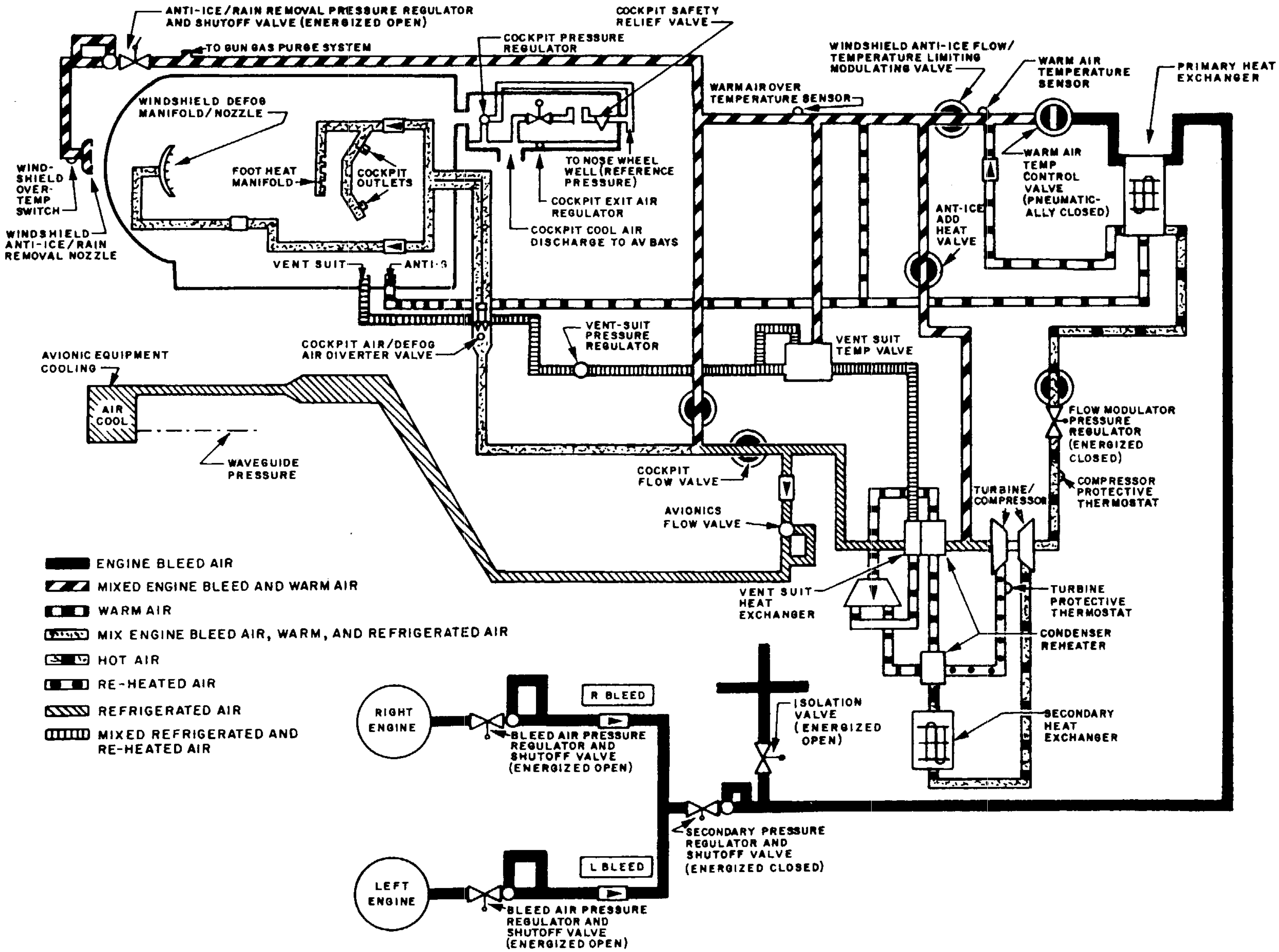


Figure 6-14.—Environmental control systems.

These systems include air-conditioning and pressurization, electronic equipment cooling, windshield washing, anti-icing, and anti-g systems. The bleed-air system also pressurizes fuel tanks, hydraulic reservoirs, and radar waveguides on several types of aircraft.

In addition to supplying aircraft systems with bleed air, some aircraft manufacturers use it to provide extra lift to the wings. Design engineers devised a system to duct engine bleed air across the leading edge of the wing to increase the lift, generating airflow. This system decreases the aircraft stall speed and increases its slow flight capability, which is desirable during aircraft carrier landings.

Airframe Deicing and Anti-icing Systems

On foggy days (visible moisture in the air), ice can form on aircraft leading edge surfaces at altitudes where freezing temperatures start. Water droplets in the air can be supercooled to below freezing temperature without actually turning into ice. Ice forms when these droplets are disturbed in some manner. This unusual occurrence is partly due to the surface tension of the water droplet not allowing it to expand and freeze. However, when the aircraft surfaces disturb these droplets, they immediately turn to ice on the aircraft surfaces. The ice may have a glazed or rime appearance. The glazed ice is smooth and hard to detect visually. The rime ice is rough and easily noticeable.

Frost forms as a result of water vapor being turned directly into a solid. It can form on aircraft surfaces in two ways. It can collect on aircraft parked outside overnight when the temperature drops below freezing and the proper humidity conditions exist. It can form on aircraft surfaces when the aircraft descends rapidly into warm, moist air after flying at higher cold altitudes. In this case, frost forms because of the

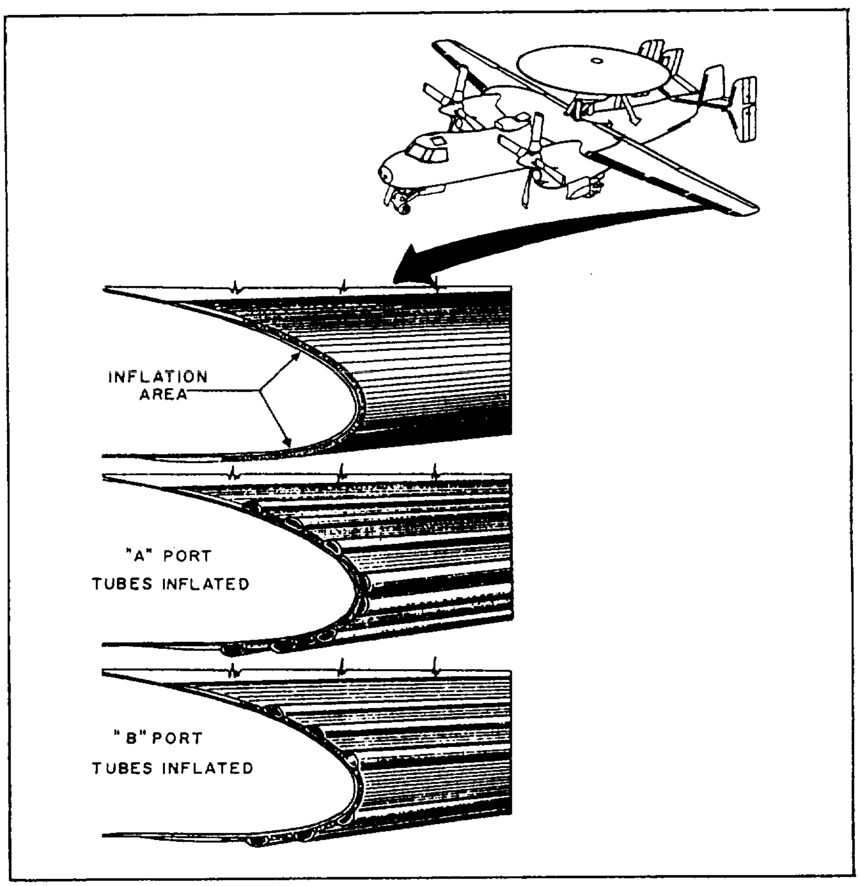


Figure 6-15.-Deicer boot location/operation.

cold air coming off the aircraft structure as it warms up.

The shape of the wing may be changed drastically because of the formation of ice or frost. Control of the aircraft may become difficult as the lift characteristics of the wing change. Uneven distribution of ice generates an unbalanced aircraft condition. Enough ice to cause an unsafe condition can form in a very short period of time. Thus, some method of ice removal or prevention is necessary.

Presently, there are two methods for eliminating or preventing ice. One method, deicing, employs a mechanical system to break up and remove the ice after it has formed. The second method, anti-icing, uses heated bleed air to prevent the formation of ice. The deicing systems are common to older aircraft. The anti-icing systems are common to newer aircraft. Both systems use bleed air to accomplish their function.

As shown in figures 6-15 and 6-16, the deicing system uses bleed air to inflate the rubber boots along the leading edge of the wing. The cells or tubes of the deicer boots are inflated and deflated alternately by pressure and suction, causing a wavelike motion, which cracks the formed ice and allows it to be carried away by the airstream. The system is pneumatically operated, electrically controlled, and regulated by a pressure regulator and relief valve. Suction and pressure gauges provide a means of monitoring the system operation.

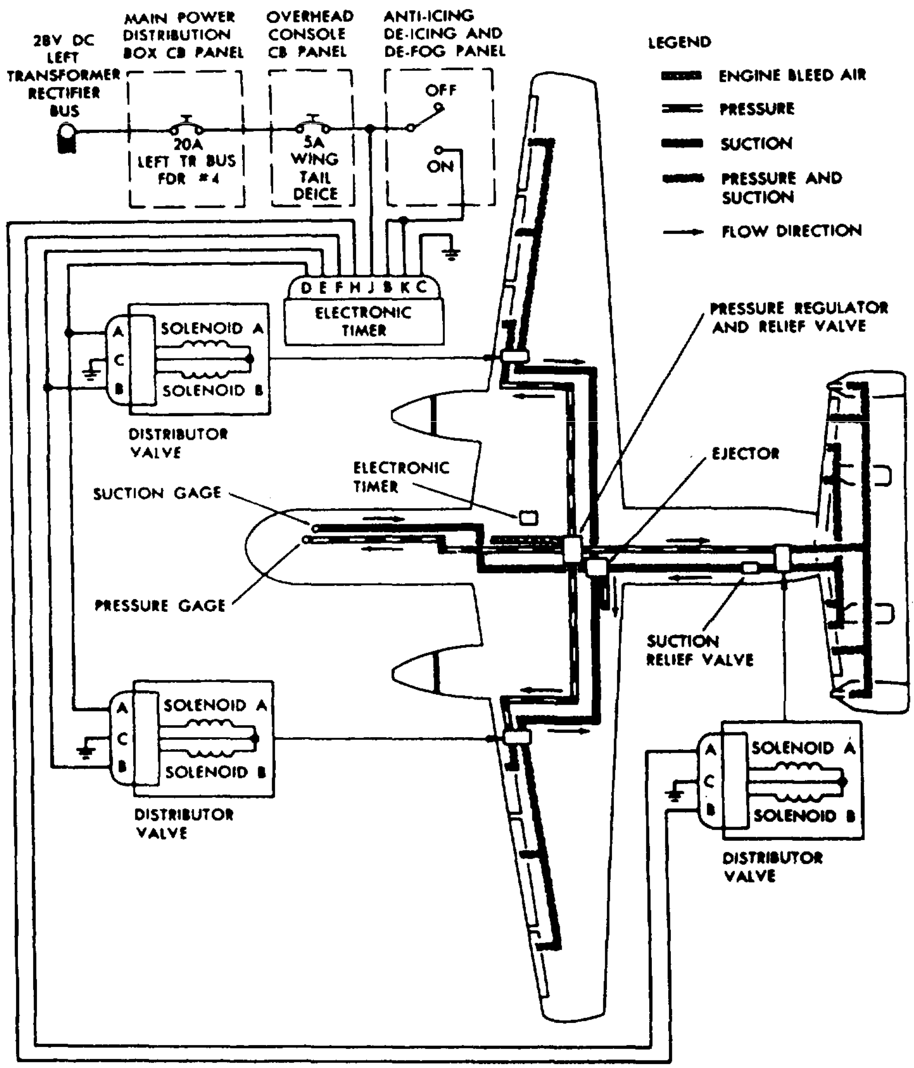


Figure 6-16.-Deicing system.

The anti-ice system shown in figure 6-17 is a combination of both deice and anti-ice systems, and is called an ice protection system. Using bleed air, temperature sensors, thermostatic switches, and various types of valves, ice protection requirements are met.

Airframes Fuel Systems

The pressurization and vent system provides regulated bleed air pressure to all fuel tanks. This prevents fuel boil-off at altitude and provides a means to transfer fuel between tanks. This system also provides pressure relief of the fuel tanks during ascent and vacuum relief of the tanks during descent if the pressurization system fails.

Internal tanks are pressurized anytime the engine is running, provided that electrical power is on, the refueling probe is retracted, the tad hook is up, and weight is off the wheels.

Fuel transfer from external tanks to the main airframe tanks using bleed air is also available, if the above conditions are met. During emergencies, troubleshooting, or checking fuel transfer after installing external tanks, an OVERRIDE switch is installed that defeats all conditions except that the tailhook must be up.

AUXILIARY POWER UNITS

Several types of aircraft now in the fleet have an onboard auxiliary power unit (APU).

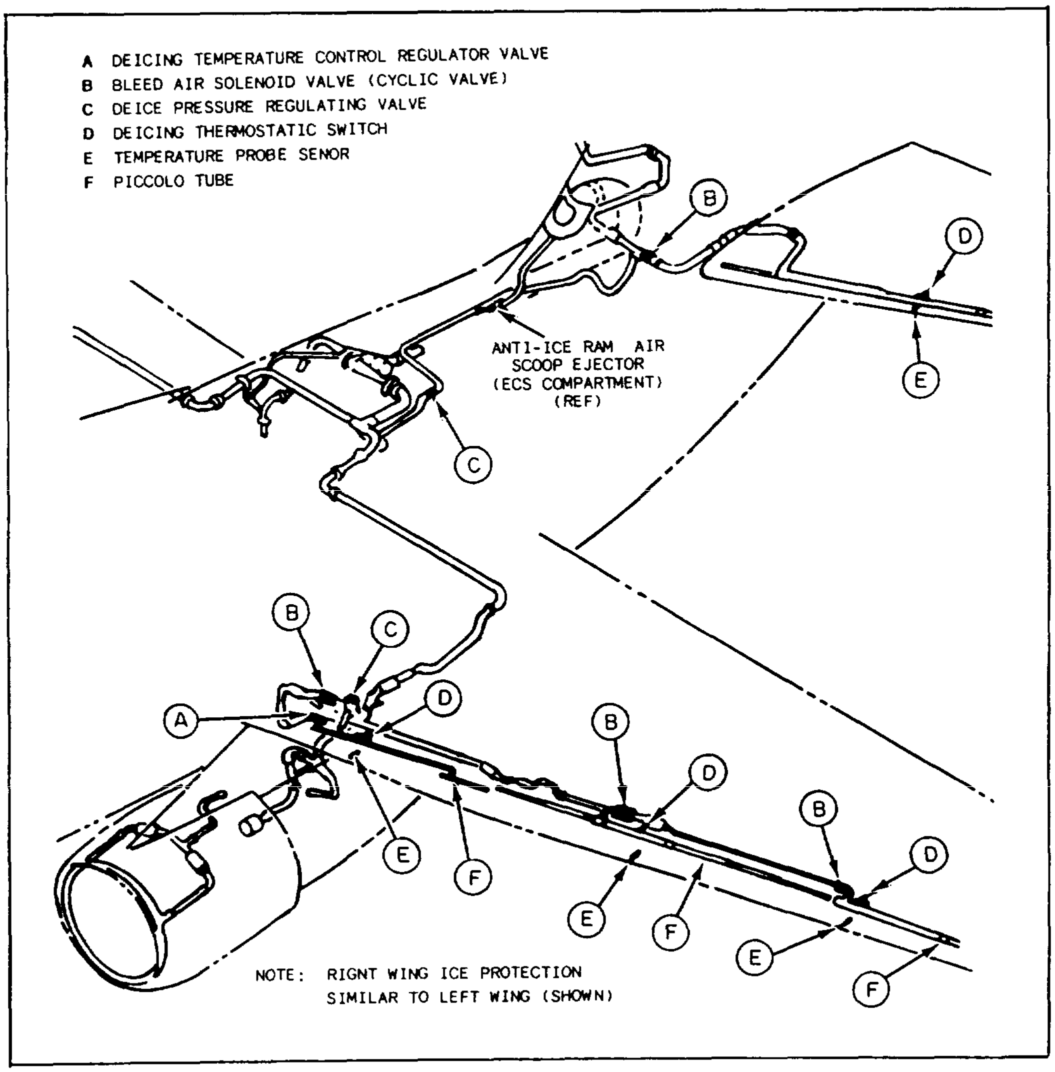


Figure 6-17.-Ice protection system.

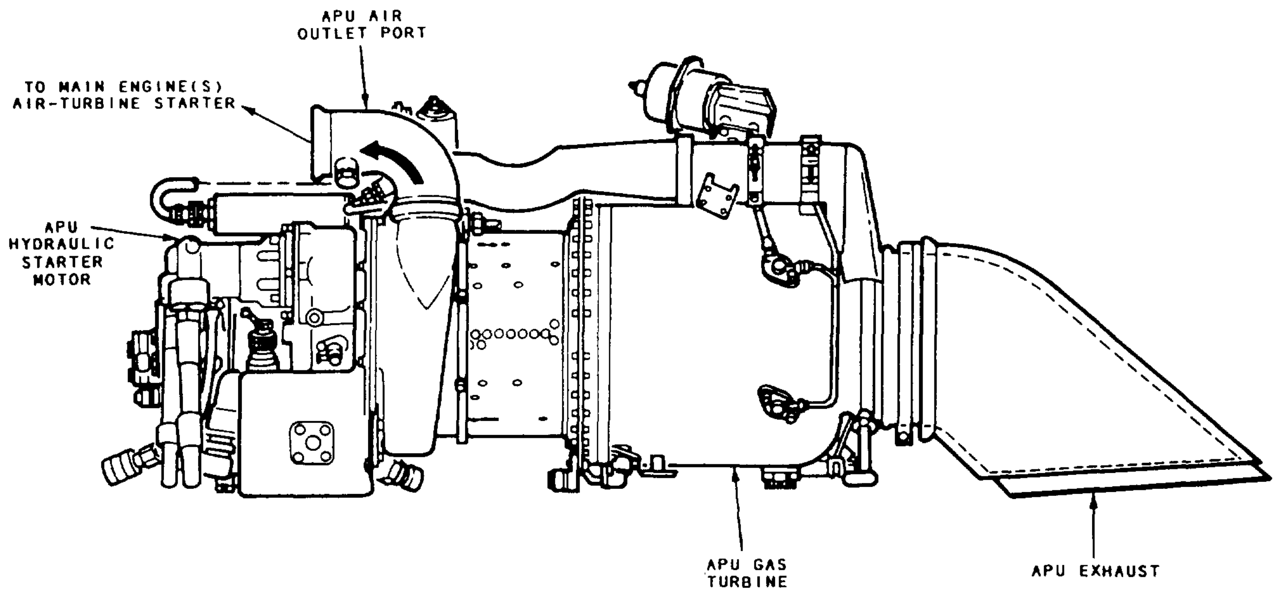


Figure 6-18.-Typical onboard auxiliary power unit (APU).

APUs are small, self-contained jet engines that are started either electrically through onboard batteries or hydraulically through a hydraulic starter motor. See figure 6-18.

In the past, APUs were too large and too heavy for practical use in tactical combat aircraft. Their use was limited to the larger land-based aircraft with missions such as patrol, cargo, transport, or special projects. Advancements in technological design and metallurgy have produced small, lightweight, yet efficient APUs. These advancements have enabled newer carrier-borne aircraft, such as the S-3 and the tactical F/A-l 8, to operate aboard ship without the requirement for flight deck support equipment. This places less demand on the flight deck crews, and makes the flight deck a somewhat safer working environment.

The use of an APU makes the modern jet aircraft completely self-sufficient. Aircraft having air turbine starters can use compressed air from the APU to start engines. They also supply electrical and hydraulic power, as well as air conditioning during ground maintenance. The aircraft is independent of the need of ground power units to carry out its mission. There are many types and configurations of gas-turbine units.

Maintenance performed on APUs can be almost as extensive as that performed on aircraft engines. The major difference, other than the size, is that most APUs use centrifugal flow jet engines instead of axial flow. The nomenclature of many of the components may be the same. However, the component itself may not look or operate in the same manner because of the basic function of the unit.

Authorized repairs for organizational activities include minor component replacements and adjustments. Common repairs include inlet/exhaust door actuator maintenance, bleed-air shutoff valve maintenance, and generator replacement. Maintenance on the ignition system, generator, oil tank, oil pressure switch, oil cooler, and scavenge oil filter, or major inspections may require APU removal because of the APU location. Major APU inspections and repairs are performed by the supporting intermediate maintenance activity (IMA) under the Auxiliary Power Unit and Support Equipment Gas Turbine Engine Management Program.

CHAPTER 7

HELICOPTERS AND TURBOSHAFT POWER PLANTS

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Identify helicopter flight characteristics.
- Recognize the purpose and major engine components of turboshaft engines and helicopter transmission and rotor systems.
- Identify maintenance procedures for helicopter transmission and rotor systems.

The helicopter has become a vital part of naval aviation. Helicopters have many uses. Some of these uses are antisubmarine warfare (ASW), search and rescue, minesweeping, amphibious warfare, and the transferring of supplies and personnel between ships. Transferring of supplies and personnel is made through internal loading or vertical replenishment (VERTREP). The advantage the helicopter has over conventional aircraft is that lift and control are relatively independent of forward speed. A helicopter can fly forward, backward, or sideways, or it can remain in stationary flight above the ground (hover). Helicopters do not require runways for takeoffs or landings. The decks of small ships or open fields provide an adequate landing area.

The main difference between a helicopter and an airplane is the source of lift. The airplane gets lift from a fixed airfoil surface (wing) while the helicopter gets lift from a rotating airfoil (rotor). The word *helicopter* comes from the Greek words meaning *relating wings.* You may find it easier to understand how a helicopter operates by imagining the following: Remove the wings from a conventional aircraft and install them above the airplane. Rotating the wings causes a low-pressure area to form on the wings' upper surfaces and provides lift. This low-pressure area and resulting lift is, the same as that formed by fixed wings on an aircraft.

The lift generated by a rotating wing enables the helicopter to accomplish its unique missions involving hovering and operating in confined areas. It also creates some unusual operating and control problems. Since rotor aerodynamics are the main difference between helicopters and fixed-wing aircraft, let's first examine the rotor in detail. We will then look at helicopter controls, types of helicopters, engines, and finally, transmission and rotor systems.

HELICOPTER FLIGHT CHARACTERISTICS

The rotor is subject to the same physical laws of aerodynamics and motion that govern fixed-wing aircraft flight. However, the manner in which the rotor is subjected to these laws is much more complex. Fixed-wing flight characteristics depend upon the forward aircraft speed and control surface movements. In a helicopter, the rotational speed and pitch variations of the rotor blades determine the flight characteristics. Since flight is independent of forward speed, a helicopter is able to move in any direction at a controlled low speed.

HELICOPTER THEORY OF LIFT

Rotor lift is explained by either of two theories. The first theory uses Newton's law of momentum. Lift results from accelerating a mass of air downward. This lift is similar to jet thrust that develops by accelerating a mass of air out the exhaust. The second theory is the blade element theory. The airflow over the rotor blade acts the same as it does on the wing of a fixed-wing aircraft. The simple momentum theory determines only lift characteristic while the blade element theory gives both lift and drag characteristics. This comparison gives us a more complete picture of all the forces acting on a rotor blade.

The blade element theory divides the blade into parts (blade elements), as shown in figure 7-1. Engineers analyze the forces acting on each blade element. Then the forces of all elements are added to give the rotor characteristics. Each rotor blade element has a different velocity, and possibly a different angle of attack. These differences make analysis a complicated problem.

If the helicopter hovers in a no-wind condition, the rotors plane of rotation is parallel to the level ground. This attitude also makes the relative wind parallel to the ground. The angle of attack is the same on any blade element throughout the cycle of rotation. The lifting force is perpendicular to the plane of rotation.

If the helicopter is rising, there is a component of velocity parallel to the axis of the rotor. Then the relative wind is the result of the rotational velocity and the vertical velocity of the helicopter. Lift acts perpendicular to the relative wind. The relative wind is no longer parallel to the plane of rotation. Lift is not acting perpendicular to the plane of rotation. The vertical thrust then, or the force acting to overcome gravity, is slightly less than the lifting force.

So far the discussion has been about the forces in the vertical direction. These forces support the helicopter, but do not give it any horizontal motion. Rotational and vertical velocities have already entered the picture. In any discussion of the principles of flight of the helicopter, the different velocities being considered must be specified. This also applies to such factors as torque, drag, and other forces.

FACTORS AFFECTING HELICOPTER FLIGHT

Helicopters are subject to several rotary-wing aerodynamic effects. These forces act independently. Their cumulative sum are factors that affect helicopter flight.

Torque

Although torque is not unique to helicopters, it does present some special problems. As the main rotors turn in one direction, the fuselage may rotate in the opposite direction. Newton's third law of motion states that "every action has an equal and opposite reaction." This tendency for the fuselage to rotate is known as torque effect. Since torque effect on the fuselage is a direct result of engine power, any change in power changes the torque. The greater the engine power, the greater the torque. There is no torque reaction when an engine is not operating. Therefore, there is no torque reaction during autorotation.

The usual method of counteracting torque in a single main rotor is by a tail (antitorque) rotor. This auxiliary rotor is mounted vertically on the outer portion of the tail boom. The tail rotor and its controls serve as a means to counteract torque, and it provides a means to control directional heading.

Dissymmetry of Lift

Dissymmetry of lift is the lift difference existing between the advancing blade half of the disk and the retreating blade half. The disk area is the area swept by the rotating blades. It is

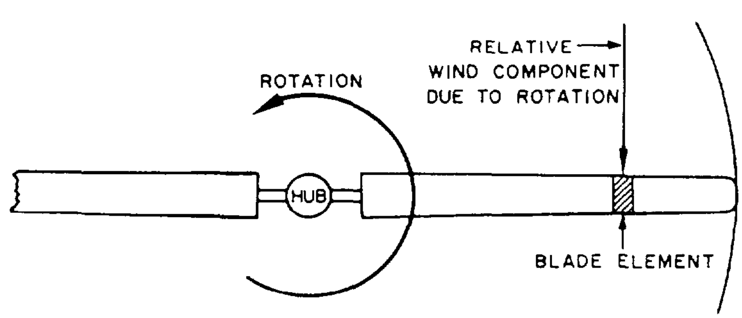


Figure 7-1.-Blade element theory.

created by horizontal flight or by wind in a hover. You should be aware that hovering in a 20 mph headwind is the same as flying forward at 20 mph. When hovering in a no-wind condition, the speed of the relative wind is the effective speed of the rotor. However, the speed is lower at points closer to the rotor hub, as shown in figure 7-2. When the helicopter moves forward, relative wind over each blade becomes a combination of the rotor speed and forward movement. The advancing blade is then the combined speed of the blade speed and helicopter speed. While on the opposite side, the retreating blade speed is the blade speed minus the speed of the helicopter. Figure 7-3 shows dissymmetry of lift at 100 mph forward flight.

During forward flight, lift over the advancing blade half of the rotor disk is greater then the retreating half. This greater lift would cause the helicopter to roll unless something equalized the lift. One method of equalizing the lift is through blade flapping.

Blade Flapping

Blades attached to the rotor hubby horizontal hinges permit the blade to move vertically. The blades actually flap up and down as they rotate. The hinge permits an advancing blade to rise, thus reducing its effective lift area. It also allows a retreating blade to settle, thus increasing its effective lift area. The combination of decreasing lift on the advancing blade and increasing lift on the retreating blade equalizes the lift.

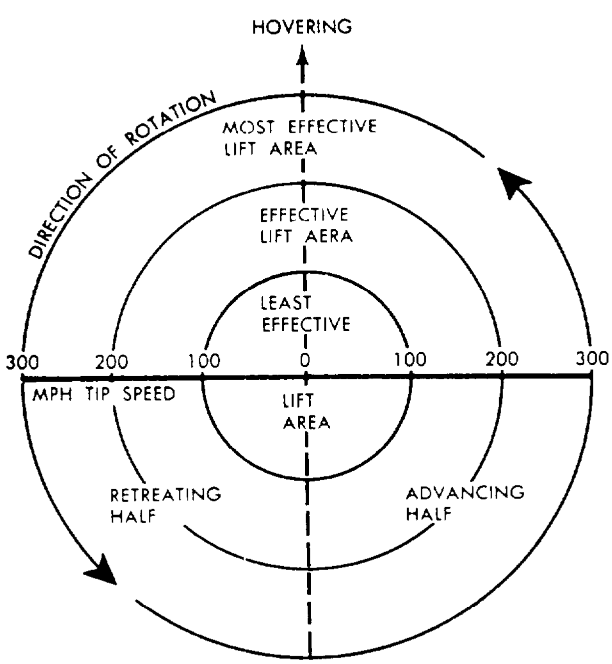


Figure 7-2.-Symmetry of lift.

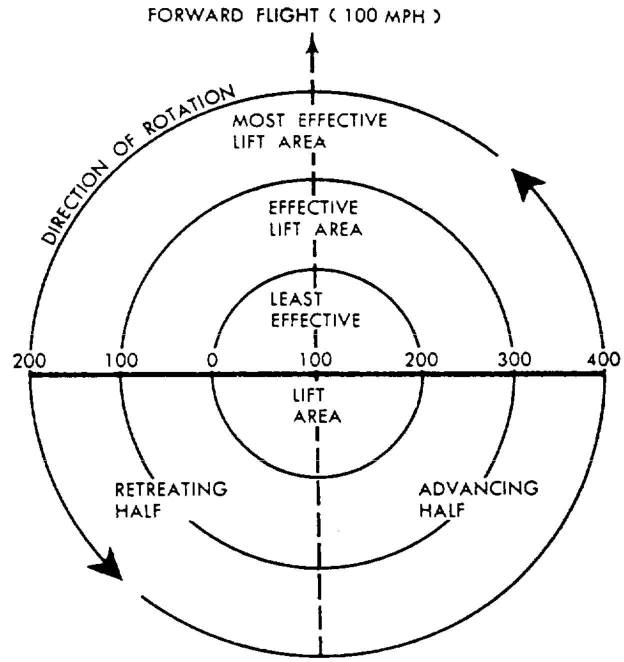


Figure 7-3.-Dissymmetry of lift.

Blade flapping creates an unbalanced condition, resulting in vibration. To prevent this vibration, a drag hinge allows the blades to move back and forth in a horizontal plane. A main rotor that permits individual movement of blades in a vertical and horizontal plane is known as an articulated rotor.

Coning

Coning is the upward bending of the blades caused by the combined forces of lift and centrifugal force. Before takeoff, due to centrifugal force, the blades rotate in a plane nearly perpendicular to the rotor hub. During a vertical liftoff, the blades assume a conical path as a result of centrifugal force acting outward and lift acting upward.

Coning causes rotor blades to bend up in a semirigid rotor. In an articulated rotor, the blades move to an upward angle through movement about the flapping hinges.

Gyroscopic Precession

The spinning main rotor of a helicopter acts like a gyroscope. It has the properties of gyroscopic action, one of which is precession. Gyroscopic precession is resulting action occurring

90 degrees from the applied force. Applying a downward force to the right of the disk area will cause the rotor to tilt down in front. This downward tilt is true only for a right-to-left (counterclockwise) rotor rotation.

The cyclic control applies force to the main rotor through the swashplate. To simplify directional control, helicopters use a mechanical linkage, which places cyclic pitch change 90 degrees ahead of the applied force. Moving the cyclic control forward (right-to-left turning rotor) places high pitch on the blades to the pilot's left. Low pitch is then found on the blades to the pilot's right. Since every pitch change causes a flap, reaching its maximum at 90 degrees, this flapping causes the disk area to tilt forward.

If offset linkage were not used, the pilot would have to move the cyclic stick 90 degrees out of phase. The pilot would have to move the stick to the right to tilt the disk forward, and forward to tilt the disk area to the left, and so on.

Ground Effect

When a helicopter hovers close to the ground, the rotor directs air downward faster then it can escape. This builds up a cushion of dense air beneath the helicopter known as ground cushion or ground effect. It is effective to a height of one-half the rotor diameter. Ground cushion effect does not occur at airspeeds greater then 10 mph.

Autorotation

Autorotation occurs when the main rotor turns by air passing up through the rotor system instead of by the engine. The rotor disengages automatically from the engine during engine failure or shutdown. During autorotation, the rotor blades turn in the same direction as when engine driven. Air passes up through the rotor system instead of down. This causes a slightly greater upward flex or coning of the blades.

Power Settling

Stalling, as applied to fixed-wing aircraft, will not occur in helicopters. However, power settling may occur in low-speed flight. Power settling is the uncontrollable loss of altitude. Heavy gross weights, poor density conditions, and low forward speed all contribute to power settling. During low forward speed and high rates of descent, the downwash from the rotor begins to recirculate. The downwind flows up, around, and back down through the effective outer disk area. The recirculating air velocity may become so high that full collective pitch cannot control the rate of descent.

FACTORS AFFECTING ROTOR BLADE LIFT

Factors that affect rotor blade lift are the rotor area, pitch of rotor blades, smoothness of rotor blades, and density altitude.

Rotor Area

One assumption in figuring the lift of a rotor is that lift is dependent upon the entire area of the rotor disk. The rotor disk area is the area of the circle. The radius of the rotor disk is equal to the length of the rotor blade. The lift of a rotor increases not in direct proportion to the length of the rotor, but in proportion to the square of the length of the rotor. The use of large rotor disk areas is readily apparent. The greater the rotor disk area, the greater the drag created. This drag results in the need for greater power requirements.

Pitch of Rotor Blades

If the rotor operates at zero angle of attack or zero pitch, no lift would result. When the pitch increases, the lifting force increases until the angle of attack reaches the stalling angle. To even out the lift distribution along the length of the rotor blade, it is common practice to twist the blade. Twisting the blade causes a smaller angle of attack at the tip than at the hub.

Smoothness of Rotor Blades

Tests have shown that the lift of a helicopter increases by polishing the rotor blades to a mirror-like surface. By making the rotor blades as smooth as possible, the parasite drag reduces. Any dirt, grease, or abrasions on the rotor blades may be a source of increased drag, which will decrease the lifting power of the helicopter.

Density Altitude

In formulas for lift and drag, the density of the air is an important factor. The mass or density of the air reacting in a downward direction causes the upward force or lift that supports the helicopter.

Density is dependent on two variables. One variable is the altitude, since density varies from a maximum at sea level to a minimum at high altitude. The other variable is atmospheric changes. The density of the air may be different, even at the same altitude, because of changes in temperature, pressure, or humidity.

FLIGHT CONTROL SYSTEM

The mechanical flight control system consists of mechanical linkage and controls. See figure 7-4.

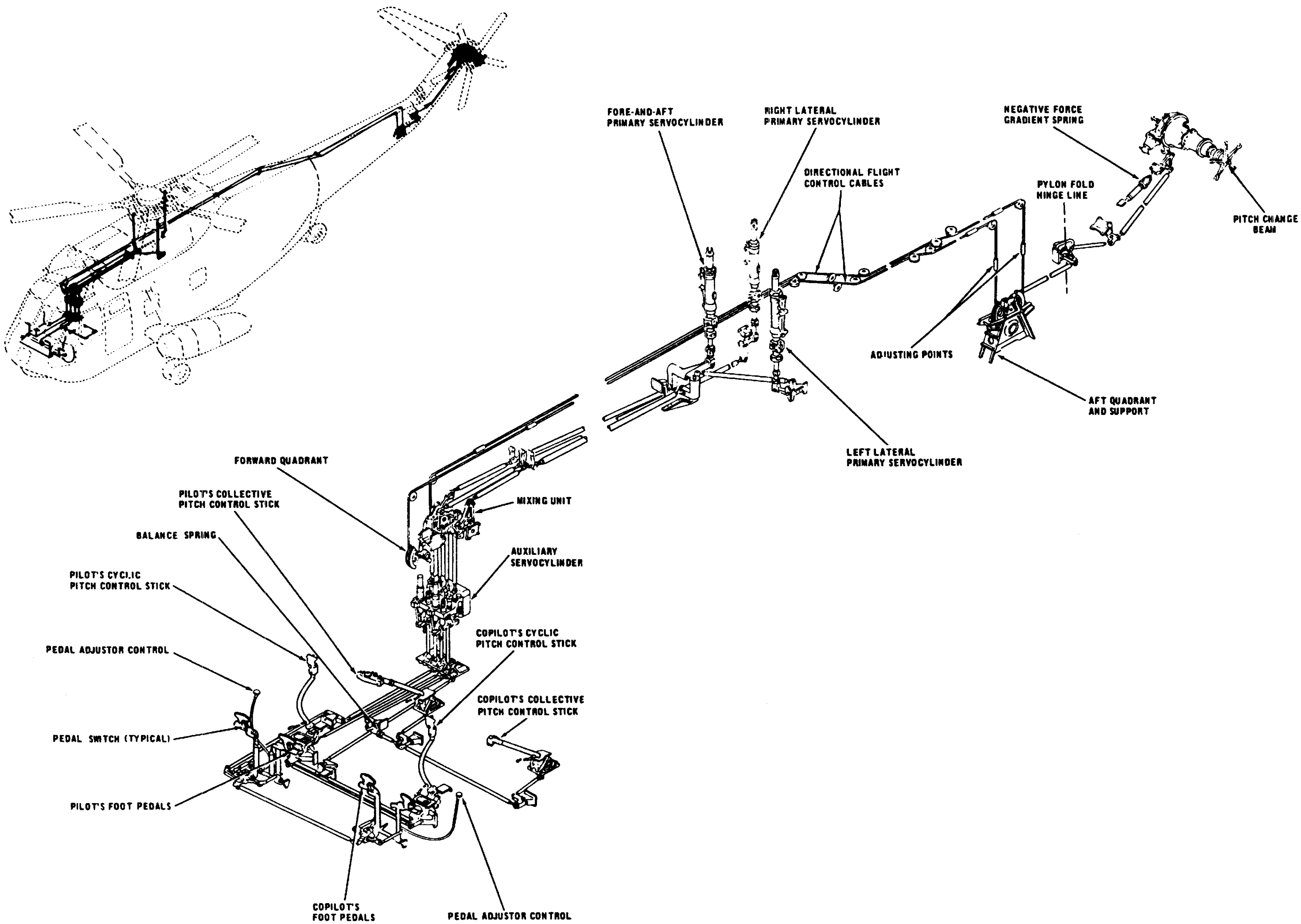


Figure 7-4.—Typical flight control system.

These linkages and controls transmit force to primary and auxiliary hydraulic system servo cylinders and to the rotary rudder. The mechanical flight controls have two independent systems. They are the rotary wing flight control and the rotary rudder flight control systems.

The rotary wing flight controls consist of cyclic and collective pitch control sticks, a mixing unit, a balance spring, and linkage. The cyclic controls give forward, aft, and lateral movement of the helicopter. The collective controls give vertical control of the helicopter.

The rotary rudder flight controls consist of pedals, pedal switches, and pedal adjusters for the pilot and copilot. Other system components are a negative force gradient spring and mechanical linkage. The rotary rudder compensates for the torque of the rotary wing. The controls provide a way to change the heading (direction) of the helicopter.

The cyclic pitch control system controls the forward, aft, and lateral movements of the helicopter. Control comes from the pilot's or copilot's cyclic stick. Control rods and bell cranks connect the stick to the auxiliary servo cylinders, then to the mixing unit, and three primary servo cylinders. The primary servo cylinders control movement of the rotary wing blades through the swashplate. The swashplate changes the pitch of the blades.

The collective pitch control system provides vertical control of the helicopter. Control comes from the pilot's and copilot's collective pitch control sticks. Control rods and bell cranks connect the stick to the auxiliary servo cylinder, then to the mixing unit. At the mixing unit, movements of the collective stick are sent to the primary servo cylinders and the swashplate. The swashplate increases or decreases the pitch of all blades equally and simultaneously. A balance spring on a control rod helps to balance the weight of the collective stick when the auxiliary servo system is off.

A collective-to-cyclic pitch coupling (fore-and-aft) is found in the mixing unit. The coupling automatically applies a nose-down pitching correction when the collective pitch stick is raised. When the collective pitch stick is lowered, a nose-up pitching correction is made. This action provides attitude control during transitions, especially during automatic stabilization equipment (ASE) system transitions.

A collective-to-yaw coupling provides automatic rotary rudder pitch changes to adjust for collective pitch changes. Rotary rudder blade angle changes result from both collective pitch stick and rudder pedal movement. The auxiliary servo irreversible transfer of collective pitch motion will act to displace the rudder. The rudder pedal motion will not affect rotary wing collective pitch blade angle.

The rotary rudder control system controls helicopter heading by moving control rods and bell cranks connected to the auxiliary servo cylinder. The auxiliary servo cylinder connects to the mixing unit by control rods. At the mixing unit, a control rod operates a forward quadrant. From the forward quadrant, cables operate a rear quadrant in the aft fuselage. A control rod from the rear quadrant connects, at the pylon hinge line, to the control rods, bell cranks, and pitch control shaft. These units are found in the tail gearbox. A hydraulic pedal damper in the servo cylinder prevents sudden movements of the control pedals from causing rapid changes in blade pitch, which might damage the helicopter.

A typical helicopter flight control system consists of four subsystems. They are the cyclic pitch control sticks for directional flight, the collective pitch control sticks for vertical flight, the directional heading control (rudder) pedals, and the throttle. The throttle may be a motorcycle-type grip mounted on the collective pitch stick. The throttle may be lever-type mounted on the center overhead console. Also included are an auxiliary servo cylinder, a mixing unit, primary servo cylinders, and mechanical linkage.

The cyclic pitch control stick controls forward, aft, and lateral helicopter movements. The collective pitch control stick controls vertical helicopter movement. The directional control pedals control helicopter headings. See figure 7-4.

Movement of the control sticks is sent by mechanical linkage to a hydraulically operated auxiliary servo cylinder for power boost. The boosted input is sent through a mixing unit for coordination with any heading directional control inputs. Stick movement is finally sent through the hydraulically actuated primary servo cylinders to the rotary wing head. At the rotary wing head, blade pitch changes.

TYPES OF HELICOPTERS

Helicopters are of two basic types. They are the single-rotor and multi-rotor types. The single main rotor with a vertical tail rotor is the most common type of helicopter. The SH-60 or SH-2, shown in figure 7-5, are examples of single-rotor

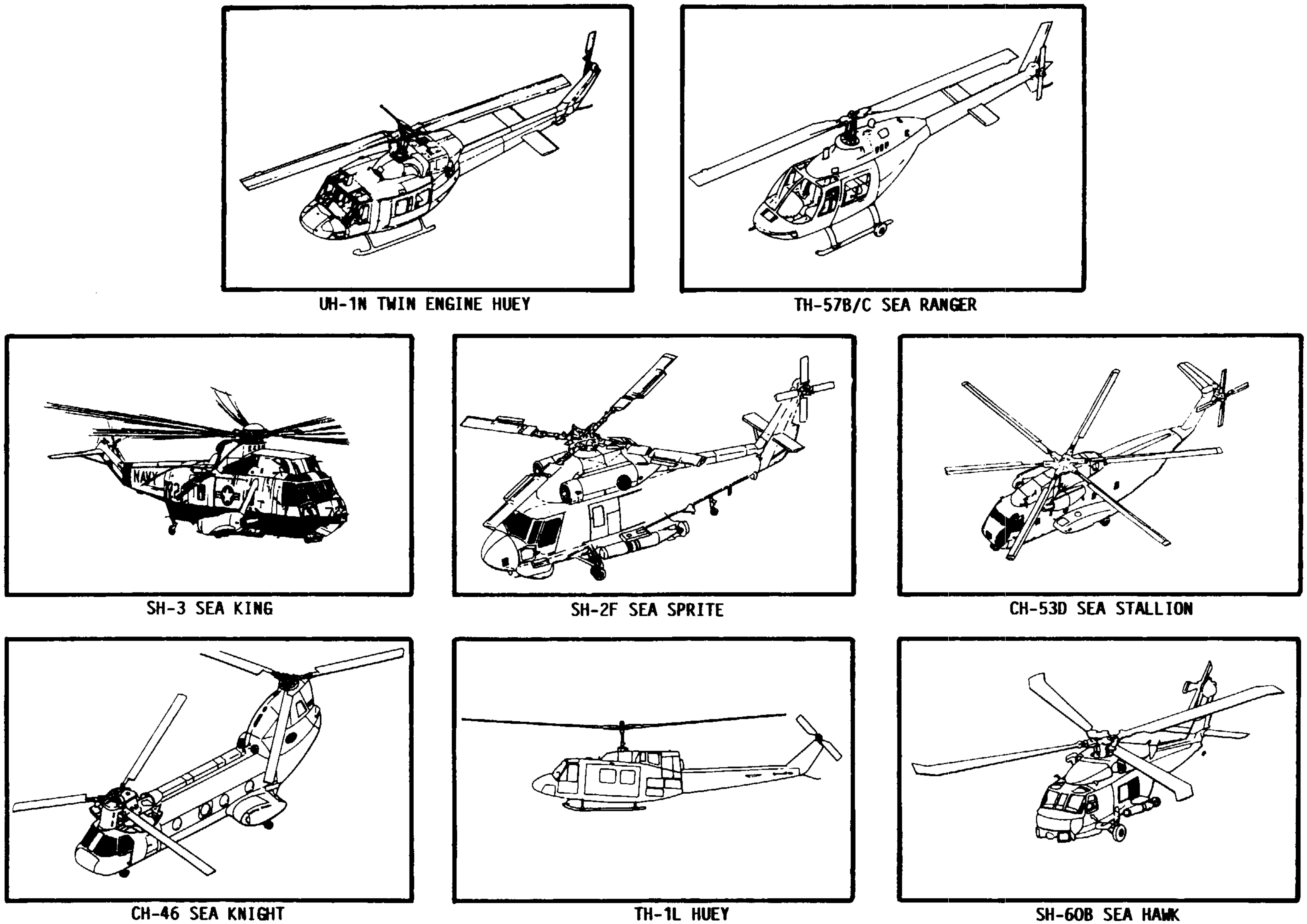


Figure 7-5.—Types of naval helicopters.

helicopters. Multi-rotor helicopters are classified into different categories according to their rotor configuration. Two different types are the coaxial rotor and tandem rotor.

The single-rotor configuration requires the use of a vertical tail rotor to counteract torque and provide directional control. The advantages of this configuration are simplicity in design and effective directional control. Coaxial rotors are two rotors mounted on the same mast and turning in opposite directions. The torque produced by the two rotors balance each other out. Coaxial rotor systems have good ground clearance and are easy to maneuver. Their arrangement and controls are more complicated then single rotor systems. In the tandem rotor design, one rotor is located forward and the other located aft. Sometimes the rotor blades are in the same plane. The blades may or may not intermesh. The design offers good longitudinal stability since the fuselage hangs at two points, fore and aft. Like the coaxial rotor, the tandem rotor has little torque to overcome since these rotors rotate in opposite directions.

Most of the Navy helicopters are a twin-turbine engine powered, single rotor design like the SH-60 and SH-3. Some small trainer helicopters like the TH-57 have only one engine, and large helicopters like the CH-53 *Super Stallion* have three turbine engines. The maintenance procedures and examples of components used are those of the representative SH-60 and SH-3 helicopters. Both types are used to compare similarities and differences between a modular and nonmodular design.

NOTE: While procedures for specific engines or aircraft are included, many pertinent or mandatory references are left out. For this reason always refer to the applicable maintenance instruction manuals.

HELICOPTER POWER PLANTS

The SH-3 uses two T58-GE-10 turboshaft engines. The SH-60 uses two T700-GE-401 turboshaft engines. See figures 7-6 and 7-7. Both of these turboshaft engines use the free turbine principle for power takeoff to the main transmission gearbox. Power takeoff comes from the power turbine section. This section is mechanically independent from the gas generator. Exhaust gases from the gas generator turbine drive the power turbine. The power turbine is connected to the main transmission gearbox through a coaxial main drive shaft. The main drive on the shaft is on the rear of the T58 and on the front of the T700 engines. See figures 7-6 and 7-7.

NOTE: The T700-GE-401 turboshaft engine is one of a new generation of aviation propulsion systems with modular construction. Modular construction allows intermediate maintenance activities to replace major engine components, such as turbine sections, with basic hand tools. The ability to replace parts at the lowest level of maintenance (third-degree intermediate) increases aircraft availability by decreasing down time.

THE T58-GE-10 TURBOSHAFT ENGINE

The T58-GE-10 engine is a compact turboshaft engine with high power-to-weight ratio. The T58 engine consists of two basic sections. These sections are the gas generator and the power turbine sections.

Gas Generator Section

The gas generator section is divided into five subsections. These subsections are the front frame, accessories, compressor, combustion, and gas generator turbine.

FRONT FRAME.— The front frame provides provisions for engine mounting and supports the accessory section. It provides for engine air inlet and anti-icing for the inlet air.

ACCESSORY SECTION.— The accessory section consists of the centrifugal fuel purifier, accessory drive gear casing assembly, lube-scavenge pump, fuel pump, main fuel control, and the pilot valve. It mounts to the bottom of the front frame section and extends under the compressor section. Power to drive the accessory section is received from the gas generator rotor.

COMPRESSOR SECTION.— The compressor is a 10-stage axial flow unit that consists of a rotor and a stator. The inlet guide vanes and the vanes in stages 1 through 3 are automatically positioned by the stator vane actuator using fuel pressure for the motive force.

COMBUSTION SECTION.— The combustion section is a singular annular type of unit. It

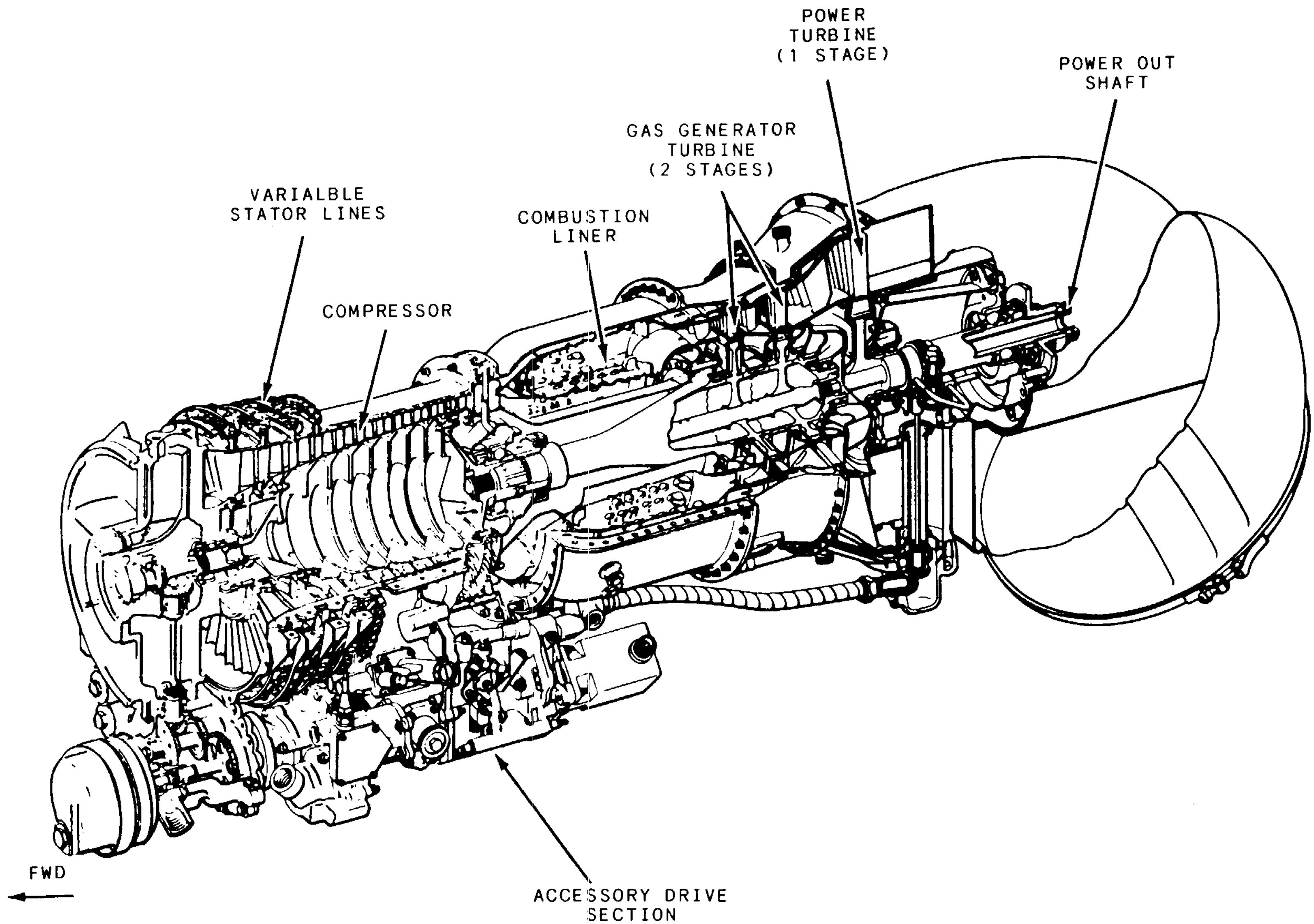


Figure 7-6.—T58-GE-10 turboshaft gas turbine engine (cutaway view).

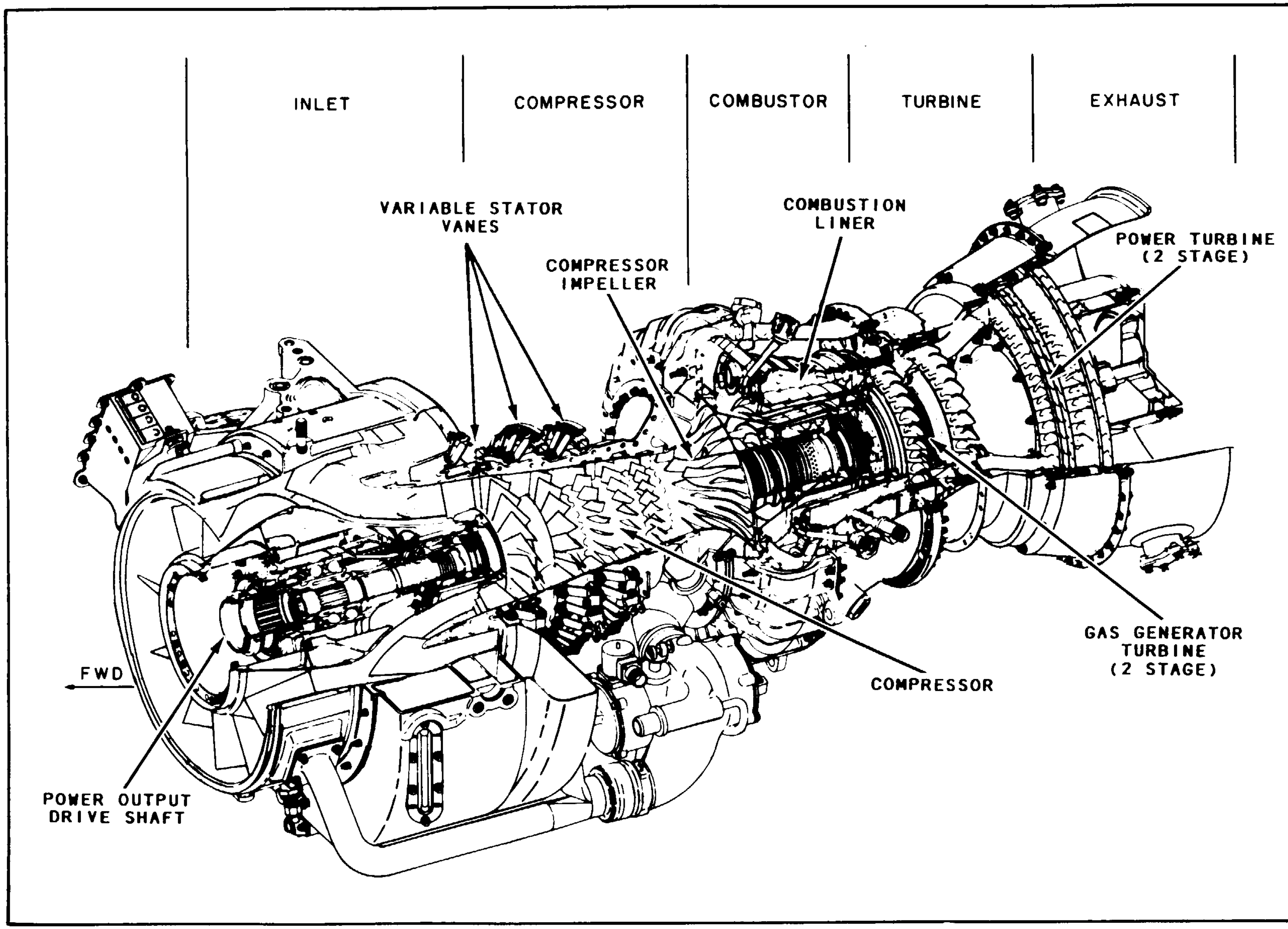


Figure 7-7.—T700-GE-401 turboshaft gas turbine engine (cutaway view).

provides a mounting place for a fuel manifold block, fuel drain, bleed air ports, and igniter plugs.

GAS GENERATOR TURBINE SECTION.— The two-stage axial flow turbine section drives the compressor. It consists of the turbine stator and turbine rotor.

Power Turbine Section

The power turbine section consists of the exhaust casing assembly, rotor assembly, and accessory drive system. The power turbine section may be positioned on the gas generator section in two different positions (exhaust pointing to the right or left), depending on the engine location.

THE T700-GE-401 TURBOSHAFT ENGINE

The T700-GE-401 is a front-drive turboshaft engine featuring a single-spool gas generator section. The engine has a five-stage axial and a single-stage centrifugal flow compressor. It has a flow-through annular combustion chamber. The engine also has a two-stage, axial-flow gas generator turbine and a two-stage, axial-flow, free-power turbine. Some features of this engine include an integral inlet particle separator and self-contained systems incorporating modular construction.

The engine consists of five major sections. These sections are the inlet, compressor, combustor, turbine, and exhaust sections.

Inlet Section

The inlet section includes all the parts forward of the compressor. It directs airflow into the compressor and provides a mount for the accessory gearbox (AGB). The engine inlet uses an integral particle separator (IPS) to prevent foreign objects from entering the compressor. The IPS includes a swirl frame, scroll case, and engine-driven blower. The 12 fixed-swirl vanes impart rotation to the airflow. Any particles are thrown into the collection scroll and dumped overboard by the blower. See figure 7-8.

Compressor Section

The compressor section increases the mass airflow delivered to the combustor through a six-stage compressor (five axial, one centrifugal). The

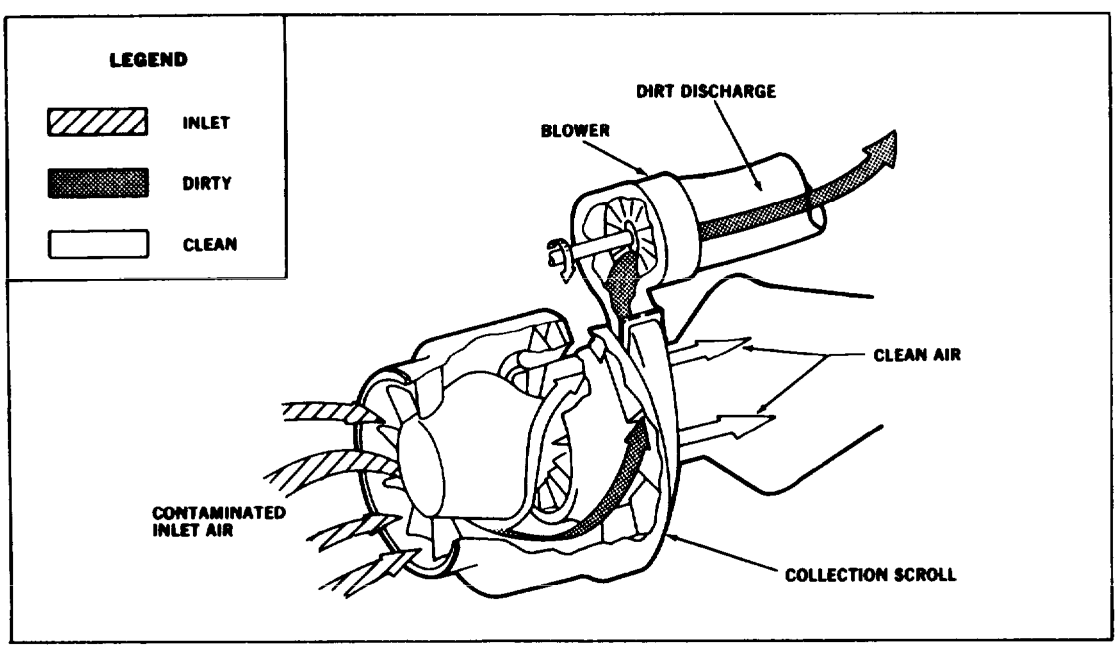


Figure 7-8.-Inlet particle separator (IPS) airflow.

inlet guide vanes and first two rows of stators are a variable geometry design.

Combustor Section

The combustor section houses an annular combustion liner. This section also contains 12 fuel injectors and 2 spark igniters.

Turbine Section

The turbine section has four axial flow turbine wheels. The first two wheels drive the compressor and AGB. These turbines are known as the engine's gas generator turbines. The last two wheels drive the main gearbox. These turbines are known as the engine's power turbines. The turbine section also houses the seven turbine gas temperature (TGT) thermocouples, which mount between the gas generator and power turbines.

Exhaust Section

The exhaust section is aft of the turbine section and contains two power turbine speed (Np) sensors. The exhaust section directs the hot exhaust gases to the atmosphere.

PRIMARY HELICOPTER COMPONENTS

Because components vary in function and complexity on different models of helicopters, we will discuss only representative units. Refer to the aircraft MIM for details on components for a specific helicopter.

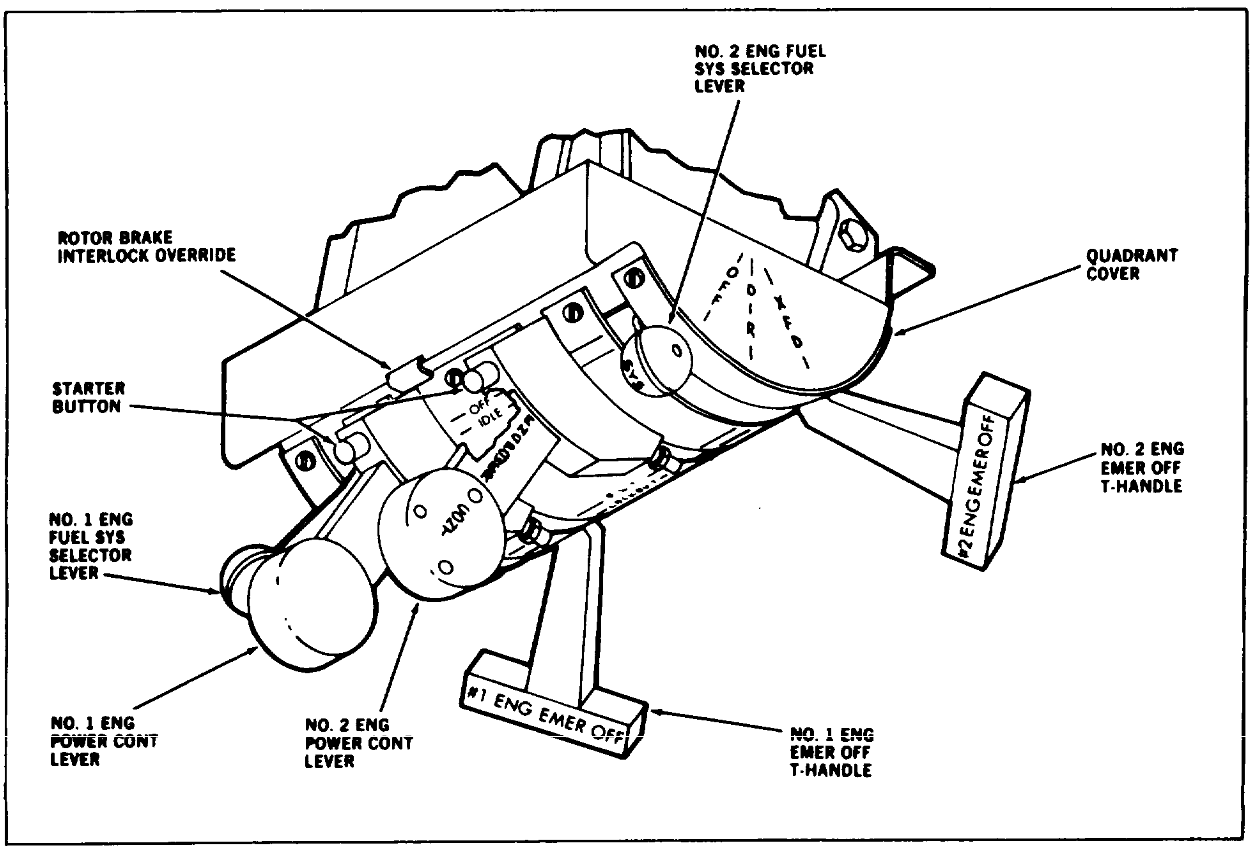


Figure 7-9.-Engine control quadrant.

ENGINE CONTROL QUADRANT

An engine control quadrant is shown in figure 7-9. It consists of two engine power control levers, two engine fuel system selector levers, and two engine emergency off T-handles. It also has a power control lever rotor brake interlock. Each power control lever has a starter button and four selectable positions. The positions are OFF, IDLE, FLY, and LOCKOUT.

Movement of the power control lever to the OFF position moves a cable to shut off the fuel. Movement of the lever between IDLE and FLY sets the available gas generator turbine speed (Ng). Move the lever to the FLY position for flight rotor speeds. If demanded, this setting gives the highest available power. When moved to the LOCKOUT position momentarily, the power control lever manually controls Ng and Np. In this mode, the electrical control unit (ECU) is disabled. The only automatic function NOT de-energized is the Np overspeed protection. To return to automatic engine control, move the power lever to the IDLE position, then back to the FLY position.

POWER TRANSMISSION SYSTEM

The transmission system takes combined power from two engines, reduces the rpm, and transfers it to the main and tail rotors. The secondary function is to provide a drive for electrical and hydraulic power generation. The transmission system of a typical helicopter consists of the main transmission gearbox, an intermediate gearbox, a tail gearbox, and drive shafts. Most systems also include an oil cooler, blower, and rotor brake system. Figure 7-10 shows the SH-3

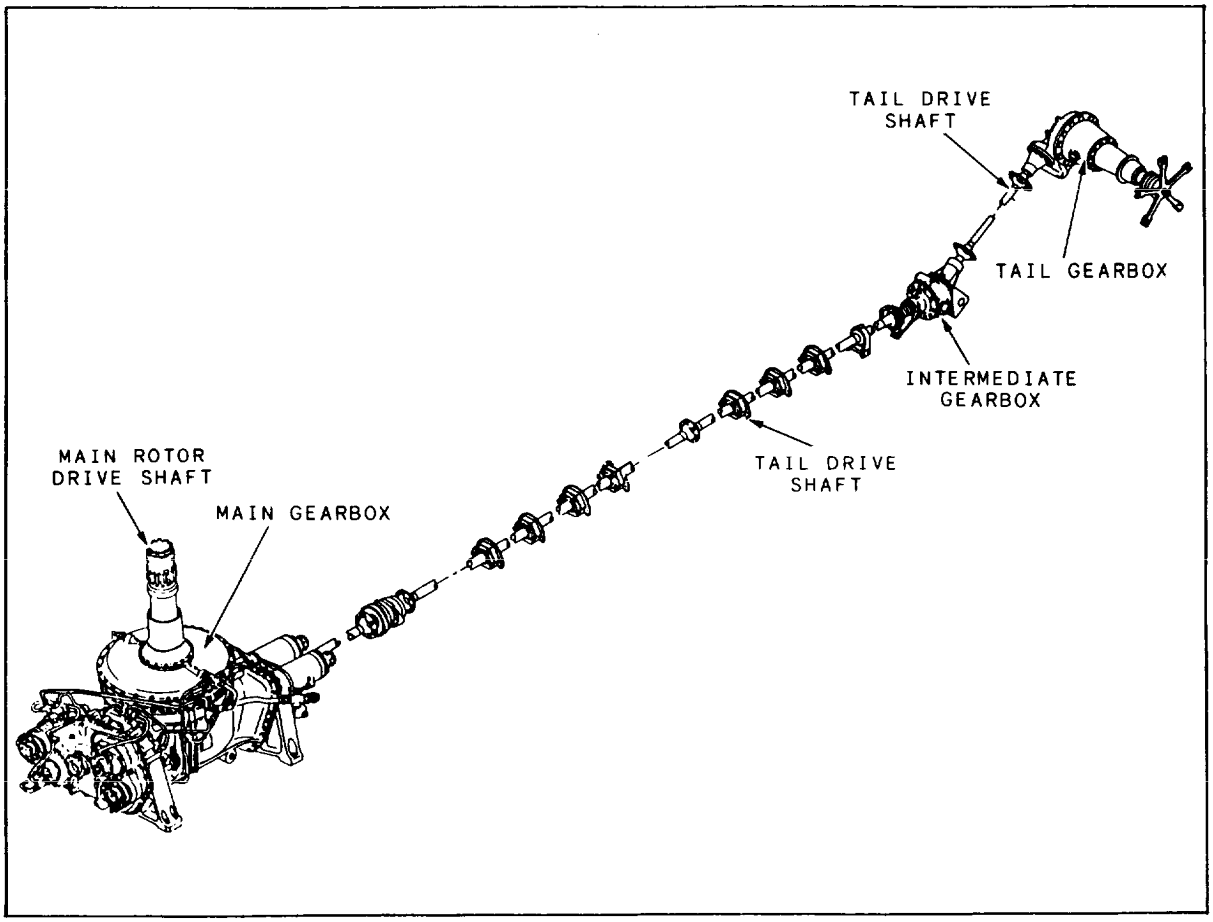


Figure 7-10.-SH-3 power transmission system.

transmission system, and figure 7-11 shows the SH-60 transmission system.

NOTE: Always refer to the applicable MIM when attempting repair on helicopter systems.

MAIN TRANSMISSION GEARBOX (SH-3)

The main gearbox mounts above the cabin aft of the engines. Its main purpose is to interconnect the two engines in order to drive the rotary wing. The main gearbox accessory section is at the rear of the main gearbox lower housing. See figure 7-12. It drives the primary, utility, and auxiliary hydraulic pumps. It drives the high-pressure torque meter oil pump, the No. 1 and No. 2 generators, and the rotary wing tachometer-generator. Dual oil pumps are on the accessory section. These pumps increase reliability through better lubrication and permit continued flight if one pump fails. The single planetary gear reduces engine rpm to drive the rotary wing and accessories. See figure 7-13.

A freewheeling unit, at each engine input to the main gearbox, permits the rotary wing to autorotate without engine drag. The action occurs in case of engine (or engines) failure or when engine rpm decreases below the equivalent of rotor rpm. The freewheeling unit also provides a means of disengaging the rotary wing head while providing power to operate accessories.

The accessory drive rotor lockout permits the pilot to use engine power to drive the accessory section of the main gearbox. This action occurs on the ground without rotating the rotary wing head. Power comes from the No. 1 engine only. A switch allows the pilot to position the linear actuator and divert power to either the accessory section or rotary wing. This switch, located on the forward overhead switch panel, is marked ACCESSORY DRIVE.

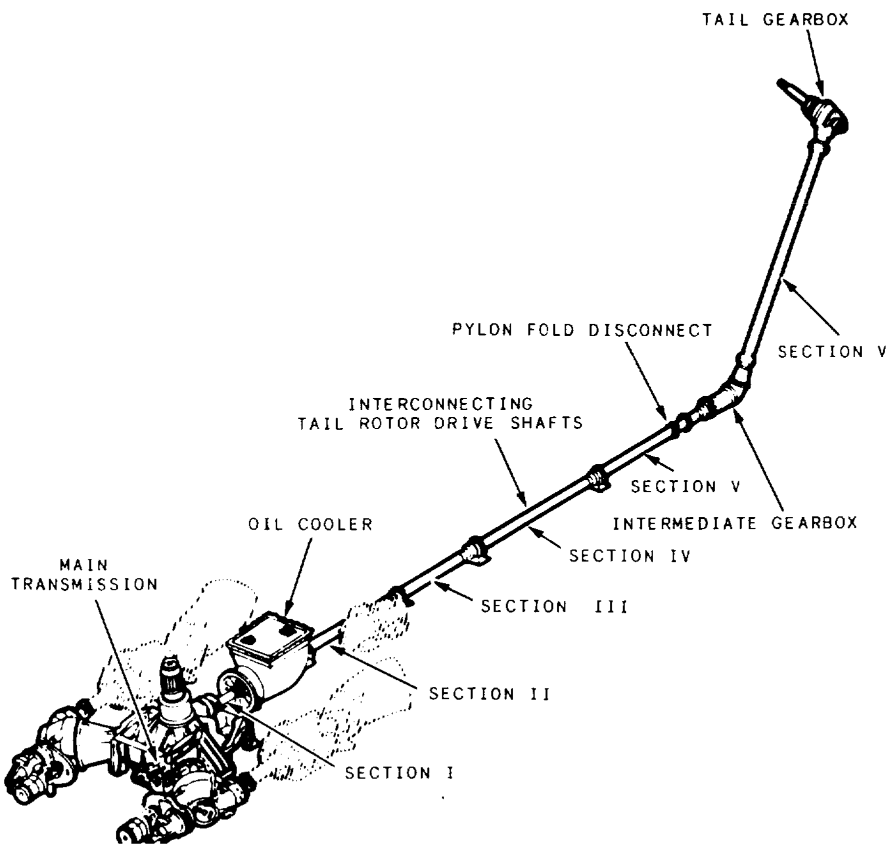


Figure 7-11.-SH-60 power transmission system.

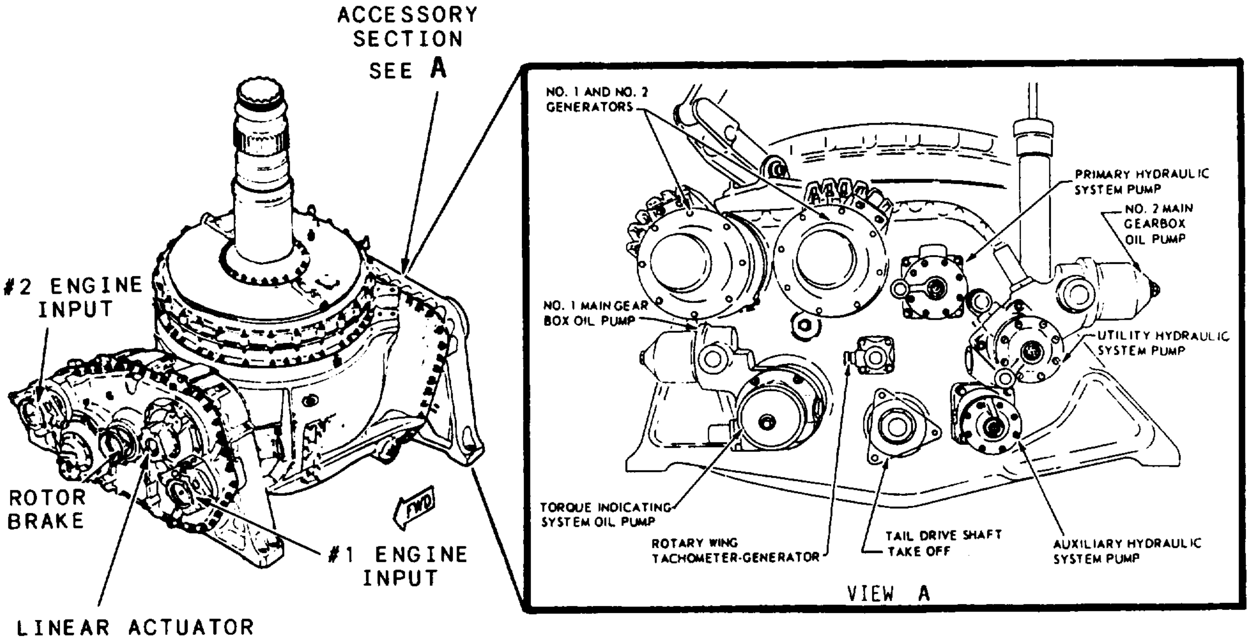


Figure 7-12.-SH-3 main gearbox.

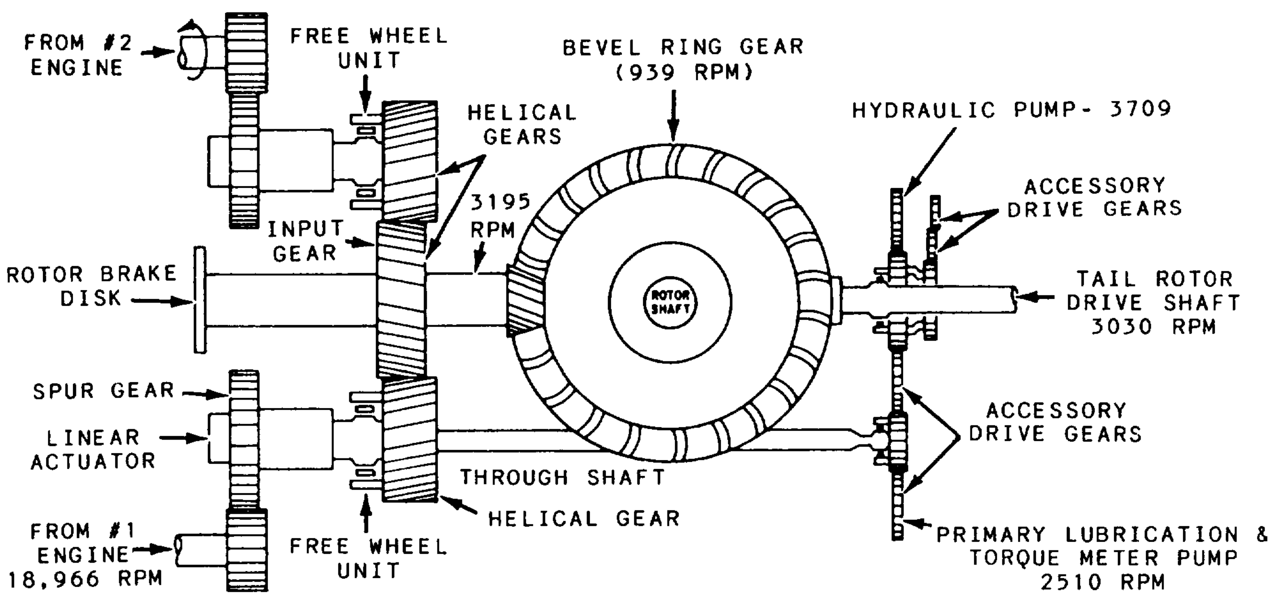


Figure 7-13.-Main transmission schematic.

MAIN TRANSMISSION (SH-60)

The main transmission gearbox drives and supports the main rotor. See figure 7-14. Notice that the SH-60 main transmission, like the engine, is of modular design. The gearbox consists of five modules. The modules are a main module, two input modules, and two accessory modules. The left- and right-hand input and accessory modules are the same, and they are interchangeable. The main gearbox is pressure lubricated and uses the standard oil indicating systems.

Main Module

The main module provides mounting for the two input and accessory units. It has oil pressure, oil temperature, low oil pressure, high temperature warning, and chip detector systems incorporated.

A rotor brake mounted on the tail takeoff provides the capability to stop the rotor system. The rotor brake disc also provides the means to position the main rotor blades for folding.

Input Module

The input modules mount on the right and left front of the main module and support the front of the engines. They each contain an input bevel-pinion and gear, and a freewheel unit. The freewheel unit allows engine disengagement during autorotation. If an engine fails, the freewheeling unit allows the main transmission to continue to drive the accessory unit. The input module provides the first gear reduction between the engine and the main module.

Accessory Module

Each accessory module provides mounting and drive for an ac generator and a hydraulic pump package. Accessory modules mount on the forward section of each input module. Identical and interchangeable sensors are mounted on them. A rotor speed sensor mounts on the right module. The left module provides a mount for a low oil pressure sensor.

INTERMEDIATE GEARBOX

The intermediate gearbox transmits torque and changes the angle of drive from the main transmission gearbox to the tail gearbox. The intermediate gearbox has an input housing and gear, a spring-loaded disconnect jaw, a center housing, and an output housing and gear. The

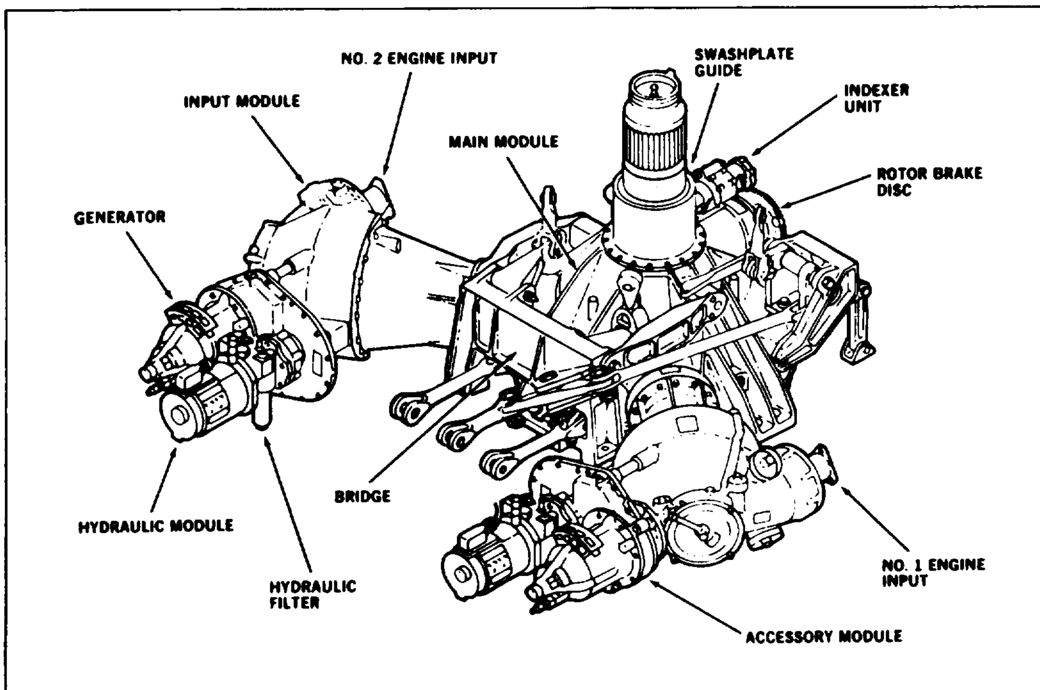


Figure 7-14.-SH-60 main transmission gearbox.

disconnect jaw permits folding and unfolding of the pylon without manually disconnecting the transmission. A transmission lock prevents the rotary rudder from windmilling when the pylon is folded. The lock is automatically unlocked when the pylon is unfolded (flight position). The input and output housings contain similar bevel gears to change the angle of drive up along the pylon. The center housing has an oil level sight gauge. It has a chip detector/drain plug on the bottom, and the filler plug at the top. See figure 7-15. The electromagnetic chip detector, in addition to normal chip detector function, also detects overheating of the intermediate gearbox. The gearbox is splash-lubricated and air cooled.

TAIL GEARBOX

The tail gearbox, mounted at the top of the tail pylon, supports and drives the rotary rudder. It reduces shaft speed and changes the direction of drive by 90 degrees. A pitch change shaft, controlled by the rudder flight controls, operates a pitch change beam. Linked to the sleeve of each rotary rudder blade is a pitch change beam. The gearbox is splash-lubricated and air cooled. See figure 7-16. An electromagnetic chip detector/drain plug is in the bottom of the input housing. It also has an oil level sight gauge and a filler plug. Access to the tail gearbox is through the tail gearbox access fairing at the top of the pylon.

MAIN DRIVE SHAFT

The main drive shaft is a dynamically balanced shaft that transmits torque from the power turbine to the main gearbox. The SH-3 drive shaft assembly consists of a high-speed shaft, Thomas coupling, engine adapter, and match-marked nuts for engine attachment. The shaft assembly has match-marked bolts and nuts for attachment to the main gearbox coupling. The Thomas coupling and engine adapter secure to the shaft by special bolts and hi-lock collars to prevent disassembly. The shaft is made of tubular steel, and it is about 13 1/2 inches long. It is flanged at both ends for connection to the Thomas coupling, adapter, and power turbine coupling flange, and to the main gearbox coupling flange. The drive shaft is within and protected by the aft engine support. The direction of shaft rotation is clockwise (when

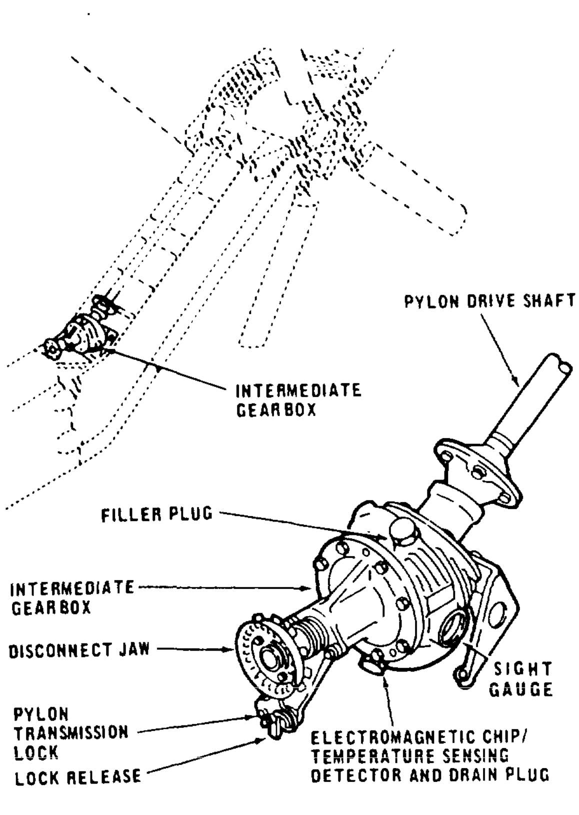


Figure 7-15.-Intermediate gearbox.

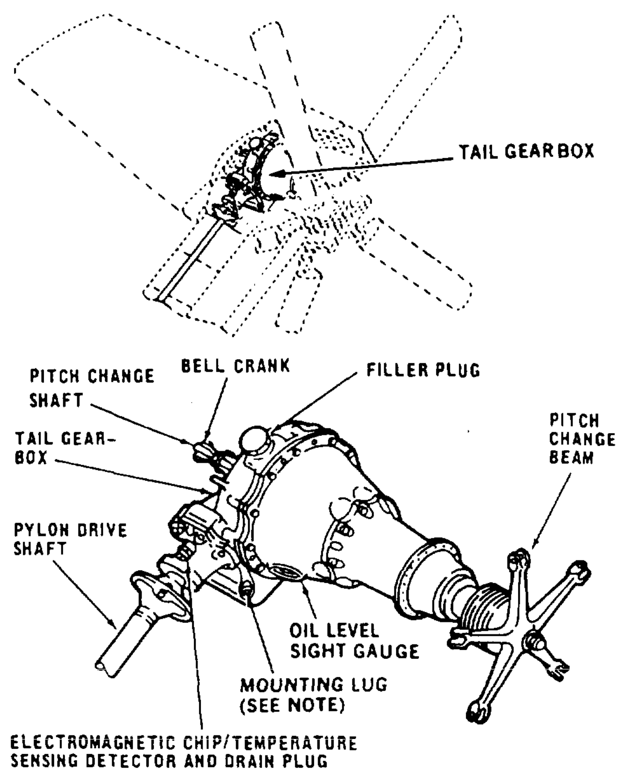


Figure 7-16.-Tail gearbox.

viewed from the aft end of the engine). To remove the main drive shafts, both remountable power plants must be removed.

TAIL DRIVE SHAFT

The tail drive shaft runs from the rear cover of the main gearbox to the disconnect coupling at the intermediate gearbox. See figures 7-10 and 7-11. The shaft between the intermediate gearbox and the tail gearbox is known as the pylon drive shaft.

The primary purpose of the tail drive shaft is to send engine power to drive the rotary rudder. On some installations it also provides a means to drive the main transmission gearbox oil cooler and blower fan. On the SH-60, there are five sections of drive shafting from the main transmission to the intermediate gearbox. There is one section of tail drive shaft between the intermediate and tail gearbox—making a total of six sections. Each section connects by a flexible steel coupling called a Thomas coupling, eliminating the need for universal joints. Each coupling has flexible stainless steel discs stacked together. Flats assure that the stack is in correct alignment. The grain in one disc runs parallel to the flats, and the grain in the other disc runs perpendicular to the flats. The shaft sections are supported by viscous-damped bearings. Each viscous-damped bearing support is a ball bearing enclosed by a thick rubber-type bag. Heavy silicone oil in the bag dampens vibrations in the tail drive shaft assembly. The pulley and belts that drive the oil cooler fan are attached to the oil cooler drive shaft. These are found between sections I and II of the tail drive shaft. See figure 7-11. The section VI drive shaft is in the tail pylon. It sends power from the intermediate gearbox to the tail gearbox.

OIL COOLER AND BLOWER

The main gearbox oil cooler and blower unit of the SH-3 helicopter is in the aft rotary wing fairing. It consists of a cooler (radiator), blower, and duct. The cooler is belt-driven by the tail drive shaft. If the temperature of the oil is less than 70°C, the oil is bypassed to the return line by a thermostatic regulator. Oil returning from the radiator or the bypass is forced through the lubricating jets located in the gearbox.

ROTOR BRAKE

The rotor brake system permits applying the main rotor brake manually or automatically. It uses a master brake cylinder, pressure gauge, panel package, rotor brake, rotor brake accumulator, check valves, and pressure switches. Operation of the system is in conjunction with the operation of the automatic blade folding system. The rotor brake at the rear of the main gearbox is hydraulically actuated. Its purpose is to stop the rotation of the rotary wing head and rotary rudder. See figure 7-14. Actuation is manual by means of the rotor brake master cylinder in the cockpit. Operation is automatic during blade folding by the blade positioner control valve. The rotor brake consists of a rotor brake disc and housing.

POWER TRANSMISSION COMPONENT MAINTENANCE

When performing inspections, removal, repairs, or installation maintenance functions on parts, you must follow procedures specified in the appropriate MIMs.

MAIN TRANSMISSION INSPECTION

Besides inspecting for corrosion, and treating the main transmission outer surface for corrosion, there are some areas that require more attention. Visually inspect these areas for signs of overstress or beyond torque limit capabilities. The main areas are the barrel nuts, the forward bell crank support bridge mounting pad, and the main module mounting feet.

Barrel Nut Inspection

On the H-60 helicopter there are three different part numbers for barrel nuts. The procedure for checking each one of them is the same. Install a mount bolt onto the barrel nut until there are two threads exposed beyond the nut. Using a torque wrench, back out the bolt. If the breakaway torque is less than that specified in the MIM for that specific part number nut, discard the nut. Replace the nut with a new one, and repeat the procedure.

Bell Crank Support Mounting Pad

Following all safety procedures, clean all traces of paint and sealing compound from the mounting pad with dry-cleaning solvent. Repair minor nicks, gouges, scratches, and corrosion pitting on the surface of the mounting pad. Measure the depth of damage to make sure that blending out the damage does not go deeper than allowable repair limits. Remove corrosion by light sanding with aluminum oxide abrasive cloth. Inspect all blended areas using fluorescent penetrant. Crack indications or damage greater than specified requires replacement of the main module.

Main Module Mounting Feet

Visually inspect the main module mounts daily for cracks radiating outward from the center of the bushings. Check for cracks extending down from the sides of the mounting feet. If no cracks are found either in the mounting feet or the sealing compound, further inspection is not required. Crack indications will require replacement of the main module. Repair minor damage as long as the repaired area stays within the specified repairable limits.

MAIN TRANSMISSION REMOVAL

To make the main transmission accessible for removal, the removal of other items is necessary. First, remove rotor blades and head, swashplate, and engine air inlets. Next, remove the left and right input modules with accessory modules attached. Remove all electrical connections and harnesses, and all oil and hydraulic lines. Disconnect and support the tail rotor drive shaft. To prevent damage to the tail rotor and drive shafts while the tail drive is disconnected, make sure the tail rotor does not rotate. Remove fore and aft bell crank support mounting nuts, bolts, and washers. Install a lifting eye on the main rotor shaft. Remove main module mount bolts, and raise the main module clear of the helicopter. Lower the module onto an adapter and secure with the appropriate bolts, washers, and nuts.

NOTE: The main transmission main module weighs about 750 pounds. With all equipment installed, it weighs 1,200 pounds. The main transmission with the rotor head and equipment installed weighs about 2,749 pounds. Be sure to use a hoist with suitable weight capacity.

MAIN TRANSMISSION INSTALLATION

The main transmission installation procedures follow the removal procedures in reverse. There are some precautions to follow during the installation. To prevent damage, carefully guide the main module into place to clear all parts on the helicopter. Apply antiseize compound to the mounting bolts.

WARNING

Antiseize compound may contain lead. Do not smoke, drink, or eat when handling it. Wash thoroughly after use. If accidently swallowed, do not induce vomiting. Seek medical attention. Sealing compounds and adhesives are toxic. Use rubber or polyethylene gloves and goggles. Wash hands thoroughly with soap and water before eating or smoking. Avoid breathing vapors during mixing, lay-up, or curing. Avoid breathing dust from sanding or grinding.

To prevent corrosion damage to locator pins and supports on the main module, seal pins and supports from moisture accumulation. Lower the main module into position on the helicopter mounting surface. To ease installation, first line up the front mounting holes and insert the mount bolts. Next, line up the rear mounting holes and insert the bolts. Follow the remainder of the installation procedures as specified in the MIMs.

TAIL DRIVE SHAFT INSPECTION

Inspect the shaft for scratches. Blend out scratches with crocus cloth. Replace the shaft section if the damaged or blended area exceeds specified limits. Inspect flexible couplings for nicks or dents. Blend out dents and nicks on the edges of individual disc, and replace the coupling if the damaged or blended area exceeds specified limits. Inspect each flexible coupling for disc separation. Each disc assembly may have disc separation or buckling, provided there are no kinks, sharp bends, or cracks. Replace the entire coupling if specified limits are exceeded. Inspect the plates in the coupling washer area for wear. Replace the entire coupling if any wear is found. Inspect the couplings for cracks in the disc. Check areas close to bolts and special washers. Replace the coupling if cracks are found.

TAIL DRIVE SHAFT REPAIR

Remove paint, dirt, and grease from the damaged area. Use a cloth moistened with methyl

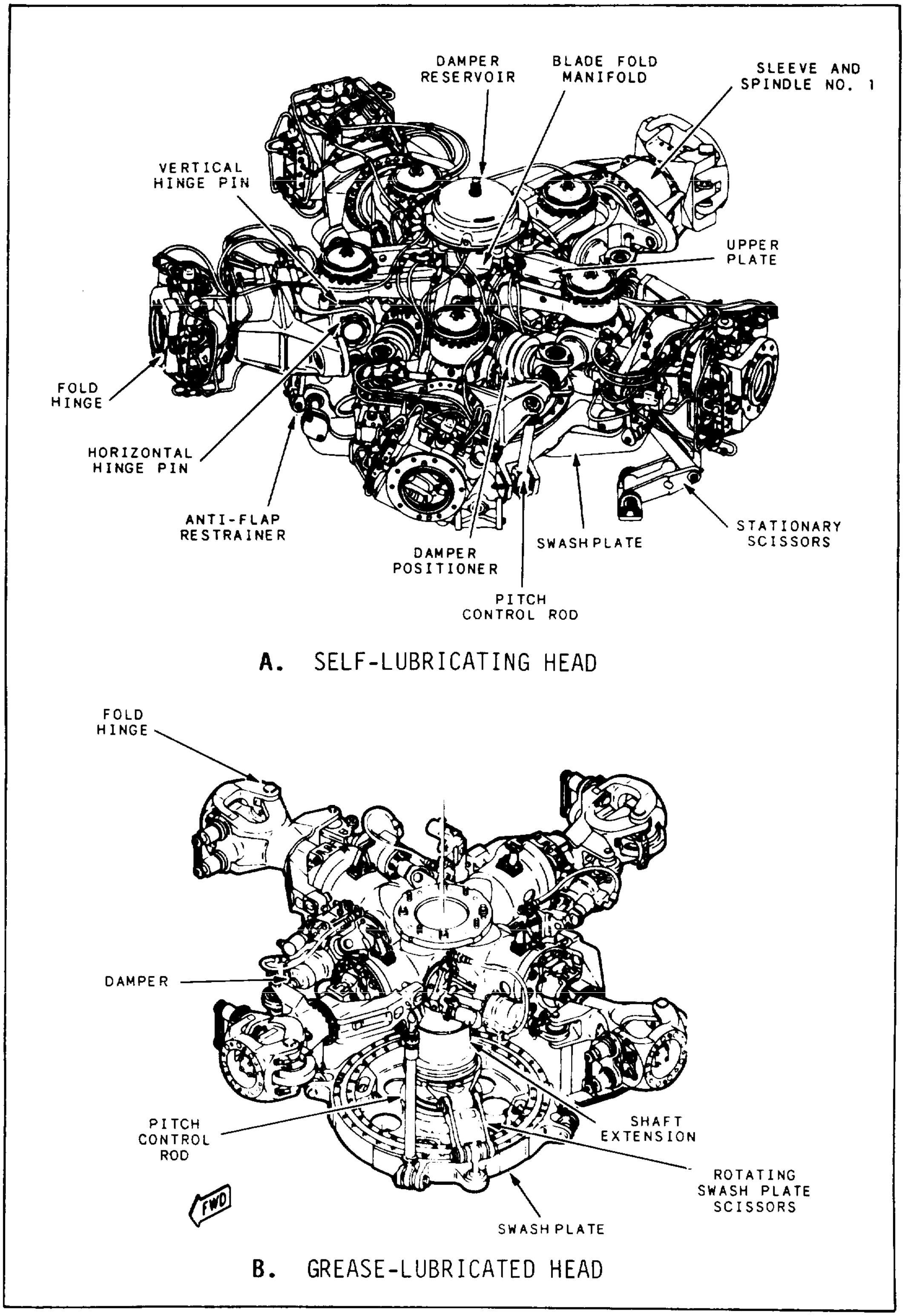


Figure 7-17.-Rotary wing head assemblies; (A) Self-lubricating head; (B) Grease-lubricated head.

ethyl ketone. Protect bearings and Thomas couplings from solvent and dirt. Blend out the damaged area using crocus cloth. The blend radius must not exceed specified limits, Wipe the area with a clean cloth moistened with methyl ethyl ketone. Prime the area with zinc chromate primer, and touchup with matching paint.

NOTE: Limit your repair of the drive shaft to the outside diameter of the tubular shaft. Repair must be done in the scratched area only.

ROTOR SYSTEMS

The rotor system consist of the main rotor head, main rotor blades, tail rotor head, and tail rotor blades. This section on rotor systems discusses the general components and identifies some of the different features or materials being used.

MAIN ROTOR HEAD

The fully articulated rotary wing head is splined to the rotary wing shaft of the main gearbox. The head is supported by the rotary wing shaft. The head supports the rotary wing blades, and is rotated by torque from the main gearbox. The head transmits movement of the flight controls to the blades. Its design permits automatic folding of the blades from a control panel in the cockpit.

There are two types of rotary wing heads in use. They are the grease-lubricated and self-lubricating heads. See figure 7-17. The grease-lubricated rotary wing head contains grease fittings for lubrication. The self-lubricated rotary wing head has fewer grease fittings, because oil reservoirs (tanks) are used on the hub plate at the vertical hinges. These reservoirs lubricate upper and lower hinge bearings and the stack bearings in sleeve spindles.

Principal parts of the head are the hub and swashplate. The hub consists of a hub plate, lower plate, and hinges between each arm of the plates. The hub contains sleeve spindles that are attached to the hinges and damper-positioners. The swashplate consists of a rotating swashplate and a stationary swashplate. The rotary wing head has antiflapping restrainers, droop restrainers, adjustable pitch control rods, and the rotating and stationary scissors. The swashplate and adjustable pitch control rods permit movement of the flight controls to be transmitted to the rotary wing blades. The hinges allow each blade to lead, lag, and flap. The damper-positioners restrict lead and lag motion and position the blades in preparation for folding. Sleeve spindles allow each blade rotation on its spanwise axis to change blade pitch. The antiflapping restrainers and droop restrainers restrict flapping motion when the rotary wing head is slowing or stopped. The control lock cylinder unlocks to permit the sleeve to turn about the sleeve spindle axis. The stationary scissors are connected to the stationary swashplate and main gearbox upper housing. The rotating scissors are connected to the rotating swashplate and lower hub plate.

MAIN ROTOR BLADES

The rotary wing blades provide the lift necessary for flight. See figure 7-18. The blades are of the nitrogen-pressurized spar type. The

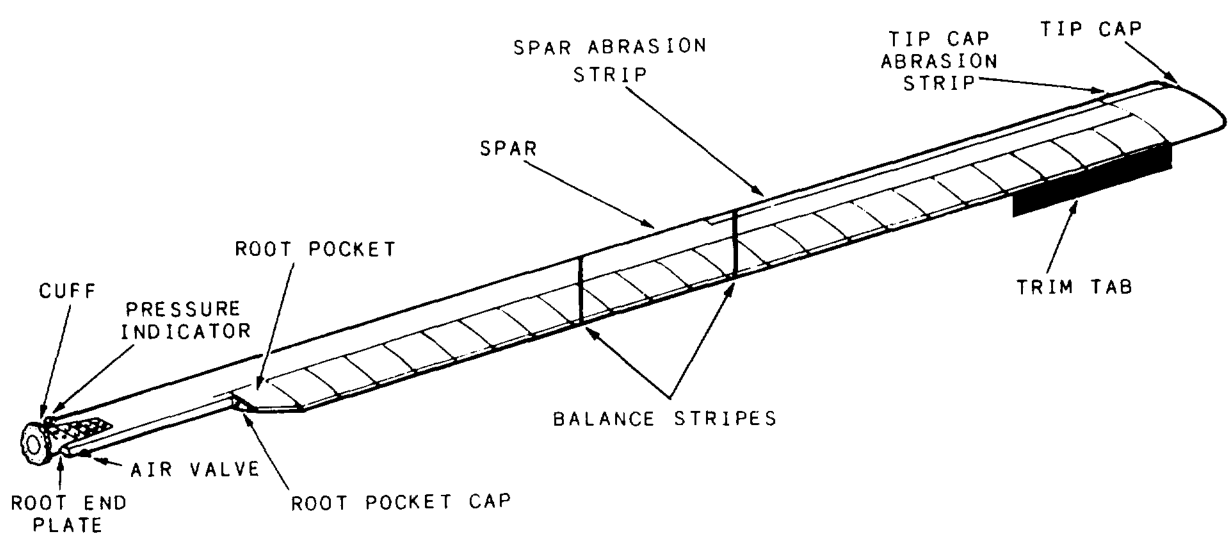


Figure 7-18.-Rotary wing blade.

blade has an air valve in the spar back wall near the root end and a cylindrical pressure plate. The root end plate is attached to the inboard end of the spar. A seal plate is found inside the spar tip end. Both are sealed for pressurization. Pressure loss in the spar shows impaired integrity of the spar or a seal leak. The cuff provides the means for attaching the blades to the rotary wing head sleeve spindles. Nickel-plated or titanium abrasion strips bonded to the spar leading edges prevent erosion.

Older blades consisted of a hollow extruded aluminum spar and aluminum pockets. They have a tip cap, a root cap, and a steel cuff. Newer blades consist of a pressurized titanium spar, honeycomb core, and fiber glass graphite skin. The newer blades are often repairable at organizational-level maintenance instead of depot level. They are repairable at the lower level of repair because of their honeycomb and fiberglass design. Both types of blades are statically and dynamically balanced to permit individual replacement and interchangeability of the blades. In addition to balancing, manufacturers and depot repair facilities stencil blades with a pretrack number to aid in blade tracking.

The pressure indicator, usually known as a BIM or a blade inspection method, compares built-in reference pressure with blade spar pressure. See figure 7-19. When pressure in the spar is within the required service limits, three white stripes show in the indicator. If pressure in the spar drops below the minimum permissible service pressure, the indicator will show three black stripes. The amount of black that shows depends on pressure in the spar. Remove from service any blade on which the pressure indicator shows any black color. The blade may be put back into service when the unsafe (black) indication is found and corrected. Replace a malfunctioning indicator, but only if the spar pressure is within permissible limits.

TAIL (ROTARY) RUDDER HEAD

The rotary rudder head provides for attachment of the rotary rudder blades and counteracts the torque of the main rotor head. See figure 7-20. It also serves as a rudder for directional control of the helicopter. The rotary rudder head is driven by the tail gearbox. Blade pitch changes by the action of the pitch change shaft. The pitch change shaft moves through the center of the output gear shaft of the tail gearbox. As the shaft moves outward from the gearbox, the pitch of the blades decrease. The pitch beam is connected by adjustable pitch change links to the forked brackets of the blade sleeves. The flapping spindles permit flapping of the blades in each direction.

Tail rotor blades are built around a spar that mounts on the tail rotor. The SH-3 has five all-metal, single aluminum pocket blades bonded to a C-shaped spar. The SH-60 blades are built around two graphite composite spars. Honeycomb paddles are then bonded to the spars with fiber glass to form the blade.

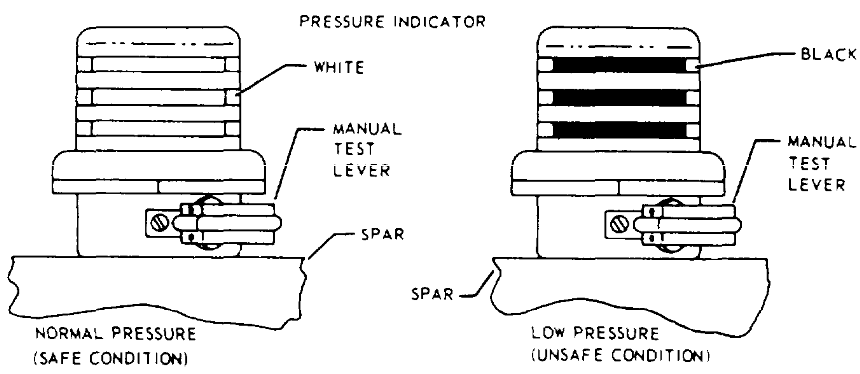


Figure 7-19.-Blade pressure indicator (BIM).

ROTOR SYSTEM MAINTENANCE

Organizational maintenance of the helicopter rotor system includes periodic inspection, lubrication, rigging, and adjustment. Organization maintenance includes the cleaning of the rotary wing and rudder blades, and the removal and replacement of malfunctioning components.

Vibration of the rotary mechanisms can result in work hardening of metals and later fatigue failure. Nondestructive testing of special parts of the rotary wing and the rotary rudder at specified intervals is necessary to prevent failures. The rotary wing head and rotary rudder assemblies are high-time removal items, as listed in the periodic maintenance information cards (PMIC).

Cleaning of the rotary wing and rotary rudder should be accomplished as necessary, using approved cleaners mixed with water. The concentration of the mixture will vary, depending on the surface condition.

WARNING

Both the rotary wing and rudder blades have areas that are joined by bonding adhesives. Never use solvents or cleaners not specifically authorized in the MIM. Never use lacquer thinner, naphtha, carbon tetrachloride, or other organic compounds for cleaning in these bonded areas. The bonding will be weakened by the solvent and may result in blade failure.

Although ADs remove and replace rotary wing parts, the airframes work center normally performs the rigging checks. Rigging checks and adjustment involve coordinating the cyclic pitch control stick, collective pitch control stick, and pedal positions with the correct rotary wing and rotary rudder blade angles. Rigging checks are necessary to ensure that the flight controls are operating under normal friction loads. At the completion of rigging, a flight test is performed by a qualified pilot. This includes a check of blade tracking.

ROTOR BLADE TRACKING

You should perform blade tracking whenever the helicopter has been rerigged. Blade tracking

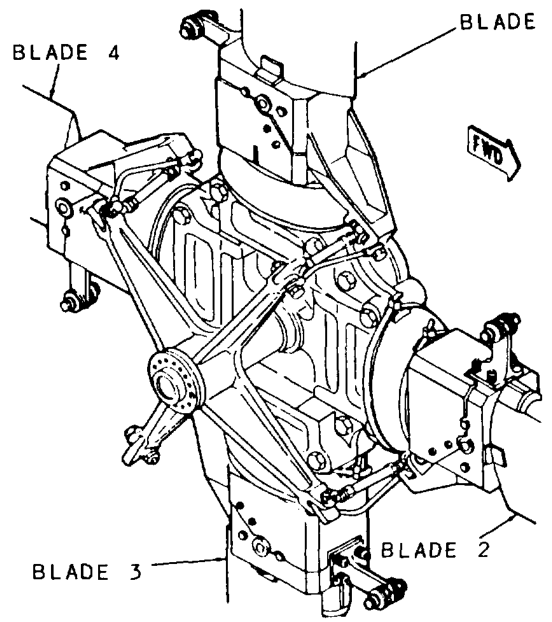


Figure 7-20.-Rotary rudder head.

is necessary when the blades, the main gearbox, or the main rotor head assembly have been replaced. Unless the blades are in proper track, vibrations will occur in the helicopter with every revolution of the main rotor. At high rpm settings, these vibrations could cause serious structural damage.

Tracking the blades is necessary to be sure that all of the blades rotate in the same horizontal plane (track). This is accomplished by pretrack rigging of the rotary wing head and by the use of pretracked blades.

Pretrack rigging of the rotary wing head involves adjusting the pitch control rods until an exact sleeve angle (within 1 minute) is attained on all sleeve spindles. When this exact angle is established, a micrometer type decal is affixed on the adjustable pitch control rods. The decal becomes a permanent reference at the overhaul activity. A pretrack number is stenciled on each blade at manufacture or overhaul, based on the effective angle of the blade. Install any pretracked blade on the helicopter simply by setting the adjustable pitch control rod to the pretrack number stenciled on the blade. The blade tracking is then checked with either Strobex or electronic tracking equipment.

STROBEX TRACKING

A Strobex blade tracker permits blade tracking from inside the helicopter in flight or on the ground. See figure 7-21. The system uses a highly concentrated stroboscopic light beam flashing in sequence with the rotation of the rotary wing blades. When aimed at a fixed target on the blade tips, the tips appear to stop.

To synchronize the strobe light and rotary wing rotation, a soft iron sweep attached to the rotating swashplate passes close to a magnetic pickup on the stationary swashplate. This causes a once-per-revolution pulse used for synchronization. Each blade has a retroreflective target number attached under the blade in a uniform location. Blade tracking is then determined by the relative vertical position of the fixed target numbers.

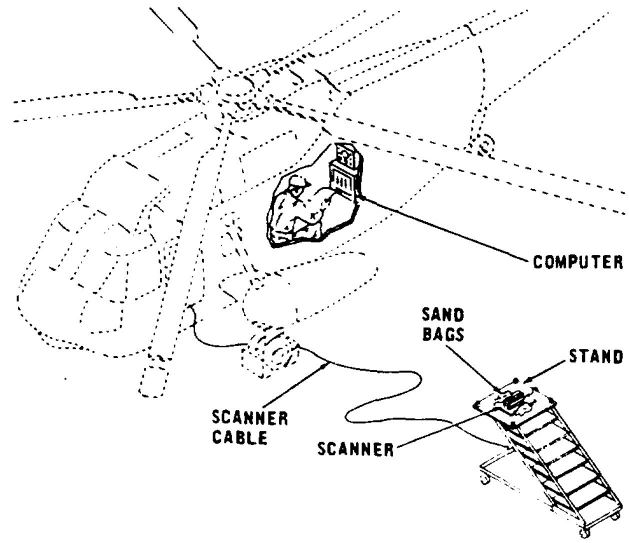


Figure 7-22.-Electronic tracking.

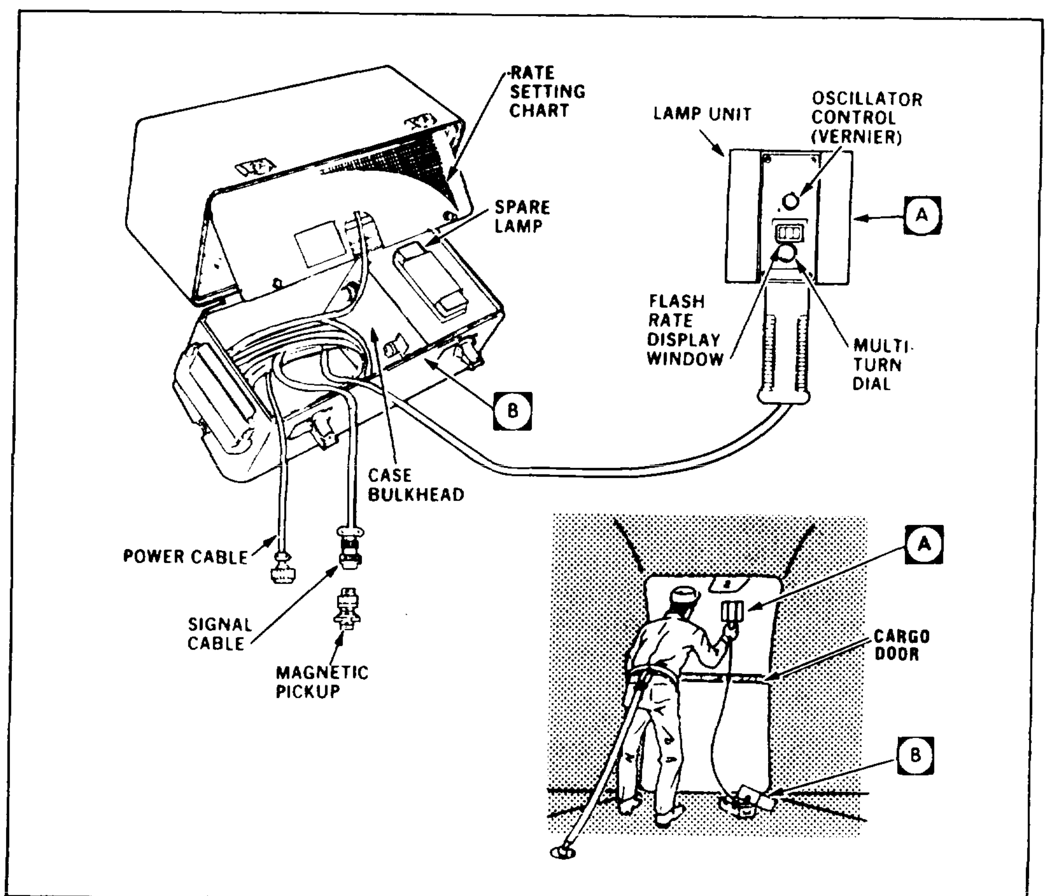


Figure 7-21.-Strobex blade tracker.

ELECTRONIC TRACKING

The electronic blade tracker has a electro-optical pickup (scanner), an electronic conversion unit (computer), and a magnetic phase detector and pulse bracket. The tracker has sun shields and connecting cables. This assembly provides continuous meter readings automatically on out-of-track conditions. See figure 7-22. The meter readings are an average of many electro-optical samplings of each blade, thus eliminating erratic readings caused by wind gusts.

CHAPTER 8

TURBOPROP ENGINES AND PROPELLERS

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Recognize the principles of turboprop operation and identify the major components of the turboprop engine.
- Identify the propeller designation system, operating principles, and basic propeller parts.
- Recognize propeller operating principles.
- Recognize power lever movement through the alpha and beta ranges, and the effects of those movements on the propeller.
- Recognize the procedures and cautions used in the removal, cleaning, and reinstallation of the propeller assembly and subassemblies.

There are a variety of turboprop aircraft in the Navy inventory. The C-130 *Hercules,* a cargo transport aircraft, is the workhorse of naval aviation. The E-2 *Hawkeye is* the fleet's airborne early warning aircraft. The C-2 *Greyhound is* a fleet logistics support aircraft. The P-3 *Orion* is our fleet antisubmarine warfare (ASW) aircraft. See figure 8-1.

In this chapter, the T56 engine and the 54H60-77 model propeller are examples of a common turboshaft engine and propeller system. There are differences in the turboprop aircraft mentioned above, but the basic operation, assemblies, and maintenance are similar.

The turboprop engine section of this chapter discusses the operating principles, parts, and systems unique to turboprop engines. After learning about the turboprop engine, we will discuss propellers. The propeller section describes basic propeller parts, operating principles, and maintenance procedures.

TURBOPROP ENGINES

If the exhaust gases from the basic part of a turbojet rotates an additional turbine that drives a propeller through a speed-reducing system, it is a turboprop engine. The aircraft turboprop is more complicated and heavier than a turbojet engine of equal size and power. The turboprop delivers more thrust at low subsonic airspeeds. This advantage decreases as flight speed increases. In normal cruising speed ranges, the propulsive efficiency of a turboprop decreases as speed increases. In a turbojet, the propulsive efficiency increases as speed increases. The ability of a propeller to accelerate a large mass of air at low airspeed results in the unusual high performance of a turboprop during takeoff and climb. This low-speed performance also enables a turboprop aircraft to carry heavier payloads, making them ideal cargo aircraft. At about Mach 1 airspeed, the turboprop engine can deliver more thrust than the turbojet engine of the same gas turbine design. For a given amount of thrust, the turboprop engine requires a smaller gas turbine with lower fuel consumption than the turbojet engine.

The turboprop engine produces thrust indirectly through the propeller. A characteristic of the turboprop is that changes in power do not change engine speed. Changes in power change the turbine inlet temperature (TIT). During flight, the propeller maintains a constant 100-percent engine speed. This speed is the design speed where power and maximum efficiency is obtained. Changes in fuel flow affect power changes. An increase in fuel flow causes an increase in turbine

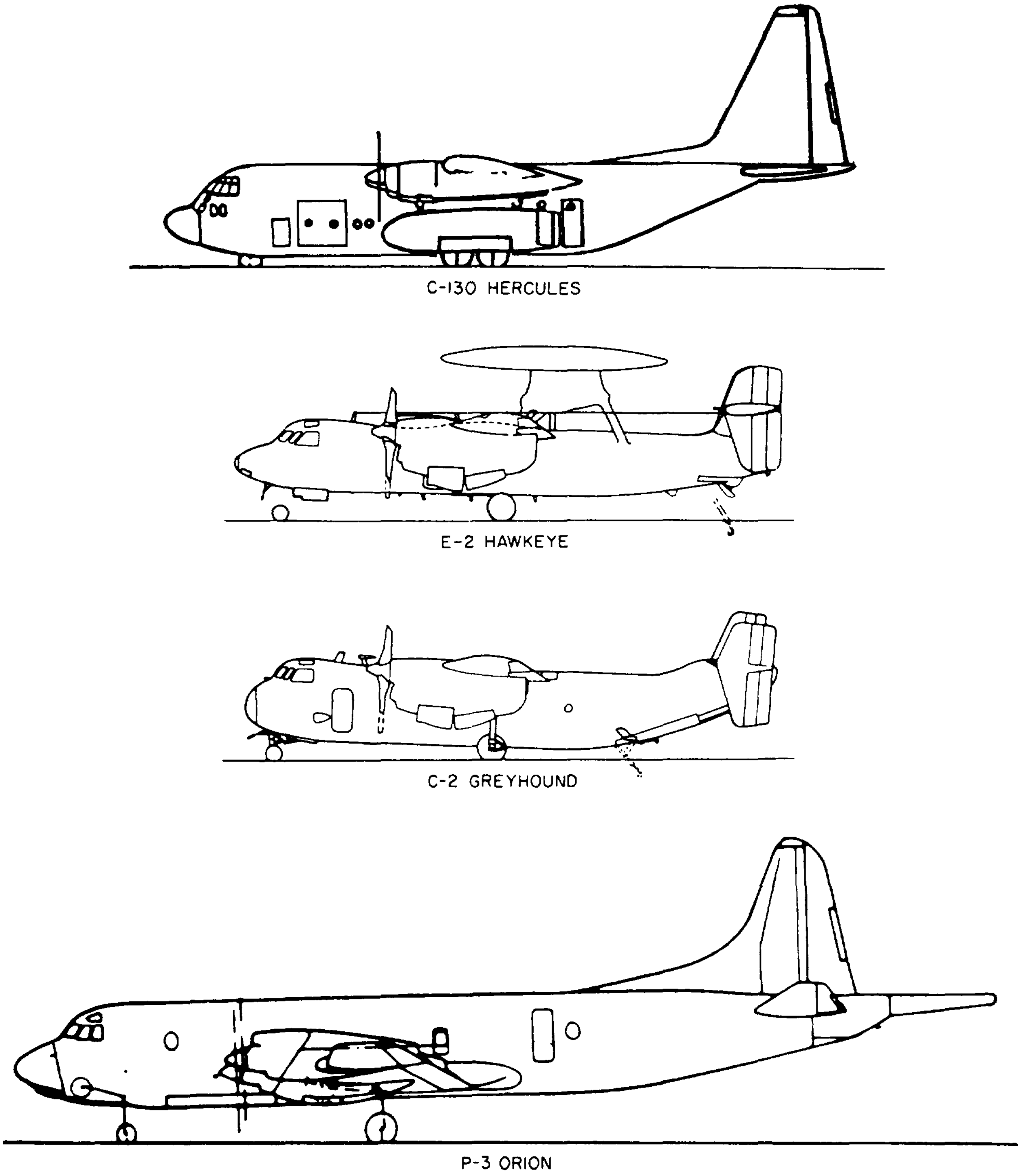


Figure 8-1.-Four types of turboprop aircraft.

inlet temperature and a corresponding increase in energy available at the turbine. The turbine absorbs more energy and sends it to the propeller in the form of torque. The propeller, in order to absorb the increased torque, increases blade angle to maintain constant engine rpm.

These changes occur through coordination between the propeller governor and the turboprop engine fuel control. Together they establish the correct combination of rpm, fuel flow, and propeller blade angle to create the propeller thrust required to provide the requested power.

TURBOPROP ENGINE ASSEMBLIES

The turboprop engine consists of three major assemblies. They are the power section assembly, the torquemeter assembly, and the reduction gear assembly. See figure 8-2. We will discuss the power section assembly first.

Power Section Assembly

The power section assembly is essentially a constant-speed turbojet engine. See figure 8-3. The major assembly consists of an axial flow compressor assembly, a can-annular combustion section, a turbine assembly, and an accessory drive

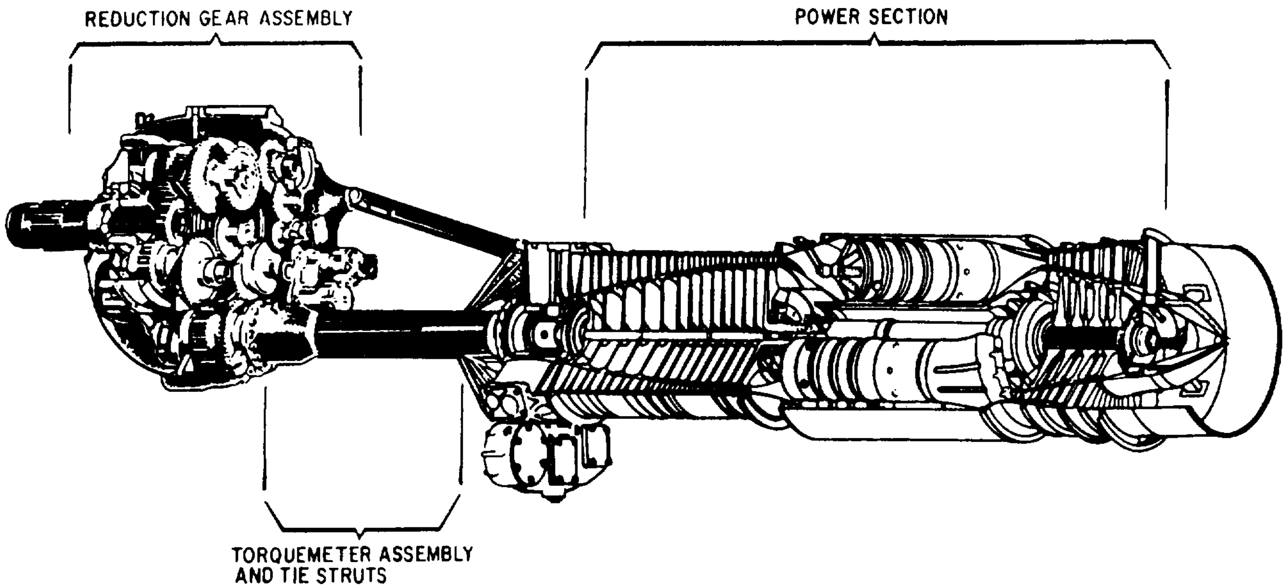


Figure 8-2.-Turboprop engine major assemblies.

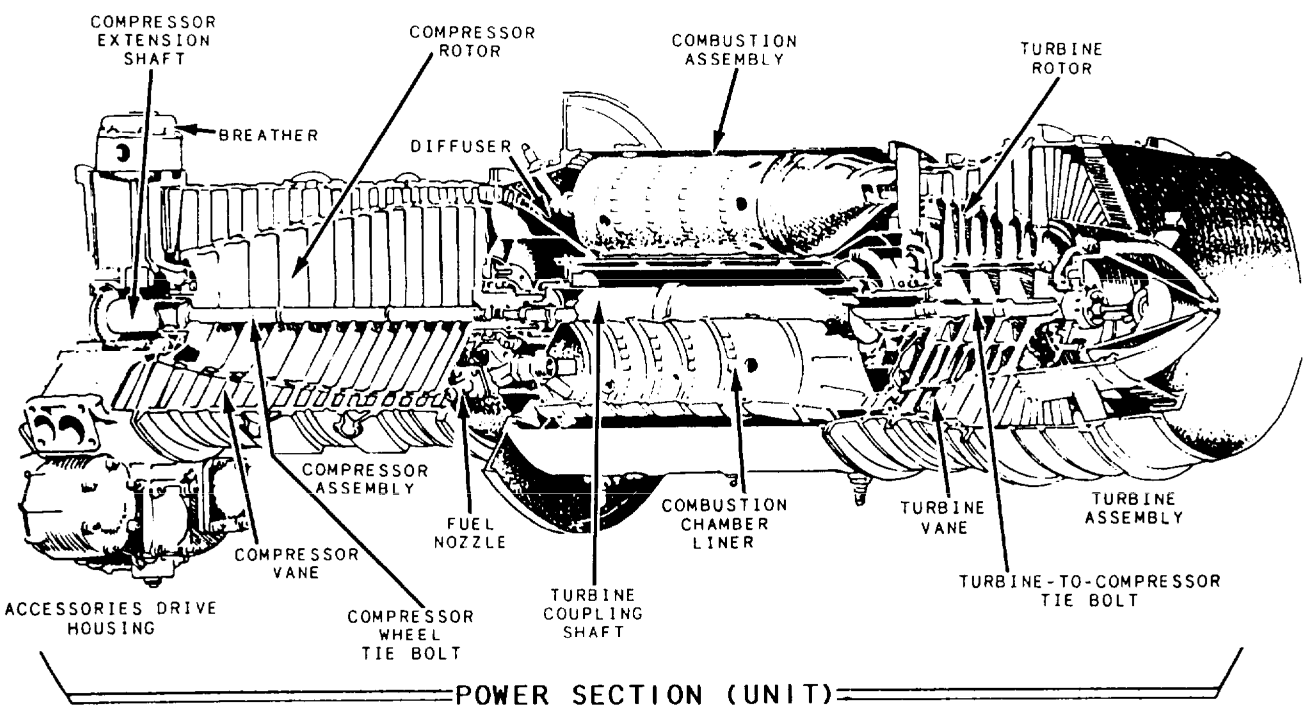


Figure 8-3.-Power section assembly.

housing. The power section assembly contains oil, fuel, ignition, control, and cooling air systems. It also has a compressor extension shaft to which the torquemeter attaches.

Torquemeter Assembly

The torquemeter assembly is located between the power section and reduction gear box assemblies. Its purpose is to transmit and measure the shaft output from the power section to the reduction gearbox assembly.

The torquemeter operates on the principle of accurate measurement of torsional deflection (twist) that occurs in any power transmitting shaft. This torsional deflection is detected by magnetic pickups. The deflection is measured electronically, and displayed on the cockpit instrument panel in terms of inch-pounds of torque, or shaft horsepower (SHP). The principle parts of the torquemeter assembly are shown in figure 8-4.

Two concentric shafts make up the torquemeter assembly. The inner shaft (torque shaft) carries the load and produces the measured twist. The outer shaft (reference shaft for measuring purposes) is rigidly connected to the torque shaft at the drive input end only. There are separate flanges on both the torque and reference shafts at the reduction gear assembly end. Rectangular exciter "teeth" are machined in line on each flange, which enable the pickups to detect the relative displacement of the two flanges.

The torquemeter housing serves as a rigid lower support between the power unit and the reduction gear assembly. It provides a mounting for the pickup assembly at the reduction gear end.

The pickup assembly consists of electromagnetic pickups mounted radially over the teeth of the torque and reference shaft flanges. These pickups produce electrical impulses at the passage of each exciter tooth. The pickups are displaced so that the reference flange impulse from its pickup and the torque flange impulse from its pickup are slightly out of phase at zero load. Because zero torque indications are not at the electrical zero of the indicator, both positive and negative torque conditions are measured.

Reduction Gear Assembly

The reduction gear assembly changes the high rpm, low torque of the turbine section to low rpm, high torque necessary for efficient propeller operation. This change is made through a two-stage reduction system of sun and planetary gears. See figure 8-5. The two stages of reduction provide an overall speed reduction of 13.54 to 1; for example, when power section rpm is 13,820, the propeller shaft rpm is 1,020. The reduction gear case also provides the drive and location to mount the propeller and accessories. Accessories mounted on the case include a starter, generator, engine-driven compressor (EDC), oil pump, and tachometer generator. The reduction gearbox assembly also uses safety systems that we will discuss next.

TURBOPROP SAFETY SYSTEMS

The complexity of the turboprop configuration brought about the possibility of certain hazardous in-flight situations. Safety features have been designed into the system to activate

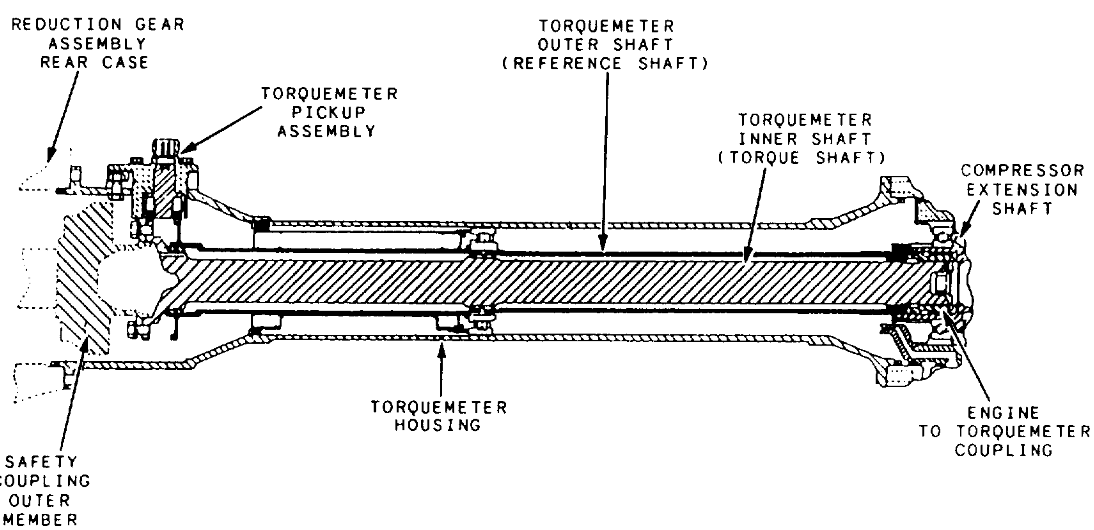


Figure 8-4.-Torquemeter assembly.

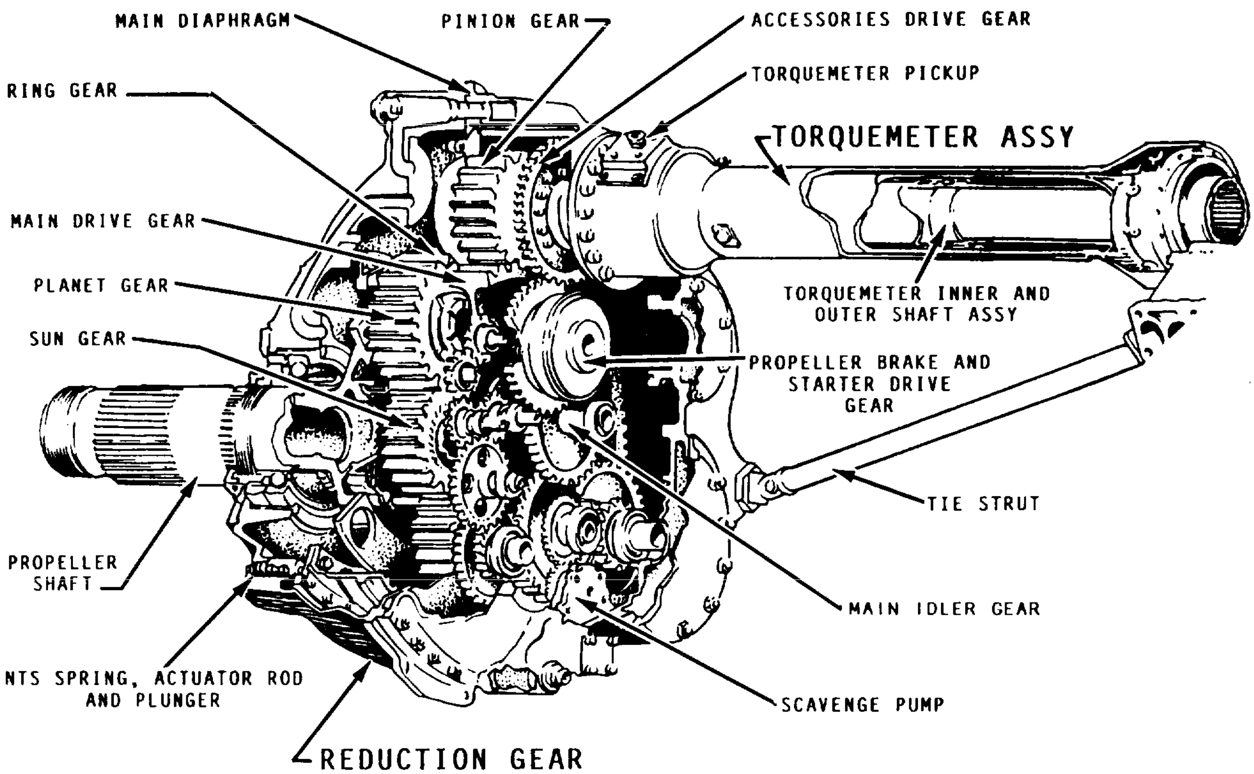


Figure 8-5.-Reduction gear and torquemeter assemblies.

automatically whenever a system-related hazard occurs. The following text discusses some of the hazards and their related safety features.

Thrust Sensitive Signal (TSS)

The thrust sensitive signal system is a safety device used during takeoffs. The TSS automagically initiates propeller feathering and shuts down the turboprop engine in case of power loss. This allows the pilot to concentrate on flying the aircraft during the critical takeoff period. Feathering the propeller reduces the yawing action (caused by drag) and asymmetric flight characteristics on multiengined aircraft. The TSS system is on the reduction gearbox (RGB), and it is armed through a switch in the flight station.

Negative Torque Signal (NTS)

The negative torque signal system momentarily prevents the propeller from driving the engine during in-flight conditions. The NTS system is mechanically locked out during engine operation in the ground range. The system's mechanical linkage and plunger are inside the front case of the reduction gearbox. They work with the propeller valve housing assembly to increase propeller blade angle during negative torque conditions. When a predetermined negative torque is applied to the reduction gearbox, a stationary (nonrotating) ring gear moves forward against spring force. This action results in a rod moving forward through the reduction gear nose case. The rod positions the feather valve in the valve housing to an increased blade angle. When the propeller blade angle has increased enough to relieve negative torque conditions, the plunger retracts and the propeller returns to normal operation.

The NTS system functions in flight during temporary fuel interruptions, air gust loads on the propeller, normal descents with lean fuel scheduling, or high compressor bleed-air conditions at low-power settings.

Safety Coupling

The safety coupling is an automatic mechanical device that decouples (disconnects) the power section from the reduction gearbox assembly when negative torque exceeds the setting of the safety coupling. The safety coupling is between the main input pinion gear shaft on the reduction gearbox and the outer member of the torquemeter drive shaft. Any transfer of torque, positive or negative, between the power section and the reduction gear assembly transmits through the safety coupling. Positive torque occurs when the power section drives the propeller through the reduction gear assembly. Negative torque occurs when the propeller drives the power section. The safety coupling backs up the NTS system to prevent engine compressor and turbine damage. If the NTS system fails to limit negative torque, the safety coupling protects the engine from extensive damage by decoupling.

Propeller Brake

The propeller brake is used when a turboprop engine is not in operation. Since the compressor and turbine rotors can rotate easily when the engine is shut down, a propeller brake is needed. The propeller brake prevents the propeller from windmilling on the ground or when it is feathered in flight. It also decreases the time for the propeller to come to a complete stop after engine shutdown. The brake is in the reduction gearbox assembly between the rear case and rear case inner diaphragm. It is part of the accessory drive gear train. The propeller brake has three positions. They are the released, applied, and locked positions.

The propeller brake is a friction-cone type, consisting of a stationary inner member and a rotating outer member. During normal engine operation, reduction gear oil pressure holds the brake in the released position. This is accomplished by oil pressure, which holds the outer member away from the inner member. When the engine is shut down, reduction gear oil pressure drops. A spring force moves the outer member into contact with the inner member or to the applied position. The propeller brake locks when it is moved in a direction opposite normal rotation. When locked, it acts upon the reduction gearbox primary stage reduction gearing to prevent movement along with the friction-cone brake.

TURBOPROP CONTROL SYSTEMS

The control of a turboprop engine involves the control of engine speed, temperature, and torque.

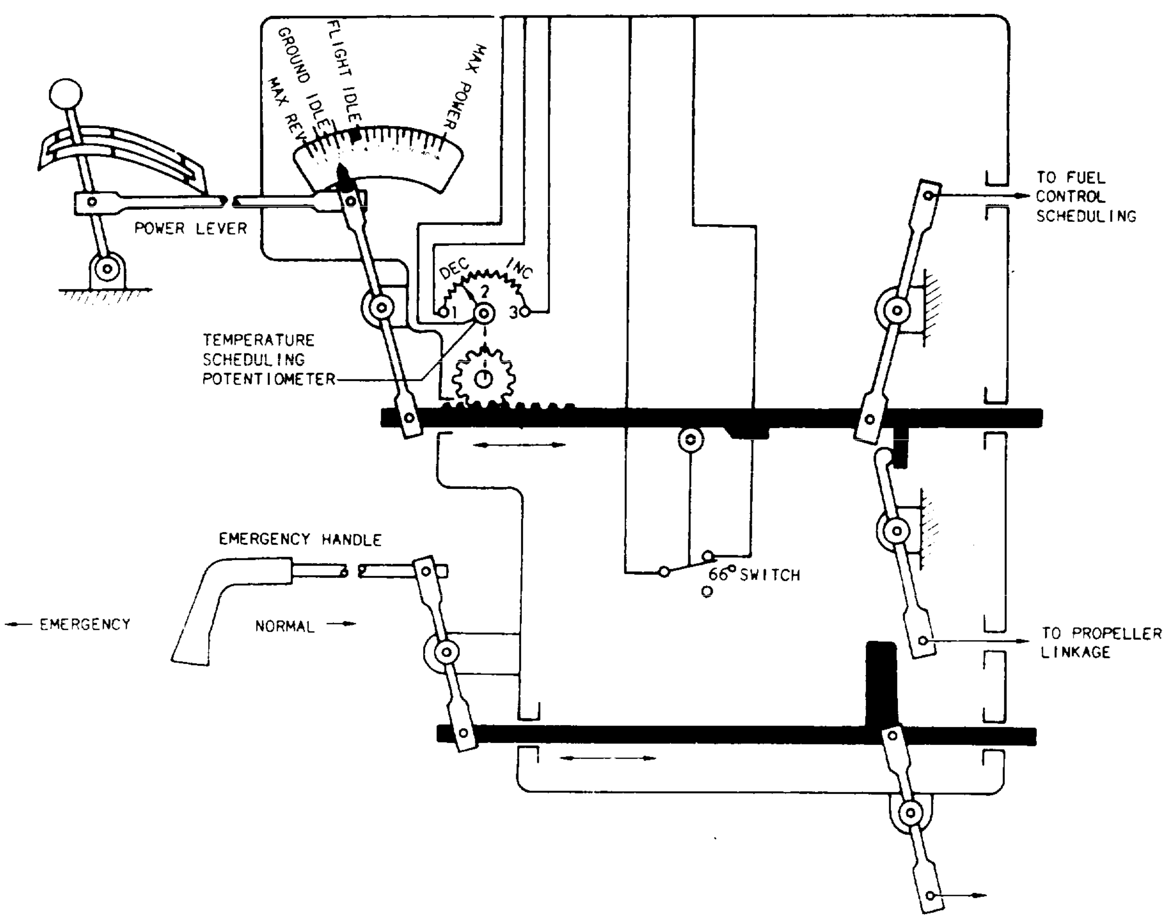


Figure 8-6.-Control schematic.

The turboprop fuel control and the propeller governor are connected and operate in coordination with each other. Together they establish the correct combination of rpm, fuel flow, and propeller blade angle to create sufficient propeller thrust to provide the desired power.

Manual control of the system is provided by the power levers and the emergency shutdown handles mounted in the flight station. See figure 8-6. The control systems are divided into two operational ranges. They are the flight control range (alpha) and ground handling range (beta).

For airborne operation, the propeller blade angle and fuel flow for any given power lever setting are governed automatically according to a predetermined schedule. Below the flight idle power lever position, the coordinated rpm blade angle schedule becomes incapable of handling the engine efficiently. Here the ground handling or beta range is encountered. In this range of the throttle quadrant, the propeller blade angle is controlled by the power lever position. Next, we will discuss the engine's control system components—power levers, fuel control, and coordinator.

Power Levers

The power lever controls power delivered by the engine. There are six positions marked on the power lever quadrant. See figure 8-7. Listed below

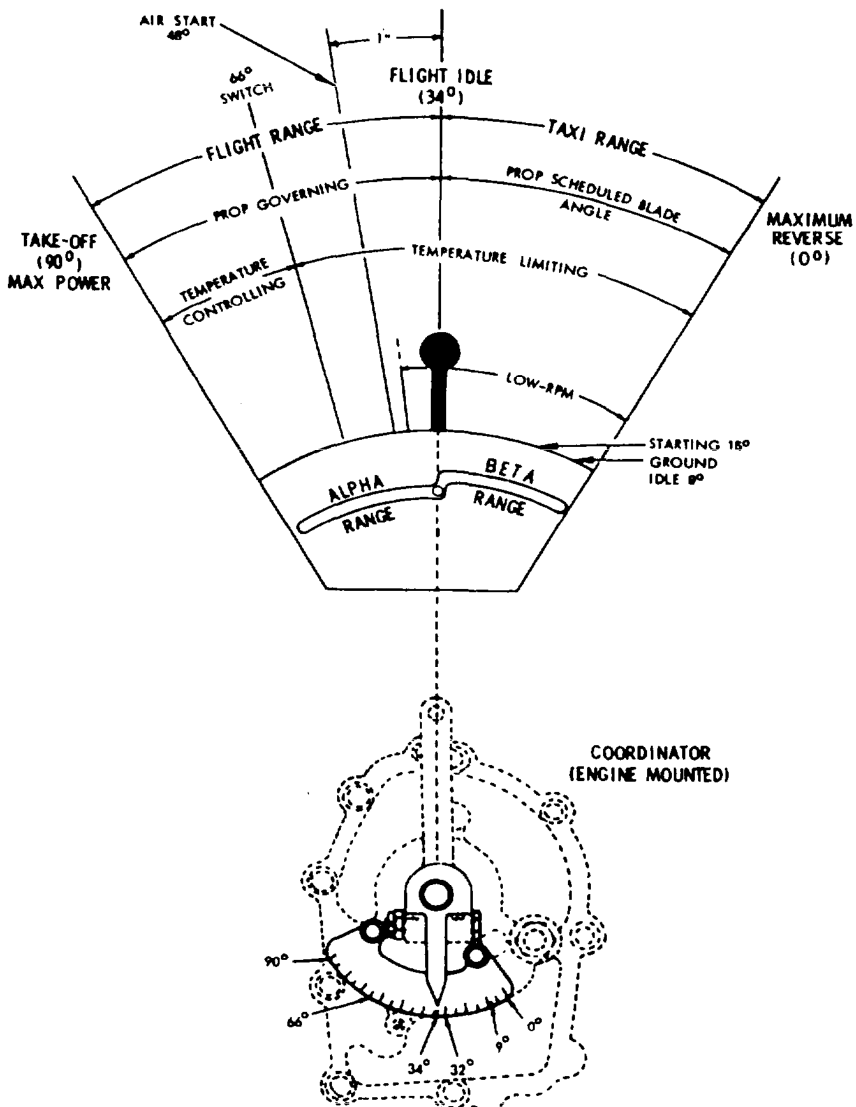


Figure 8-7.-Coordinator quadrant markings.

are the corresponding degrees as read from the engine coordinator.

Max reverse — 0°

Ground idle — 9°

Start — 15°

Flight idle — 34°

Air start — 48°

Takeoff — 90° (max power)

The two ranges of operation of the power lever quadrant are alpha and beta ranges. The beta range is the portion of the quadrant from max reverse (0°, to flight idle (34°). With the power lever set at ground idle, the propeller is at a 5-degree negative blade angle to compensate for power section thrust. Movement of the power lever toward flight idle increases fuel flow and blade angle. Movement from ground idle towards max reverse increases fuel flow, but causes the propeller to schedule reverse blade angle. In the flight range (alpha), the power lever schedules fuel flow only.

Fuel Control

A turboprop fuel control is similar to a turbojet fuel control. The difference is the turboprop fuel control operates in conjunction with a propeller governor. The fuel control mounts on the engine accessory drive housing. It is mechanically linked to the coordinator. The fuel control is designed to perform the following functions:

1. Provide a means of varying fuel flow to permit a selection of power that is coordinated with propeller blade angle and engine speed.

2. Regulate the rate of fuel metering during acceleration to prevent excessive turbine inlet temperature.

3. Control the rate of decrease of fuel metering during deceleration to prevent flameout.

4. Control engine and propeller speed outside the limits of operation of the propeller governor. This includes reverse thrust, low-speed ground idle, flight idle, and high-speed ground idle.

5. Provide a measure of engine protecion during overspeed conditions by reducing fuel flow and turbine inlet temperature.

6. Provide a starting fuel flow schedule that, with the temperature datum valve, avoids overtemperature and compressor surge.

7. Compensate for changes in air density due to variations in compressor inlet air temperature and pressure.

8. Provide a means of cutting off fuel flow electrically and manually.

The fuel control senses compressor inlet pressure, compressor inlet temperature, and engine speed. Using these three factors and the setting of the power lever, the fuel control meters the proper amount of fuel. Pressure and temperature compensating systems are designed to maintain constant turbine inlet temperature as the compressor inlet conditions vary.

The fuel control includes a cutoff valve for stopping fuel flow to the engine. This valve operates both electrically and manually. Electrical control is made possible by moving the fuel and ignition switch to the OFF position. This signals the cutoff valve motor to close the valve. Actuation of the emergency shutdown control closes the valve mechanically through a cable and control rod system from the flight station.

Coordinator

Mounted on the rear face of the fuel control is the engine coordinator. The function of the engine coordinator is to coordinate the propeller, temp control, and fuel control. A system of levers, bell cranks, and linkages connect the coordinator with the fuel control and the propeller control. Refer to the system schematic in figure 8-7.

PROPELLERS

The propeller converts the power output of the engine into forward thrust to move the aircraft through the air. A propeller is essentially a "rotating wing, " or airfoil. When the aircraft engine turns the propeller, relative motion is developed between the wing-like propeller blades and the air. As it pulls itself through the air, the propeller carries along anything that is attached to it, within the limitations of the power developed. The faster the propeller spins, within certain limits, the greater the resulting pull or thrust.

BASIC PROPELLER PARTS

There are different propeller manufacturers and many varied designs. These designs include the experimental multicurved blade for propellers. All propellers have the same basic parts. Terms for the parts of one propeller are applicable to other propellers. The basic parts of a propeller are as follows:

1. BLADE. One arm of a propeller from the butt to the tip. Propellers usually have two or more blades. See figure 8-8.
2. BLADE BACK. The surface of the blade as seen by standing in front of the propeller. See figures 8-8 and 8-9.
3. BLADE FACE. The surface of the blade as seen by standing directly behind the propeller. See figure 8-9.

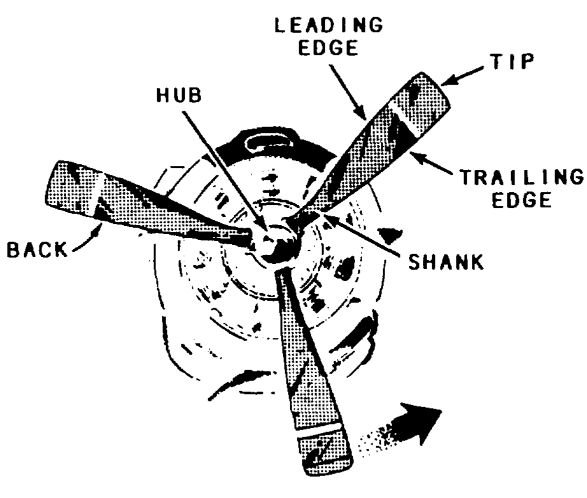


Figure 8-8.-Propeller basic parts.

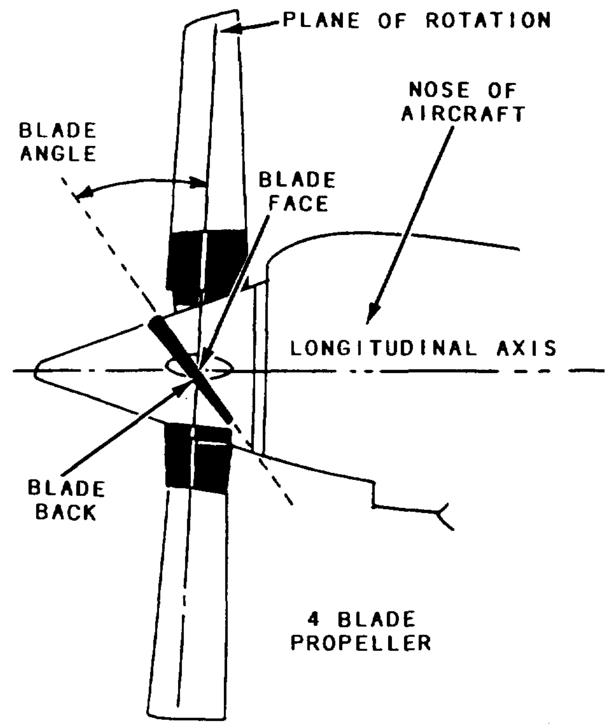


Figure 8-9.-A four-blade propeller.

4. SHANK. The thickened portion of the blade near the hub of the propeller. The shank is sometimes referred to as the root. See figure 8-8.

5. TIP. The portion of the blade furtherest from the hub. See figure 8-8.

6. HUB. The central portion of the propeller that is fitted to the propeller shaft, securing the blades by their roots. See figure 8-8.

7. LEADING EDGE. The forward or "cutting edge" of the blade that leads in the direction the propeller is turning. The other edge (rear edge) is called the TRAILING EDGE. See figure 8-8.

8. PROPELLER RETAINING NUT. The nut that locks the propeller hub to the propeller shaft. It is part of the propeller rather than the engine.

9. BLADE STATIONS. These are reference lines, usually designed as measurements, made from the hub. These lines are numbered and locate positions on the propeller blade. They are usually designated at 6-inch intervals. The first station is

normally 12 inches from the hub. Figure 8-10 shows the blade stations of a propeller blade.

10. BLADE ANGLE (PITCH). Blade angle is the angle formed by the chord of a section of the blade and a plane perpendicular to the axis of rotation. The blade angles in figure 8-11 are representative of standard low- and high-pitch, as well as the feather angle. These angles will vary with different propeller installations.

11. BLADE CHORD. Blade chord is the distance between the leading and trailing edges. This is an imaginary line extending from the center of the leading edge to the center of the trailing edge. It is important for blade balancing.

12. FEATHERING. Feathering is streamlining the propeller blade with the relative wind. This feature is found in most multiengined propeller installations. Feathering serves to reduce the drag caused by a windmilling propeller on a dead engine and to stop rotation that could cause further damage. See figure 8-11.

13. REVERSING. A reversing propeller allows for a negative blade angle. With a negative blade angle, a propeller produces reverse thrust (thrust in a direction opposite to that normally produced by the propeller in flight). Reverse thrust produces a braking action used during landing to reduce the landing roll-out distance. It can also be used to taxi an aircraft backwards.

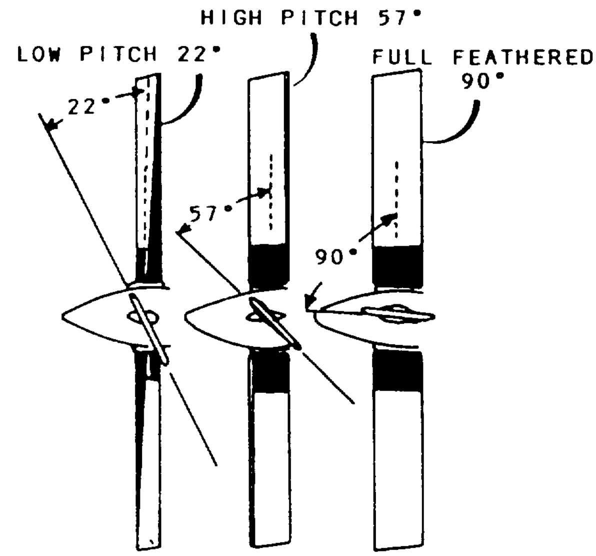


Figure 8-11.-Propeller blade angles.

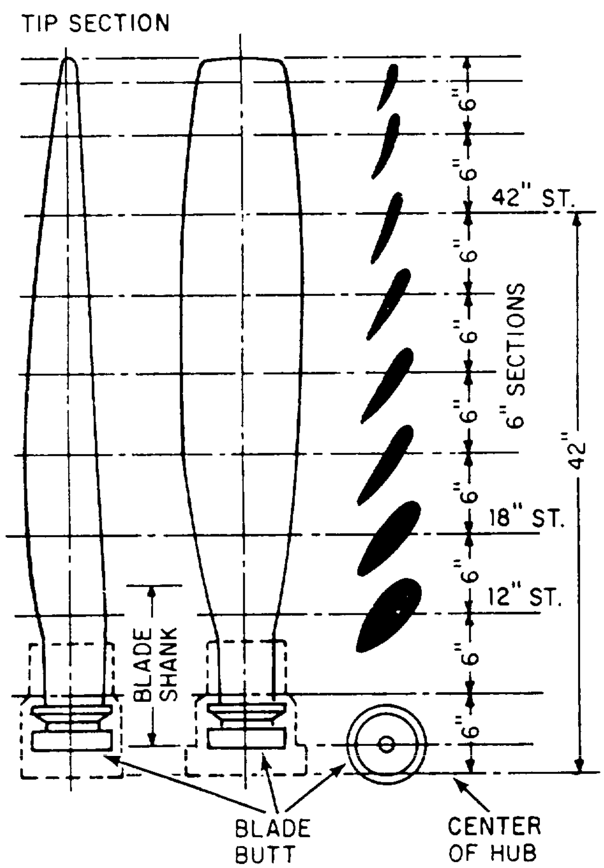


Figure 8-10.—Blade stations.

PROPELLER MODEL DESIGNATION

The model designation for the propeller assembly, shown by markings on the barrel, identifies the type of propeller. The number and letter group describes the basic model, and the number group that follows the dash indicates the number of minor modifications.

A breakdown of the designation of the 54H60-77 propeller is as follows:

5—Indicates the number of major changes incorporated in the propeller.

4—Indicates the number of blades.

H—Describes the blade shank size. (The use of a LETTER here also indicates that the blades are made of aluminum. A NUMBER here would indicate the shank size, and also that the blades were made of steel, as in model 24260.)

60—Indicates the spline size of the propeller shaft.

77—Indicates minor modifications made to the propeller.

BASIC PROPELLER OPERATION

The first propellers were fixed-pitch and designed mainly to get the aircraft off the ground. The pitch (blade angle) was small so that the engine could quickly turn over to its full rpm and use its full horsepower for takeoff. Once an aircraft with a fixed-pitch propeller of low blade angle is in the air, forward speed of the aircraft is limited. The low blade angle allows the propeller to turn too fast to take a big enough bite of the onrushing air. As a result, the engine must be throttled to prevent excessive overspeeding.

The first improvement over the fixed-pitch propeller was the ground adjustable-pitch type. On this type, the blade angle (pitch) could be changed or adjusted on the ground by manually twisting the blades in the hub to the desired angle. When the angle was increased to improve cruising conditions, takeoff conditions suffered. An aircraft taking off from the ground with the propeller at a high blade angle position is much the same as setting a car into motion in high gear. The engine is not able to produce full horsepower because the high blade angle loads the propeller too much to enable it to turn over at the full rpm of the engine.

The next design was the two-position propeller. It enabled a pilot to use a low blade angle (high rpm setting) for takeoff, climb, and necessary operational acceleration. The pilot could then change the propeller blade angle in flight to a higher blade angle (low rpm setting) for cruise. With this propeller, full engine rpm could be developed for takeoff. Aircraft speed could be increased at cruise with a decrease in engine power because the high-pitch propeller takes larger bites out of the air. The two-position propeller did not, however, produce the most efficient and economical use of engine horsepower for all of the numerous intermediate flight conditions encountered by aircraft.

Constant-speed propellers were eventually designed to maintain a preselected rpm automatically. Suppose the aircraft is heading into a gradual climb. The constant-speed propeller maintains the selected rpm automatically by turning the propeller blades to a lower angle. That is, the propeller takes a smaller bite of air when the load on the engine is increased. Now, should the aircraft assume a nose-down attitude, the propeller blades move automatically to a higher blade angle; hence, the propeller takes a larger bite of air. In other words, increase the load on the engine and the propeller takes a smaller bite of air. Decrease the engine load and the propeller takes a larger bite of air. This function will keep the turboprop engine at 100-percent rpm.

On constant-speed propellers, the blade angle must be adjusted to provide the most efficient angle of attack at all engine and aircraft speeds. The most efficient angle of attack is very small; it varies from 1 to 4 degrees positive angle. The actual blade angle necessary to maintain this small angle of attack varies with the forward speed of the aircraft. With constantly increasing aircraft speeds and high-altitude operations, it is necessary to have a wide range of blade angle settings. This range of settings must adapt the propeller to conditions encountered in takeoff, climb, and cruising.

FORCES ACTING ON THE PROPELLER

One of the main requirements of any propeller is its ability to withstand severe stresses. We will discuss these stresses, which are greatest near the hub, in the following paragraphs. Figure 8-12 shows the forces acting on propeller blades.

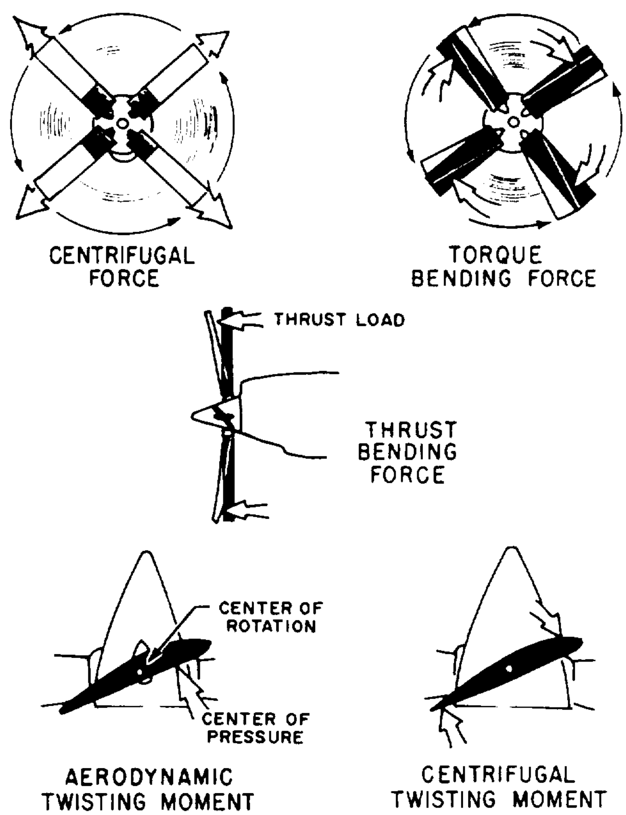


Figure 8-12.-Natural forces acting upon propeller blades.

Centrifugal Force

The greatest force acting upon the propeller blade is centrifugal force. This force tends to pull the blade of a spinning propeller out of its hub. To prevent the blades from breaking into fragments or flying off into space, the blade is thicker near the hub. The hub is made from a strong steel forging.

Thrust Bending Force

Thrust bending force causes a rotating propeller to try to pull away from the aircraft. Because it is held back by the hub and the load of the aircraft it is pulling, the blade tips, which are thinner and lighter than the blade shank, bend forward. The sum of these bending forces on the blades is carried at or near the hub. Hence, the section of the blade at the hub must be proportionately thicker. Centrifugal force counteracts thrust bending force by its tendency to pull the blades in a straight line.

Torque Bending Force

Torque bending force is the tendency for a blade to bend backwards, throughout its length, in a direction opposite rotation. This bending force is created by the density of the air.

Aerodynamic Twisting Force

Aerodynamic twisting force tries to rotate the blades in the hub to an increased blade angle. The point at which this force is exerted most strongly on the chord of the airfoil is known as the center of pressure. During normal cruise conditions, this center of pressure is nearer the leading edge of the propeller, so the force tends to rotate the blades to a higher pitch.

Centrifugal Twisting Force

The centrifugal twisting force on the blades tends to twist them to a lower pitch angle. This occurs because all parts of the propeller try to remain in a plane parallel to the plane of rotation.

Propeller Vibration

Sometimes, in the face of these forces, a propeller loses some of its rigidity. The result is a flutter, which is a type of vibration in which the tips of the blades attempt to twist rapidly back and forth while the propeller is turning. Fluttering causes a distinctive noise, which is nearly drowned out by the exhaust noises of the engine. Fluttering will weaken the propeller and may result in structural failure unless detected early and corrected.

PROPELLER SYSTEM ASSEMBLIES

The propeller system has one primary function—increasing or decreasing pitch as required by power lever movement. Safety features incorporated in the 54H60-77 propeller system include the automatic mechanical pitchlock, the automatic negative torque control, the mechanical low pitch stop with a secondary hydraulic low pitch stop (referred to as the beta follow-up), and an emergency feathering system.

The complete 54H60-77 model propeller, shown in figure 8-13, consists of the front anti-icing propeller spinner, the hub mounting bulkhead assembly, the variable pitch aircraft propeller (propeller assembly), the rear deicing propeller spinner, the air baffle assembly, the propeller control (integral oil control) assembly, and the propeller afterbody assembly.

Spinners and Afterbody Assemblies

The main purpose of the front and rear spinners is to streamline the airflow around the outside of the propeller assembly for cooling. The front and rear spinner assemblies improve the aerodynamic characteristics of the whole propeller assembly. They enclose the dome, barrel, and oil control assemblies. The front spinner has an air inlet in the middle of it. Cooling ram air enters to cool the dome, barrel, and oil control assemblies.

The propeller afterbody assembly streamlines airflow into the engine air inlet. The afterbody assembly has a top and bottom half. The two halves of the afterbody have electrical deicing wires to prevent ice buildup on the back side of the propeller assembly.

Hub Mounting Bulkhead Assembly and Propeller Assembly

The hub mounting bulkhead is the mounting surface for the front and rear spinner assemblies. The variable pitch aircraft propeller (propeller assembly) has four major subassemblies. They are the barrel assembly, the blade assembly, the dome assembly, and the pitchlock regulator assembly.

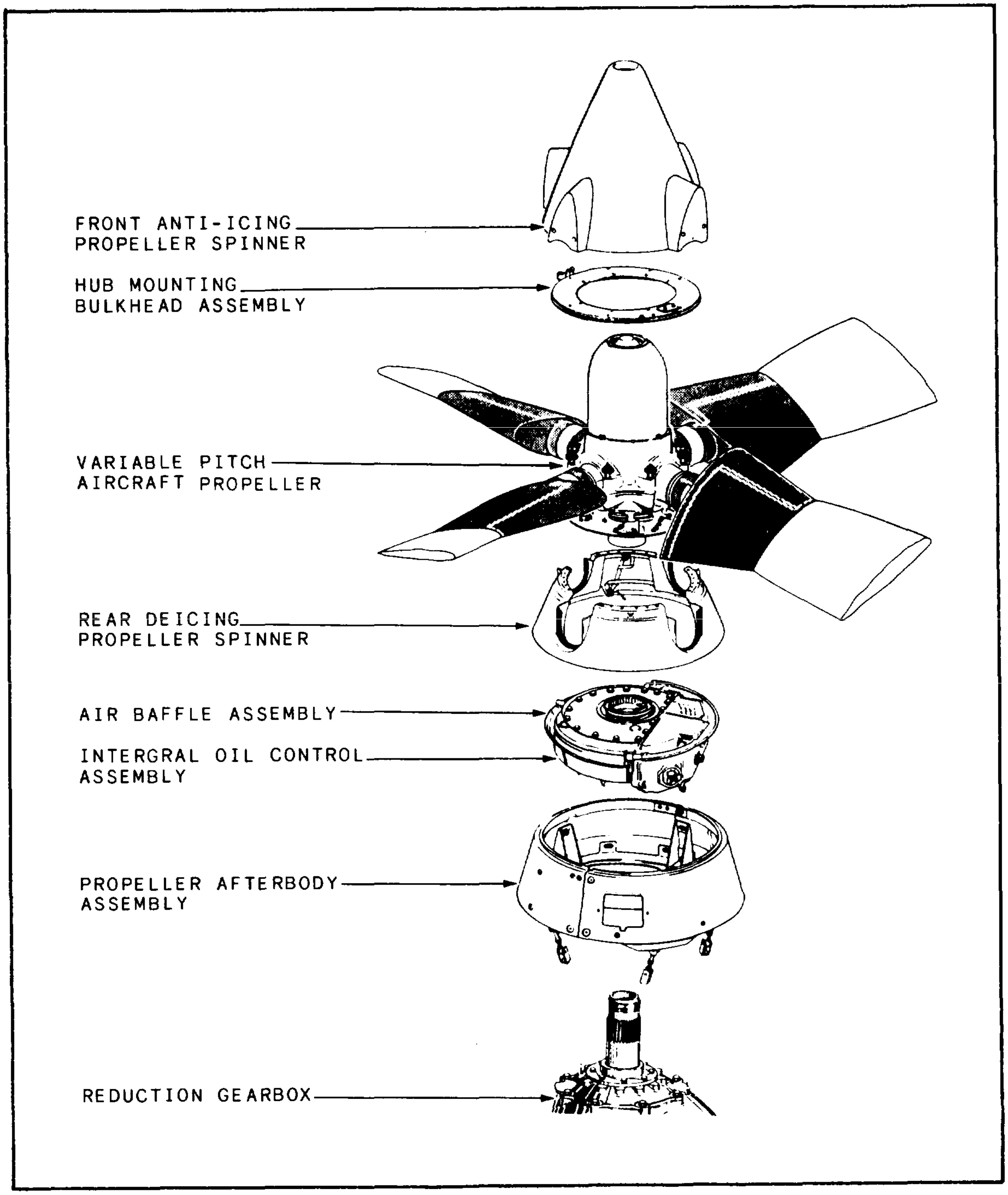


Figure 8-13.-Propeller system.

As we discuss the propeller assembly, refer to figure 8-14.

BARREL ASSEMBLY.— The propeller barrel assembly serves several functions. It retains the four propeller blades and also supports the dome assembly and the propeller control assembly. Engine torque is transmitted to the propeller by the barrel assembly, which mounts and secures to the front of the reduction gearbox propeller shaft.

The barrel assembly is a split type; the front and rear barrel sections are manufactured and balanced as a matched pair. These sections are kept together throughout the service life of the propeller. The high centrifugal blade loads are carried by the barrel shoulders and lips at each blade position.

A machined integral extension on the rear barrel half is splined internally and has seats at both ends. The front and rear cones are beveled to match the extension seats for centering and securing the propeller on the propeller shaft. The extension is splined externally for driving pumps in the propeller control assembly. A propeller hub nut locks the barrel assembly to the reduction gearbox propeller shaft. The propeller hub nut has a flange on its inboard end that butts against the front cone.

BLADE ASSEMBLY.— The broad, lightweight propeller blade is forged from a solid aluminum alloy, which gives it the strength necessary to obtain the high thrust capability at low aircraft speeds. The blade butt is partially hollow to allow for installation of the blade bushing and blade balancing assembly. Propeller balancing is discussed in the balancing section of this chapter.

The blade shank has a molded fairing that is composed of a plastic foam material covered with a nylon reinforced neoprene material. The heater assembly is bonded to the leading edge of the fairing. It contains the necessary blade deicer elements to prevent ice buildup on the blade assembly. Blade heater element damage, involving cut or broken heater wires because of weather corrosion or foreign object damage (FOD) strikes, can be repaired if no more than four wires are damaged. If more than four wires are damaged, the heater assembly must be replaced. The purpose of the blade fairing (cuff) is to streamline and direct the airflow to the engine intake.

DOME ASSEMBLY.— The propeller dome assembly is the blade angle changing mechanism of the propeller system. The dome assembly is mounted on the front barrel shelf and held in position by the dome retaining nut. The principal components of this pitch-changing mechanism are the rotating cam, the stationary cam, the piston assembly, and the low pitch stop assembly. The low pitch stop assembly is screwed into the lever sleeve bushing at the front of the dome.

Preformed packings are used throughout the dome assembly for internal leakage control and to seal the piston assembly in order to separate the inboard and outboard hydraulic pressure necessary for blade movement. Shims are used to establish the proper clearance between the rotating cam and the blade segment gears. The dome assembly is mounted in position on the front barrel shelf. It is held in place by the dome retaining nut that is locked in place by a special head screw.

The low pitch stop assembly screws into the dome assembly. It sets the desired low pitch stop blade angle. In the flight range of operation, the low pitch stop lever assembly prevents the propeller blade angle from going below 13 degrees. In the ground range, extra high hydraulic fluid pressure actuates the low pitch stop assembly, allowing the piston to move further outboard. This turns the blades from the low pitch stop position towards the reverse blade angle.

PITCHLOCK REGULATOR ASSEMBLY.— The propeller pitchlock regulator assembly mounts within the propeller barrel and is splined to the propeller hub nut. The pitchlock regulator assembly directs hydraulic pressure to the outboard and inboard sides of the dome piston. It also serves as a safety feature by preventing a decrease in blade angle, by pitchlocking, under certain conditions. Pitchlock occurs if hydraulic control pressure is lost or during an overspeed of 103 to 103.5 percent.

The pitchlock regulator assembly contains two ratchet rings that are spring-loaded together, but are held apart by hydraulic pressure. One ratchet ring is splined to the rotating cam of the dome assembly. The other ratchet ring is splined to the propeller rear barrel half and does not rotate. If hydraulic pressure is lost, the ratchet rings come together, and their teeth mesh to prevent a decreased blade angle. This is referred to as pitchlock, and can only occur between approximately 15 to 60 degrees of blade angle. Pitchlock is

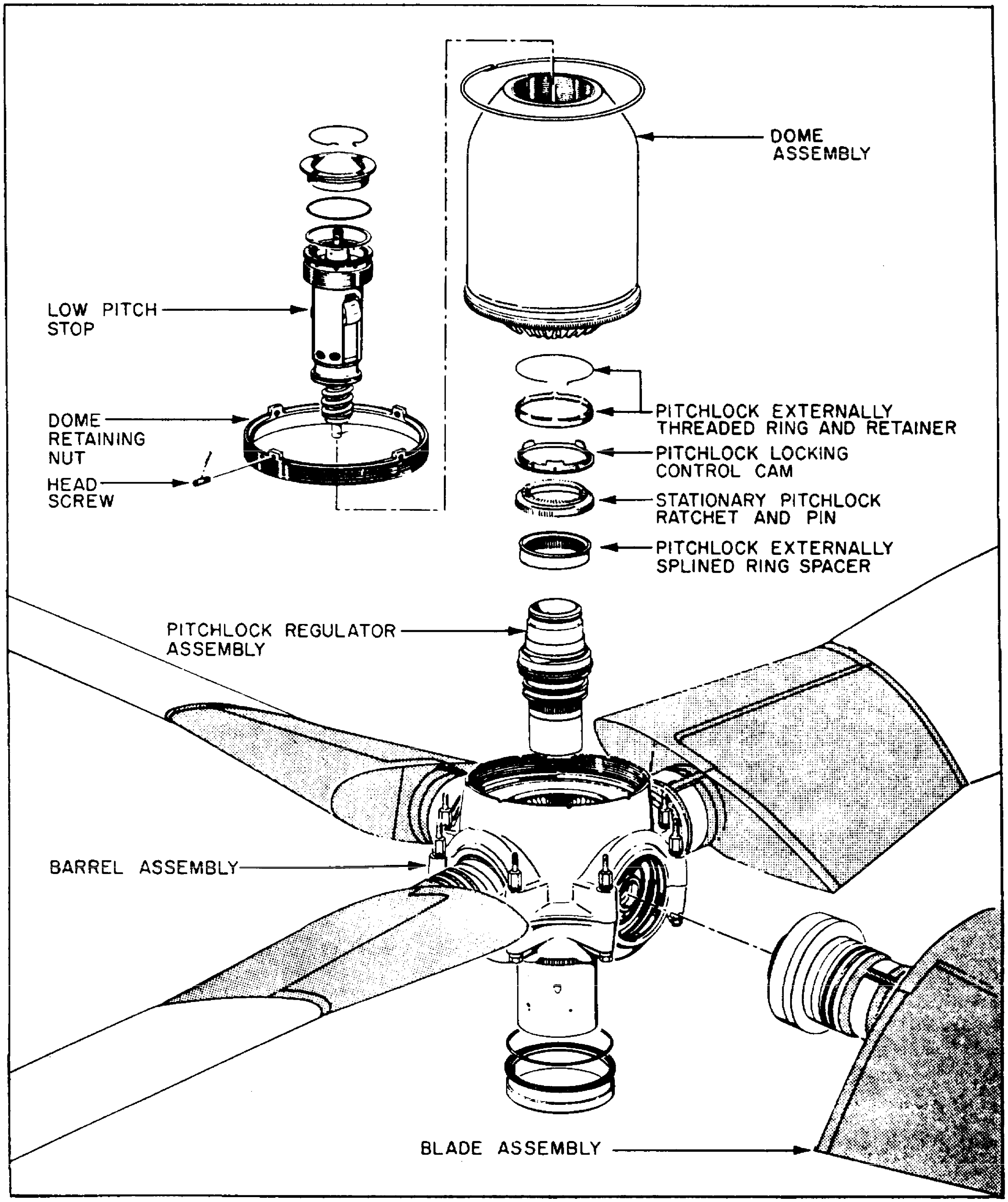


Figure 8-14.-Variable pitch aircraft propeller.

mechanically cammed-out below 15 and above 60 degrees. When in pitchlock, the propeller operates as a fixed-pitch propeller. However, the reverse rake of the pitchlock ratchet teeth allows rotating of the propeller into higher blade angles for feathering or to regain control of the propeller.

Propeller Control Assembly (Integral Oil Control Assembly)

The propeller control assembly is a nonrotating integral oil control mechanism. It mounts on the rear extension of the propeller barrel. See figure 8-15. The control assembly contains two major components—the pump housing assembly and the valve housing assembly. The pump housing assembly contains the hydraulic reservoirs, pumps, and valves. The valve housing assembly is where all mechanical and electrical connections necessary for propeller operation are made. The mechanical connections include the linkages between the engine control system and the negative torque system (NTS). The electrical connections are for the pulse generator coil, the auxiliary pump motor, the synchrophasing system, and the anti-icing and deicing systems.

PUMP HOUSING ASSEMBLY.— The pump housing assembly forms the lower part of the propeller control assembly. The pump housing contains five positive displacement gear-type pumps (three mechanically driven and two

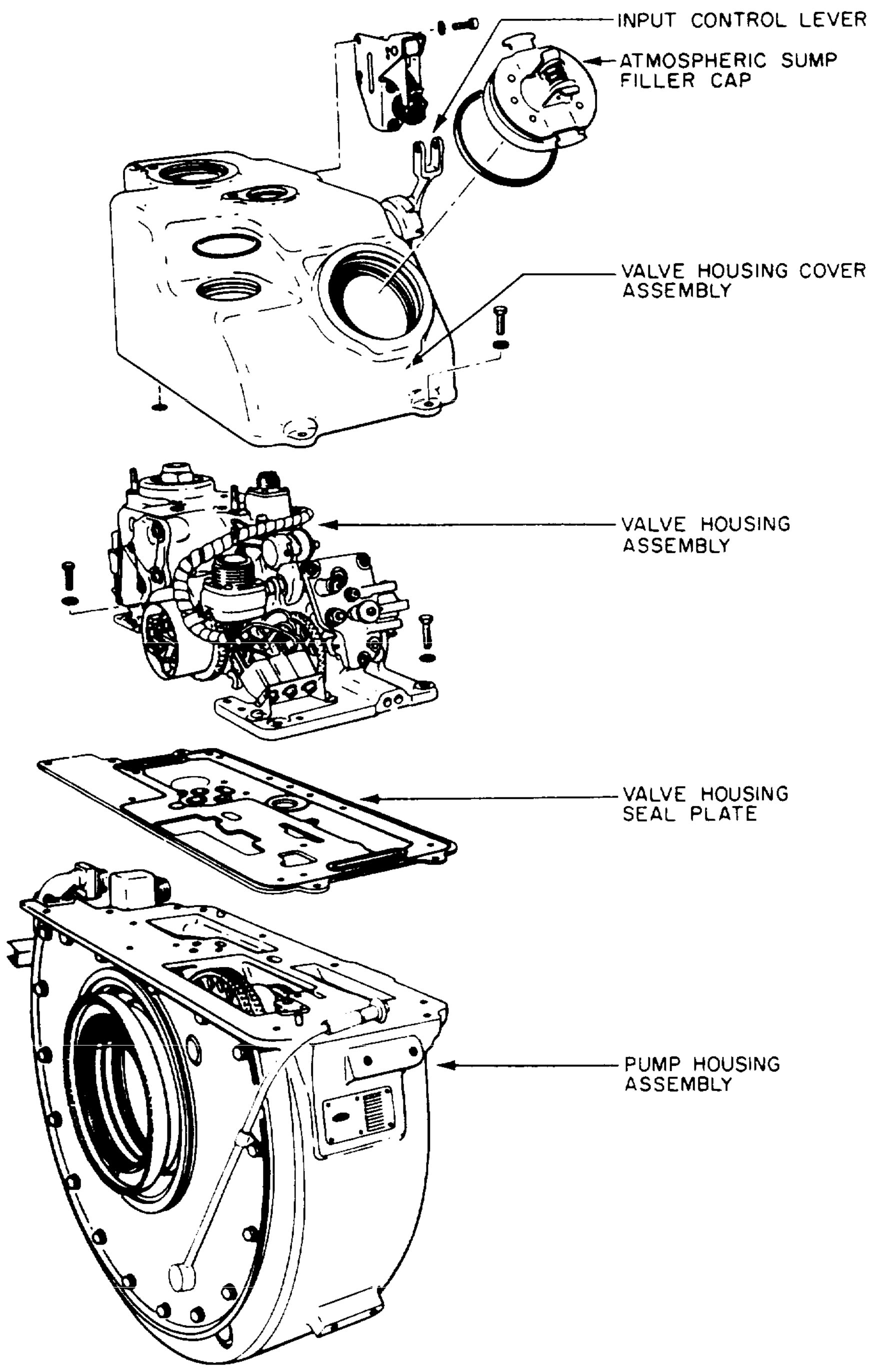


Figure 8-15.-Propeller control assembly.

electrically driven). An externally mounted ac electric motor drives the two common shafted auxiliary pumps. Two hydraulic fluid sumps are contained in the pump housing assembly. One is a pressurized sump with a capacity of 6 quarts. The other is an atmospheric sump with a capacity of 4.5 quarts. A pressure cutout switch located in the pump housing serves to terminate the action of the auxiliary pumps. This action occurs when the feather blade angle is reached.

The three mechanically driven gear-type pumps are the main pump, the main scavenge pump, and the standby pump. The electrical pumps are the auxiliary scavenge pump and the feather pump. The feather pump is used for static ground operations. It also serves to complete the feather operation in flight. An electrical motor-driven pump is needed since the output pressure of the mechanically driven pumps is reduced in proportion to the decaying propeller rpm.

VALVE HOUSING ASSEMBLY.— The valve housing assembly is considered the brains of the propeller system. It mounts to the upper part of the pump housing assembly, forming the propeller control assembly. The valve housing assembly is the most complex assembly of the propeller system. Major units of the valve housing assembly are the speed servo governor assembly, flyweights, speeder spring, pilot valve, feather valve, feather solenoid valve, main and standby regulating valves, high-pressure relief valve, beta and speed-setting lever assembly, alpha and beta pinion shafts, linkage support assembly, and the electrical branch cable.

The two ranges of operation controlled through the valve housing assembly are the governing range and the taxi range. The governing range is commonly called the alpha or the flight range. The taxi range is commonly called the beta scheduling or the ground handling range. All primary propeller operations, except for feathering and unfeathering the propeller, are determined by the position of the pilot valve in the speed servo governor. Hydraulic fluid for blade angle change operation is pumped from the pressurized sump by the main pump (and standby pump if needed) to the pilot valve chamber.

Flyweights are geared to the propeller shaft. This causes their rotation to develop centrifugal force in direct relation to the engine speed. The centrifugal force extends the flyweights outward and pushes the pilot valve toward the increased pitch position. This movement of the pilot valve opposes the speeder-spring force, which pushes the pilot valve toward the decrease pitch position. When speeder-spring force is equal to the flyweight centrifugal force, the pilot valve centers in the pitch change sleeve to block pitch change hydraulic pressure from the propeller dome. Any change in the engine speed will change the outward position of the flyweight. The flyweight shifts the pilot valve to direct pitch change hydraulic pressure to the dome.

Constant-speed governing is blocked out in the ground handling range. The propeller blade angle is coordinated with the position of the power lever. Interaction of the cams on the alpha and beta shaft control the position of the pilot valve in the speed servo governor. When the power lever is moved, a cam on the alpha shaft positions the pilot valve to obtain a corresponding blade angle. As the blade pitch changes, a cam on the beta shaft returns the pilot valve to a position that will maintain the blade pitch at the angle scheduled by the power lever,

Rigging pin holes are located on the valve housing assembly for rigging the valve housing to the propeller assembly and power lever. Adjustments are provided to set the mechanical governor speed and the reverse and ground handling blade angles.

PROPELLER MAINTENANCE

In today's Navy, comprehensive and systematic means of maintaining a multiengined propeller system is essential. You, as an Aviation Machinist's Mate, must know the procedures for day-to-day maintenance. You must know the procedures for removal and installation of a propeller, rigging, adjustment, and troubleshooting of propeller systems. You should also be familiar with the procedures for propeller balancing and leakage test requirements. The modern-day propeller system is a complex and durable system, and, with proper maintenance, a highly reliable aircraft system.

NOTE: The information noted here is general. Refer to applicable technical instructions for the specific methods used on a particular model of propeller.

Propeller Inspection

Inspect the blades daily for any gouges, nicks, scratches, or gross damage. If the propeller has struck any object (static or rotating), inspect the blades carefully for damage. For example, yellow paint marks on a blade indicate that the propeller could have possible damage from hitting a piece of support equipment.

Propeller Repair

Cuts, scars, scratches, surface cracks, nicks, etc., are common types of damage. Repair by forming a "saucered out" depression smoothly blended into the blade surface. Carefully examine the area with no less than a three-power magnifying glass. Use the magnifying glass to make certain the bottom of the damage is completely removed. Use local etching to be sure there are no cracks at the bottom of-the rework. To avoid removing excessive metal, make a local etching check at regular intervals during the process of removing the damage. After removal of metal, measure carefully any blade that has a finished depression. Send blades with depressions exceeding repair limits to overhaul.

First, measure the depth of each damaged area with a dial gauge. Raised edges may interfere with the setting of the knife edge of the gauge. Using aluminum oxide paper, remove any raised edges adjacent to the damaged area. Set the base of the gauge parallel to the longitudinal axis of the blade. Gouge depth is the difference between the deepest point in the damaged area and the adjacent blade surface. In a reworked area, it is the difference

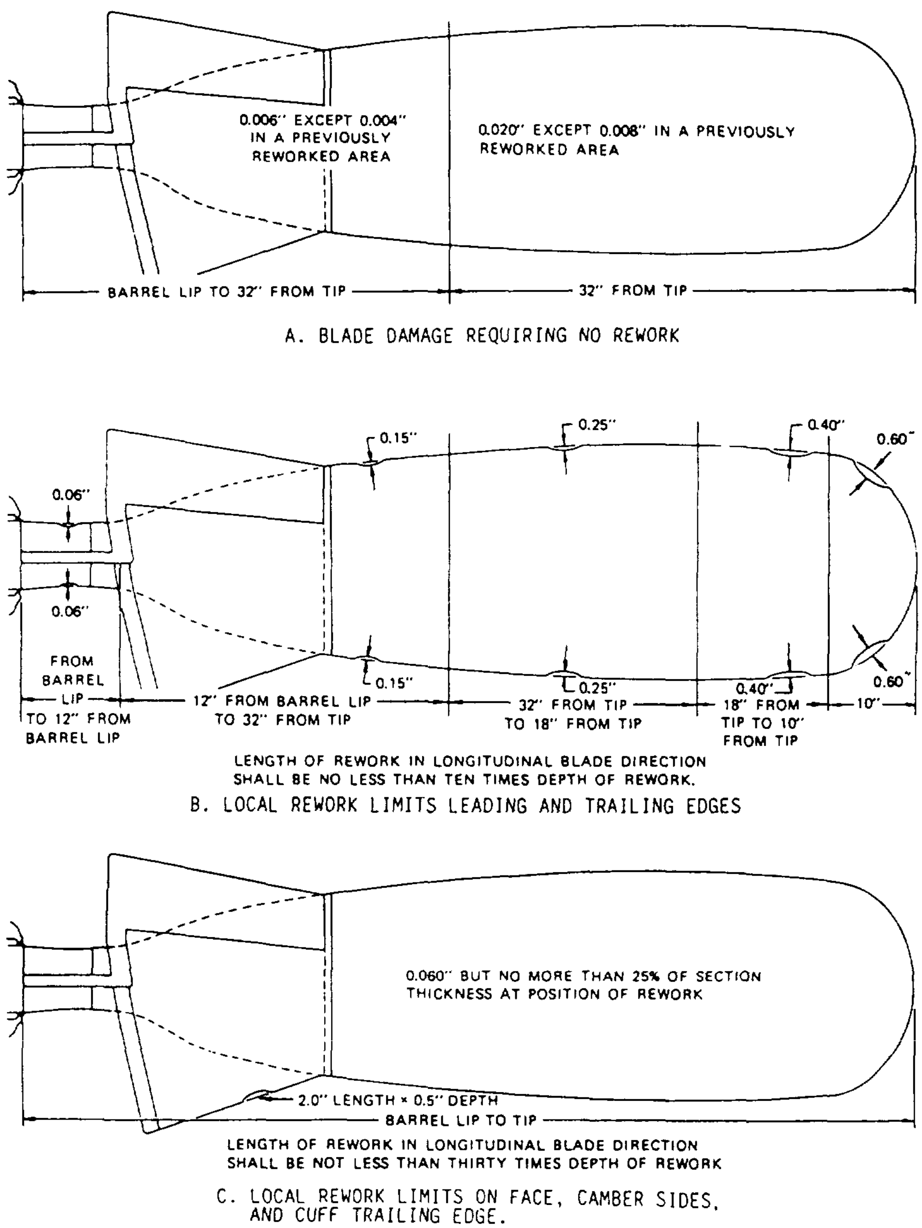
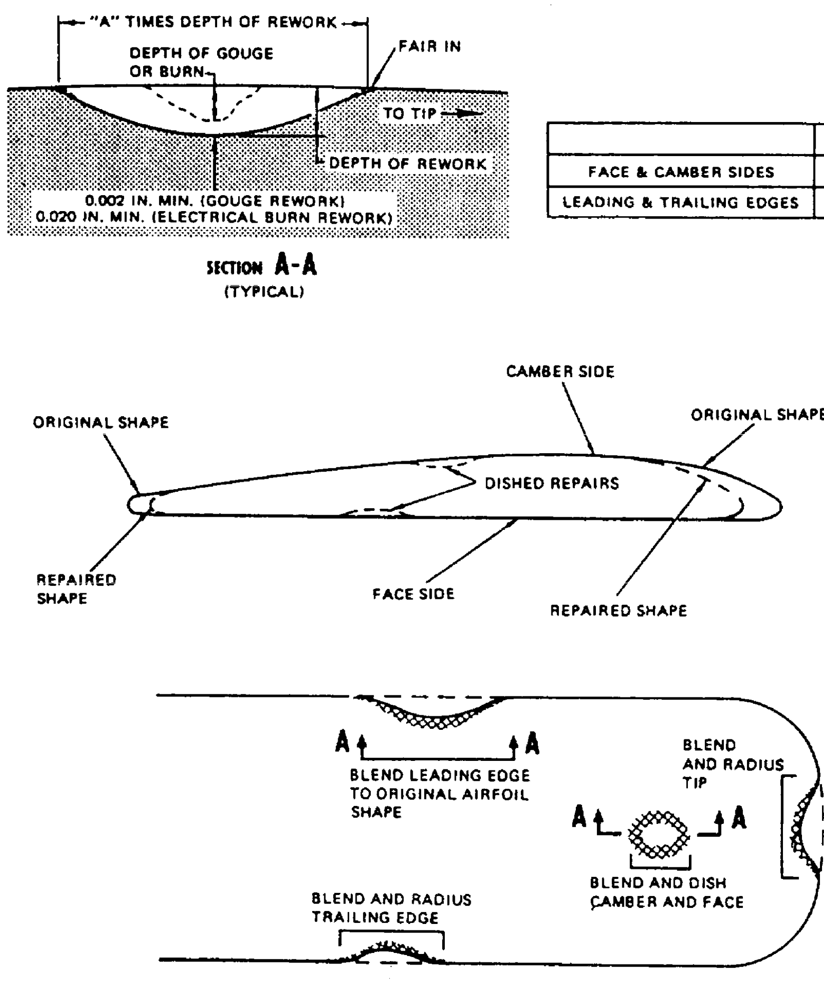


Figure 8-16.-Propeller blade damage rework limits.

between the deepest point in the damaged area and the reworked surface.

To remove damage from a blade, remove the damaged metal and the adjacent area with die-makers' rifflers and aluminum oxide paper. Work the damage from the blade and smoothly blend the resulting depression into the surrounding blade surface. Do not try to move any of the metal in the damaged area by cold-working. Repairs in a given area on a blade are unlimited provided their locations do not form a line of continuous repairs. A line of continuous repairs would materially weaken the blade structure. For an illustration of minor repairs to the aluminum alloy propeller blade, refer to figures 8-16 and 8-17.

NOTE: The blade damage repair limits shown in figures 8-16 and 8-17 are examples of repair limits found in maintenance instruction manuals. Refer to the specific maintenance instruction manual for the propeller that you are working on.



	"A"
FACE & CAMBER SIDES	30
LEADING & TRAILING EDGES	10

NOTE

1 REPAIRS ARE EXAGGERATED IN PROPORTION TO BLADE SIZE TO PROVIDE CLARITY – SEE REWORK LIMITS

2 ALL REPAIRS SHOULD BLEND SMOOTHLY INTO ADJACENT UNDAMAGED AREAS

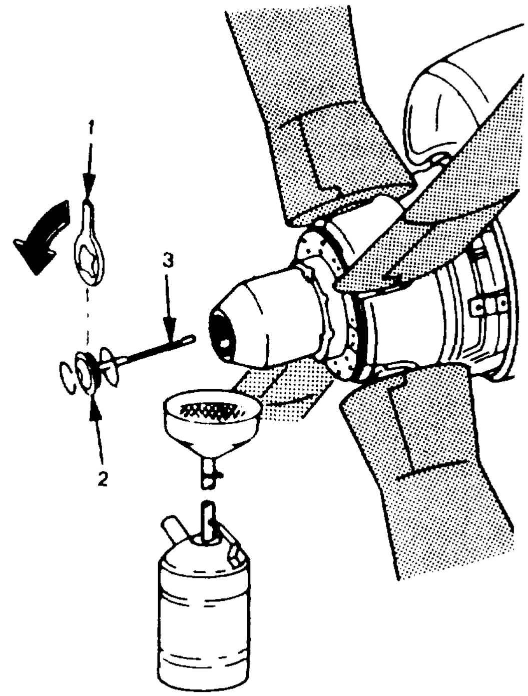
3 CROSS-HATCHING INDICATES BLENDING AREAS.

4 ALL DAMAGED MATERIAL MUST BE REMOVED DURING REWORK – SEE REWORK LIMITS

Figure 8-17.-Propeller rework guide.

Propeller Removal

It usually takes a crew of three to remove the propeller and place it on the dolly. Refer to the applicable maintenance instructions for a list of tools and procedures used to remove the propeller assembly. Cycle the propeller to maximum reverse to aid in the removal of the afterbody assembly. Maximum reverse is the only position that allows afterbody removal without causing damage to the afterbody or propeller blades. After you remove the top and bottom sections, cycle the propeller back to the feather position. Secure all electrical power to the propeller. Disconnect the cannon plugs and propeller control input linkage, and stow them away to prevent snagging during removal. Remove the propeller spinner. Remove the dome cap and oil transfer tube. Position an oil shield under the dome to catch oil spillage. See figure 8-18.



1. Dome cap spanner wrench
2. Dome cap
3. Transfer tube

Figure 8-18.-Dome cap removal.

CAUTION

The propeller should NOT be cycled for at least 10 minutes before removing the dome cap.

Unscrew the dome retaining nut and remove the dome assembly. Remove the pitchlock assembly with the puller. This assembly includes the pitchlock control cam, pitchlock stationary ring and pin, and externally splined spacer ring. Install a dynamometer between the hoist and yoke assembly.

NOTE: When removing or installing the propeller, do not turn the No. 1 blade beyond positive 100 degrees or minus 15 degrees. Movement passed these limits will damage the propeller. Damage occurs when the beta follow-up shaft releases from the beta gear segment. Damage also occurs when the beta shaft moves into the control assembly beyond its stops.

Remove the propeller and control assembly from the propeller shaft. Install them on a dolly, and secure them before removing the hoist. Remove the rear cone from the engine shaft and retain it with the propeller assembly. See figures 8-19 and 8-20.

Propeller Cleaning

If you disassemble the propeller, clean all the parts with approved cleaning solution except the deicing brushes and slip rings. Thoroughly dry all parts after cleaning. Vapor blasting is NOT permitted on this propeller. The use of rags or paper for cleaning or wiping internal parts of the propeller and control assembly is NOT permitted. The use of these materials may cause lint or minute particles to enter the hydraulic system. Malfunctioning of parts is possible. Unused parts or parts not reassembled within a reasonable time should be preserved with a corrosion-preventive compound. Exact procedures for the cleaning and prevention of corrosion on propellers are found in the applicable maintenance instructions.

Propeller Installation

Installation procedures are the reverse of removal. Before installing the propeller on the propeller shaft, install (or clean and inspect) the torque retainer (drive bracket assembly) and the negative torque bracket assembly on the engine

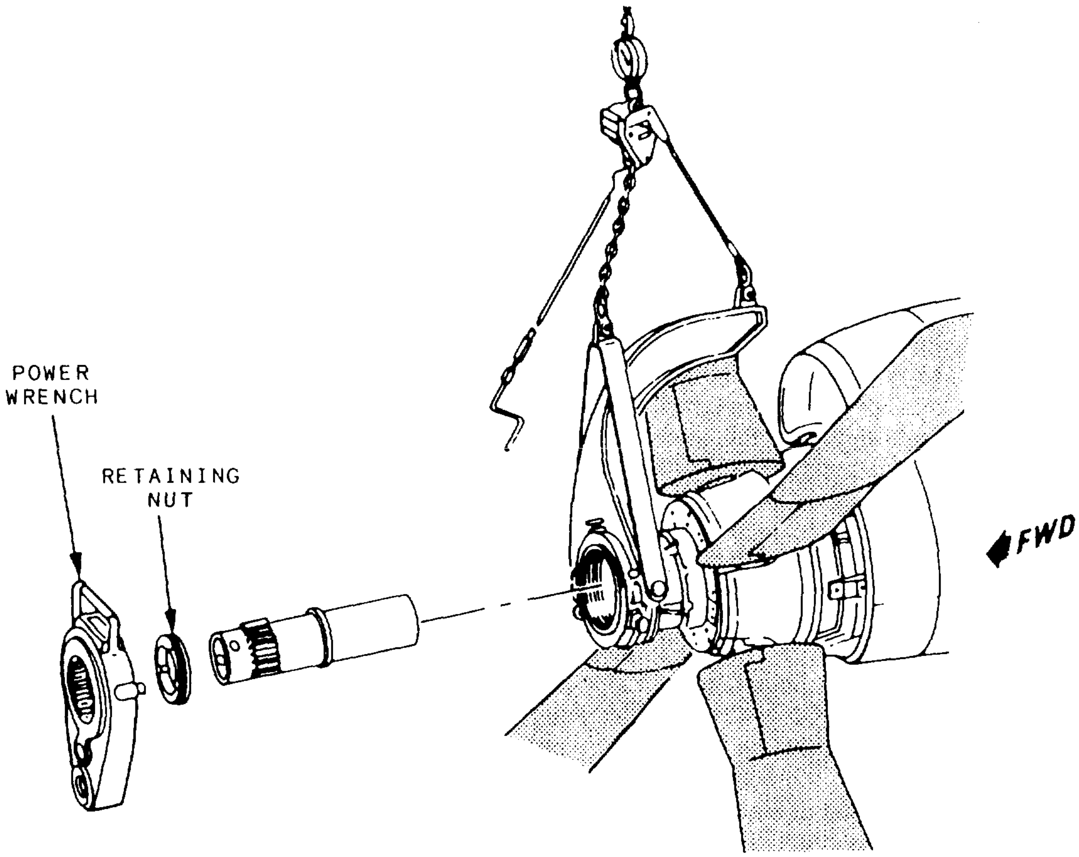


Figure 8-19.-Propeller removal.

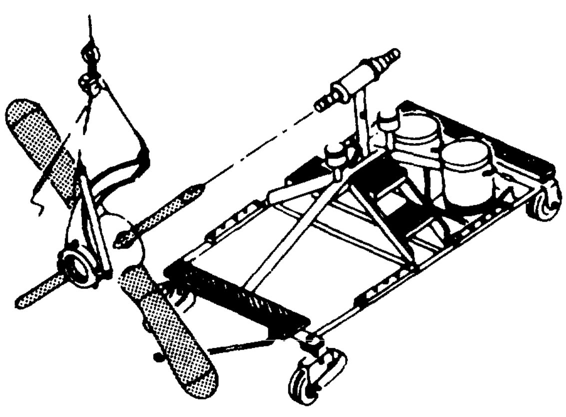


Figure 8-20.-Propeller stowage.

reduction gearbox. Reclean the propeller shaft and apply a light coating of hydraulic fluid over the entire shaft.

Propeller Servicing

The propeller fluid fill cap is under the access doors of the top half of the spinner afterbody. The total capacity of the propeller system is about 25 quarts.

CAUTION

DO NOT use engine oil in the propeller system. If engine oil is added to the control by mistake, remove the propeller. Remove both the control and propeller. Send the assembly to an overhaul activity for complete seal replacement. Observe duty cycle for the feather pump to avoid overheating and damage.

Upon initial installation, fill the propeller with hydraulic fluid, Add as much propeller hydraulic fluid as possible to the atmospheric sump and the pressurized sump. Statically cycle the propeller several times between feather and reverse. Add fluid each time the PROP PUMP No. 1 light illuminates. Repeat this procedure until you add a total of 25 quarts. After completion of the first engine runup, inspect the pressurized sump capacity. Note the fluid level, using the shoulder within the filler hole as a guide. If necessary, completely fill the pressurized sump.

If the system was full on the last flight and is below FULL at the next check, suspect external leakage. Make a thorough visual inspection of the propeller and control to locate the site of the leakage. Statically cycle the propeller before checking the fluid level. Do not remove the filler cap for at least 10 minutes after operation of the propeller or actuation of the auxiliary pump. If the fluid level is low at the initial check, run the auxiliary pump. Recheck the fluid level. Operating the propeller into the feather position and back should be sufficient. If the fluid level is still low, add the amount required to bring the fluid level up to that specified by the MIM.

It is important to check the fluid level in the control assembly before checking the operating propeller system. This procedure is especially true before feathering. Without fluid, the pressure cutout switch will not operate to stop auxiliary pump motor operation.

During static system operation, intermittent operation from about 75 degrees to air or ground start positions may cause the pitchlock to engage. Decreased pitch operation cannot continue until the pitchlock releases. This disengagement is made by moving the propeller toward the feather position a few degrees.

Rigging and Adjustment

During the initial engine/propeller installation, or whenever a fuel control, coordinator, or linkage has been replaced, make a complete rigging check. The final propeller control linkage rigging and valve housing adjustment is done with the propeller installed. In most cases, when a T56 engine is ready for issue (RFI) from an aircraft intermediate maintenance department (AIMD) to a squadron, the fuel control to coordinator rigging has been completed.

A minimum of five rigging pins are necessary to rig and adjust the propeller control linkage and valve housing. Refer to the appropriate technical publication for the special tool requirements. Check for freedom of movement for both power levers and E-handles. There must be NO binding or interference. Check cable tension with a tensiometer. Insert rigging pins in slots. Rig pins should go in with slight finger pressure. Adjust control rod lengths if needed. Remove rig pins. Check rigging at max reverse, takeoff, and flight idle by comparing coordinator readings and inserting rig pins in appropriate engine or valve housing slots. After mechanical rigging checks agree, adjust valve housing assembly for setting blade angles. See fig 8-21.

After all rigging has been completed, check for installation of bolts, nuts, and safety wire. Torque all bolts and nuts, and safety wire all rod ends, as required by the appropriate technical manual. At this point, you should remove all rigging pins and install the valve housing atmospheric sump filler cap. Now complete propeller and engine checks to test for proper operation.

Feathering Check

Depressing the feather button in the flight station causes normal feathering. This action supplies voltage to the holding coil of the feathering switch, auxiliary pump, and feather solenoid. Hydraulic fluid positions the propeller control feather valve to feather the propeller. When the propeller has fully feathered, pressure buildup will operate a pressure cutout switch. The switch causes the auxiliary pump and feather solenoid to become de-energized through a relay system. Feathering also occurs by pulling the emergency shutdown handle (E-handle). This action mechanically positions the feather valve and electrically energizes the feather button holding coil to send the propeller to feather.

Unfeathering Check

To unfeather the propeller, pull the feather button and hold in the unfeather position. This action causes the auxiliary pump to come on. Fluid pressure flows to the decrease side of the pitch change piston in the dome. This action unlatches the feat her latches. The propeller will start to unfeather. Upon reaching the air start pitch angle (45 to 48 degrees), the air start beta switch closes. Closing the switch energizes the air start control relay. This relay energizes the feather valve solenoid, which sends the blades back towards feather. The return of the blades toward

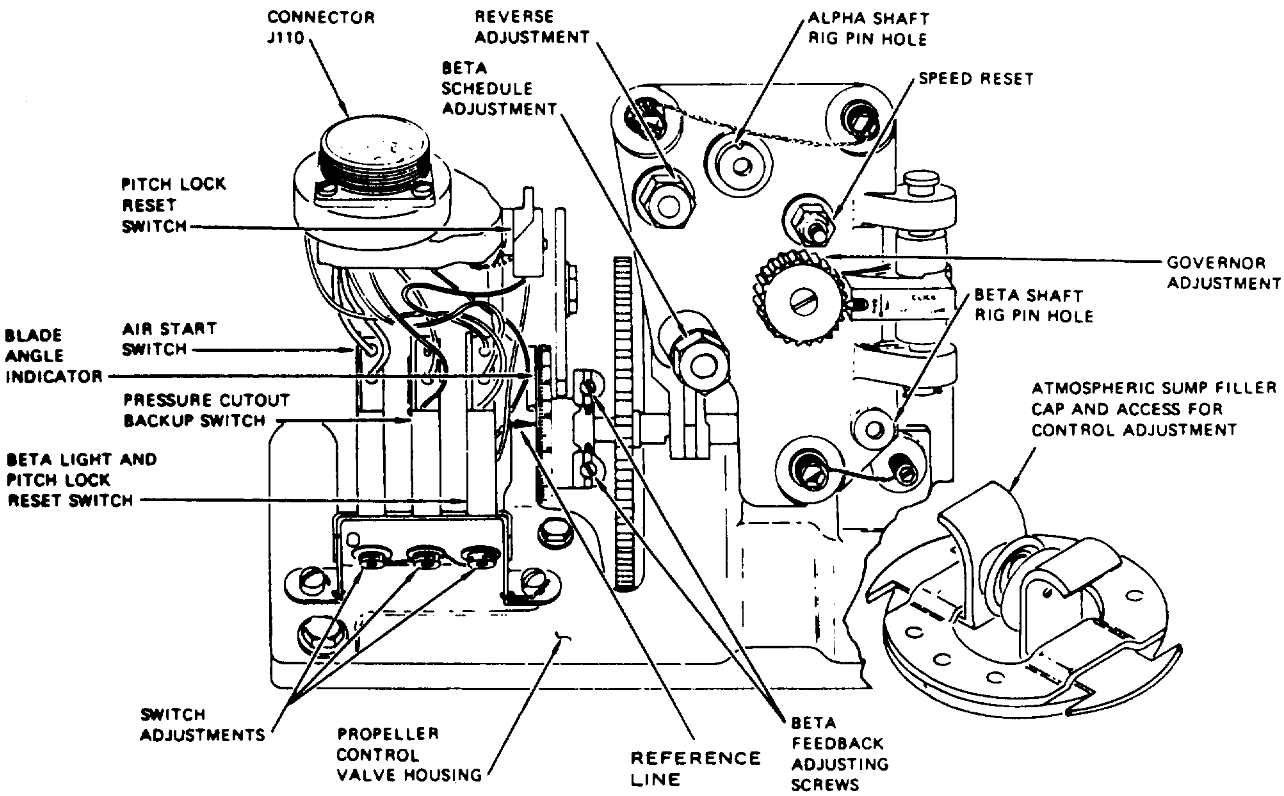


Figure 8-21.-Valve housing assembly (adjustments).

feather opens the air start beta switch to re-energize the air start relay. Now the blades are cycling around the air start blade angle to stabilize the propeller speed and engine speed. These stabilized speeds prevent a NTS condition from occurring during an air start. The air start blade angle for unfeathering cuts out ground unfeathering when you depress the pressure cutout override (PCO) button. This button is usually adjacent to the feather button. Depressing the PCO button prevents the blades from cycling around the air start switch. The PCO button allows the blades to go to a lower blade angle setting.

NOTE: Stopping a decreasing blade angle during ground operations may cause a problem. If stoppage occurs above the low pitch stop, do not, under any circumstances, attempt to decrease the blade angle any further.

Increase the blade angle before trying a decrease, so the pitchlock teeth will disconnect. The pitchlock teeth will engage upon release of the feather button. Failure to increase the blade angle will cause damage to the pitchlock teeth.

Fuel Governor, Pitchlock, and Reverse Horsepower Checks

The purpose of the fuel governor check is to be sure that the fuel control governor will limit the engine speed if the propeller governor fails. The pitchlock check makes sure that the propeller pitchlock will engage to prevent the propeller from going to a lower blade angle. The reverse horsepower check will ensure that the reverse horsepower will operate normally.

NTS Check On Shutdown

With the engine running at low rpm, place the NTS/feather valve check switch in the NTS check position. Turn the fuel/ignition switch to OFF. NTS action should develop and illuminate the NTS light. If unsuccessful, maintenance action is necessary.

PROPELLER BALANCING AND LEAKAGE TESTS

Accomplish all propeller balancing in a horizontal plane using the propeller balancing kit 7A100, or its equivalent. See figure 8-22. Before performing actual propeller assembly buildup and balancing, you must always refer to the appropriate technical publication.

Preliminary and final balance has already been completed on new and overhauled propellers before they are disassembled and shipped to an AIMD. Do not perform preliminary balance if final balance can be obtained first.

NOTE: The final balance check can be erroneous because of residual hydraulic fluid in the propeller dome assembly. You must make sure the dome assembly is completely drained of any residual hydraulic fluid before installing the dome assembly for the final balance cheek.

You must obtain horizontal balancing on all propellers during assembly. Horizontal balancing must be performed in a room free of air currents and with the propeller assembly clean and dry. The plane of the blades must be horizontal, and the blade pitch must be set at 45 degrees.

Do not install the dome cap, low pitch stop assembly, pitchlock regulator assembly, propeller hub nut, hub mounting bulkhead assembly, and their associated parts. These units are not included as part of the balancing procedure. Install the dome assembly without the dome-to-barrel preformed packing and gear preload shims. Tighten the dome retaining nut snugly past its normal locking position. Use masking tape to hold the dome retaining nut special head screw (without its cotter pin) in place at its normal locking position.

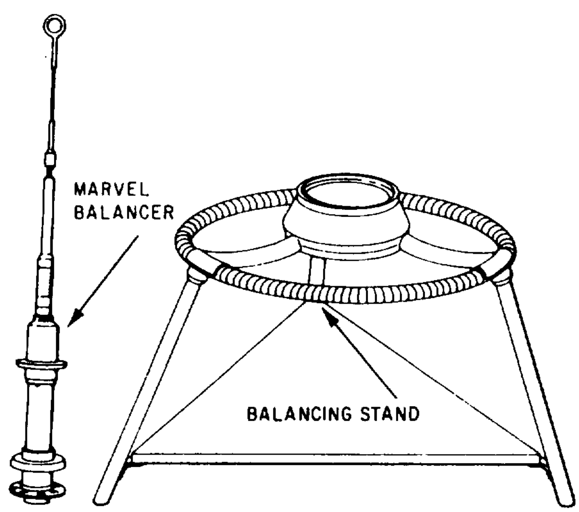


Figure 8-22.-Propeller balancing kit (7A100).

Final Balance Check

The final balance check is obtained by adding bolts, washers, and nuts to balancing holes in the deicer contact ring holder assembly near the outer edge. If possible, bolts, washers, and nuts should be divided equally on each side of the deicer contact ring holder assembly. Do not disturb similar bolts, washers, and nuts, which are painted red and already located in the balancing holes. They are used for balance of the holder assembly itself, not the propeller. Use special bolts, washers, and nuts on the deicer contact ring holder assembly installed on the propeller. For the plastic molded holder assembly, use no more than six AN960-10 washers on one bolt; use no more than six NAS514P1032-16 bolts and six MS20364-1032A nuts.

Obtain final balance with the propeller assembly mounted on the horizontal balance machine, with the plane of the blades horizontal and the dome assembly installed. The sensitivity of the balance machine must be calibrated so that any unbalance shown by the machine may be corrected or reversed by applying a restraining moment of 6 inch-ounces.

If final balance cannot be obtained because of the maximum limit on the number of bolts, washers, and nuts that can be added to the deicer contact ring holder assembly, it is necessary to obtain preliminary balance first, and then final balance. Remove the final balance bolts, washers, and nuts from the holder assembly, if they are installed.

CAUTION

The bolts, washers, and nuts that are colored red must not be removed. These are used for balance of the holder assembly itself, not the propeller.

Preliminary Balance

If final balance cannot be obtained, preliminary balance must be obtained by installing balance washers on the blade balancing plugs of the light blades.

With the propeller suspended on the balancing stand, you should place the balance washers on the shanks of the light blades next to the outboard electric contact rings. See figure 8-23, Preliminary balance has been obtained when the propeller shows no tendency to tilt, or when tilting maybe stopped or reversed by the addition of the lightest balance washer to one or more blades on the light side of the propeller.

After you have determined the amount of washers to install, remove the propeller from the balancing stand, Disassemble the propeller until the light blades have been removed. Install the required washers on the blade balance plugs.

Reassemble and reinstall the propeller on the balancing stand. Recheck the preliminary balance and obtain the final balance check, as previously described.

After you obtain final balance, remove the special head screw taped on the dome assembly. Remove the dome assembly from the propeller, using care not to disturb the 45-degree setting of the rotating cam. Remove the balancing arbor from the propeller.

Remove the propeller from the balancing stand. Remove the deicer contact ring assembly and the packing seal ring with its preformed packing. The propeller must be reassembled prior to performing the external and internal hydraulic leakage test.

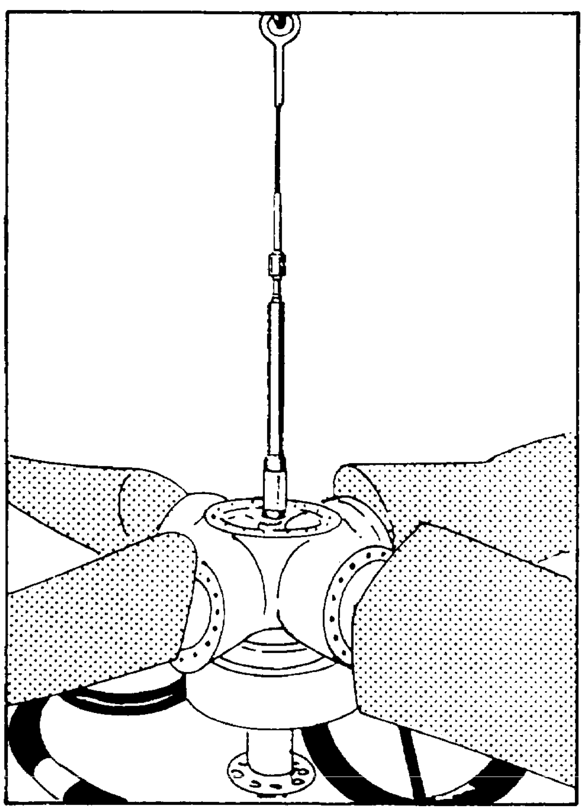


Figure 8-23.-Propeller suspended for balancing.

External and Internal Hydraulic Leakage Test

Before you begin the propeller test, first verify that the propeller test equipment has been inspected, serviced, and properly assembled. This must be done prior to the installation of the propeller. Install the propeller on the test equipment in accordance with the appropriate technical publication before beginning the hydraulic leakage test.

After the hydraulic fluid is warmed up, exercise the propeller between the high and the low blade angles several times to purge air from both the test equipment and propeller system. Purging will avoid erratic operation during the external and internal leakage tests.

CAUTION

Attempting to initiate a decrease in propeller blade angle when the propeller is in a range from about 60 degrees to 15 degrees may cause the pitchlock to engage or cause damage to the ratchet teeth. If it becomes necessary to stop in this range, first increase the blade angle to above the pitchlock range, and then proceed to a decreased blade angle.

EXTERNAL LEAKAGE TEST

The test equipment used to supply the various pressures and flow requirements is the hydraulic propeller test stand GS1221. With the test stand maintaining 150 psi, cycle the propeller blades between a low blade angle and a high blade angle until a total of eight cycles are completed. No external leakage is permissible during the cycling.

If any external leakage occurs at the junction of the barrel half seals and the blade packings, eliminate the leakage by separating the barrel halves and adding zinc chromate putty, MIL-P-8116, to the junction. You must control the amount and location of the putty to prevent it from getting into the barrel cavity. Leakage from the blade bores can be eliminated by replacing the blade preformed packing. The complete external leakage test must be rerun after any external leakage corrective work has been completed.

INTERNAL FLOW AND LEAKAGE TEST

The internal flow and leakage tests are designed to ensure the proper internal operation of the propeller system. The test equipment will supply the various hydraulic pressures to the inboard and outboard side of the dome piston, surge valve, and pitchlock mechanism ensuring smooth blade angle movement to the reverse and feather blade angles.

If internal flow and leakage requirements are not in compliance with the appropriate technical publication, you must disassemble the propeller and inspect all visible packings for damage and/or proper location. All internal flow and leakage tests must be completed before you can issue the propeller to an operating activity. The time for discovering external/internal leakage is NOT when the propeller has been installed and is ready for final rigging.

CHAPTER 9

POWER PLANT TROUBLESHOOTING

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Recognize basic troubleshooting procedures and common troubleshooting errors.
- Identify the types and uses of the various drawings used in aircraft maintenance publications.
- Recognize the codes and methods for the identification of various fluid lines.
- Recognize the characteristics of a multimeter and the use of the high-voltage insulation tester.
- Recognize the purpose of, and the procedures for, the use of the two types of borescopes.
- Recognize the main variables involved when performing engine tests and the purpose of the materials used in engine field cleaning.

Efficient maintenance of any aircraft depends upon the operating and maintenance personnel's familiarity with the aircraft and its associated parts. You must have a thorough knowledge of the engine and know its normal operating conditions. You should know the oil pressures, fuel pressure, rpm limits, and exhaust gas temperatures for all of the engine operating ranges. In addition to knowing the normal engine conditions, you should understand the effects of atmospheric conditions on the engine. You must consider such things as air temperatures and pressure, fuel temperatures, and wind effects.

GENERAL ENGINE TROUBLESHOOTING

All aircraft maintenance activities are plagued by repeat discrepancies. These discrepancies show up repeatedly on the same aircraft. They show up even after being signed off as previously corrected. There are many possible causes for repeat discrepancies. The most common cause is poor troubleshooting procedures.

It is often unsafe to assume that the engine is completely repaired when some obvious corrective measure has been taken to correct a malfunction. Never be hasty in assuming any conclusions. Do not confuse the significance of cause and effect. For example, low oil pressure, in itself, is not truly a trouble. It is only an indication that a problem exists. the true cause of which is the trouble.

The preceding paragraph emphasizes the importance of tracing an abnormal indication to its source. Do not be satisfied that restoration to a normal condition is accomplished by some obvious adjustment. Adjusting the oil pressure relief valve setting may not be the only correction or the correct step for a low oil pressure discrepancy. Refer to table 9-1 for possible low oil pressure causes. Invariably, there is a reason for an abnormal engine indication. You must know the reason and make sure that proper corrective measures are taken before the discrepancy is signed off. Proper corrective measures require the use of time-proven methods, not guesswork.

As previously stated, to troubleshoot intelligently, you must know the system and the function of each component in the system. You must have a mental picture of the location of each component in relation to other components in the

Table 9-1.-Oil Pressure Troubleshooting Chart

Trouble	Cause	Remedy
High oil pressure.	Low oil temperature.	Check temperature indicator.
		Check grade of oil.
	Improper setting of relief valve.	Reset pressure relief valve.
	Defective pressure indicator.	Replace with new or serviceable indicator.
Low oil pressure.	High oil temperature.	Check temperature indicator.
	Clogged oil filter.	Remove and clean oil filter.
	Improper setting of relief valve.	Reset pressure relief valve.
	Defective pressure pump.	Repair or replace pump.
	Defective pressure indicator.	Replace with new or serviceable indicator.
	Low oil level.	Fill oil tank to the proper level.
	Viscosity of oil is too light.	Drain system; refill with correct grade of oil.
	Air leak in the supply line.	Locate and eliminate air leak.

system. Studying schematic diagrams of the system is one way to establish this mental picture.

GENERAL SAFETY PROCEDURES

In the performance of your duties, you may come across many potentially dangerous conditions and situations. When working, there is one rule to stress strongly—SAFETY FIRST. Whether you are working in the shop, on the line, or during a flight, you should follow prescribed safety procedures. When working on or near aircraft, there is the danger of jet blast, intake duct, propeller, or rotor blades. Because of these dangers, you need to develop safe and intelligent work habits. You should become a safety specialist, trained in recognizing and correcting dangerous conditions and unsafe acts.

You should study the cardiopulmonary resuscitation (CPR) training section of *Basic Military Requirements,* NAVEDTRA 10054, and *Standard First Aid Training Course,* NAVEDTRA 10081. These texts provide valuable information, but they do not replace training. It is your responsibility to get first aid training, including CPR. Personal CPR training is available at many Navy medical facilities. Many local fire stations and Red Cross agencies also offer this type of training. It is important for you to be currently certified in the special skills of CPR when troubleshooting electrical systems or ignition systems.

WARNING

Do not perform CPR unless you have had the proper training.

COMMON ENGINE PROBLEMS

The need for troubleshooting is shown by poor engine performance or system operation. The maintenance instruction manuals for an aircraft or engine contains specific information for understanding and troubleshooting engine problems. Understanding the cause of common engine problems will help you avoid them.

Air System

All personnel should clearly understand that any obstruction or interruption of the air as it moves through the engine will affect the entire operation of the engine. Entrance of foreign matter into the air system is one of the main causes of service trouble. As the foreign matter passes rearward, it causes improper combustion, blockage of cooling air passages, and combustion section damage. The turbine section and the afterburner section may be damaged.

Compressor Section

The compressor section of the turbojet engine is subject to a variety of service troubles from foreign matter passing through the compressor. Small pebbles, nuts, bolts, and washers can cause damage to the compressor rotor blades and stator vanes. Damage severe enough to warrant complete overhaul of the engine may result from the ingestion of foreign matter.

Combustion Chamber and Turbine Section

High temperatures take place in the combustion and turbine sections. Few major service troubles occur when maximum temperature and maximum rpm limits are closely monitored. Hot starts, overtemperatures, and exceeding maximum rpm will cause extensive service troubles in the combustion and turbine sections.

Fuel System

The fuel system of the gas turbine engine begins at the engine-driven fuel pump. The system ends with delivery of fuel to the combustion chambers through fuel nozzles in the form of highly atomized spray. Common service troubles are wrong types of fuel, water or other foreign matter in the fuel, defective fuel-boost pumps, and clogged fuel filters.

Lubrication System

The proper grade of oil and cleanliness when replenishing the oil supply are absolute requirements to avoid lubrication system troubles. Gas turbine engines have few moving parts, but the speed at which the parts move, especially the rotor, requires constant lubrication to the bearings. Oil starvation for a short period of time can result in having to remove the engine for overhaul.

TROUBLESHOOTING PROCEDURES

Troubleshooting procedures are similar in practically all applications. Troubleshooting is the logical or deductive reasoning procedure used when determining what is causing a particular system malfunction. There are six steps involved in good deductive troubleshooting.

1. Conduct a visual inspection. This inspection should be thorough and searching. Check all lines, units, mechanical linkages, and parts for evidence of leaks, looseness, material condition, and proper installation. During this visual inspection, check all systems for proper servicing. Check reservoirs for proper servicing levels, accumulators for specified preload, etc.

The aircraft discrepancy book (ADB) and the visual information display system/maintenance action forms (VIDS/MAFs) are invaluable troubleshooting tools. The type of flight and previous maintenance actions may give an indication of the engine's problem. You may save many man-hours of troubleshooting an engine discrepancy by first screening the ADB for prior maintenance. You may find prior maintenance that has contributed to the cause of the new problem. You may find improperly performed maintenance, and trends of prior malfunctions.

2. Conduct an operational check. Check the malfunctioning system or subsystem for proper operation. This includes checking the mechanical movement of throttles and linkages for the correct movement without binding. Check for the proper sequence of operation and speed, and whether a complete cycle was obtained. Sometimes an operational check requires special test equipment or engine turnup to check out the system properly.

3. Classify the trouble. Malfunctions usually fall into four basic categories. They are the hydraulic, pneumatic, mechanical, and electrical groups. Using the information gained from steps 1 and 2, you must determine under which classification the malfunction occurs. Something affecting normal flow of fluid would be classified under the hydraulic classification. The flow of fluid may be affected by external and internal leakage, total or partial restriction, or improper lubrication.

Something affecting the normal flow of compressed gases is classified as a pneumatic malfunction. This type of malfunction stems from the same general sources as hydraulic malfunctions mentioned in the previous paragraph.

Many units that operate hydraulically or pneumatically use mechanical linkage. If a discrepancy in the linkage exists, it will affect the system's operation. Many mechanical discrepancies are found during visual inspections. Common mechanical problems are worn linkages, broken linkages, improperly adjusted linkages, or improperly installed linkages.

You must be able to determine if the electrical system is functioning normally. Common electrical problems are complete power failure, circuit failure, or component failure. Electrical components have circuit breakers and switches to operate or control them. Check the obvious things such as tripped circuit breakers or switches in the wrong position. Although AEs normally troubleshoot electrical problems, sometimes you will work together on a problem. Learn to read electrical schematics and use a multimeter so you can trace electrical power requirements throughout the affected system.

4. Isolate the trouble. This step calls for sound reasoning. A full and complete knowledge of engine theory, as well as a complete understanding of the affected system is necessary. During this step you must use knowledge and known facts to determine where the malfunction exists in the system. Usually the trouble can be pinned down to one or two areas. Eliminate those units that could not cause the known symptoms and those that can be shown to operate normally.

Accomplish the isolating and correcting of engine discrepancies by comparing symptoms with probable cause. Begin with the most obvious and proceed to the less likely causes. A combination of several small maladjustments or malfunctions may contribute to make a complex discrepancy.

5. Correct the trouble. Accomplish this step only after the trouble has been definitely located. Malfunctions are corrected by servicing, adjustments, and part replacement. Part replacement is often needed to correct a malfunction, but you never use part replacement as a method of troubleshooting. Each year, thousands of dollars worth of engine parts are returned to overhaul activities with labels stating that they are faulty. Upon completion of test and check by the overhaul activity, many parts show no defect. This practice is wasteful and very expensive. Another problem occurs when mechanics replace a major assembly. The problem could have been corrected by replacing a subassembly. The replacement of an entire unit when only a small part is at fault reflects poor maintenance practices. When troubleshooting, remember you are working with equipment that is both expensive and scarce. Replace equipment only after it is thoroughly tested and determined to be faulty.

6. Conduct a final operational check. The affected system must have a thorough check to determine proper operation. Checking the engine for proper operation consists primarily of reading engine instruments. Compare the readings with those given by the manufacturer for specific engine conditions, atmospheric pressures, and temperatures.

Early model engine test procedures used rpm as the engine operating parameter to establish thrust. Today's engine test procedures use engine pressure ratio (EPR) as the primary thrust indicator. EPR is the ratio of the total pressure at the front of the compressor to the total pressure at the rear of the turbine.

Using EPR as the thrust indicator means that on a hot day it is quite possible for the engine rpm to exceed 100 percent. If you use rpm on a hot day instead of EPR, you would actually have a lower amount of thrust at 100 percent, Just the opposite is true on a cold day; desired thrust ratings may be reached at something less than 100 percent using EPR. Other variables, such as a dirty or damaged compressor, will also affect thrust. These conditions reduce thrust for a given rpm. Exhaust gas temperature (EGT) is NEVER used for setting thrust. Monitor EGT carefully to prevent excessive temperature readings.

TROUBLESHOOTING ERRORS

There are certain errors that you should avoid if you are to become an effective troubleshooter.

These errors may result from faulty procedures or by the way you think about your work. A report entitled "A Preliminary Investigation of Troubleshooting" lists common troubleshooting practices to avoid. The report indicates that you should avoid making the following common errors:

1. Checking parts of the system that had nothing to do with the cause of the symptom.

2. Ignoring part of a system because you didn't know that the unit was a possible cause of the symptom.

3. Making a difficult check when a simple one would have done the job.

4. After isolating the engine trouble between two points, making further checks beyond, rather than between these points. Sometimes making a check between two points despite the fact that no engine trouble was found between them.

5. Omitting a check even though you know it is related to the situation.

6. Attempting to remember a lot of information, This finding points out the necessity of writing down all information during checks, and using the maintenance manuals, not your memory.

The report pointed out that troubleshooters sometimes made errors because of previous experience in similar situations. When they analyze and repair the engine trouble successfully, they have a feeling of satisfaction. They then tend to use the same procedures, even though the procedures are not relevant to the present engine trouble. Similarly, if the mechanic tried certain checks in the past and they did not fix the problem, the mechanic was reluctant to use them again, even when they provided required information to correct the problem.

To become an expert troubleshooter, you must know the function of each part and how the operation of one part or system affects another. A good way to learn engine systems and the different relationships is to study schematics and diagrams. Trace out all the systems you work on, and recognize normal readings. Learn how to use test equipment and read schematics before you are required to troubleshoot a problem.

USE OF DIAGRAMS, DRAWINGS, AND CHARTS IN TROUBLESHOOTING

The diligent use of the applicable maintenance instruction manual (MIM) is essential in preventing poor troubleshooting procedures. The MIM for each aircraft provides troubleshooting aids that cover the six steps listed in the previous section. These manuals provide a variety of troubleshooting aids. Table 9-2 shows examples of troubleshooting chart formats. These charts list a definite sequence of action for a problem, according to the probability of failure and ease of investigation. These charts supply the trouble, probable cause, and the remedy for some of the more common malfunctions.

The MIM also contains schematics and diagrams for use in troubleshooting. Diagrams of the various electrical circuits, fuel systems, and lubrication systems are very useful in isolating discrepancies. There are many types of diagrams, but those most important for troubleshooting include schematics and pictorials. There are some MIMs that combine different types of diagrams to provide more information. To understand how a system or component of the aircraft functions, you must be able to read these diagrams.

Schematic diagrams enable maintenance personnel to trace the path of electrical circuits, fuel systems, and lubrication systems of aircraft. Schematic diagrams use symbols for a graphic representation of the assembly or system. Electrical components or circuits use the standard electrical symbols shown in figure 9-1. Look at this figure and notice the electrical symbols for FUSE, SPLICE, GROUND, and POLARITY. Some of the mechanical symbols used in schematics are shown in table 9-3. A complete listing can be found in the *Military Standard, Mechanical Symbols for Aeronautical, Aerospace, and Spacecraft Use, Part 2,* MIL-STD-17B-2.

Schematic diagrams show the relationship of each part with other parts in the system. They do not always indicate the physical location of the

Table 9-2.—Samples of Various Troubleshooting Charts

Trouble	Possible cause	Suggested remedy
1. Transfer fuel quantity indicator inaccurate.	a. Malfunction in indicator or probes; electrical circuit malfunction.	a. Check electrical circuit (sections VI and IX).
	b. Indicator not calibrated correctly.	b. Check calibration (section VI).
2. Aft fuselage cells fail to transfer fuel.	a. Electrical circuits out.	a. Check electrical circuits (section IX).
	b. Transfer booster pump failure, or lines obstructed.	b. Replace pump or clear obstruction.
	c. Main fuel low level float valves failed.	c. Replace low level float valves.

1. Turbine inlet temperature OFF flag is visible during all operations.

Release clamp and remove temperature indicator from instrument panel. Disconnect electrical connector. Is 28 volts d.c. indicated between pins B and C of connector?

YES → Replace indicator.

NO → Replace or repair defective wiring.

TABLE 45. FAULTY ENGINE OIL INDICATION SYSTEM

Question	Action if Answer is Yes	Action if Answer is No
1a. Check for Ng and oil pressure indication while motoring engine. Oil pressure and Ng indication?	1b. Check oil level in oil tank. Proceed to step 2a.	1c. Check oil pump for sheared shaft. Proceed to ENG OIL PRESS Light On But Oil Press Indicator Displays Low or No Oil Pressure.
2a. Tank full?	2b. Install direct reading pressure gages to oil pump supply discharge port and to B-sump scavenge tee. Perform Engine Start Procedure and advance throttle 80% Ng for 5 minutes. Record flight station gage oil pressure, oil pump discharge pressure, and B-sump scavenge pressure. Calculate oil pump discharge pressure less B-sump scavenge pressure. Proceed to step 3a.	

CAUTION

To prevent damage to electrical connectors due to arcing, power must be removed from pins before disconnecting or reconnecting plug connectors.

Question	Action if Answer is Yes	Action if Answer is No
3a. Is calculated pressure within 5 psi of oil transmitter pressure?	3b. Indicator system is OK. Proceed to appropriate symptomatic table.	

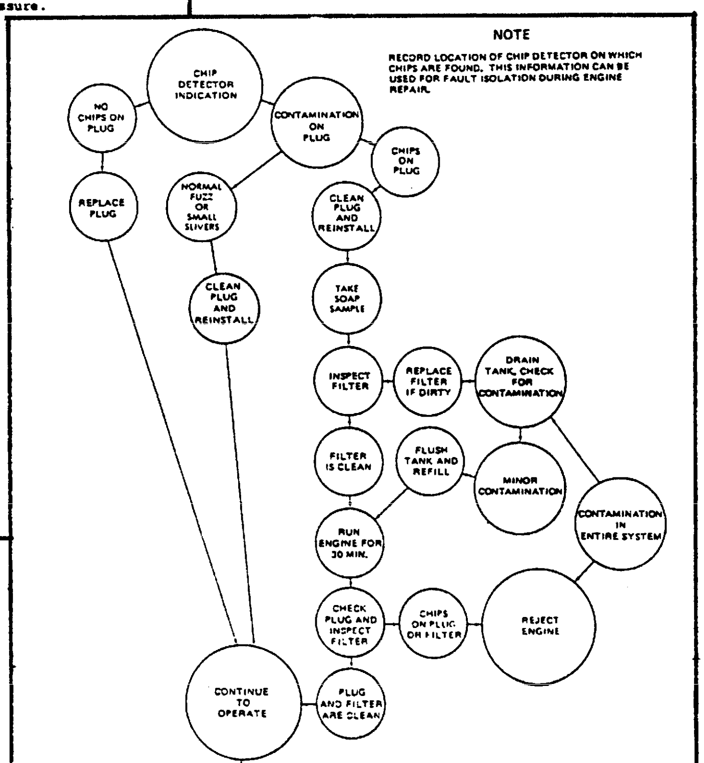
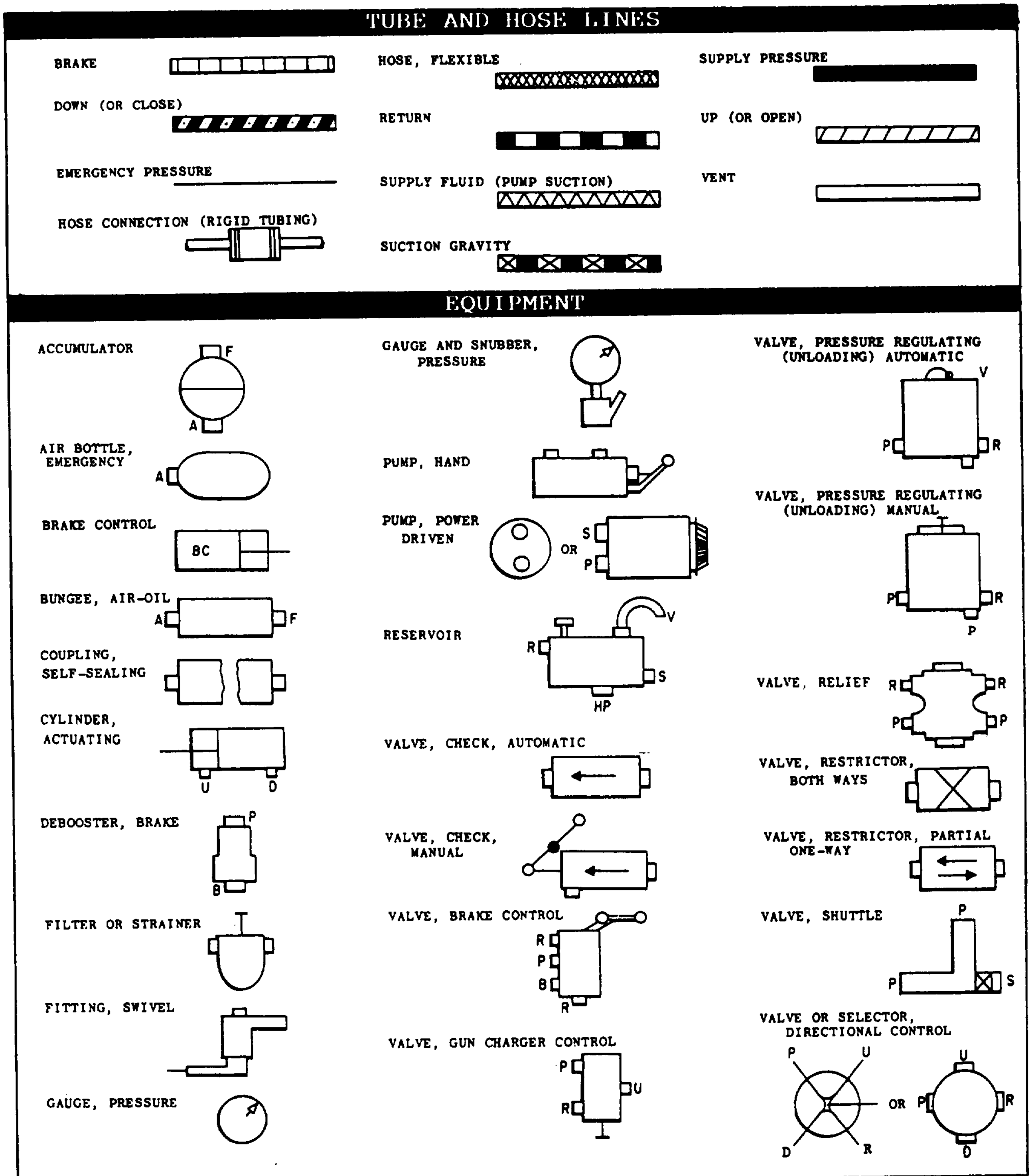


Table 9-3.-Aeronautical Mechanical Symbols



ALPHABETIC CODE

A - AIR	D - DOWN (OR CLOSE)	P - PRESSURE	U - UP (OR OPEN)
B - BRAKE	F - FLUID (LIQUID)	R - RETURN	
BC - BRAKE CONTROL	HP - HANDPUMP	S - SUCTION (OR SUPPLY)	

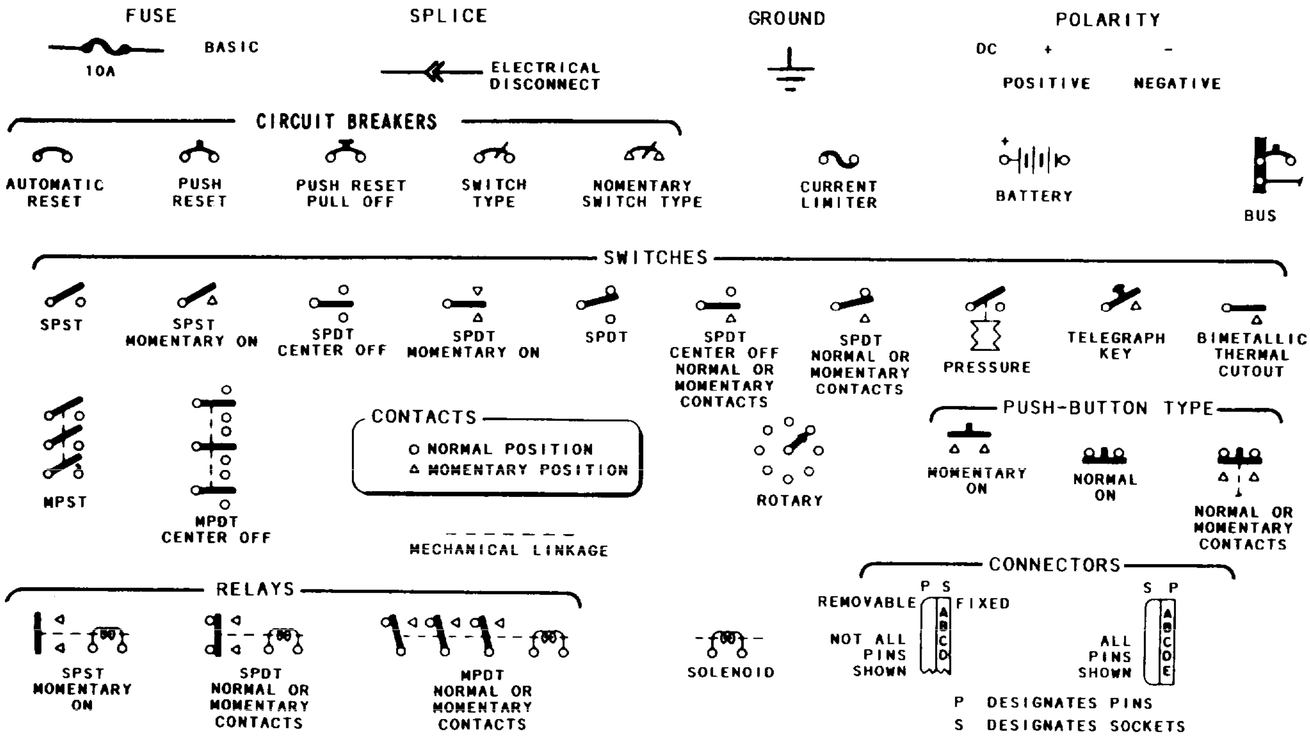
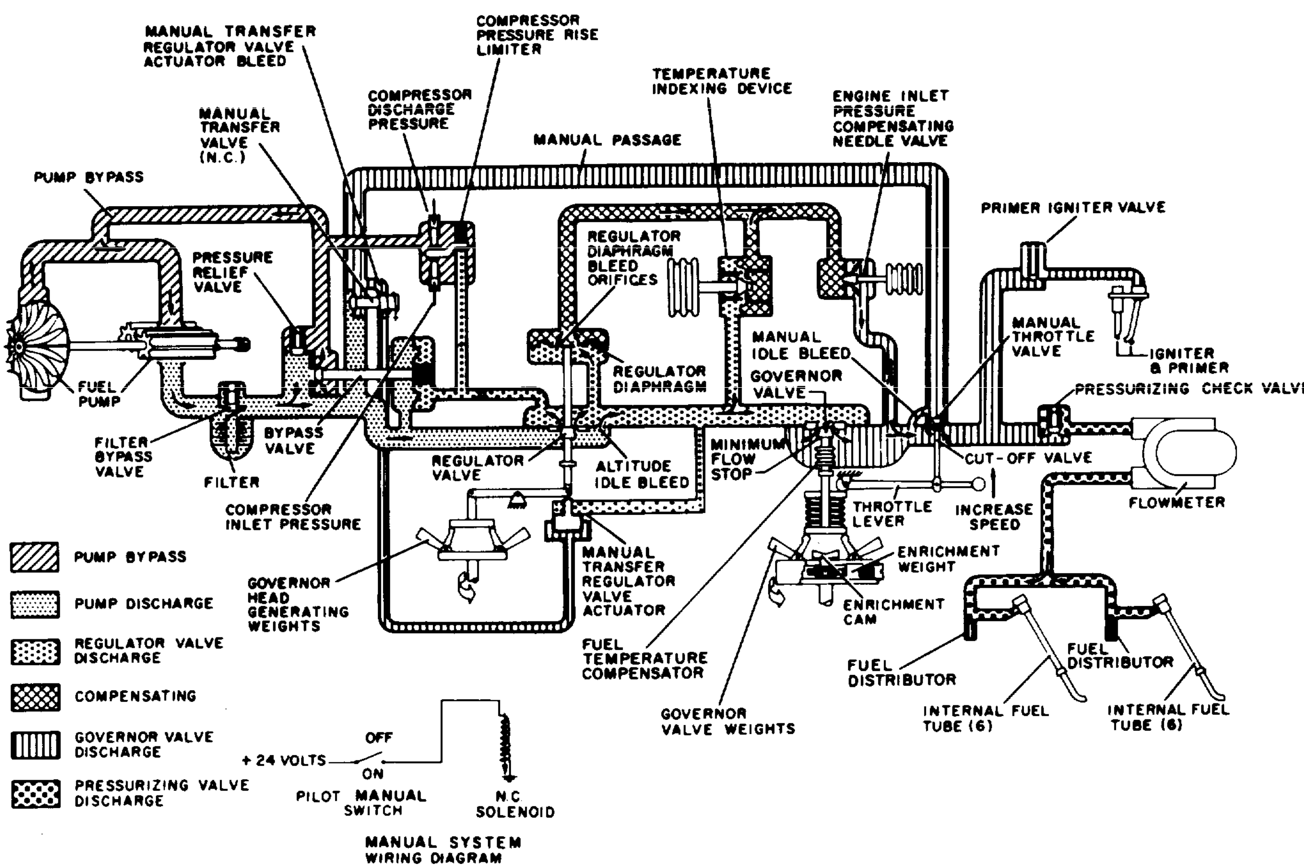


Figure 9-1.-Electrical symbols.



9-2.-Fuel control schematic.

part. Figure 9-2 is a schematic diagram that shows the fuel flow of a turbojet engine fuel control. It shows the flow of fuel from the fuel pump through the fuel control, the fuel distributors, and the internal fuel tubes. Fuel from the internal fuel tubes enters the combustion chambers through fuel lines to the fuel manifold. Each part is illustrated and identified by name. The arrows show the direction of flow through each line and component within the fuel control.

Pictorial diagrams show location, function, and appearance of parts and assemblies. This diagram is sometimes called an installation diagram. Pictorial diagrams are valuable for locating and identifying parts. See figure 9-3.

Other uses for this type of drawing is the disassembled or exploded view and the cutaway. Cutaway drawings show the internal construction of parts, and exploded views show how the various parts of a component are assembled.

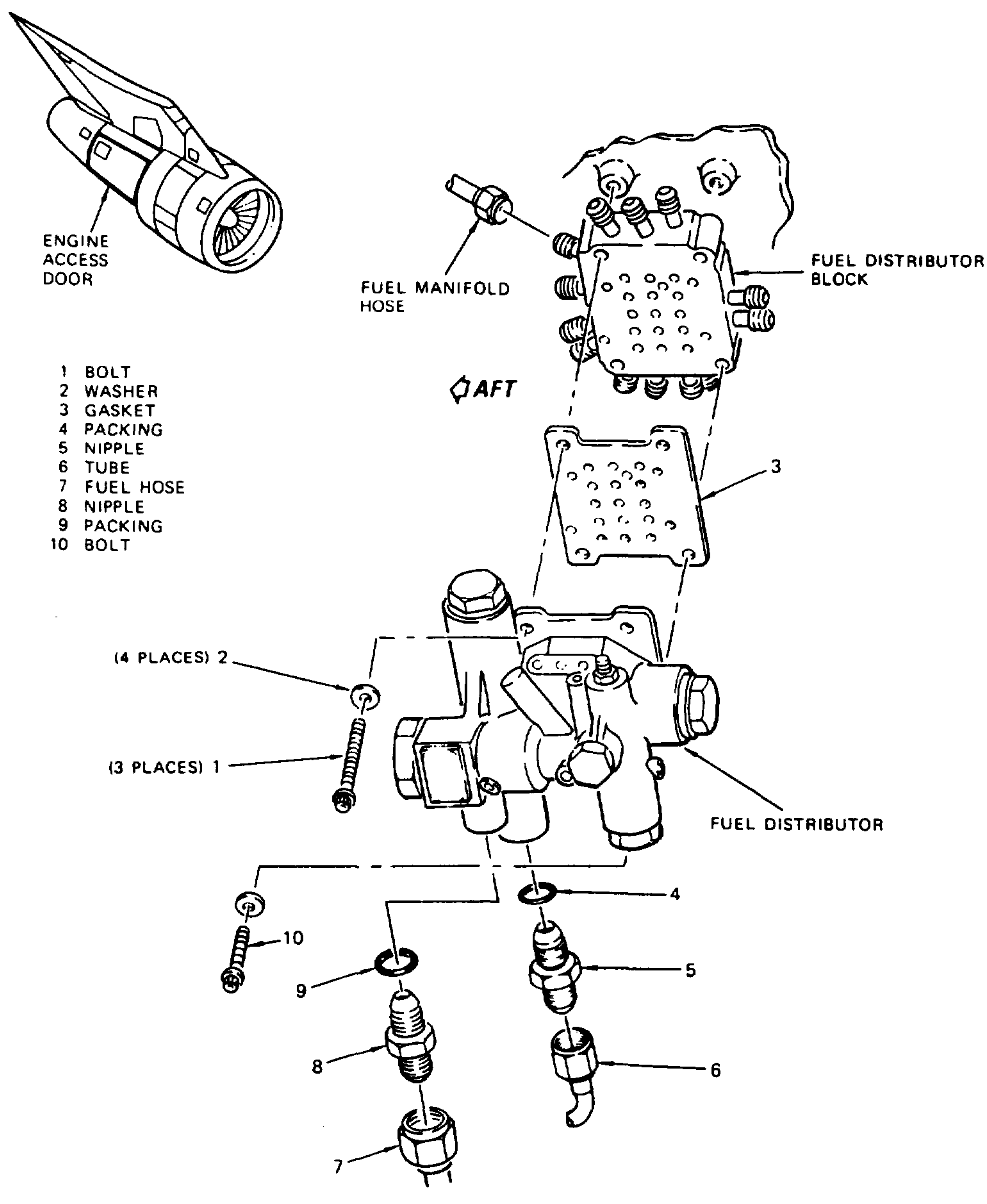


Figure 9-3.-Pictorial diagram of a fuel distributor.

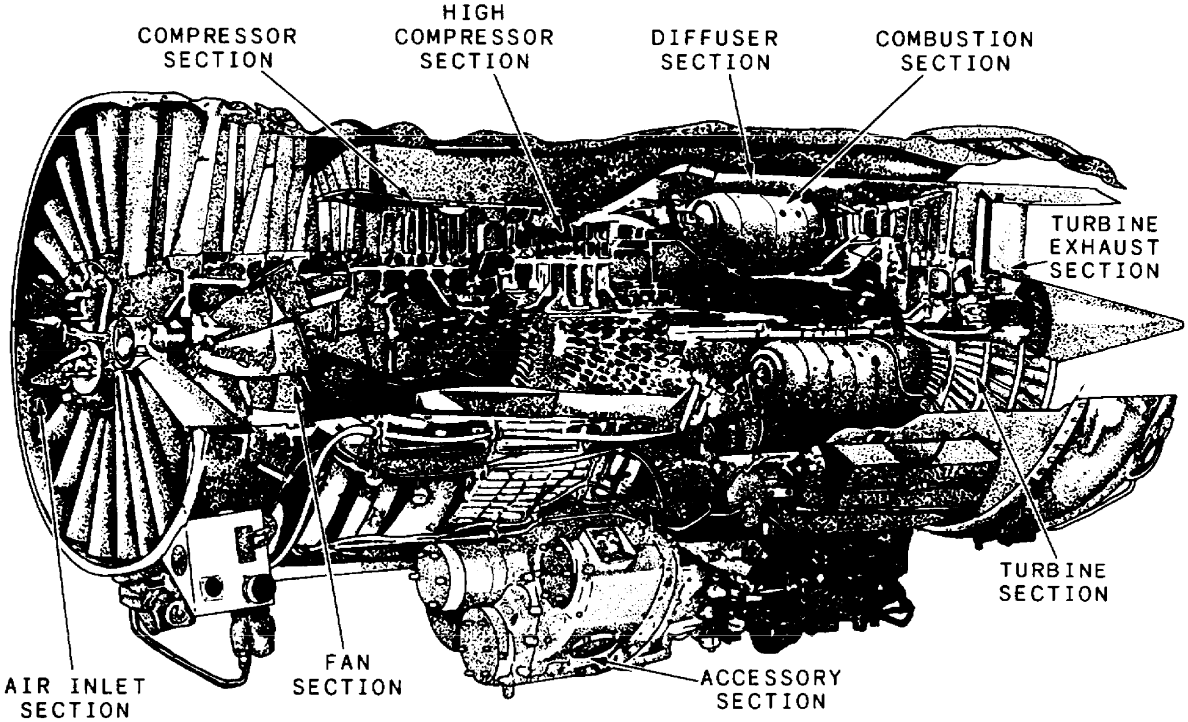


Figure 9-4.-Turbofan, cutaway view.

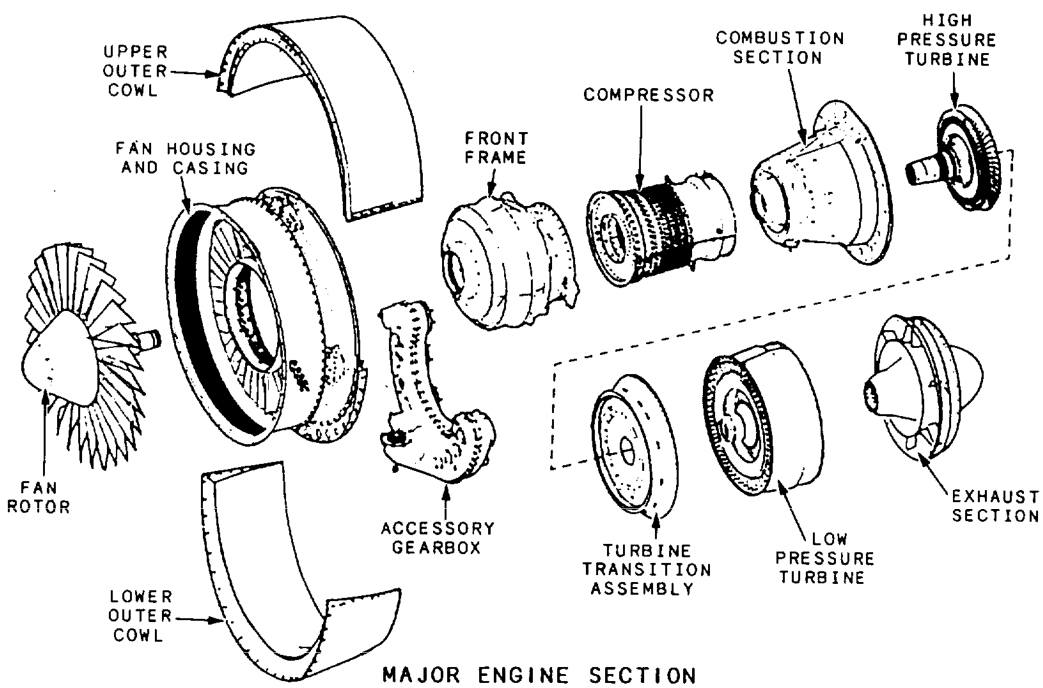


Figure 9-5.-Turbofan, exploded view.

Figure 9-4 shows a cutaway drawing, and figure 9-5 shows an exploded view drawing.

Additional information concerning diagrams is contained in the training manual *Blueprint Reading and Sketching,* NAVEDTRA 10077 (series).

FLUID LINE IDENTIFICATION

You can identify fluid lines in aircraft by markers made up of color codes, words, and geometric symbols. These markers identify each line as to function, content, primary hazard, and direction of flow. Figure 9-6 lists the various types

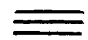
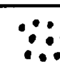
FUNCTION	COLOR	SYMBOL
Fuel	Red	
Rocket Oxidizer	Green, Gray	
Rocket Fuel	Red, Gray	
Water Injection	Red, Gray, Red	
Lubrication	Yellow	
Hydraulic	Blue, Yellow	
Solvent	Blue, Brown	
Pneumatic	Orange, Blue	
Instrument air	Orange, Gray	
Coolant	Blue	
Breathing Oxygen	Green	
Air Conditioning	Brown, Gray	
Monopropellant	Yellow, Orange	
Fire Protection	Brown	
De-Icing	Gray	
Rocket Catalyst	Yellow, Green	
Compressed gas	Orange	
Electrical Conduit	Brown, Orange	
Inerting	Orange, Green	

Figure 9-6.-Fluid line color codes and symbols.

of fluid lines and indicates the color code and symbol for each line. Figure 9-7 shows the markers used for rocket fuel lines.

In most instances, fluid lines are marked by the use of 1-inch tape or decals, as shown in figure 9-7, view A. On lines 4 inches or larger in diameter, lines in an oily environment, hot lines, and some cold lines, steel tags replace tape or decals. See figure 9-7, view B. On lines in engine compartments, where there is a possibility that tapes, decals, or tags can be drawn into the engine intake, paint is used. See figure 9-7, view C.

As shown in figure 9-7, view A, reading from left to right, the line function is indicated by color code (red, gray), name (ROCKET FUEL), and symbols (four-pointed star and crescent). Content of the line is indicated by name (HYDRAZINE). The primary hazard is indicated by the word TOXIC. Pressure is indicated in pounds per square inch (125 psi). Direction of flow is indicated by arrows. Two-headed arrows are used to show reversible flow. In addition, certain lines may have a special code for lines that have a specific function within a system. Some examples include drain, vent, pressure, and return lines.

There are four general classes of hazards found in connection with fluid lines. These hazards are shown by special fluid line markings.

1. Flammable material (FLAM). The hazard marking FLAM is used to identify lines containing

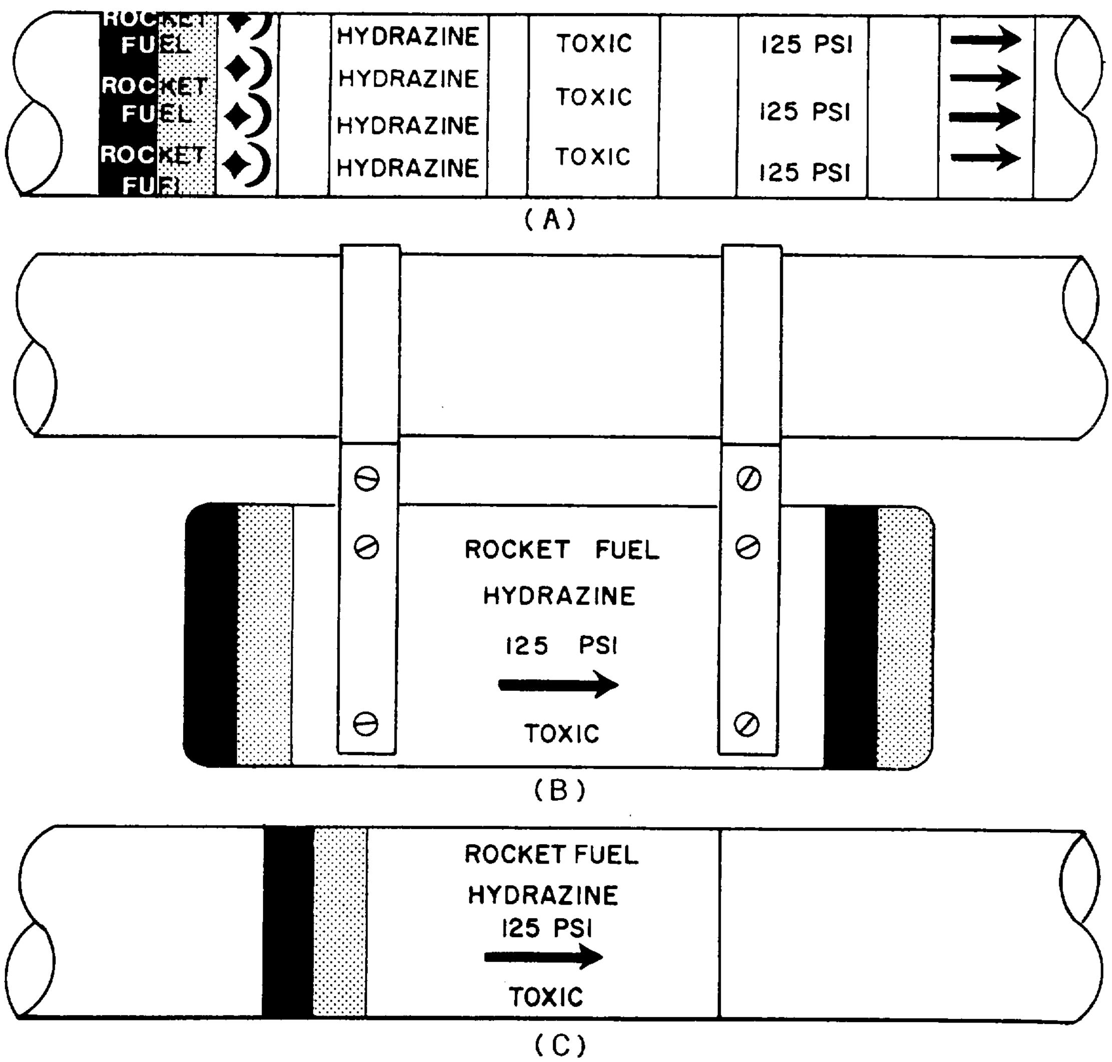


Figure 9-7.-Fluid line identification group (A) using tape and decals; (B) using metal tags; (C) using paint.

materials known as flammable or combustible materials.

2. Toxic and poisonous materials (TOXIC). The word TOXIC identifies lines that contain materials that are extremely hazardous to life or health.

3. Anesthetics and harmful materials (AAHM). The AAHM markings identify lines containing materials that produce anesthetic vapors and all liquid chemicals that are hazardous to life and property. These materials do not produce dangerous quantities of fumes or vapors.

4. Physically dangerous materials (PHDAN). The PHDAN marking identifies lines that carry a material that is not dangerous within itself but is asphyxiating in confined areas. The material in the line may be in a dangerous physical state of high pressure or temperature.

Aircraft and engine manufacturers are responsible for the original installation of identification markers, and maintenance personnel are responsible for replacement as necessary. Tapes and decals are on both ends of a line and at least once in each compartment through which the line passes. In addition, identification markers are found next to each valve, regulator, filter, or other accessory within a line. Location requirements are the same for tapes and decals as they are for tags and paint.

Additional information is listed in Aviation *Hose and Tube Manual,* NAVAIR 01-1A-20. Complete instructions for installing fluid line identification markers are contained in MIL-STD-1247B.

GAS TURBINE TEST EQUIPMENT

You will find that certain test equipment will prove invaluable in troubleshooting engine systems. We will briefly discuss the necessary test equipment available for maintaining aircraft systems. More detailed information can be found in the technical manual for the particular piece of equipment.

ELECTRICAL TEST EQUIPMENT

During troubleshooting, you will often measure voltage, current, and resistance. Although AEs normally troubleshoot and repair electrical systems, you should have a knowledge of basic electricity and test equipment. This knowledge will increase your troubleshooting abilities since there are few aircraft systems independent of electrical operations. In addition, many troubleshooting charts call for continuity checks that a properly trained AD can easily accomplish.

NOTE: Only authorized personnel may repair and maintain electronic and electrical equipment because of the chance of injury, the danger of fire, and possible material damage. To use electrical test equipment correctly, you need to have a working knowledge of basic electricity. You should adhere to the special and general rules for the handling of electrical devices.

GENERAL RULES FOR ELECTRICAL TEST METERS

Always connect an ammeter in series—never in parallel. Always connect a voltmeter in parallel—never in series. Never connect an ohmmeter to an energized circuit. On test meters, select the highest range first, then switch to lower ranges as needed.

When you use an ohmmeter, select a scale that gives a near midscale reading. Midscale is the point where the meter is most accurate. Do not leave the multimeter selector switch in a resistance position when the meter is not in use. The leads may short together, discharging the internal battery. There is less chance of damaging the meter if the switch is on a high at-volt setting, or in the OFF position. Meters that have an OFF position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when moving the meter.

View the meter from directly in front to eliminate parallax error. Observe polarity when measuring dc voltage or current. Do not place meters in the presence of strong magnetic fields. Never measure the resistance of a meter or a circuit with a meter in it. The high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-filament-current tubes and to some types of semiconductors.

When you are measuring high resistance, do not touch the test lead tips or the circuit because it may cause body resistance to shunt the circuit, causing an erroneous reading. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

Multimeter

The process of fault detection often leads beyond visual inspection and power checks. Use a voltmeter to find out if a power circuit is delivering power to the proper place. However, the voltmeter won't identify what is wrong. An ohmmeter is a better instrument for identifying the problem. With the ohmmeter, you can find opens, shorts, grounds, or incorrect resistance values. With schematics you can trace circuits until you isolate the trouble.

The multimeter contains circuitry that allows it to be a voltmeter, an ammeter, or an ohmmeter. A multimeter is often called a volt-ohm-milliammeter (VOM).

The VOM does have two disadvantages—it can load the circuit under test, and the meter movement is easy to damage because of improper testing procedures.

Two common multimeter are the Simpson 260 and the newer digital model Fluke 8100A. See figures 9-8 and 9-9.

Ohmmeter

Use an ohmmeter to measure circuit continuity and total or partial circuit resistance. An ohmmeter is shown in figure 9-10. The ohmmeter's

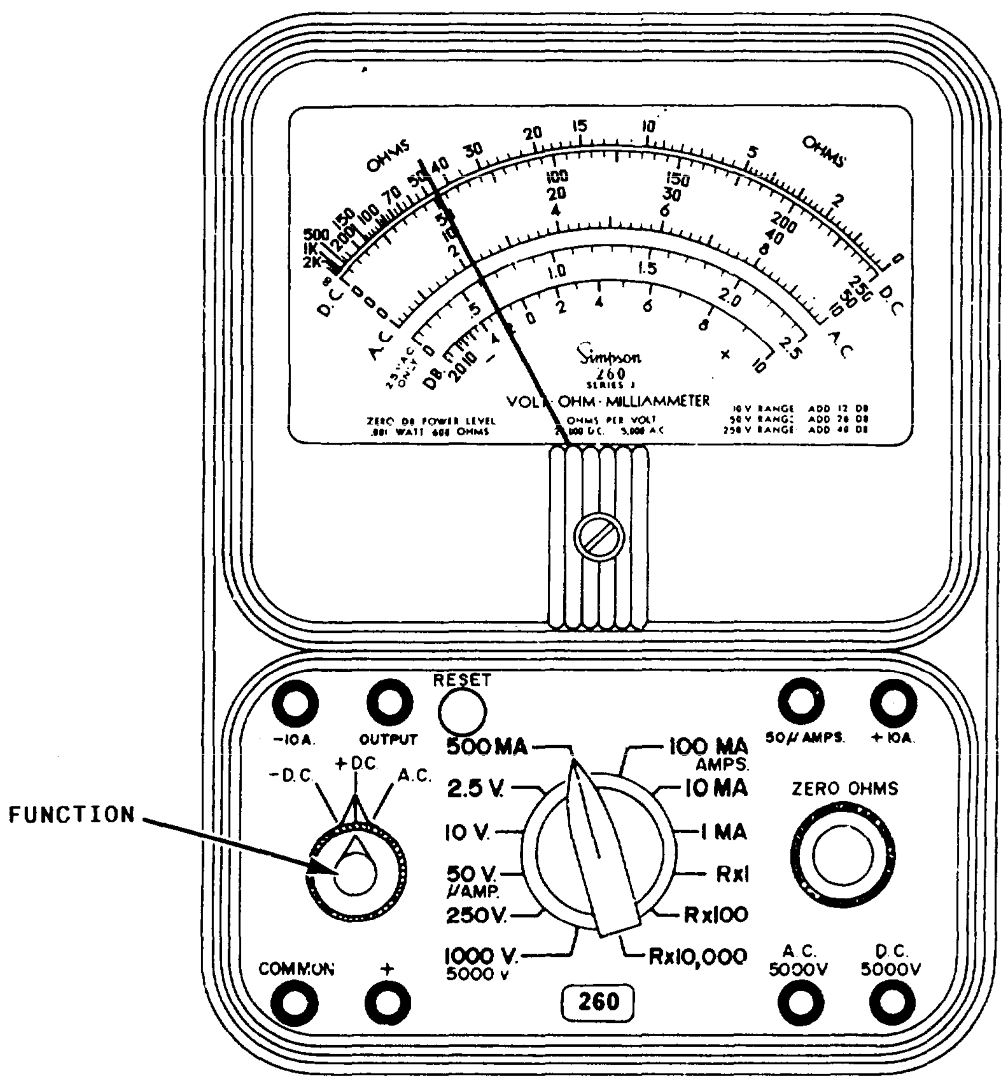


Figure 9-8.-Standard multimeter.

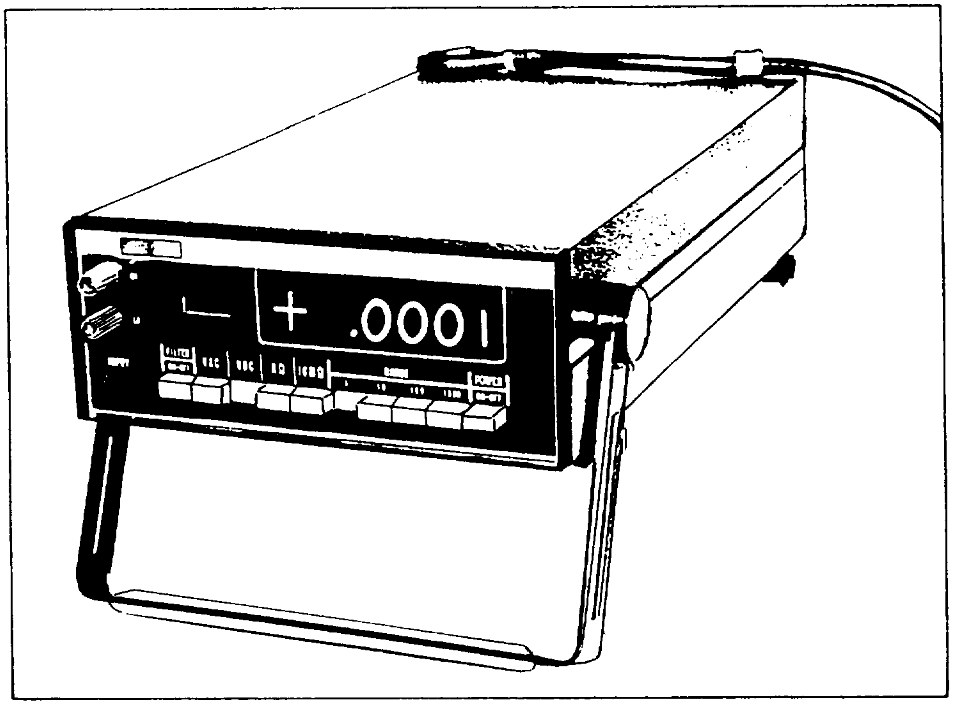


Figure 9-9.-Digital multimeter.

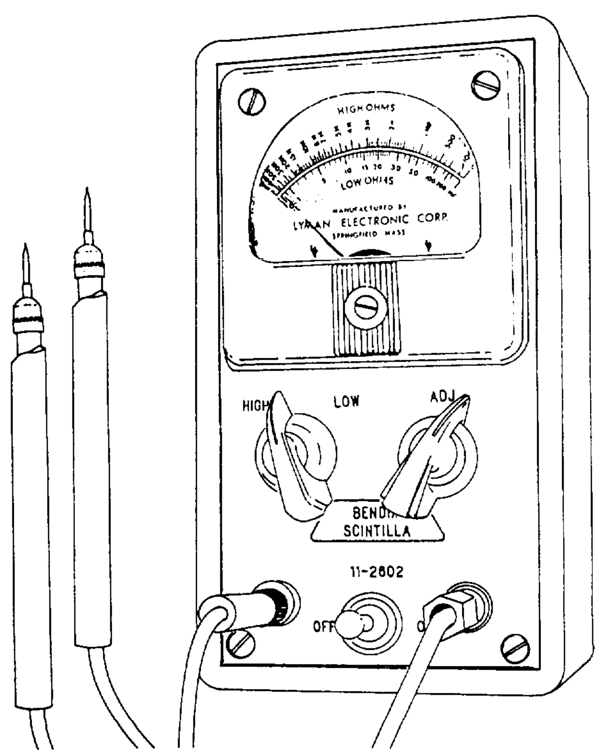


Figure 9-10.-Ohmmeter.

pointer deflection is controlled by the amount of battery current passing through the moving coil. Before measuring the resistance of an unknown resistor or electrical circuit, the test leads of the ohmmeter are first shorted together, as shown in figure 9-11. With the leads shorted, calibrate the meter for proper operation on the selected range.

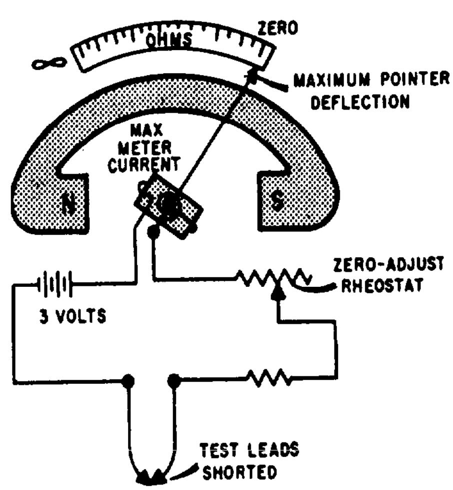


Figure 9-11.-Simple ohmmeter circuit.

When the variable resistor is adjusted properly, with the leads shorted, the pointer of the meter will come to rest exactly on zero. This reading indicates zero resistance between the test leads. When the test leads of an ohmmeter are separated, the pointer of the meter will return to the left side of the scale. This happens because of the interruption of current and the spring tension action on the movable coil assembly.

After you adjust the ohmmeter for zero reading, it is ready to be connected in a circuit to measure resistance. The power switch of the circuit to be measured should always be in the OFF position. Circuit voltage applied across the meter could damage meter movement.

Connect the test leads of the ohmmeter across (in series with) the circuit to be measured. The current produced by the meter must now flow through the circuit being tested. The reading obtained from the ohmmeter between zero and infinity shows the number of ohms resistance in that circuit. An infinity reading shows there is an open circuit.

In open circuits, current flow stops. The cause may be a broken wire, defective switch, etc. To detect open circuits, you must perform a continuity test, which will tell if the circuit is complete or continuous.

Look at figure 9-12. It shows a continuity test of a cable connecting two electronic units. You can see that both plugs are disconnected, and the ohmmeter is connected in series with conductor A, which is under test. The power should be off. When checking conductors A, B, and C, the current from the ohmmeter flows through plug 2 (female), conductor A, B, or C, to plug 1 (female). From plug 1, current passes through the jumper to the chassis, which is grounded to the aircraft structure. The aircraft structure serves as the return path to the chassis of unit 2 and completes the circuit through the series-connected ohmmeter.

The ohmmeter shows a low resistance because no break exists in conductors A, B, or C. However, checking conductor D reveals an open. The ohmmeter shows maximum resistance because current cannot flow in an open circuit. With an open circuit, the ohmmeter needle is all the way to the left, since it is a series-type ohmmeter (reads right to left). When you have finished using the ohmmeter, turn the ohmmeter switch OFF to conserve the batteries,

High-voltage Insulation Tester

The high-voltage insulation tester detects or measures leakage of high-voltage insulation. Figure 9-13 shows one of the several types of testers now in use.

The high-tension voltage tester is composed of four sections. They are as follows:

- A vibrator invertor, which converts a 24-volt dc source to 110-120 volts ac.

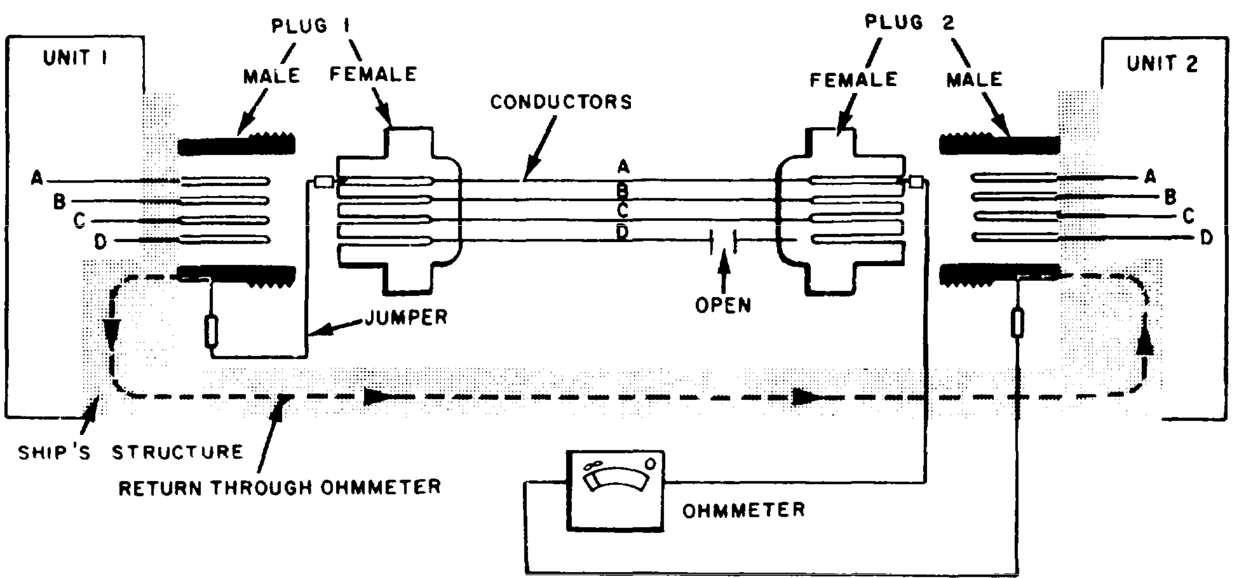


Figure 9-12.-Continuity test.

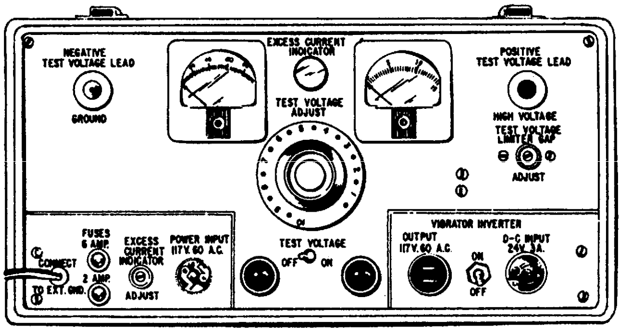


Figure 9-13.—High-voltage insulation tester.

● A voltage control, which controls the amount of high voltage applied to the test circuit.

● A step-up transformer, which steps up the low voltage from the vibrator invertor or 110-volt source to high voltage.

● A rectifier that changes ac to dc. The test leads are connected to the rectifier dc output side.

To calibrate the high-voltage tester, follow these four steps:

1. Set the microampere and kilovolt meters to indicate ZERO when the machine is OFF.
2. With the current ON, connect the test leads.
3. Move the voltage control until the needle is about one-sixteenth inch past 10, 000 volts. Then set the test voltage limiter gap. If it is properly adjusted, the neon light will not flash at the test voltage setting.
4. Adjust the excess current indicator to flash on and off continually when the microampere meter shows an excess of 100 microampere leakage.

When operating the high-voltage tester, be sure to make a continuity test with an ohmmeter before you apply the high-voltage insulation test. To hookup the high-voltage tester, follow these steps:

1. Ground the high-voltage insulation tester to a good local ground with the grounding lead.
2. Connect the red high-voltage test lead to the high-voltage side of the part to be tested.
3. Connect the black ground test lead to the ground side of the part to be tested.

WARNING

The insulation tester operates on high voltages that are dangerous. Always discharge the ground circuits before you touch them. Always connect the ground lead to a good earth ground before you turn the tester on. When testing a lead, connect the tester to the lead before you turn the test voltage switch on. Be safe. Operate the equipment and secure the leads with one hand only.

JETCAL ANALYZER AND JET CALIBRATION TEST UNITS

Two of the most important factors affecting turbine engine life are engine speed (rpm) and engine exhaust gas temperature (EGT). Excess exhaust gas temperatures of a few degrees reduce turbine blade life up to 50 percent. Low exhaust gas temperatures reduce engine efficiency and thrust. Excess engine speed can cause premature engine failure.

A jet calibration test unit tests tailpipe temperatures, engine speed, and other engine parameters more accurately than the cockpit gauges. Errors in reading cockpit instruments are made due to the position or height of the seat or the angle of viewing the gauge. In addition to more accurate readings, the new jet test units provide a printed readout of engine conditions for trend analysis.

BORESCOPE INSPECTION

You will find borescope inspection requirements listed in the periodic maintenance inspection cards (PMIC) for scheduled or conditional inspections. Borescopes provide illumination of internal areas of aircraft engines or engine parts. This illumination allows for internal inspections that require minimum disassembly, such as the removal of port covers or thermocouples.

Types of Borescopes

The rigid borescope assembly allows for inspection of internal engine conditions having a direct access. Another type of borescope has a flexible probe and is commonly known as a fiber-optic borescope, or fiberscope. The fiber-optic scopes have a flexible probe, which can be snaked around, behind, and into areas impossible to reach with the other scope. See figures 9-14 and 9-15.

The advantage of the flexible probe is that many areas can now be inspected without opening the engine. The probe can be worked back through the compressor from the front of the engine. It can also be inserted through a fuel nozzle opening, and worked back to the turbine area to as close as one-quarter of an inch from the surface being inspected. Being able to assess possible damage at that close range has a distinct advantage over the rigid type of borescope. A fiber-optic borescope and an inspector experienced in its use could make the difference between the man-hours spent rejecting a perfectly good engine or obtaining more flight hours from that same engine after damage was suspected.

BoreScope Use

Know your equipment. Borescopes are easily damaged and have different characteristics. For example, optical characteristics of the small borescope magnify and distort all areas other than the turbine blade leading edge. This often results in what appears to be an alarming vane condition. Know and be able to locate all inspection areas or ports on your engine. Figure 9-16 shows an example of inspection ports and areas that you can inspect from that port.

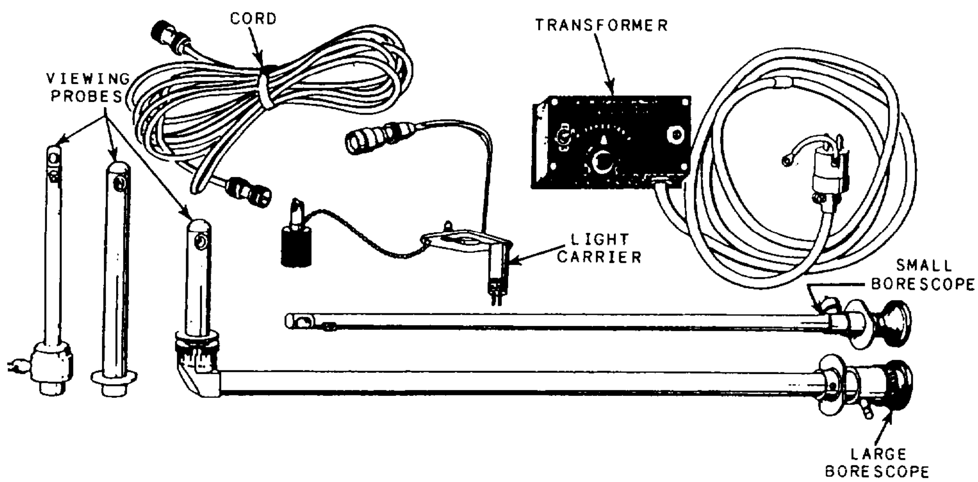


Figure 9-14.-Rigid borescope.

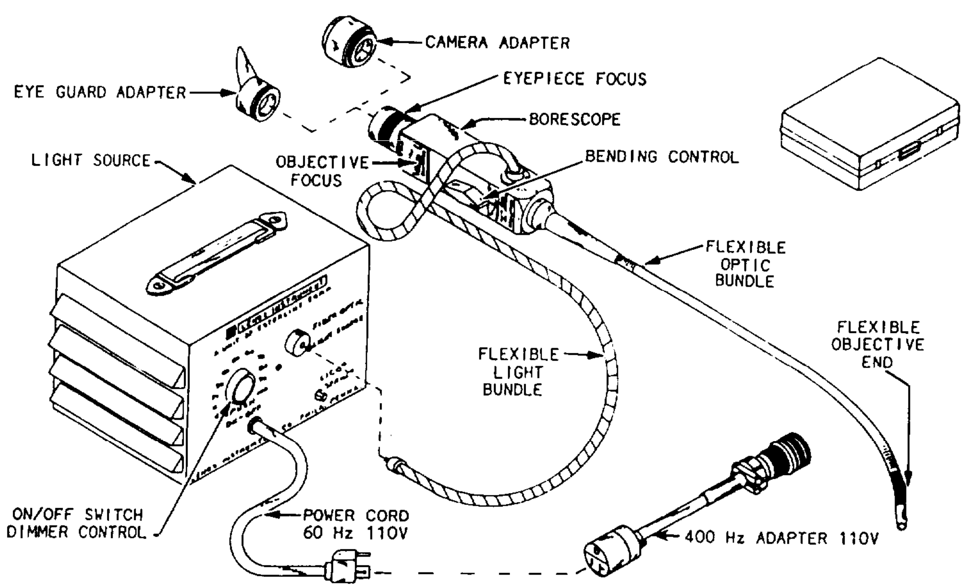


Figure 9-15.-Fiber-optic (flexible) borescope.

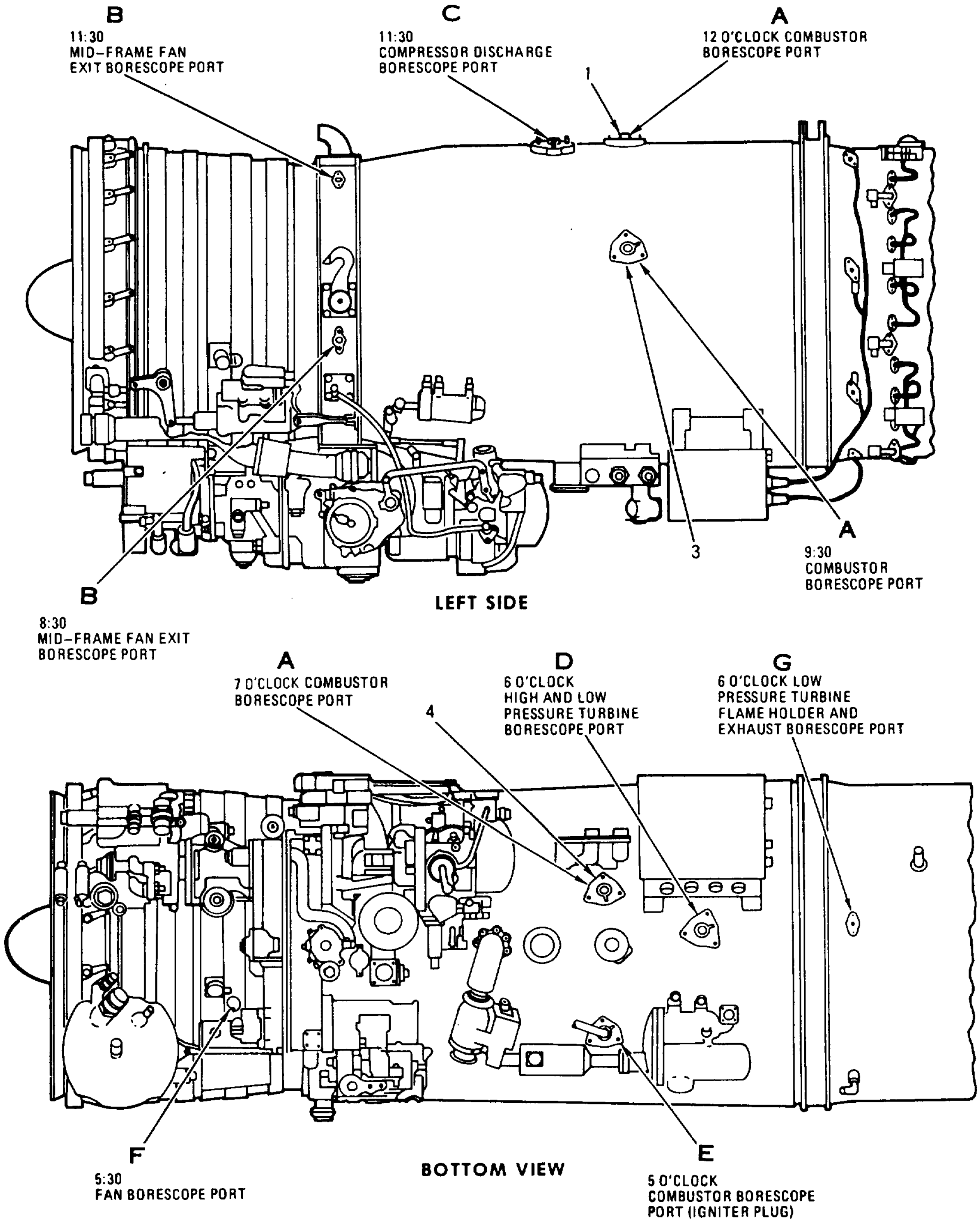


Figure 9-16.-Engine inspection ports.

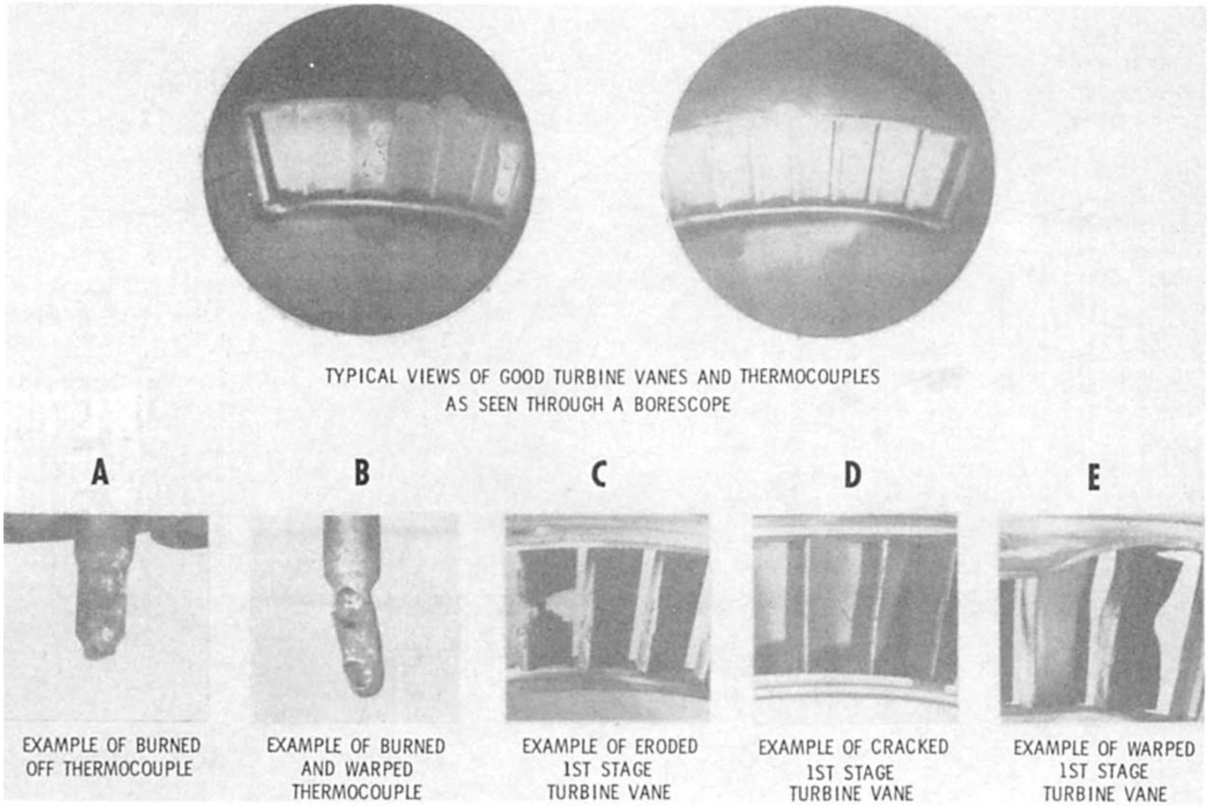


Figure 9-17.—Borescope view of thermocouple and turbine blades.

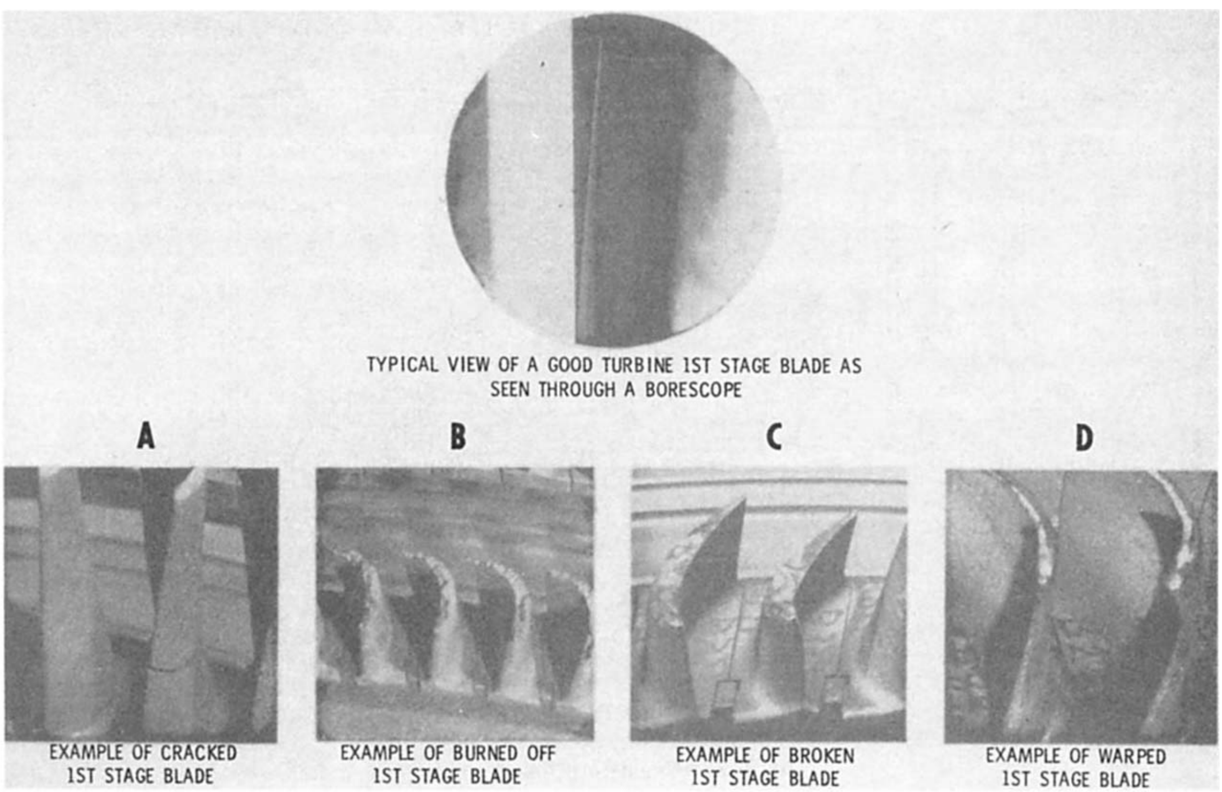


Figure 9-18.—Borescope view of turbine blades.

Establish internal reference points. Pictorial and cutaway diagrams help establish these reference points. When the probe is in the inspection port, it is easy to lose your sense of direction. Some borescopes have an index mark on the eyepiece to show direction.

Scan the inspection area thoroughly and in an orderly manner. Compressor cracks can be difficult to detect because of small close parts, rotating the engine too fast, or because of deteriorated borescope optics. Note and evaluate any inconsistencies. Record all information, including stage, area, magnitude, direction, and adjacent material conditions. Some inspection cards instruct you to mark or bend an 18-inch length of lockwire, and then insert the wire through an adjacent inspection port. You can then use this wire as a gauge to measure vane cracks while viewing through the borescope.

Figures 9-17 and 9-18 show different engine parts seen through a borescope. You must know the words to describe the damage found. Then compare this information with serviceability limits in the maintenance instruction manuals. See table 9-4.

Table 9-4.-Examples Of Serviceability Limits

Inspect	Usable Limits	Corrective Action
	NOTE Usable limit is the limit which is allowable without repairing or replacing part. Corrective action is what must be done before part or engine is serviceable. If no corrective action is listed and defect is out of usable limits, engine must be replaced.	
a. Fan stage two blades and vanes:		
(1) Cracks	None allowed.	
(2) Torn metal	Any amount 0.030 inch deep on leading and trailing edges. Missing corners on tips of blades up to 0.250 inch wide by 0.250 inch long, a maximum of three blades.	
(3) Missing pieces of airfoil	None allowed.	
(4) Nicks, pits and scratches	Any number, 0.030 inch deep on leading and trailing edges.	
(5) Curled edges on tips of blades	0.350 inch of blade length, no more than 4 blades.	
(6) Dents:		
(a) Blade	Any number 2.70 inches of airfoil surfaces, up to 0.030 inch deep.	

Report your conclusions and recommendations. Carefully read and follow the procedures in your aircraft maintenance manuals for borescoping. Different procedures are required for different types of engines to prevent damage or to inspect properly. For example, on the turboprop engine, the turbine blade inspection is made easier by releasing the propeller brake. This makes it possible to rotate the turbine smoothly in both directions. On turbofan engines, you should not borescope if there is a possibility that wind can rotate the fan rotor.

Although water washing is not required before borescoping, it helps clean the engine so you get the best possible evaluation. Dirt and small carbon particles may obscure small cracks or pitting that could be missed in a dirty engine. Water washing also improves engine performance by removing sulfidation.

WATER WASHING

Water washing consists of an emulsion of demineralized water and cleaning liquids. Field cleaning of this nature is accomplished as a desalination wash to remove salt deposits when operating in salt-laden air. Field cleaning maybe done as a performance recovery wash to remove dirt and other deposits.

Specific steps to follow in cleaning a particular engine are found in the maintenance instructions for the particular engine. These steps generally include blocking some lines and ports and removing any equipment in the inlet duct. This is done to prevent damage by the cleaning material. The engine is then motored over for specific periods of time while the cleaning compound is fed into the inlet duct. After cleaning, the engine must be returned to its original configuration. The engine is dried by running it. Engine performance for trend analysis is often checked after engine washing.

CHAPTER 10

POWER PLANT INSPECTION, REPAIR, AND TESTING

CHAPTER OBJECTIVES

After completing this chapter, you will be able to:

- Recognize the types of repairs accomplished at the intermediate maintenance level.
- Identify the repair limits for the intermediate level of maintenance.
- Identify the different methods of cleaning and marking engine parts.
- Identify the different types of test cells and their components.
- Recognize the purpose and entries on the engine test log sheets.

The purpose of this chapter is to familiarize you with the types and authorized repair limits for intermediate maintenance activities (IMAs). Intermediate maintenance applies to those maintenance functions normally performed in centrally located facilities for support of the operating units. The facilities are designated as aircraft intermediate maintenance departments (AIMDs).

The primary purpose of the IMA is to support and supplement the work of organizational maintenance activities. Squadron personnel assigned to the IMA, ashore or afloat, are assigned to perform the total work (within their skills) of the intermediate activity and not just the work related to support of the squadron from which they were assigned.

The Gas Turbine Maintenance Program defines the repair functions of AIMD power plants. Repair capabilities are different for each particular engine and AIMD. It is important that you become familiar with the repair capabilities and functions of your intermediate maintenance activity.

This chapter covers some of the procedures and equipment used in an intermediate maintenance department. Because of the number of different engines used in naval aviation, the maintenance procedures in this chapter are general in nature. Components and repair limits discussed are representative. Do not refer to them when working on a specific engine or its components.

THREE-DEGREE GAS TURBINE ENGINE REPAIR PROGRAM

The Gas Turbine Engine Maintenance Program was formed under the three-degree concept as specified in OPNAVINST 4790.2 (series). Under this concept, each engine's intermediate maintenance manual defines specific engine maintenance actions as either first-, second-, or third-degree functions. These functions are determined largely by degree of difficulty and frequency of repair.

FIRST-DEGREE REPAIR

First-degree repair is the repair of a damaged or nonoperating gas turbine engine and its accessories or components. When the compressor rotor is replaceable, the repair includes compressor rotor replacement and/or disassembly.

NOTE: The terms "first-degree repair" and "complete engine repair" (CER) are synonymous. CER is used primarily with older engines that are not included in the three-degree program.

SECOND-DEGREE REPAIR

Second-degree repair is also the repair of a damaged or nonoperating gas turbine engine and its accessories or components. The difference is that second-degree repair will normally include the repair/replacement of turbine rotors and combustion sections. Repairs include afterburners and the replacement of externally damaged, deteriorated, or time-limited components, gearboxes, or accessories. Minor repair to the compressor section is made in second-degree repair. The repair or replacement of reduction gearboxes and torque shafts of turboshaft engines comes under second-degree repair. The repair or replacement of compressor fans of turbofan engines also comes under second-degree repair activities.

THIRD-DEGREE REPAIR

The third-degree repair encompasses major engine inspections and the same gas turbine engine repair capability as second-degree maintenance. Certain functions that require high maintenance man-hours and are of a low incidence rate are excluded. The functions described represent broad generalities. Refer to the appropriate engine maintenance plan or intermediate maintenance manual to determine the degree of assignment for specific repair functions.

AIRCRAFT INTERMEDIATE MAINTENANCE DEPARTMENT

Once an engine arrives at an AIMD activity, it is cleaned and evaluated for repair. If inducted for repair, a major inspection and all repairs required to place the engine back in ready-for-issue (RFI) status are accomplished. The first steps for inspecting aircraft engines include the cleaning and the marking of parts. After cleaning, engines are inspected in accordance with applicable MIMs or disassembled for further repair.

WARNING

Many of the chemical solutions and their components used in cleaning, inspection, and repair are toxic, flammable, and extremely corrosive. Improper mixing or use of these chemical can produce violent reactions, rapid heat generation, and explosive/toxic gases. Personnel performing maintenance procedures should consult the applicable maintenance instruction manuals and be familiar with the safety precautions associated with the hazardous materials or equipment. The warnings in these technical manuals identify the types of hazards and precautions to take. The Material Safety Data Sheets (MSDS) and your safety office have specific information for hazardous material in your work center.

CLEANING

Good mechanics clean all engine parts thoroughly before inspecting them. Cleaning and close inspection make it possible to detect faults that endanger safe engine operation and maximum performance. The primary purpose of engine parts cleaning is to accomplish the following:

1. Permit thorough inspection of components for flaws, damage, and dimension wear.
2. Prepare surfaces for repair (plating, welding, or painting).
3. Remove organic or inorganic coatings for inspection of underlying surfaces or remove coatings adversely affecting engine performance.

Selection of cleaning materials and processes for any engine part is determined by the nature of the soil, the type of metal or coatings, and the degree of cleanliness necessary for a thorough inspection and repair.

Generally, engine parts operating in relatively low temperature ranges (cold section parts) are cleaned by solvent washing, decreasing tanks, and vapor decreasing. Cleaning engine parts that operate in hot sections of the engine (combustion and turbine sections) require more comprehensive cleaning. This cleaning includes using a heavy-duty alkaline cleaner and blasting.

Soft carbon deposits are removed by decreasing and steam cleaning. Decreasing removes dirt and sludge by immersing or spraying the part with cleaning solvent. Hard carbon deposits are removed by decarbonizing, brushing, scraping, or grit-blasting. The following text provides general cleaning procedures to familiarize you with the methods and materials used for cleaning parts. Always refer to the appropriate maintenance manual for the latest cleaning procedures. Constant changes are made in cleaning and finishing (coatings) materials.

Degreasing (Solvent Cleaning)

Small accumulations of grease, oil, and dirt may be removed by hydrocarbon solvent cleaning. This method is not effective in removing baked-on oil deposits or most surface coatings.

WARNING

Decreasing solvents are flammable, and their vapors are toxic. Keep all solvents away from open flames, and use only in well-ventilated areas. Avoid solvent contact with skin, eyes, and clothing by wearing rubber gloves, a face shield or goggles, and an apron or coveralls.

Dry-cleaning solvent (P-D-680) is the recommended cleaner. Solvent cleaning uses a tank with cleaning solvent to soak the part clean. Some tanks have pumps to provide mechanical agitation to help clean parts. You can also use a soft-bristle brush to remove stubborn stains. The cleaning tank should have a hinged, counterweighted cover so it can be covered when not in use. Since some plastic- and rubber-based materials are attacked by hydrocarbon solvents, steam clean these parts to remove contaminants.

Steam Cleaning

Steam cleaning is a cleaning process used when you do not want to remove paint and surface coatings. To properly clean with steam, it is necessary to add cleaning compounds. Do not steam clean oil-impregnated parts.

Set steam valve to the proper strength and force required for the job. Hold the steam gun about 12 inches from the part at a 45-degree angle. When cleaning plastic parts, you should be careful to avoid heat buildup. After cleaning thoroughly, dry the part and apply corrosion prevention compounds.

Vapor Decreasing

Vapor decreasing removes oil, grease, and preservative compound by solvent vapor. A flat bottom tank with heating coils on the bottom and cooling coils midway around the tank is required. The part is suspended in the vapor area below the cooling coils. Heated cleaning solvent vapor condenses on the cool part. It dissolves oils, grease, and preservatives. Cleaning action stops when the part reaches the vapor temperature. If further decreasing is necessary, the part must be cooled before using vapor degreaser again. Vapor decreasing cannot be used on titanium parts because recommended solvents cause stress-corrosion at high temperatures.

Recommended solvents for vapor decreasing are trichloroethane (O-T-620), trichlorotrifluro-ethane (MIL-L-81302), and perchloroethylene. These solvents are designed to clean metals by the vapor cleaning method because their high vapor density results in small vapor loss.

Decarbonizing

Decarbonizing is the chemical removal of carbon deposits. Decarbonizing agents are detergents, sodium silicates, chlorinated hydrocarbons, and various acid solutions. This cleaning method is effective for paint stripping, rust removal, and general cleaning of ferrous and high-temperature parts. Parts are soaked in hot or cold tanks and rinsed with high-pressure water.

WARNING

Carbon removers require careful handling. Wear goggles, rubber gloves, and aprons when using these solutions.

Some carbon removers attack aluminum and magnesium parts if they are left in the solution too long. There is also the possibility of a chemical reaction when aluminum, magnesium, and steel parts are immersed in the same tank. This practice often results in damage to magnesium parts, such as dissimilar metal corrosion.

Upon removal from cleaning solutions, rinse the parts in a soap-and-water solution or with a petroleum solvent. Change the rinse water frequently to prevent a buildup of acid or alkaline in the water. Air-dry the engine parts, and then coat them with a corrosion preventive if they are not to be processed further.

Decarbonizing loosens most hard carbon deposits remaining after decreasing. The complete removal of all hard carbon deposits generally requires brushing, scraping, or grit blasting. Use caution during these procedures to avoid damaging parts. In particular, do not use wire brushes or metal scrappers on machine surfaces or bearings.

Abrasive Blasting

Use abrasive blasting to remove hard carbon or lead deposits, rust, and heat scale. The type (wet or dry) and size of abrasives vary for different engine parts. Mask all openings, identification markings, and other areas as required before blasting. Grit materials such as ground corn, apricot or peach pits, walnut shells, clover seed, and cracked wheat or rice are in general use.,

Dry grit blasting is sometimes done in a sand-blast cabinet. The part must first be degreased or put through a decarbonizing solution, and then rinsed and dried thoroughly. After grit blasting, remove the dust by air blasting, and clean with petroleum solvent or hot water. Some types of soft grit leave a light grease film on the part. Remove this film by decreasing if the part is to be subjected to fluorescent penetrant inspection.

Wet abrasive blasting is an effective method to remove heat scale, carbon deposits, and temporary markings, and to produce a uniform satin finish on metals. This type of blasting removes metal, but so slowly that dimensions change very little.

MARKINGS

Marking engine parts and assemblies aids in identification, reassembly, and tracking the service life of parts. All marks are applied to produce maximum legibility and durability without affecting the function or serviceability of the part. Markings are either permanent or temporary. Permanent markings are those markings that remain during the entire service life of the part. They are applied during manufacturing or after modification of parts. Temporary markings maintain identification of parts or reference positions during ordinary handling, storage, and final assembly. Temporary markings ensure parts may be returned to original assembly position. If a part is going to be cleaned, inspected, and repaired, temporary markings will probably be removed by solvents during cleaning. If part identification needs to be maintained, attach tags or place parts in separate containers.

Temporary Markings

Certain materials must be used for temporary marking during assembly and disassembly. Use only approved pure dye markers to mark engine hardware. Using nonapproved markers can leave harmful elements on engine parts. You may use layout dye (lightly applied) to mark parts that are directly exposed to the engine gas path. Some exposed items are the turbine blades and disc, turbine vanes, and combustion chamber liners.

NOTE: Do NOT use any temporary marking method that leaves a heavy carbon deposit. Do NOT use any marking that leaves a deposit of copper, zinc, lead, or similar residue, such as pencil or black grease pen. These deposits may cause carbonization or intergranular attack when the part gets very hot. Parts marked with unauthorized materials should have all traces of markings removed before using them.

Permanent Markings

Permanent markings should be positioned in the area of lowest stress. Do not apply markings within 0.030 inch of corners, radii, fillet, or edges. Choose an area where markings will not be worn off or obliterated by contact with another part. If possible, place new markings next to original markings. Always refer to applicable engine manuals and power plant changes for recommended marking met hods and details. Some of the methods of permanent markings include using a metal stamp, vibropeen, blasting, and acid-etching.

GENERAL ENGINE REPAIR AND INSPECTIONS

Before starting disassembly of an engine, check the applicable technical instructions to confirm the scope of repair necessary. Use the step-by-step procedure and repair limits contained in the current technical publications for the particular engine. In the process of engine disassembly, many associated parts become accessible for inspection. Inspect these parts as closely as possible to prevent later failure.

Support the engine during disassembly and buildup to prevent overstressing of the parts being removed. In addition to preventing stress, it allows proper alignment of parts being removed or installed.

Immediately upon removing each subassembly or individual part from the engine, transfer it to a parts rack. Arrange the part to protect it or the assembly from damage. Provide proper covering and supports to protect shafts, gears, studs, or any projecting piece from being bent, scratched, or otherwise damaged. Be careful to prevent the entrance of dirt and other foreign materials into the engine. Whenever practicable, use temporary covers to seal all openings in dismantled engines. Cover the ends of all removed tubing. Take extreme care not to lay carbon seals and plates on the sealing surfaces. Provide appropriate containers to hold each part separately until the time for reinstallation. During disassembly, examine all parts and assemblies for cracks, scoring, and burning. Check the engine for indications of work incorrectly performed during any previous repair or overhaul.

You must pay particular attention to the material requirements for the nuts and bolts used in the turbojet engine. Hot sections require common hardware (nuts, bolts, safety wire and cotter pins) that are resistant to high operating temperatures. Other engine parts may require special hardware, and it is imperative that all properly coded parts (if serviceable) be placed in their original positions.

Welding is permissible on some parts of the turbojet engine. Refer to the applicable technical instructions before attempting to repair an engine or component by welding.

COMPRESSOR SECTION REPAIRS

Most intermediate-level maintenance activities are responsible for the replacement of compressor sections and the repair of those compressor blades in the later compressor stages that cannot be serviced without the removal of the compressor halves. Compressor repair usually results from foreign object damage (FOD), although other failures occur. A number of compressor failures may be broadly classified under air leaks and compressor contamination. The AIMD may also be required to modify the compressor rotor or stator blades as a result of a technical change or bulletin. Modifications may include reworking the components, changing blades by stages, or replacing the entire rotor assembly.

NOTE: Compressor cases are machined in matched sets. Damage beyond repair to one case is cause for rejection of the opposite case. A new compressor rotor is not required when replacing the entire case assembly.

Compressor Contamination

Accumulation of dirt on the compressor blades reduces the aerodynamic efficiency of the blades. Dirt hurts engine performance. The efficiency of the blades is impaired by dirt deposits similar to that of an aircraft wing under icing conditions. High exhaust gas temperature (EGT) may result when foreign deposits are on compressor components. On some turbojet engines, high EGT requires early engine overhaul. Slow acceleration could also result from foreign material obstructing the compressor outlet vanes. This obstruction could result in a needless engine overhaul.

Compressor Leaks

Air leaking from the compressor results in low engine performance. Air leakage may occur between the high and low compressors, or at some intermediate stage. It may also occur because of bleed-air valves stuck open or cracks in the compressor case itself. Air leaks in the compressor are found through engine monitoring or low engine performance; for example, when the engine fails to meet minimum power requirements for takeoff.

Compressor Failures

Loose objects often enter an engine's compressor either accidentally or through carelessness. Thousands of dollars worth of damage to a compressor rotor can result from pliers being left in the air intake, as shown in figure 10-1. The nut and bolt holding the pliers together came loose and went through the compressor, causing the damage shown in the illustration. A simple solution to the problem of tools drawn into an engine is to check the tools against a tool checklist.

Internal mechanical failures, such as a compressor blade breaking off, result in compressor efficiency loss. These failures are difficult to detect. Broken blades and vanes result in high exhaust gas temperatures or an increase in compressor rpm due to loss of efficiency. Of course, mechanical failures of compressor blades could result in severe damage to the compressor, combustion chamber, and the turbine as foreign object damage (FOD).

Compressor Blade Damage and Repair

Defining and showing examples of damage may help you to recognize damage and make

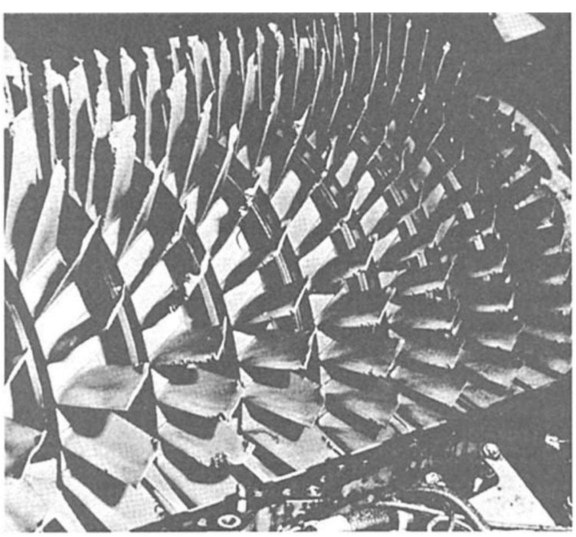


Figure 10-1.-Compressor damage caused by pliers passing through compressor.

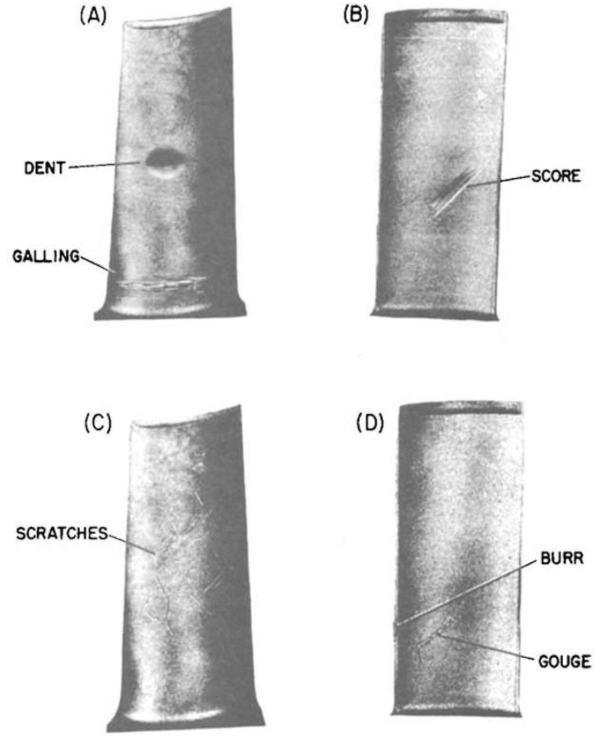


Figure 10-2.-(A) Blade showing dent and galling; (B) blade showing a score; (C) blade showing scratches; (D) blade showing gouge and burr.

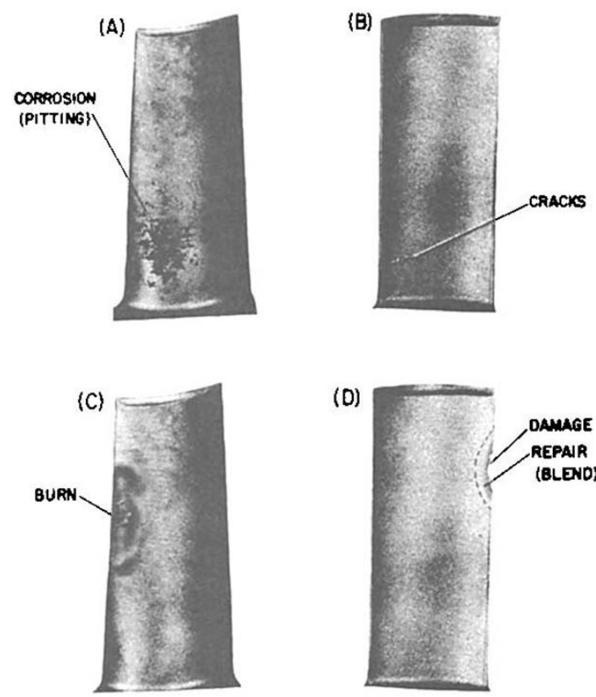


Figure 10-3.-(A) Blade showing corrosion (pitting); (B) blade showing cracks; (C) blade showing burn; (D) blade showing damage and repair (blend).

Table 10-1.-Blade Maintenance Terms

Term	Appearance	Usual causes
Blend	Smooth repair of ragged edge or surface into the contour of surrounding area.	
Bow	Bent blade.	Foreign objects.
Burning	Injury to surfaces evidenced by discoloration or, in severe cases, by flow of material.	Excessive heat.
Burr	A ragged or turned out edge.	Grinding or cutting operation.
Corrosion (pits)	Breakkdown of the surface; pitted appearance.	Corrosive agents—moisture, etc.
Cracks	A partial fracture (separation).	Excessive stress due to shock, overloading, or faulty processing; defective material; overheating.
Dent	Small smoothly rounded hollow.	Striking of a part with a dull object.
Gall	A transfer of metal from one surface to another.	Severe rubbing.
Gouging	Displacement of material from a surface; a cutting, tearing effect.	Presence of a comparatively large foreign body between moving parts.
Growth	Elongation of blade.	Continued and/or excessive heat and centrifugal force.
Pit	(See Corrosion).	
Profile	Contour of a blade or surface.	
Score	Deep scratches.	Presence of chips between surfaces.
Scratch	Narrow shallow marks.	Sand or fine foreign particles; careless handling.

repair of damage easier. Figures 10-2 and 10-3 show examples of possible blade damage to an axial-flow engine. The damages are enlarged to show detail. See table 10-1 for the definitions or descriptions and possible causes of blade damage. If you know by close examination what causes the damage, you may be able to reduce the cause.

You may make minor repairs to compressor blades, provided the repairs are made without exceeding allowable limits in the prescribed MIM. Well-rounded damage to leading and trailing edges is acceptable without rework. No rework is necessary provided the damage is in the outer half of the blade. The indentation may not exceed values specified in the MIM. Figure 10-4 illustrates representative repairable limits. Figure 10-5 shows examples of blade repairs.

When working on the inner half of the airfoil, you should treat damage with extreme caution. Make no attempt to remove damage by straightening. Inspect repaired compressor blades by dye check, magnetic particle inspection, or by fluorescent penetrant inspection methods. Remove all traces of the damage. All surfaces must be smooth. All repairs must be well blended. No cracks of any extent are tolerated in any area. Bowed or bent blades are not reused. If gauges are not available, the repaired blades are aligned and compared with a new blade of the same stage.

Use a smooth file when removal of considerable amounts of material is necessary. File or blend at right angles to the width of the blade. When you cannot reach the damaged area with a file, use course emery cloth. Use a medium stone on areas that have been reworked with a file or emery cloth. Use a medium stone for areas containing small nicks and dents.

Use fine emery cloth and/or a fine abrasive stone to polish the reworked area. Polish until the finish looks and feels like the original. If two blended areas overlap to form a sharp point or ridge, blend out the point or ridge. Blend the contour surfaces with a medium stone and finish with emery cloth and/or a fine abrasive stone. The finished repair should be as much like the original finish as possible.

Front compressor blades that require replacement are replaced by blades having the same moment balance code. The moment balance codes are marked on the front face of the root of the blade. At the original buildup of the compressor rotor discs and blades, a set of blades coded according to individual moment were installed. The installation on the disc minimizes the static imbalance due to variations in the blade moment. The blades are numbered in clockwise sequence,

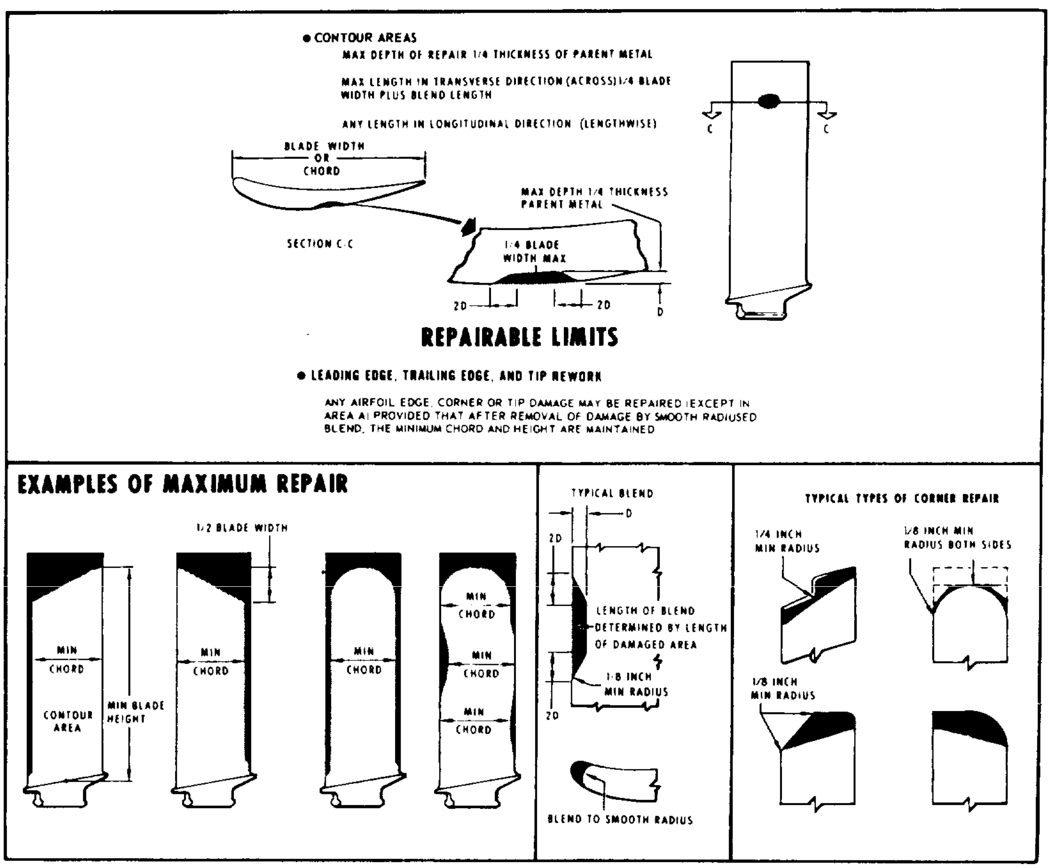


Figure 10-4.-Repairable limits and examples of maximum repair.

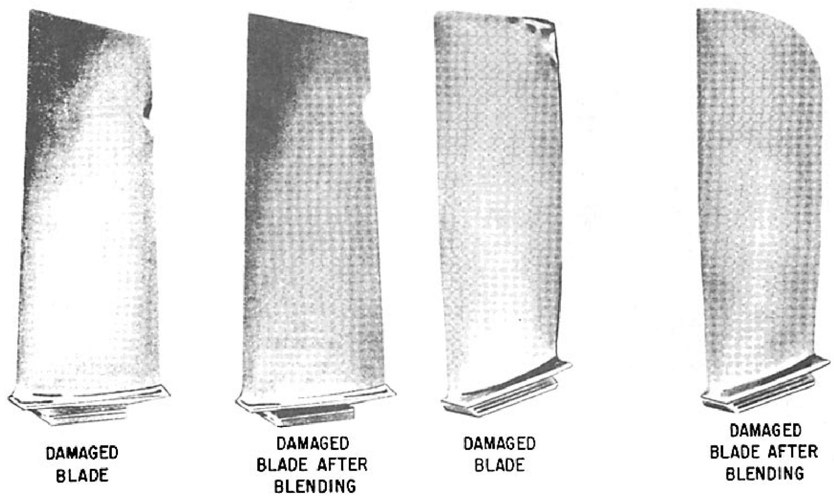


Figure 10-5.-Compressor blade repair.

as viewed from the front. Install blades in their correct numbered position. Make sure new blades are correctly numbered for the blades they replace.

NOTE: The blade part number follows a change designation number. Never take this number as the moment weight code of the blade. The code letter i s stamped adjacent to, but not following, the part number.

Compressor Stator Vanes

Pitting or corrosion, if within the allowed tolerance, is not serious on the compressor stator vanes of axial-flow engines. Do not attempt to repair any vane by straightening, brazing, welding, or soldering. Use crocus cloth, fine files, and stones to blend out damage. Remove a minimum of material, and leave a surface finish comparable to that of a new part. The purpose of this blending is to minimize stresses, which concentrate at dents, scratches, and cracks. Maximum blend out limit damage greater than 50 percent of the stator assembly vanes requires assembly replacement. When vanes are damaged, to the maximum blend out limit in any 60-degree sector of one stage, replace the assembly. Send parts damaged beyond maximum repair limits to overhaul for repair and replacement of vanes. The use of prebored compressor vane and shroud assemblies permits the replacement of one-half of any low-compressor stator. The inspection and repair of air inlet guide vanes and swirl vanes on engines require the use of a strong light. Attach this light to a rigid support to enable positioning in hard-to-reach areas. Inspect all sections of both screen assemblies for breaks, rips, or holes. Screens may be tin-dipped to tighten up the wire mesh, provided the wires are not worn too thin. If the frame strip or lugs have separated from the screen frames, rebrazing may be necessary.

Inspect guide and swirl vanes for looseness. Inspect the outer edges of the guide vanes. Pay particular attention to the point of con-tact between the guide and swirl vanes. Check for cracks and dents due to the impingement striking of foreign particles. Also, inspect the edges of the swirl vanes. Inspect the downstream edge of the guide vanes very closely, as cracks are more prevalent in this area. Cracks which branch in such a manner that a piece of metal could fall into the compressor are cause for rejection.

Blending of hollow vanes on the concave and convex surfaces, including the leading edge, is limited, Some small, shallow dents are acceptable. The damage may be rounded or gradual contour type, but not a sharp or V-type. Do not allow any cracked or torn vane material to exist in the damaged area.

Blend the trailing edge if one-third of the weld seam remains after repairs. See figures 10-6 and 10-7. Concave surfaces of rubber-filled vanes may have allowable cracks extending inward from the outer airfoil. These cracks are allowable provided there is no suggestion of pieces breaking away. Using a light and mirror, inspect each guide vane trailing edge and vane body for cracks and damage caused by foreign objects. Cracks in the vane body are cause for rejecting the entire weld.

COMBUSTION SECTION REPAIRS

The combustion section can be removed, repaired, or replaced in part or entirely depending on the extent of damage encountered. The combustion section consists of liners, support duct, outer and inner case, and the first stage turbine nozzle assembly. Most repairs to this section are accomplished by welding or replacement of components.

Combustion Chamber Liners

Inspect combustion chamber liners for cracks by using dye penetrant or the fluorescent penetrant method of inspection. Cracks con-verging so that metal could break loose or any loose, cracked, or damaged swirl vanes are cause for rejecting a liner. Remove liners having buckled areas in a weld seam. Areas that have more than a three-sixteenths-inch wave, which does not include the weld seam, require removal from service. See figure 10-8.

Combustion chamber liners may be retained in service with some flaws. For example, liners with cracks less than 0.125 inch long starting from combustion air holes (no more than three per sec-tion) may remain in service. Liners with radial or circumferential cracks less than 0.750 inch long extending from or around the crossover tubes or igniter plug bosses may also remain in service. You may reuse combustion liners that are burned, except when burned in the area identified in item 5 of figure 10-8. Rework cracked deflectors to remove the cracked area by blending or cutting before reuse. Burning of the cooling louver must not exceed two tabs totally burned or a total area of two tabs per liner.

Combustion Chamber Support

Cracks in the combustion chamber support can be repaired by inert-gas fusion welding.

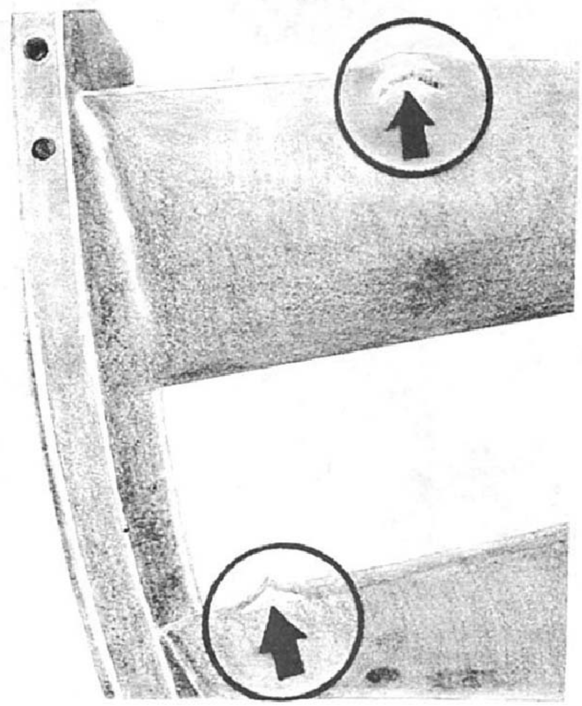


Figure 10-6.-Guide vane trailing edge before blending.

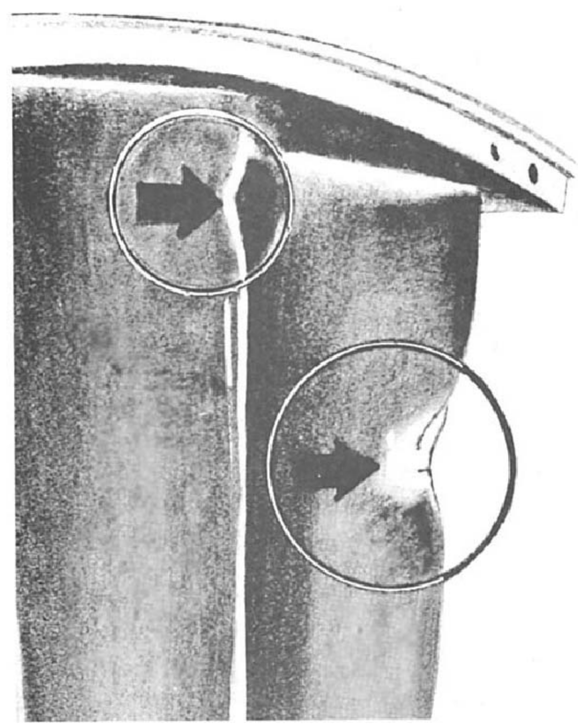
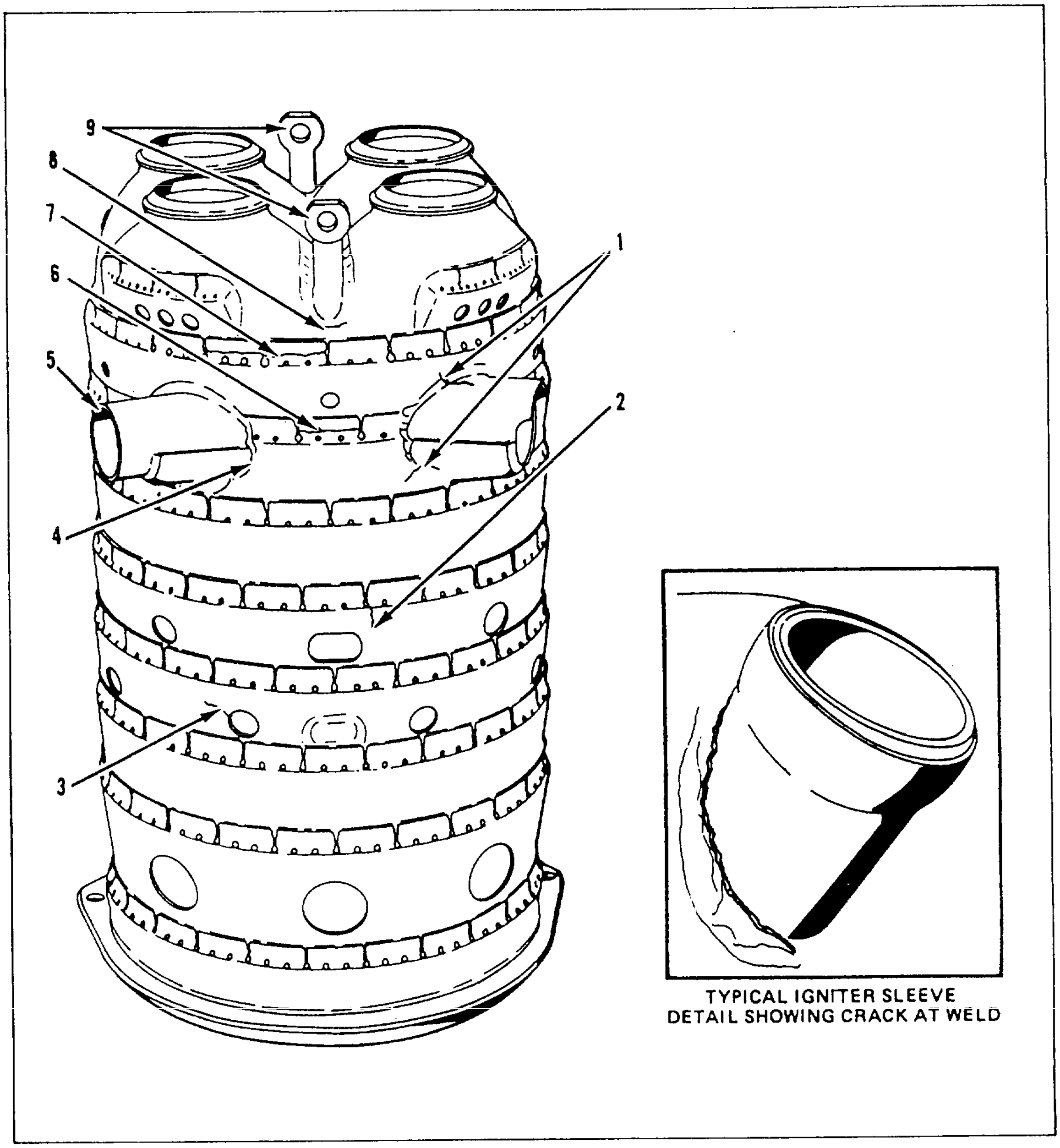


Figure 10-7.-Guide vane trailing edge after blending.



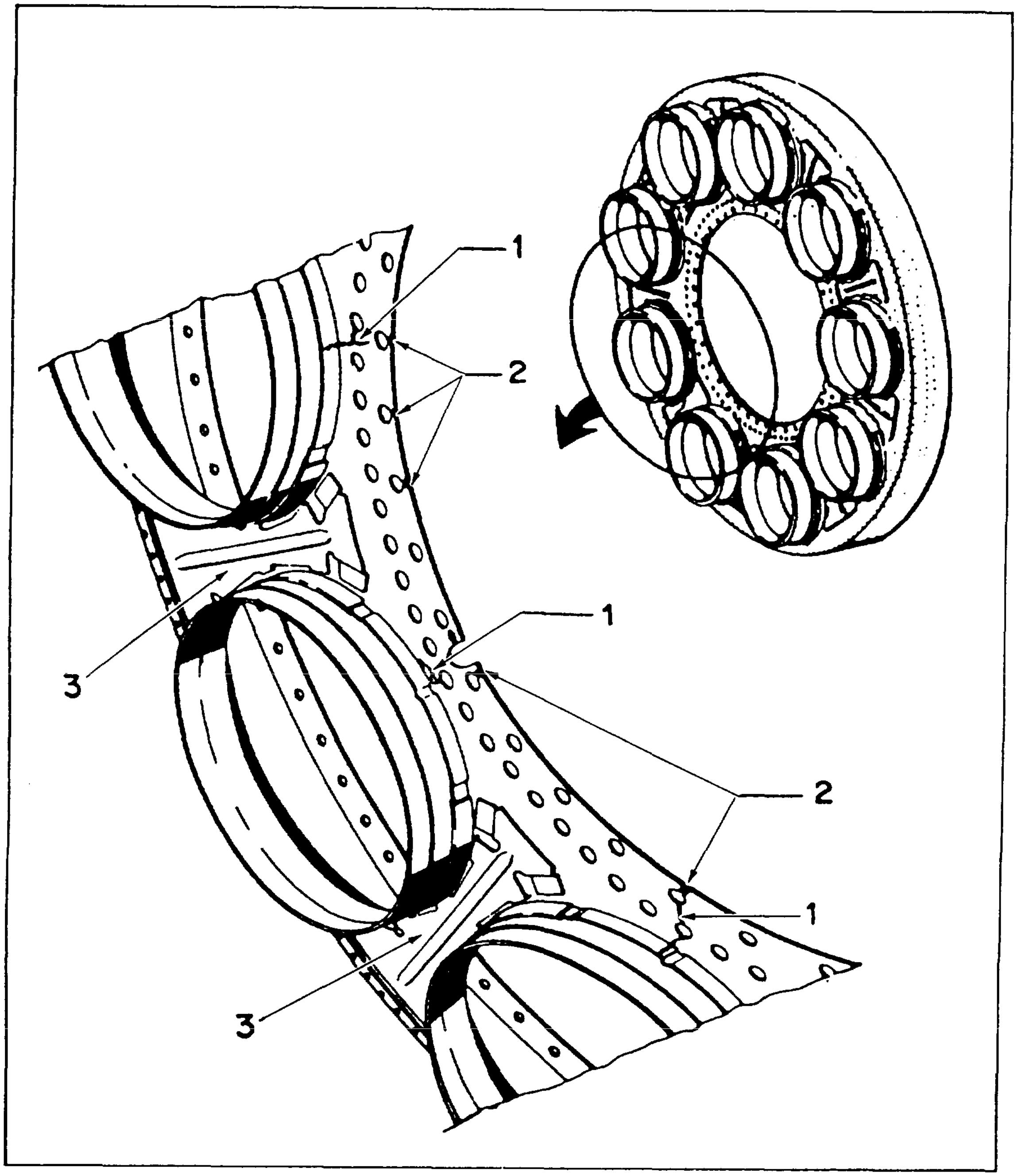
1. Minor cracking or buckling is serviceable.
2. Cracks visible on OD must be weld-repaired; minor cracks visible on ID of cooling air louver lip are serviceable.
3. Minor cracks 0.125 inch or less long are serviceable if not more than three in number per segment.
4. Minor cracks 0.060 inch or less long are serviceable.
5. Burned or warped areas are not serviceable.
6. Typical 2d louver crack; not serviceable without weld-repair.
7. Typical 1st louver crack; not serviceable without weld-repair. Reparable limits: single crack maximum length 3 inches: maximum of four cracks around circumference with maximum 6-inch cumulative length.
8. Crack in weld at base of mount lug is not serviceable without repair. Lug pinhole axis alignment must be maintained.
9. Mount lug radial or circumferential cracks are not serviceable without repair.

Figure 10-8.-Combustion chamber liner limits.

Repairs must not result in distortion or misfit of parts at assembly. If a hole is distorted as a result of welding, use a file to restore it to its original configuration. The weld bead must be blended by hand after the welding. See figure 10-9.

Combustion Chamber Inner and Outer Ducts

Operational cracks in the inner and outer outlet ducts are permissible. The cracks may not



1. Maximum length of crack 2 inches.
2. Cracks, maximum of 33 percent and not more than three adjacent holes.
3. Only one crack per section permitted, and it must be welded.

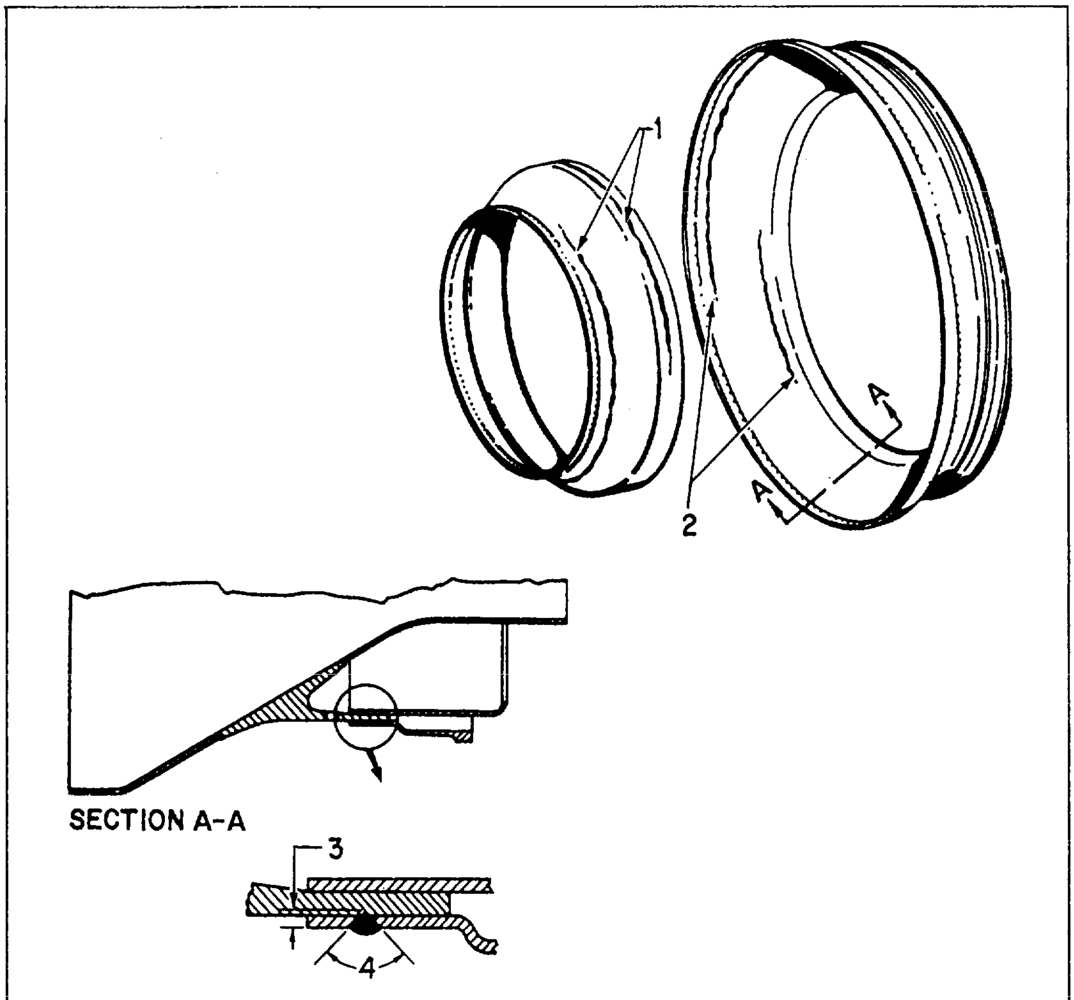
Figure 10-9.-Combustion chamber support limits.

exceed 3 inches in length. Repair cracks more than 3 inches long and exceeding 75 percent of the entire circumference of the duct by gas fusion welding. When repairing a duct, use a silicone carbide grinding wheel. Grind a 90-degree "V" groove, 0.035-inch deep, for the entire length of the crack. It is permissible to remove some of the parent material when grinding. Adequate depth is necessary to be sure that the grinder removes all material from the crack. Repairs must not result in distortion or misfit of the parts at assembly. File out any distorted hole, as a result of welding, to restore it to the original configuration. See figure 10-10 for an example of inner and outer ducts repair limits.

TURBINE SECTION REPAIRS

Inspect turbine sections and components thoroughly because of the extreme heat encountered in this section. Turbine sections can be replaced in whole or in part. The turbine rotor is usually repaired by changing individual blades or an individual rotor. It is not feasible to describe all of the damage conditions that may be found in the turbine. If the damage is within prescribed limits, but there is doubt about the rework, you should replace the turbine rotor or part.

Some first-stage turbine blades are coated with a protective coating to prevent sulfidation. Alpak is normally used for coating these blades. Without



1. Cracks, inner duct
2. Cracks, outer duct
3. 0.035 inch
4. 90 degrees

Figure 10-10.-Combustion chamber inner and outer duct.

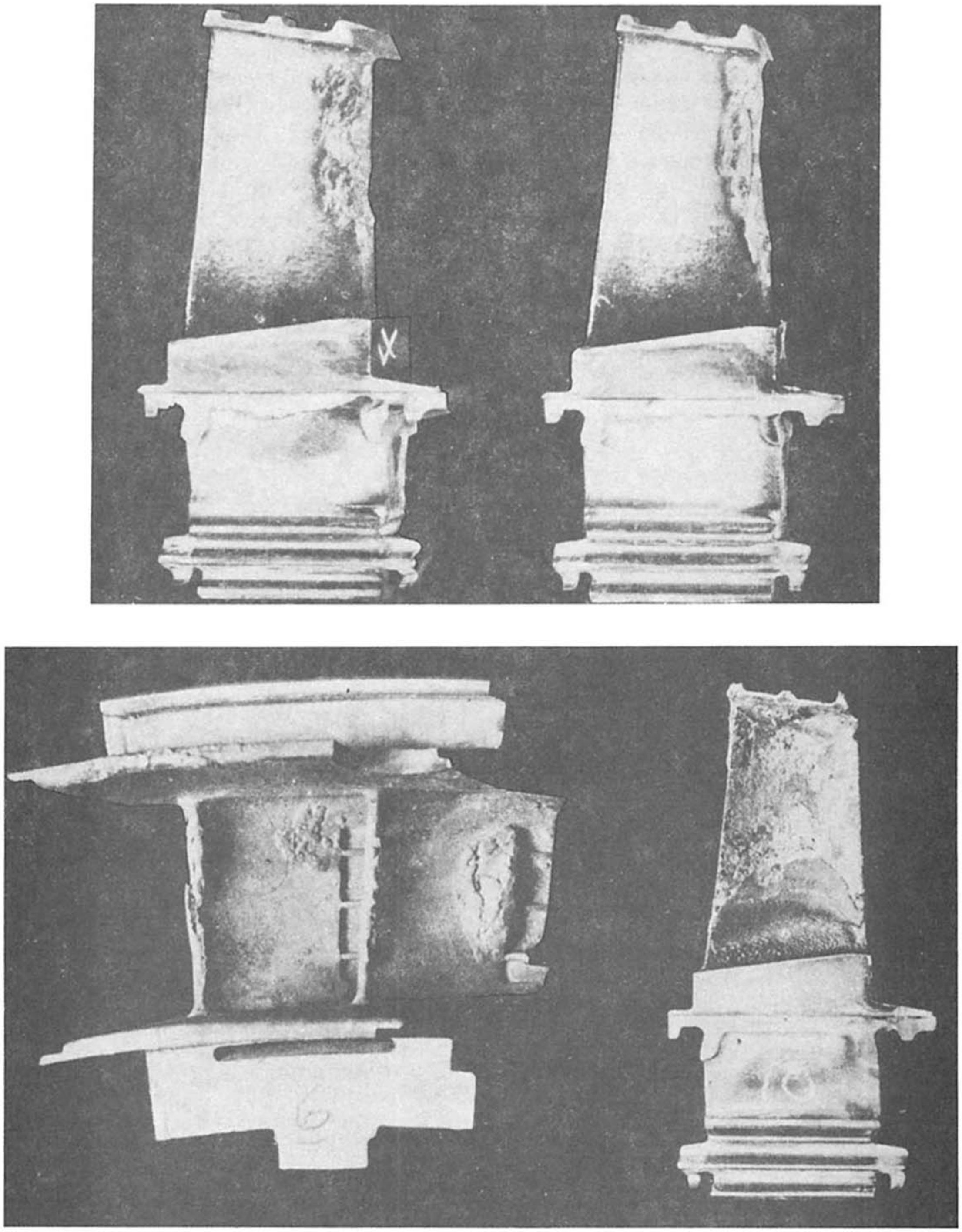


Figure 10-11.—Examples of unacceptable sulfidation of turbine blades and vanes.

this coating, these blades are very susceptible to sulfidation.

Turbine Blade Sulfidation

Sulfidation is high-temperature corrosion. Sulfidation starts with the excessive levels of sodium and sulfur in the air and fuel mixture entering the engine. This type of environment attacks turbine blades and stator vanes. Sulfidation first appears as a rough or crusty surface on the leading edge and concave surface of the airfoil. It progresses to scaling, splitting (delamination), and eventual metal loss. The sulfidation process accelerates with an increase in sulfur intake and an increase in engine operating temperature.

All blades should be inspected for sulfidation. This form of corrosion is permissible if evidenced only by a rough or crusty appearance at the leading edge, on the concave side of the airfoil section, or on the platform at the root of the air-foil. The rotor should be replaced if there is evidence of splitting, delamination, separating, flaking, or loss of material in any area of the blade. Figure 10-11 shows an example of unacceptable sulfidation of turbine blades.

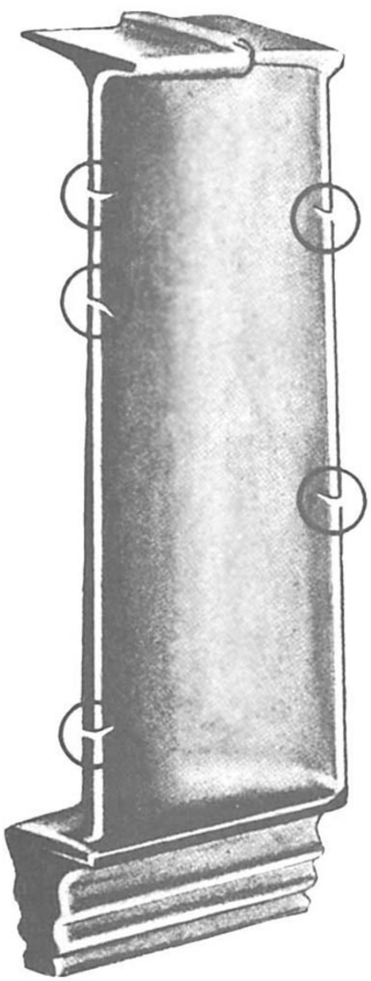


Figure 10-12.-Stress rupture cracks.

Turbine Blades

You may inspect turbine blades on axial-flow engines, and clean them in the same manner as compressor blades. However, because of the extreme heat under which the turbine blades operate, they are more easily damaged. Inspect the turbine blades for stress rupture cracks and deformation of the leading edge. See figures 10-12 and 10-13.

Stress rupture cracks usually appear as fine hairline cracks. These cracks are found on or across the leading or trailing edge at a right angle to the edge length. Visible-cracks may range-in length from one-sixteenth inch upward.

Deformation, due to overtemperature, appears as waviness along the leading edge. The leading edge must be straight and of uniform

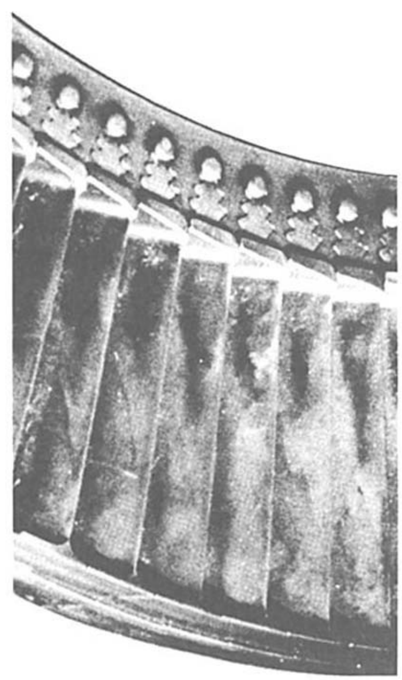


Figure 10-13.-Turbine blade waviness.

thickness along its entire length, except areas repaired by blending. Stress rupture cracks or deformation of the leading edge are often mistaken for foreign material impingement damage. When any stress rupture cracks or deformation of the leading edge of the first-stage turbine blades is found, suspect an overtemperature condition. Check the individual blades for stretch, and the turbine disc for hardness and stretch.

NOTE: Install blades removed for detail inspection or for check of disc stretch in the same slots from which they were removed. Number the blades before removal.

Inspect the turbine blade outer shroud for air seal wear. If you find evidence of shroud wear, measure the thickness of the shroud at the worn area. Use a micrometer (or another suitable measuring device) to be sure of a good reading in the bottom of the narrow wear groove. If the remaining radial thickness of the shroud is less than specified in the appropriate technical manual, replace the stretched blade.

Turbine Blade Replacement

There are two categories of moment-balance-weight classifications for turbine blades in axial-flow engines. These are individually classified blades and sets (two or three) of matched blades. The first category includes individual blades with permanently marked moment-balance-weight classifications. The second category includes sets of blades with the same classifications and temporary markings.

NOTE: Never mix blades. Classification of the two categories does not follow the same schedule. Always refer to the Turbine Rotor Disc Assembly Service Record to determine which category applies.

If visual inspection of the turbine assembly shows that blade replacement is necessary, use the following example procedures as a guide. Replace any number of blades through 100 percent in the turbine rotor. Replacement is permissible if the pan weight of the replacement is within 1 gram of the old blade.

In the following blade removal and replacement procedures, read the numbered steps while referring to figure 10-14.

NOTE: Before removing any blades, match mark all blades and baffles. Install the original or its proper replacement in the original position.

Steps 1 through 3 refer to figure 10-14, view A.

1. Locate and mark damaged blade.
2. Straighten locking strip tab of damaged blade.
3. Straighten locking strip tab of two adjacent blades.

Steps 4 through 6 refer to figure 10-14, view B.

4. Slide leading blade, baffle, and trailing blade from slot; weigh damaged blade.
5. Remove remaining loose blades from slots.
6. Remove and discard locking strips. Do not reuse locking strips.

Steps 7 through 9 refer to figure 10-14, view C.

7. Place new locking strip in blade dots.
8. Position baffles and trailing and leading blades into slot.
9. Slide leading blade, baffle, and trailing blade into the last two serration.

Figure 10-14, view D, is a hydraulic tab bender and consists of a hydraulic foot pump and adjust able tab-bending adapter.

Step 10 refers to figure 10-14, view E.

10. Prebend locking strip tabs using special tool provided or a common screwdriver. Set adjusted tab bender onto tab to be bent. Apply hydraulic pressure with foot pedal until tab is set. Remove tab bender and check clearance, as shown in figure 10-14, view F.

Turbine Stator Vanes

The inspection of turbine vanes is accomplished in the same manner as described in the previous section for the compressor vanes. Damage may be greater as turbine vanes experience extremely high heat. Blend minor nicks and dents with fine stones or emery cloth. Visually

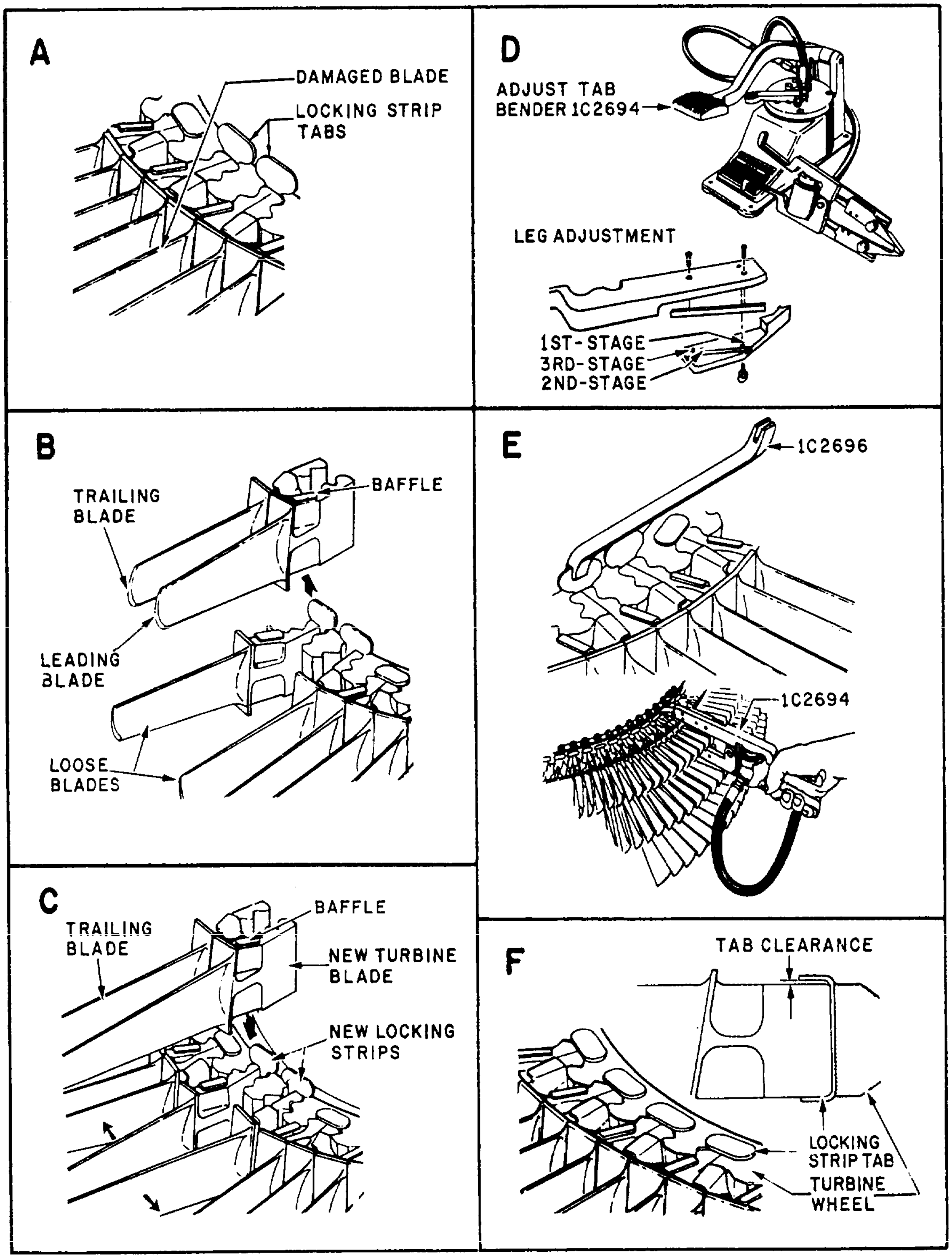


Figure 10-14.-Turbine rotor blade removal and replacement.

inspect the vanes for signs of bowing. Replace bowed vanes that are in excess of the allowable clearance with vanes of the same classification. Use a straightedge and feeler gauge stock to measure bowing. See figure 10-15. Damage that does not crack the metal or reduce the vane thickness by more than allowed is acceptable without rework. This is true if the damage is of a gradual contour shape and not sharp or V-shaped. Round bottom dents on the leading edge may be acceptable without rework. Dents must not exceed allowable limits in depth and must not crack or tear the vane. Blend sharp indentations to remove stress concentration.

Determine how many vanes you need to replace on the particular engine before you measure the nozzle guide vane area. If the replaced blades exceed the allowed number and you must measure the area, it is better to replace the assembly.

One of the final procedures in the maintenance of the turbine section of a turbojet engine is to check for clearances. The service instructions manual gives the procedures and tolerances for checking the turbine. Figures 10-16 and 10-17 show clearances being measured at various locations. Use special manufacturer's tools to obtain accurate readings. Also, use the tools described in the service instructions manual for specific engines.

EXHAUST SECTION INSPECTION

The exhaust section of the turbojet engine is very susceptible to heat cracking. Inspect this

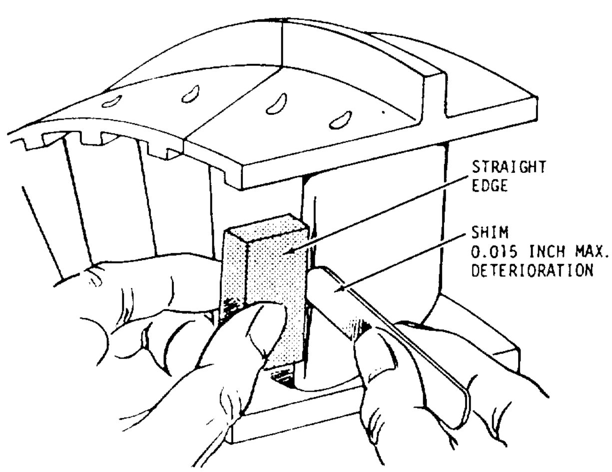


Figure 10-15.-Checking vane bowing.

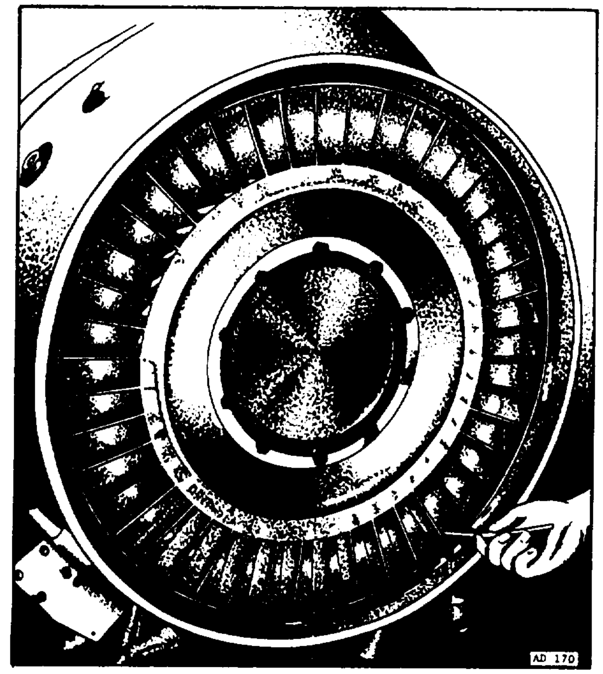


Figure 10-16.-Measuring the turbine blade to shroud tip clearance.

section thoroughly, along with the combustion section and turbine section of the engine. The exhaust section of an afterburning engine is subject to extreme heat and pressures. Inspect the external area of the exhaust cone and tail pipe for cracks, warping, buckling, and hot spots. Hot spots on the tail cone are a good indication that a fuel nozzle or combustion chamber is not functioning properly. If there is an afterburner, inspect the afterburner flap segments for burning, warping, or misalignment. Figure 10-18 shows an afterburner duct and nozzle assembly with flap segments closed. Inspect the afterburner synchronizing gear segments for worn and missing teeth and security of installation. Inspect the nozzle actuation pistons for cracks and/or bent, chafed, or scored piston rods. Inspect the roller guides for warpage and the turnbuckle for security of installation.

Inspect the internal area of the exhaust pipe and afterburner for evidence of hot streaks, buckling, and warping, including the flame holder. Also, inspect all external fuel and hydraulic lines for evidence of distortion, buckling, or leakage. Accomplish the repair and replacement of parts of the exhaust section using

Figure 10-17.-Measuring the turbine wheel to exhaust cone clearance.

the latest technical instructions for that particular engine.

MAIN ENGINE BEARINGS INSPECTION

Because of the high rpm, main engine bearings are critical sections of an engine. The number of main engine bearings may differ from one model engine to another. With the engine disassembled and in the vertical position, all bearings and housings can be inspected and replaced as necessary.

ACCESSORIES DRIVE SECTION AND MATING GEAR INSPECTIONS

The accessories drive section contains the various gearboxes for driving the accessories. These gearboxes should be inspected for cracks and worn areas, and the splines should be checked for proper fit and clearances. When you remove or replace gearboxes, the splined drive shafts must be carefully removed or installed to prevent spline damage.

Most mating gears require backlash as well as end clearance checks. You should carefully inspect the gear and spline teeth for irregular or excessive wear, galling, and flaking. Usually, runout measurements are not required if there is no evidence of gear teeth spalling. These checks may require partial assembly of the parts, and will be accomplished during assembly of the components.

JET ENGINE TEST CELLS

For a jet aircraft engine to operate properly, it must be adjusted properly. The checks for proper adjustment can best be made during controlled operation of the engine. The various types of test facilities, or test cells, are designed for service testing of the jet engine according to procedures and manuals published by the Naval Air Systems Command (NAVAIRSYSCOM). Most engine test cells are used at the intermediate-or depot-level maintenance facilities.

Operators of these test facilities are required by OPNAVINST 4790.2 (series) to be certified by completion of at least one of the following three basic methods of operator training:

1. Completion of formal training at a Naval Aviation Depot (NADEP) school, based on the specific model of test facility.

2. Completion of on-site training provided by a Naval Air Engineering Service Unit (NAESU) engineer.

3. Completion of on-the-job training (OJT) under the direct supervision of a senior petty officer or civilian technician who is a certified test

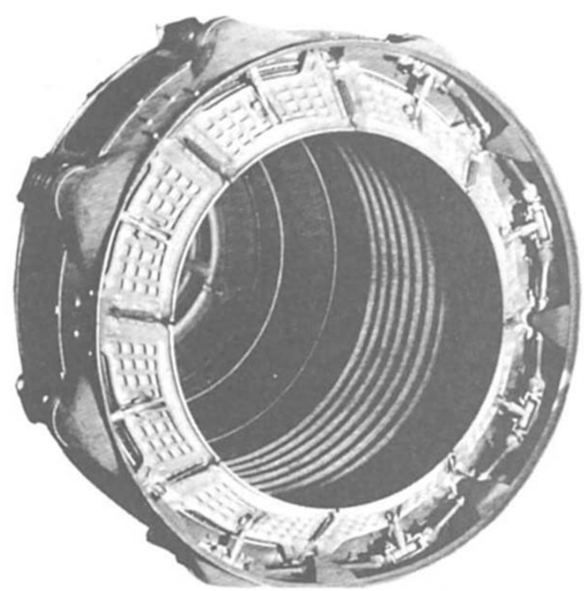


Figure 10-18.-Afterburner duct and nozzle assembly.

stand operator and who has been designated by the activity's commanding officer to provide this training.

All certified test cell operators must hold a valid support equipment (SE) license and ensure that each particular engine and engine test system is indicated on the license. Refer to OPNAVINST 4790.2 (series) for training and licensing procedures.

Engine testing is accomplished primarily in a test cell or test house that is fully equipped to measure all of the desired engine operating parameters. The building is usually of concrete construction and contains both the control and engine rooms, although in some installations only the control or the instrumentation room is enclosed. Most of these cells have noise silencers installed in the inlet stack for noise suppression and a water spray in the exhaust section for cooling. Many of the test cells use computers to automatically record all instrument readings and correct them to standard day conditions. A typical enclosed test facility is described in the following paragraphs. Portable universal engine runup test systems and the engine test log sheets are also described.

ENCLOSED TEST FACILITY

The test equipment is capable of handling 30,000 pounds of jet thrust during performance tests. The test facility building configuration has an engine mass airflow capacity of 180 pounds per second, or approximately 17,000 pounds of thrust, including afterburner operation.

The complete test equipment consists of nine interconnected major assemblies. These assemblies are installed in the test facility building. The test facility building is constructed of reinforced concrete throughout. Removable concrete panels are provided in the primary intake and exhaust stack systems to permit airflow and acoustic expansion of the test facility to a 30,000-pound thrust capacity.

The test cell consists of horizontal primary and secondary air intake stacks, a vertical exhaust stack, an engine room, and a spray room. Immediately adjacent to the test cell is a one-story structure containing an engine control room, a pump room, and a fuel-filter room.

The pump room contains a cooling water pump, an air compressor, a 28-volt dc generator set, and a 115-volt, 400-Hz ac generator set for operation of the test facility. In addition, the pump room contains batteries for operation of the CO_2 fire-extinguishing system. The fuel-filter room contains a fuel flow measuring package in addition to a fuel-filter separator.

The test facility operates on the principle that the accumulation of sufficient data for comparison with known or desired optimum values will satisfactorily indicate the relative service of an engine under test. To accomplish this result, you compare the engine performance and test cell environmental data to standard day performance criteria for the engine model being tested. Various controlling, sensing, and indicating systems are provided to accurately measure engine performance and test cell environmental conditions during the test.

Engine harness and hookups between engine and connector panel, as well as special test items, are the responsibility of the using activity.

A brief discussion of the purpose of each of the major assemblies is given in the following paragraphs. System description and operating principles are also discussed.

Variable Height Stand Assembly

The variable height stand assembly, or thrust bed, is used to support, restrain, and position the engine in the desired testing attitude. This assembly is also used to transfer the engine from the trailer to the thrust bed. The thrust bed positioning system and the thrust measuring system are part of the variable height stand.

THRUST BED POSITIONING SYSTEM.— The thrust bed positioning system is essentially a pneumatic-powered, hydraulic oil-driven device capable of raising and lowering the test engine to any attitude within operating range. Operating controls are mounted on the left front A-frame of the thrust bed.

In addition to supplying lifting force for height positioning of the thrust bed, oil pressure is used to drive the calibration cell cylinder whenever controlled thrust pressure is required.

THRUST MEASURING SYSTEM.— The thrust measuring system becomes operative when the thrust button is acted against by the load cell as a result of slight forward motion of the engine under power. If desired, the load cell may be preloaded by the preload unit. As thrust is developed by the engine, the pressure between the button and the cell produces an electric potential within the cell. The electric current thus established is connected to the thrust measuring circuit box, where it is amplified sufficiently to power the thrust indicator. The thrust indicator is calibrated to read directly in pounds of engine thrust.

Engine Test Connector Panel Assembly

The engine test connector panel assembly (connector panel) is provided as a terminal board for interconnecting the engine with the test equipment.

The engine test connector panel system contains 75 essential connectors and fittings for interconnecting the test engine, control board, and the remaining test equipment. High- and low-pressure quick-disconnect fittings (self-sealing) for pressure lines and capped electrical fittings for electrical lines are provided.

Control Board Instrument Assembly

The control board instrument assembly (control board) provides for central control of the engine and the test equipment. The necessary indicating and recording instrumentation for monitoring engine and test facility conditions is located here. An operator can exercise complete control of the test facility from this control board.

The control board instrument system consists of four panels designated as panel A, panel B, panel C, and panel D. See figure 10-19. The panels contain instruments and control components required to properly operate the test equipment to functionally test turbojet engines.

The electronic counter is an instrument designed to count specific events during variable intervals of time. As installed on the control board, it is used to indicate engine rotor revolutions per minute.

The interlock system is a simple series circuit consisting of manual and automatic switches, relays, and fuses. An electric motor-driven test generator provides all 28-volt dc power used by the interlock system and the test equipment. It is started with a 28-volt dc motor-generator set switch. The switch opens and closes the main relay of the generator output line. The 28-volt engine master switch is the master input switch for the 28-volt system, including the interlock system.

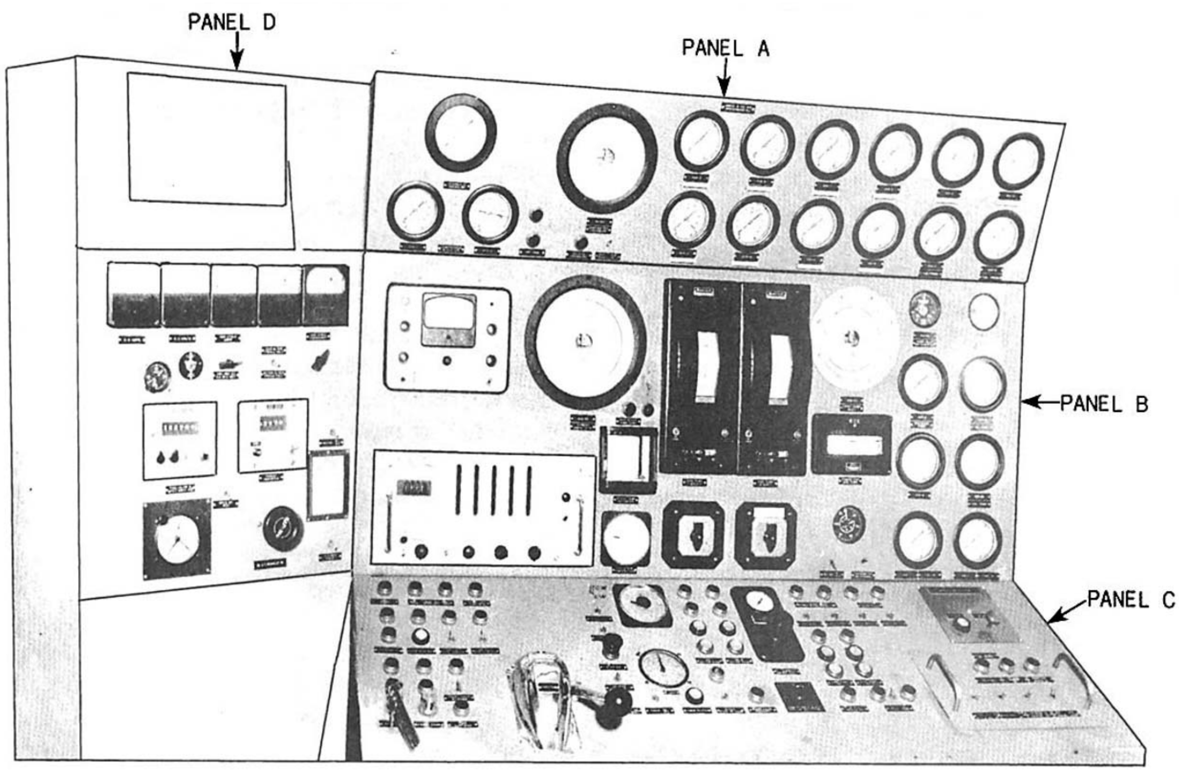


Figure 10-19.-Control board.

When this switch is raised to the ON position, its mating green pilot light is illuminated and engine master relay is energized. Power is then available at the 28-volt engine control switch, having arrived by way of the closed contacts of a normally open relay.

NOTE: All ON and OFF switches installed on the control board are positioned so that their respective ON positions in relation to the lower edge of the applicable panel are established with the toggle raised.

Control point No. 1 consists of a CO_2 pressure switch and mating green pilot light. The switch is a manual reset switch, remotely located at the connector panel in the test cell, and is programmed to seek the OFF position whenever the test cell of the CO_2 fire-extinguishing system is energized manually or automatically. If the pressure switch contacts are broken, they must be manually reset to the ON position before the interlock system circuit can be completed.

Control point No. 2 consists of a front door key-operated switch and two mating pilot lights. The key that operates the switch is the key locking the front door of the test cell; this key cannot be removed from the door lock mechanism until the door is locked.

Before the interlock system can be energized by the switch, the key from the front door must be removed and brought to the control room for use with the switch. The two mating pilot lights indicate the key switch position—green for CLOSED and red for OPEN.

Control point No. 3 consists of a front door bypass switch and mating red pilot light. This switch is provided to permit removal of the front door key from the switch at control point No. 2. The key cannot be removed without placing the switch in the OPEN position, so that the key may be used to open the front door when it is necessary for authorized personnel to attend to the engine or test equipment during periods of engine operation.

Exhaust Augmenter Assembly and Exhaust Gas Cooling System Assembly

The exhaust augmenter assembly (augmenter) and the exhaust gas cooling system assembly (exhaust cooling system) are provided to ensure proper disposition of engine exhaust by controlling exhaust gas, flow characteristics, and temperature. These factors can be monitored, both manually and automatically, with the controls and instrumentation installed. For example, if exhaust stack temperatures in excess of a preset temperature are experienced during afterburner operation, the afterburner is automatically cut off by a latching relay. When this occurs, the afterburner cannot be relit until safe temperature conditions prevail and the relay is reset. Provisions have been made for manually overriding the exhaust stack temperature control system should it fail or otherwise prove inadequate.

The principle of automatic safety control is a built-in characteristic of test equipment. An interlock system has been provided for automatic engine shutdown or prevention of engine start when the following conditions prevail:

1. Inadequate water pressure to maintain exhaust gas cooling, except when bypassed by the WATER-FUEL INTERLOCK switch.
2. Thrust bed not locked and interlocked in height position.
3. Front door key not in control panel lock, or door unlocked without utilization of front door bypass switch and rear door key not inserted in control panel lock.
4. Primary air supply fire curtain not open.
5. CO_2 fire-extinguishing system energized, either manually or automatically.
6. Electric power failure.
7. System-wide loss of compressed air supply.

The exhaust augmenter system consists of two stages. Both stages are adjustable to meet specific engine exhaust conditions.

The first-stage exhaust augmenter is located in the forward test cell wall of the spray room. The horizontal center line of the first-stage and the second-stage exhaust augmenter is approximately 5 feet above the test cell floor. The first-stage augmenter receives the exhaust discharge of the test engine and by venturi action tends to draw such exhaust to the second-stage augmenter in the spray room. The first-stage augmenter spray ring, which is controlled manually from the control board, is included in the first stage.

The size of the first-stage augmenter orifice and the distance from the plane of the engine exhaust exit nozzle to the mount of the insert should be correlated for each engine model to obtain true engine performance and proper control of secondary airflow. Improper sizing and positioning of the first-stage augmenter may result in the following:

1. Excessive turbulence in the region of the exit nozzle.
2. Excessive buildup of exhaust back-pressure.
3. An increase in exhaust gas temperature.
4. Loss of thrust.
5. Insufficient or excessive secondary airflow. (Excessive secondary airflow produces ram drag across the engine; and with operation of high-thrust engines, an excessive test cell depression results.)

The second-stage exhaust augmenter is located in the spray room. A movable collector section is provided along with a flat orifice plate. Movement of the collector section and the indexing of the orifice plate afford quantity adjustment of the airflow from the secondary air intake stack through the second-stage augmenter. The lateral diffusing vanes are water cooled and afford additional exhaust gas cooling. Discharged exhaust gases, mixed with spray water and air, pass from the second-stage augmenter into upward diffusing vanes. These vanes are located at the base of the exhaust stack and upward and out the exhaust stack.

Fuel System Monitoring Assembly

The fuel system monitoring assembly (fuel system) consists of the devices required for fuel filtration, flow and specific gravity measurement, and flow control.

The fuel system consists of two 10,000-gallon underground fuel tanks, two fuel pumps, two motor-driven fuel line valves, the fuel system monitoring assembly, and various controls and pilot lights at the control board. The fuel system is interlocked to the basic interlock system, to the CO_2 fire-extinguishing system, and to the exhaust gas cooling system.

Engine Oil Assembly

The engine oil reservoir and engine auxiliary lubricating oil-cooling system component assembly (lubricating system) provide a 20-gallon engine oil reservoir and an auxiliary means of cooling engine oil to a controlled temperature.

The engine oil reservoir system is made up of a 20-gallon tank equipped with suitable fittings, a sight gauge, and breather vent. The engine lubricating oil is supplied from the storage tank, by way of the oil outlet to the engine lubricating system and back to the tank, through the oil inlet. The amount of oil in the tank can be readily determined by observing the oil level in the sight gauge. The storage tank is located at an extension of the connector panel in the test cell.

The auxiliary lubricating oil-cooling system is provided for use as required by specific engines. Refer to applicable engine test instructions. It consists of an oil temperature regulator valve, a heat exchanger, and suitable plumbing. Water, by way of the oil temperature regulator valve, passes through the cooling elements of the lubricating oil heat exchanger, which is used to cool the engine oil circulating through the exchanger. The temperature of the oil returned to the engine is sensed by the oil temperature regulator valve by a sensing bulb installed in the heat exchanger oil line. The oil temperature regulator reacts to the bulb signal by positioning a poppet valve. This increases or decreases water flow through the heat exchanger, thus maintaining the oil outlet temperature between proper limits. The oil temperature regulator is provided with a handwheel so that the temperature range maybe adjusted to maintain outlet oil temperature within the allowable range. The water used for cooling the engine lubricating oil flows from the main water supply system to the load bank water tank (containing heating elements), and then to the oil temperature regulator valve.

Compressed Air Component Assembly

The compressed air component assembly (compressed air system) provides pneumatic power, air system hardware, and pneumatically operated controls and actuating cylinders necessary for remote control of numerous devices throughout the test facility.

The air compressor (a two-stage, air-cooled, electric motor-driven system) is located in the pump room, and is controlled by a switch located on the master control center in the control room. Two plug-in outlets supply unregulated compressed air for test cell utility purposes as required. Air filtration and partial dehydration are accomplished by two float-type air filters for two main branch supply lines. The pressure to each branch line is controlled by two manually set air pressure regulators. Beyond the pressure regulators, the air system branches off to the various control components for other major systems, such as the fuel system and the exhaust gas cooling system.

Intercommunication System

The intercommunication system consists of an eight-station intercom master in the control room, a suitable amplifying system, and two remote stations equipped with trumpets and microphones. The six spare station switches at the master control are not used as installed. The master unit is equipped with a volume control, a push-to-talk button, and push-to-talk lock button. Remote stations are equipped with push-to-talk buttons only. Station No. 1 is located in the test cell; station No. 2 is located at the test cell observation port.

Electrical Power Systems

Three primary sources of electric power are provided for the test facility. They are as follows:

1. Main service to facility: 120/208-volt ac, three-phase, 60-Hz, four-wire.
2. Motor-driven generator test set: 28-volt dc.
3. Motor-alternator test set: 115-volt ac, one-phase, 400-Hz.

Electric power, developed by any test engine equipped with an engine-driven alternator, is not used for test purposes. If power is required by the applicable engine test instructions, a water-cooled load bank provides for application of a token 5-kva alternator load, consisting of immersion heater elements.

Engine Starting and Ignition System

The starting of a jet engine or any other type of gas turbine engine requires that the engine be rotated at a speed that will provide sufficient air for the required fuel-air ratio. Provisions are made for energizing the ignition system to fire the spark (igniter) plugs at the proper time, and for the engine to be accelerated until the power developed by the turbine is adequate for self-sustained rotation. Initial rotation of the engine during starting may be accomplished by use of either an

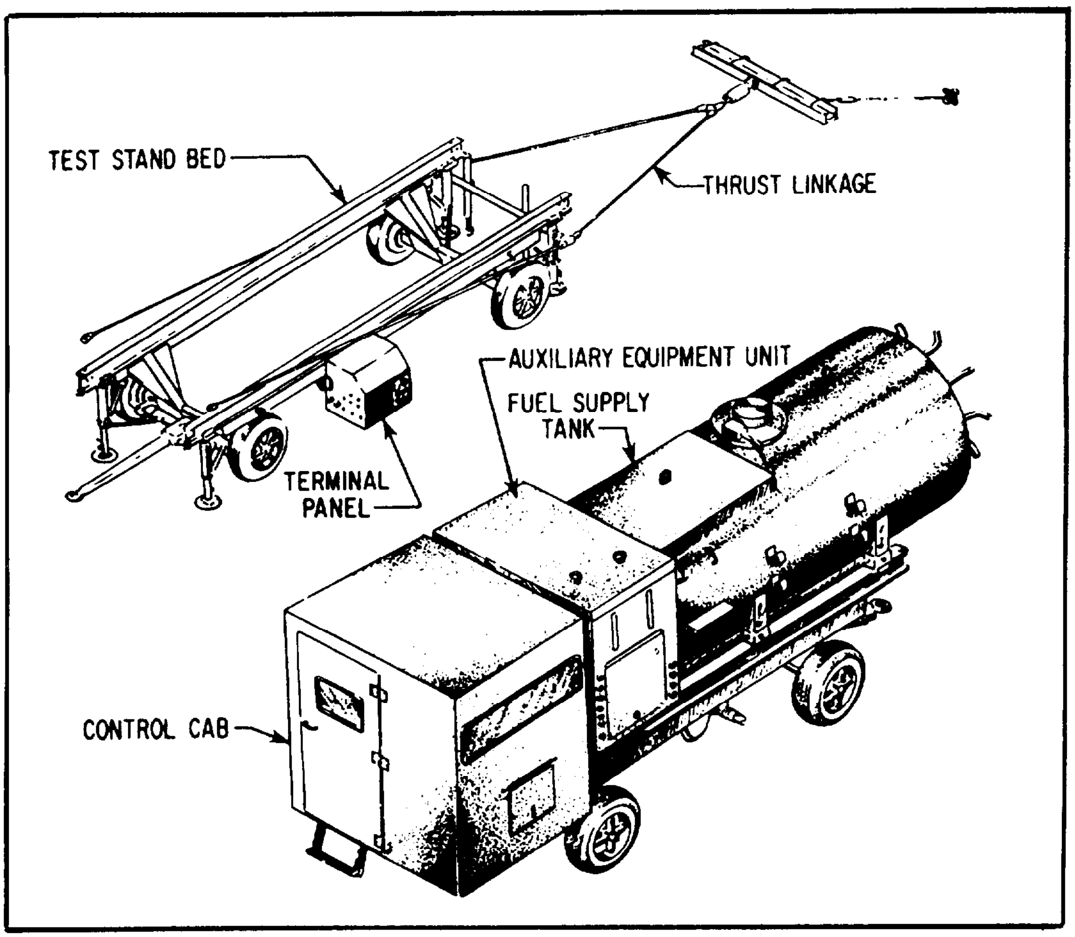


Figure 10-20.-Portable universal engine runup test system.

electrically operated starter motor or a compressed, air-operated, air turbine starter motor. The electric starter motor requires a source of dc voltage. The air turbine motor requires a source of compressed air.

CO_2 System

The CO_2 fire system for the test facility consists of a 2-ton CO_2 storage tank, which incorporates a refrigeration system to maintain the liquid carbon dioxide at the proper storage pressure; a handwheel-operated shutoff valve on the dip tube of the storage tank; pressure-operated control valves for quickly releasing the carbon dioxide; a piping system terminating in the CO_2 discharge nozzles, strategically located in the protected areas; and various controls, relays, thermostats, alarm gongs, spurt and flood push buttons, and pressure-operated switches. For complete fire control coverage, the CO_2 system is electrically linked to the interlock system and pressure linked to the main fuel line valve of the engine fuel supply.

The CO_2 storage tank is designed for maximum working pressure and is equipped with a complete Freon (F-12) refrigeration system, which is automatically controlled by an internally mounted pressure switch. The refrigeration system maintains a nominal storage tank pressure. The storage tank is protected by a safety assembly consisting of a dual switching valve, which, when in the normal position, places in service one auxiliary automatic refrigeration valve, one safety valve, and one high-pressure relief disc. The safety devices provide complete protection against abnormally high tank pressures. An abnormally high pressure usually results from power or compressor failure continuing over a period of several hours.

PORTABLE UNIVERSAL ENGINE RUNUP TEST SYSTEMS

There are several different models of universal test cells in use. Figures 10-20, 10-21, 10-22, and 10-23 show some of the more commonly used test

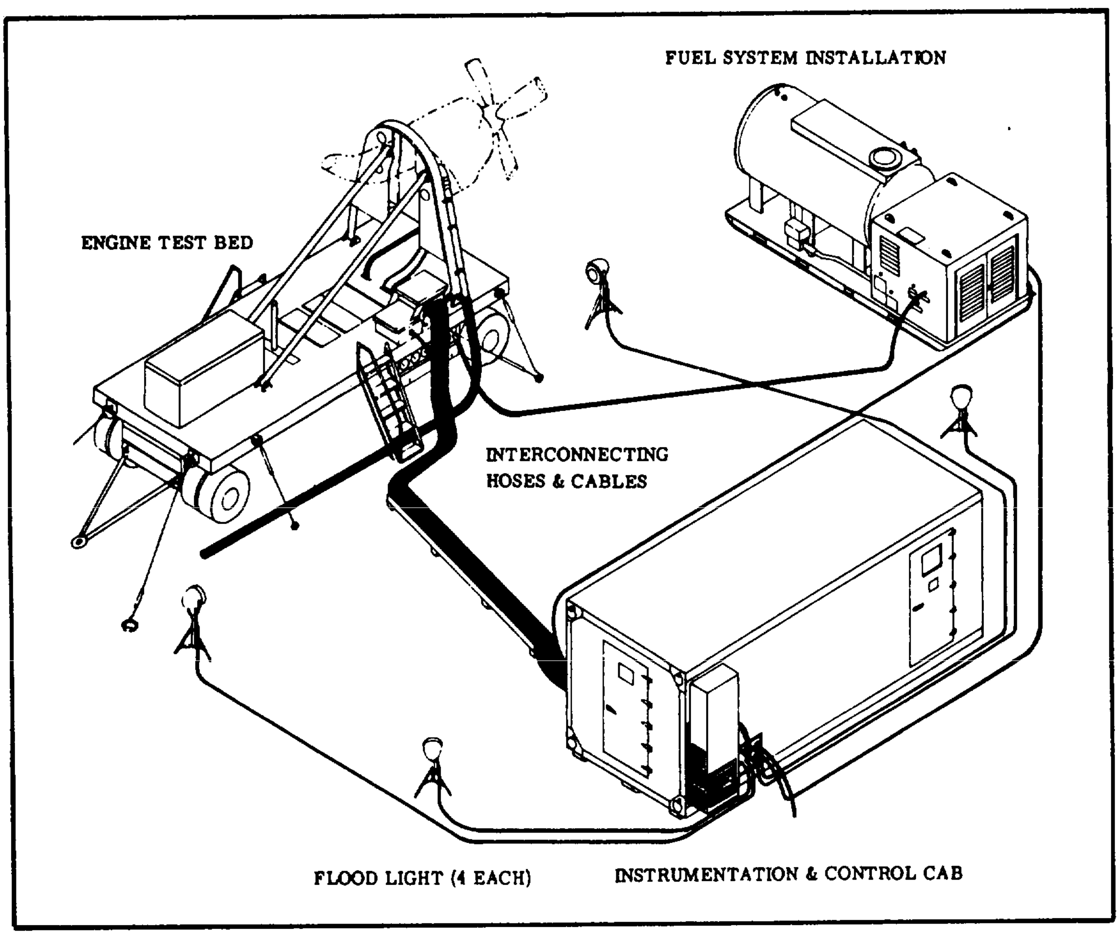


Figure 10-21.-Turboprop engine test system.

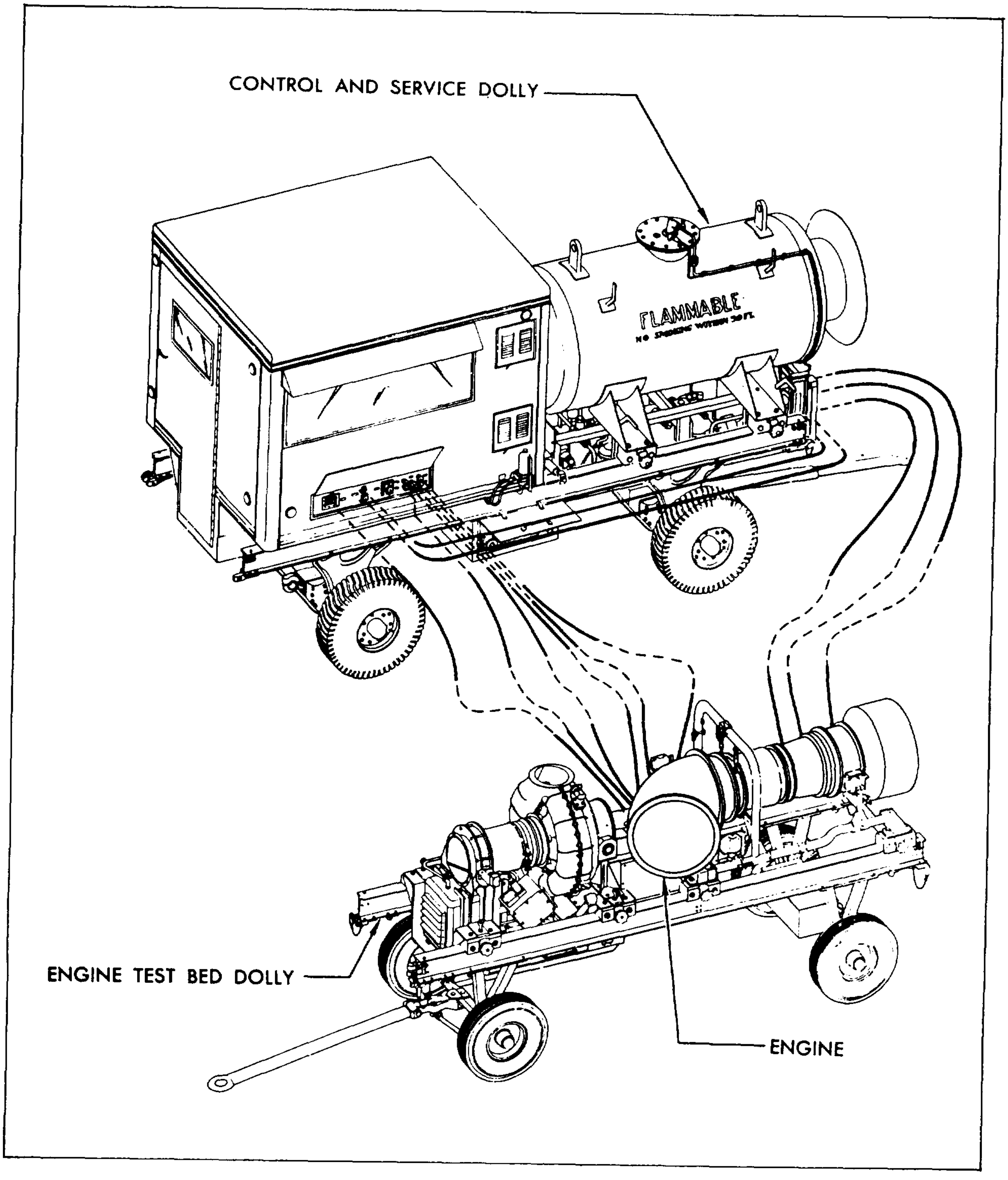


Figure 10-22.-Portable engine runup test system.

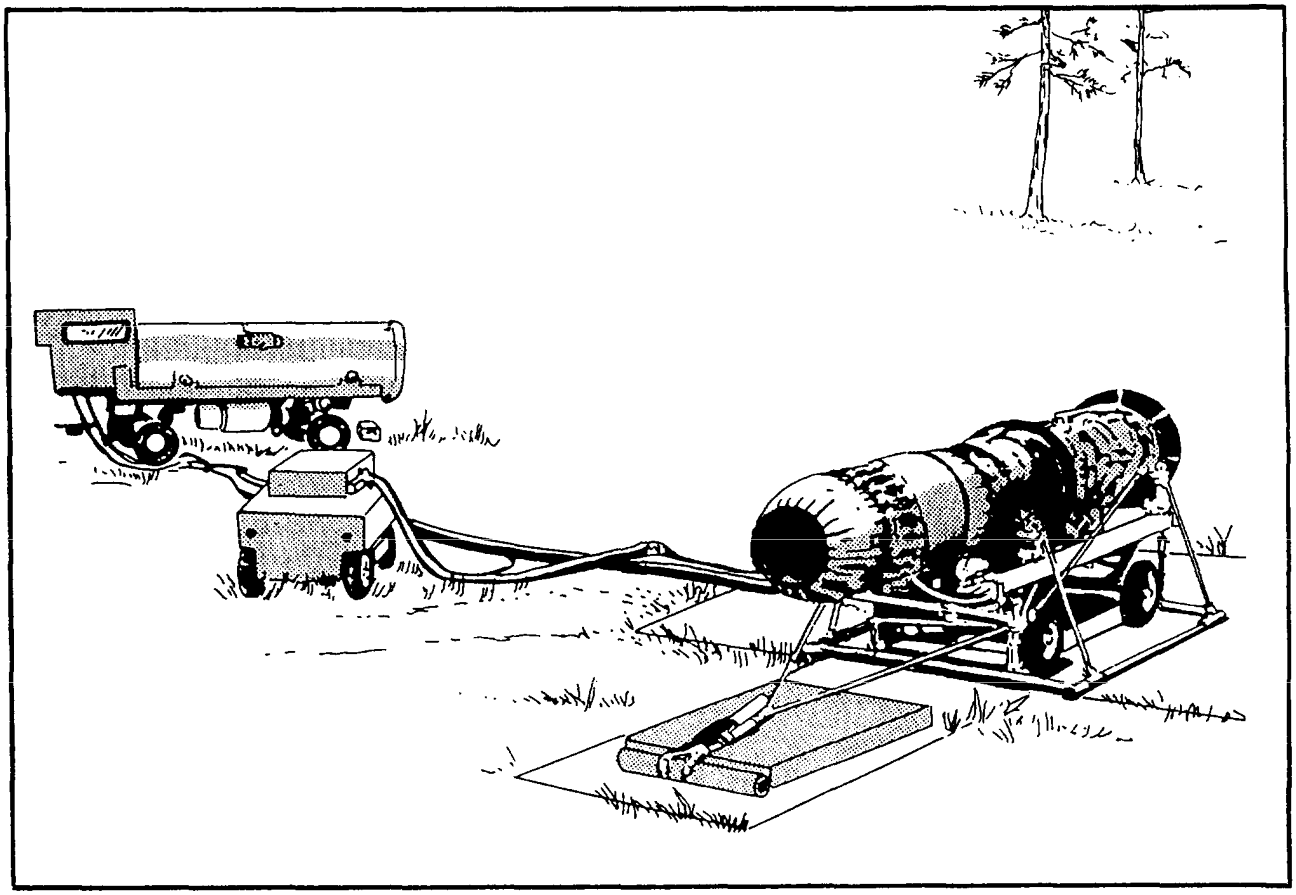


Figure 10-23.-Engine test and runup system.

cells that provide the aircraft maintenance activities with a portable and universal system for the operational and functional testing of jet aircraft engines.

These systems perform the basic functions of checking all the engine performance characteristics against the engine manufacturer's operational parameters, as approved by NAVAIRSYSCOM. The test cells display engine temperatures, vibrations, fuel metering, fuel flow pressures, thrust, lube oil temperatures and pressure, compressor pressure, hydraulic oil pressure, anti-ice pressure, turbine rpm, and position indications such as nozzle and stator vane and throttle.

NOTE: These test systems may be used at any site location that has been provided with adequate tie-downs (either concrete embedded or buried expansion anchors).

Some engines require special testing consoles. The console provides the electrical circuits (not normally found in a test cell) needed to satisfactorily conduct functional and performance tests.

The console provides junction facilities to connect the cell power to the engine, a system for remote control measurement of throttle position, a transmitter and receiver to indicate inlet guide vane position, and a dc electronic indicating system for measuring nozzle position. A thermocouple type of anti-icing temperature indicator, a starter circuit, and switches and cables necessary for operation of the engine and console under test conditions are included in some consoles.

Just as starting procedures vary with the various types of engines, the controls and instrumentation vary with different test cells. Checking the engine for proper operation consists primarily of reading engine instruments and then comparing the deserved values with those given by the manufacturer for specific engine conditions, atmospheric pressures, and temperatures.

Engine S/N	Fuel Control S/N	Oil Spec	1st NGV Area Class Avg.	Test Spec & Revision Date
Model	Fuel Pump S/N	Fuel Spec	2nd NGV Area Class Avg.	Data Plate Speed RPM %
T_{t5} Limiter S/N	A/B Meter S/N	Fuel Specific Gravity —— Temp ——	3rd NGV Area Class Avg.	Total Test Time Hrs. Min.
Ignition S/N	A/B Fuel Pump S/N	Oil Consumption Gal/Hr	4th NGV Area Class Avg.	A/B Nozzle Area / Number Starts

Test	PARAMETER		IDLE	INTER.	ZONE 3	ZONE 5	75% MAX. CONT.	MAX. CONT.
			← Test 1 & 2			→		
			← Test 3					→
Test 1, Test 2, Test 3	CPRSR INLET TEMP.	T_{t2} °F						
	RPM	N_1 Observed						
		N_1 Corrected						
		N_2 Observed						
		N_2 Corrected						
	FUEL (W_f) PHR	Fuel Flow Observed						
		Fuel Flow Corrected						
	TURB INLET TEMP	Tt5 Observed						
		Tt5 Corrected						
	OIL	Main Oil Pressure psig						
		Breather Pressure "Hg						
		Oil in Temp °F						
	VIBRATION (mils) S/A ____ D/A ____	Inlet Case						
		Diffuser Case						
		Turbine Case						
Test 3	INLET PRESSURE (P_{t2})	in. H_2O						
		in. Hg Gage						
		in. Hg Absolute						
	BAROMETER	in. Hg Absolute						
		Pt7m "Hg Gage						
		Pt7m "Hg Abs						
		Pt7m/Pt2						
	GASPATH PRESSURES	Ps3 (psi)						
		Ps4 (psi)						
		Pcp (psi)						
		Ps3/Pt2						
		Ps4/Pt2						
		Pcp/Ps4						
	Power Lever Angle (Degrees)							
	Nozzle Position							

All Tests	Acceleration Checks	Idle to Intermediate ____ Secs. Max to Intermediate ____ Secs. Intermediate to Max ____ Secs.
All Tests	T_{t5} Limiter Check	Limiter Activates @ °F Incr / Deactivates @ °F Decr.
All Tests	LPC Bleed Check N_1 Decrease ______	Anti–ice Check Temp. Increase ______
Test 2 & 3	12th Stage Bleed Check – Close @ Ps3 Psia	Open @ Ps3 Psia

Test 3 — T_{t7} Spread Check (°F)

T_{t7} PROBE NUMBER	1	2	3	4	5	6	Avg.
Probe reading							
Deviation from Avg.							

Test 2 & 3		
W_f (at lightoff) ____ PHR	T_{t5} (max during start) ____ °F	Time to Idle ____ secs.

ENGINE TRIM DATA

POWER SETTING	Tt2	Tt5	% N1 Corr.	%N2	EPR
INTERMEDIATE					
ZONE 3					
ZONE 5					
IDLE					

OPERATOR	FOREMAN	INSPECTOR	DATE OF TEST

N-1544-1 (51–2)

Figure 10-24.—Engine runup test log sheet.

ENGINE TEST LOG SHEETS

The engine test log records the data obtained during the engine test run. See figure 10-24. The log provides a record of the engine test for future reference and acts as documentary proof that the engine was subjected to the prescribed test procedures. The data must be complete, accurate, neat, and legible. Upon receipt of the engine for testing, the operator will enter the name of the testing activity, the engine model, serial number of the engine, and the date of the engine test.

During the test, record all unusual occurrences in the remarks section of the test log. Record all starts, shutdowns, times for accelerations, and times for adjustments and settings. During starts, record the time of day the engine was started, maximum turbine inlet temperature encountered, and the duration of that temperature. Record the time for acceleration and the stabilization time.

At the end of the test, record the engine coast-down time. Coast-down time is defined as the time elapsed from the moment fuel is cut off to the time the engine comes to a complete stop. Coast-down time has no absolute value. A record maintained for engines will show what the expected average coast-down time should be. Any engine with an abnormally short coast-down time should be viewed with suspicion and investigated for compressor rub or other malfunctions. The operator is required to sign all the test run logs, and is held responsible for the accuracy and completeness of all the test data.

Test schedules will vary with each different model of engine and manufacturer. Always refer to the appropriate engine manual when performing engine test runs.

APPENDIX I

GLOSSARY

ABORT—To cut short or break off an action, operation, or procedure with an aircraft, guided missile, or the like, especially because of equipment failure; for example, to abort a mission.

ACCELERATION—A change in the velocity of a body, or the rate of such change with respect to speed or direction.

ACCESSORY—A part, subassembly, or assembly designed for use in conjunction with or to supplement another assembly or unit. For example, the fuel control is an accessory for a turbojet engine.

ADDITIVE—A chemical that is added in minor proportion to a parent substance (fuel or oil) to create, enhance, or suppress a certain property or properties in the parent material.

AERODYNAMICS—The science that deals with the motion of air and other gaseous fluids and the forces acting on bodies in motion relative to such fluids.

AFTERFIRE—The term used when a tail-pipe fire develops after engine shutdown.

ALLOY—A substance composed of two or more metals.

AMBIENT—Surrounding; adjacent to; next to. For example, ambient conditions are physical conditions of the immediate area such as ambient temperature, ambient humidity, ambient pressure, etc.

ANGLE OF ATTACK—The angle at which a body, such as an airfoil or fuselage, meets a flow of air. The acute angle between the chord of an airfoil and the direction of the relative wind.

ANODIC—The term used for the terminal point where electricity passes from the electrolyte to an external point; for example, the negative terminal on a cell or battery.

ANODIZE—To coat a metal by chemical or electrolytic processes.

ANTI-ICING—To prevent ice formation on an aircraft's surface or engines.

APU—Auxiliary power unit.

ARTICULATED—A movable joint between segmented parts. An articulated rotor system is one whose individual or collective main rotor blades are free to flap, feather, and drag individually or collectively.

ATE—Automatic test equipment.

ATMOSPHERE—The body of air surrounding the earth. The atmospheric pressure at sea level is 14.7 psi.

ATOMIZE—To reduce a fluid (fuel) to a fine spray or mist.

AUTOROTATION—The process of producing lift with airfoils that rotate freely and are not engine driven. When a helicopter autorotates, the air flows upward through the rotor system, rather than downward, as is the case when the rotors are engine driven.

AVGAS—Aviation gasoline for reciprocating engines.

AXIS—An imaginary line that passes through a body about which the body rotates or may be assumed to rotate. For example, the horizontal axis, the lateral axis, and the longitudinal axis about which an aircraft rotates.

BAROMETRIC—The term used for instruments and devices that measure atmospheric pressure and respond in some way to the changes in pressure.

BERNOULLI'S PRINCIPLE—If a fluid flowing through a tube reaches a constriction, or narrowing of the tube, the velocity of fluid flowing through the constriction increases and the pressure decreases.

BITE—Built-in test equipment.

BTU—British thermal unit. A unit of heat commonly used in heat engineering. It is the amount of heat necessary to raise the temperature of 1 pound of water 1 degree Fahrenheit.

CAUTION—An operating procedure, practice, or condition, etc., that may result in damage or destruction to equipment if not carefully observed or followed.

CELSIUS—The temperature scale using the freezing point of water as zero and the boiling point as 100, with 100 equal divisions between called degrees. A reading is usually written in the abbreviated form; for example, 75°C. This scale was formerly known as the centigrade scale, but was renamed Celsius in recognition of Anders Celsius, the Swedish astronomer who devised the scale.

CENTRIFUGAL—Moving or directed outward away from the center or axis.

COLLECTIVE PITCH—The mechanical means of simultaneously increasing or decreasing the pitch of all main rotor blades.

COMPRESSOR INLET TEMPERATURE (CIT or T_2)—The temperature of the air entering the gas turbine compressor as measured at the front frame. One of the parameters used to calculate engine power output (torque) and scheduling combustion fuel flow and variable stator vane angle.

CONCENTRIC—Having a common center.

CONDENSATION—The act of reducing a gas or vapor to a liquid or solid form.

CONING—The upward flexing of the rotor blades resulting from the vectorial combined effects of centrifugal force and lift.

CONTAMINATION—Any foreign material or substance whose presence (in the fluid) is capable of adversely affecting the performance or reliability of a system.

CONVERGING—To tend to meet at a point or line; incline toward each other.

COORDINATOR—An electromechanical unit that mounts to the back of the fuel control in turboprop engines. It coordinates the propeller, electrical temperature datum control, and the fuel control through signals received from the power levers.

COWLING—A removable cover or housing placed over or around an aircraft component or section, especially an engine.

CSE—Common support equipment.

CURE—The changing of matrix properties (hardening) by chemical reaction, usually accomplished with heat and vacuum pressure.

CYCLIC PITCH—The mechanical means to change the pitch of the main rotor blades during the rotor system cycle of rotation to control the tilt of the rotor disk.

DE-ICING—The breaking off or melting of ice from aircraft surfaces or fuel induction systems.

DELAMINATE/DELAMINATION—The splitting or separating of a laminated composite material between laminate plies.

DENSITY—The weight per unit volume of a substance.

DIFFUSER—A specially designed duct, chamber, or section equipped with guide vanes, which decrease velocity and increase pressure.

DILUTENT—A substance or medium to reduce strength or make thinner.

DISILICATES—Compounds containing two atoms of silicon in conjunction with other elements.

DISSIPATE—To scatter or spread.

DIVERGENT—To extend in different directions from a common point.

DYNAMICALLY—As in balanced by rotating at high speed.

EAMP—Engine Analytical Maintenance Program.

ELECTROCHEMICAL—Chemical changes produced by electricity and the production of electricity through chemical reactions.

ELECTROLYTE—A conducting medium in which the flow of current is accompanied by the movement of ions.

ELECTROPLATE—To coat with a metal through the use of electricity.

ENERGY—The ability or capacity to do work.

ENGINE TRIMMING—The term used for fine tuning a newly installed engine to the airframe, or whenever engine fuel system major components have been removed and/or replaced.

FAIRING—A part or structure that has a smooth, streamlined outline, used to cover a nonstreamlined object.

FAHRENHEIT—The temperature scale that registers the freezing point of water at 32 degrees and the boiling point at 212 degrees.

FERRIC—Containing iron.

FLAMMABLE—Describes any combustible material that can be easily ignited and that will burn rapidly.

FLASH POINT—The lowest temperature at which a sufficient amount of vapor is given off by a liquid to form an ignitable mixture with air.

FOD—Foreign object damage. Damage resulting from foreign objects (nuts, bolts, rocks, etc.) entering the engine inlet.

FORCE—The action of one body on another tending to change the state of motion of the body acted upon. Force is usually expressed in pounds.

FRICTION—Surface resistance to relative motion.

GAS GENERATOR SPEED—(Ng), See N.

GRAPHITE—A soft, native black to dark-gray carbon used for pencil leads and lubricants.

HELICAL—Pertaining to or having the form of a spiral.

HERO—Hazard of electromagnetic radiation to ordnance.

HORSEPOWER—A unit of power equal to the power necessary to raise 33,000 pounds 1 foot in 1 minute.

HOT START—The term used when exhaust gas temperatures rise above specified limits during the engine starting cycle.

HYDRAULICS—The branch of mechanics that deals with the action or use of liquids forced through tubes and orifices under pressure to operate various mechanisms.

HYDROUS—Containing water or its elements in some form.

IMPEL—To propel or impart motion.

IMPINGEMENT—The act of striking against. An impingement starting system is where starter air is directed to strike against the turbine blades, causing the engine to rotate.

INERTIA—The tendency of a body at rest to remain at rest, and a body in motion to continue to move at a constant speed along a straight line, unless the body is acted upon in either case by an unbalanced force.

INFLAMMABLE—Same as FLAMMABLE, with flammable being the preferred term.

INHIBITOR—A substance that decreases the rate of or stops completely a chemical reaction.

JETTISON—To throw or dump overboard. For example, to drop or eject fuel, tanks, or gear from an aircraft to lighten the load for emergency action.

JOAP—Joint Oil Analysis Program.

KINETIC—Energy in motion.

LABYRINTH SEALS—Oil seals with a nonrubbing surface. Designed to allow minimal amounts of leakage, which is controlled by air pressure on one side.

LAMINATE—A combination of two or more single plies of laminae bonded together to form a structure.

LAMPS—Light Airborne Multipurpose System (Helicopter).

LATERAL—The width dimension; for example, the lateral axis of an aircraft runs lengthwise from wing tip to wing tip.

LONGITUDINAL—The lengthwise dimension; for example, the longitudinal axis of an aircraft runs lengthwise from the nose to the tail.

MACH—A number indicating the ratio of the speed of an object to the speed of sound in the medium through which the object is moving.

MASS—The amount of fundamental matter of which an object is composed.

MATTER-The substance or substances of which all physical objects consist or are composed.

MAY AND NEED NOT—Terms indicating that the application of a procedure is optional.

MICA—Any member of a group of minerals, hydrous disilicates of aluminum with other bases, that separate readily into thin, tough, often transparent laminates.

MICRON—A millionth of a meter or about 0.000039 inch.

MIL-C—Military compounds.

MIL-H—Military hydraulic fluids.

MIL-L—Military lubricants.

MILSPEC—Military Specification.

MILSTD—Military standard.

MOLECULES—The smallest physical units of an element or compound.

N—Abbreviation for speed or rpm. When used with other letters, it indicates the speed of that section. Examples include N_g for compressor speed and N_f for power turbine or fan speed.

NACELLE—A streamlined structure, housing, or compartment on an aircraft; for example, a housing for the engine.

NAVOSH—Navy Occupational Safety and Health.

NOAP—Navy Oil Analysis Program.

NOTE—An operating procedure, practice, or condition, etc., that is essential to emphasize.

OCCUPATIONAL STANDARDS—The minimum requirements for rating and rate, as set forth by the Chief of Naval Personnel.

OXIDATION—In general, the process where oxygen is added to a compound. The oxidation process in petroleum may lead to gum or resin formations.

OXIDE—A compound containing oxygen and one or more elements.

PLENUM CHAMBER—A chamber in which the gas or air pressure is greater than atmospheric pressure.

POSITIVE DISPLACEMENT—The term used for oil, fuel, and hydraulic pumps that deliver more fluid to the system than is actually required.

PPB—Power plants bulletin.

PPC—Power plants change.

PRESSURE DIFFERENTIAL—The difference or ratio between input and output pressure.

PRESSURE—The amount of force distributed over each unit of area. Pressure is expressed in pounds per square inch (psi).

PROPAGATION—The act of transmitting and controlling heat in a flame.

PROPORTIONAL—Having the same or constant ratio or relation.

PSE—Peculiar support equipment.

PSI—Position sensitive indicator. Pounds per square inch.

PYLON—A structure or strut that supports an engine pod, external tank, etc., on an aircraft.

QEC—Quick engine change.

QECA–Quick engine change assembly.

QECK–Quick engine change kit.

RAM AIR—Air forced into an air intake or duct by the motion of the intake or duct through the air.

RAM PRESSURE—Air pressure in the inlet caused by a jet aircraft's forward motion.

RATIO—The relation between two similar items in respect to the number of times the first contains the second.

RESERVOIR—A receptacle or chamber for holding a liquid or fluid.

ROTOR—A system of rotating airfoils.

RPM—Revolutions per minute.

SCAVENGE OIL—The term used for oil that has been through the engine lubrication system and is on its way back to the tank.

SCUPPER—Any drain for fluid runoff.

SE—Support equipment. All of the equipment on the ground needed to support aircraft in a state of readiness for flight.

SEGTE—Support equipment gas turbine engine.

SELECTOR VALVE—A valve used to control the flow of fluid to a particular mechanism, as in a hydraulic system.

SERVICING—The refilling of an aircraft with consumables such as fuel, oil, and compressed gases to predetermined levels, pressures, quantities, or weights.

SHALL—Term indicating that application of a procedure is mandatory.

SHOULD—Term indicating that application of a procedure is recommended.

SLIPSTREAM—The stream of air driven backward by a rotating propeller.

SLUGGING—In airplanes, loss of liquid fuel from tank vents because of the pulling action of escaping vapors.

SOAPSTONE—A hand talc with a soapy or greasy feel.

SPECIFIC GRAVITY—The ratio of the weight of a given volume of a substance to the weight of an equal volume of some standard substance, such as water.

SPECTROMETER—An optical device used to determine the amounts and types of contaminants in oil sample droplets under the Navy Oil Analysis Program.

SPEED—The distance a body in motion travels per unit of time.

STATOR—A system of stationary airfoils.

SUMP—A chamber into which a fluid drains for pickup and recirculation.

T—Abbreviation for temperature. Combined with a number it will indicate temperature at a specific engine station. For example, T_2 indicates compressor inlet temperature.

TEFLON®—Trademark used in making a tough, nonsticking coating for gaskets, backup rings, bearings, electrical insulators, etc.

TENSION—A force or pressure that exerts a pull or resistance.

THERMOCOUPLE—A device for measuring temperature, consisting of two dissimilar metallic conductors joined at their ends.

THERMODYNAMICS—The science concerned with the relations between heat and mechanical energy or work, and the conversion of one to the other.

THRUST—The forward-direction pushing or pulling force developed by an aircraft engine or rocket engine.

TORQUE—A turning or twisting force.

TOXIC—Harmful, destructive, deadly; poisonous.

TRACKING—To ensure that helicopter blades rotate in the same horizontal plane.

TURBULENCE—The flow of a fluid (liquid or gaseous) within an object such that the velocity at any fixed point in the fluid varies irregularly.

VARIABLE GEOMETRY—A design that allows the angle of a wing, intake ramp, or exhaust duct to adjust to the best condition for the most efficient use.

VELOCITY—The rate of motion in a particular direction.

VISCOSITY—The internal resistance of a liquid that tends to prevent it from flowing.

VOLATILITY—The ability of a fluid to evaporate.

WARNING—An operating procedure, practice, or condition, etc., that may result in injury or death if not carefully observed or followed.

WILL—A term used to indicate futurity, never to indicate any degree of requirement for application of a procedure.

WINDMILLING—Rotating a gas turbine engine without energizing the ignition system.

INDEX

I

J