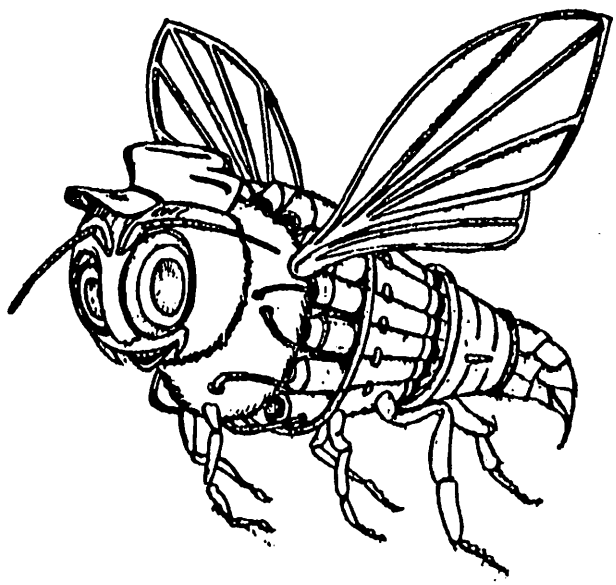
C141A

5 JUN

ENGINE GENERAL



443d TECHNICAL TRAINING SQUADRON

443d MILITARY AIRLIFT WING, TNG (MAC)

ALTUS AIR FORCE BASE, OKLAHOMA

Revised 19 Jan 78 GPO 1200
Supersedes previous edition

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OBJECTIVES

When you complete this program you will be able to:

a. Define the following:

1. Newton's Third Law.
2. Axial Flow.
3. Flat Rated.
4. Forward Fan.
5. How EPR is measured.

b. List the Maximum Exhaust Gas Temperature for:

1. Takeoff Rated Thrust (TRT).
2. Military Rated Thrust (MRT).
3. Normal Rated Thrust (NRT).
4. Starting.
5. Idle.
6. Engine Acceleration.

c. List the engine time limits for TRT, MRT, and NRT.

d. List the RPM range for N_1 and N_2 Compressors.

e. State the purpose of the Compressor Surge Bleed System.

f. Identify the major sections of the TF33-P-7 engine on an engine schematic.

The jet propulsion principle is NOT A NEW IDEA. For centuries, jet propulsion has been used in mechanisms of war and devices of amusement. Even nature makes use of this principle in the propulsion of various types of aquatic life.

Man's first application dates back more than 2000 YEARS to approximately 100 BC when Hero of Alexander invented the Aeolipile. Unfortunately, the Aeolipile was regarded as only a toy and the world would wait more than 16 centuries before its operating principle would be put to practical use.

The principle of jet propulsion is not a new idea and dates back more than 2000 YEARS.

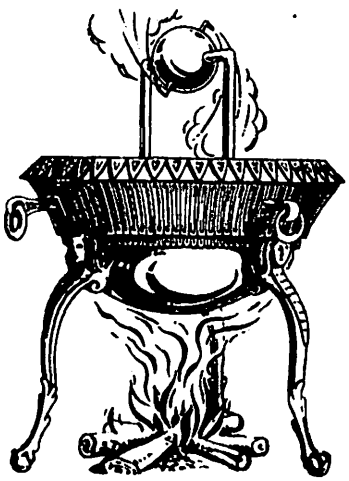
A. TRUE

B. FALSE

ANSWER = A

The jet propulsion principle is in some cases as old as nature itself. Man's first attempt was with the Aeolipile in approximately 100 BC.

Hero's Aeolipile was regarded as a toy, but the principle was there.



Hero's Aeolipile

Centuries later, Sir Isaac Newton, discovered certain laws governing energy exchanges. His THIRD LAW says that for every ACTION there is an equal and opposite REACTION.

In the case of Hero's Aeolipile, heat was used to produce steam and to build pressure. The escaping steam and the pressure was then used to give the ACTION-REACTION necessary for movement of the ball. Heat in this case was transferred through the use of steam into mechanical energy.

Which of the following statements is NEWTON's THIRD LAW.

A. Everything that goes up must come down.

B. A change in motion is proportional to the force applied.

C. For every action there is an equal and opposite reaction.

ANSWER = C

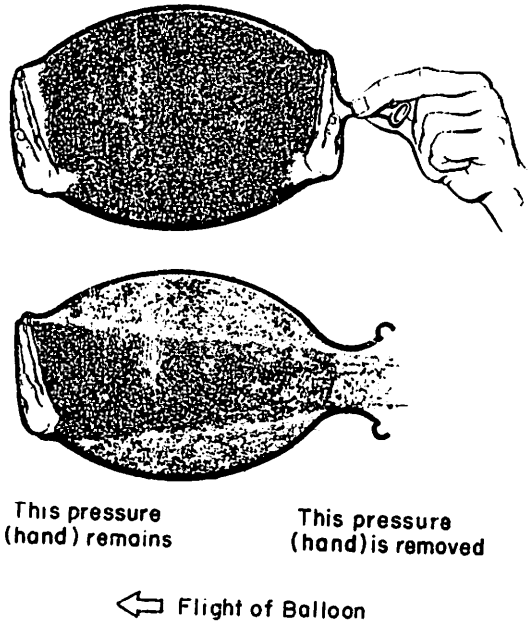
Jet engines a mystery to you? A brief glance of a very simple analogy will serve to clear up most of this mystery.

When a balloon is inflated, the inside air pressure, which is stretching the skin, is greater than outside pressure. When the neck is tied, the inside air pushes equally in all directions, and the balloon will not move. Now if you place the balloon in a vacuum and release the neck the escaping air would not have anything to push against, yet the balloon will move in a direction away from the neck.

Why?

Releasing the pressure at the neck removes a section of skin against which air has been pushing from the inside. Opposite the neck the air continues to push on an equal area of the skin. This opposite push causes the balloon to move.

Examine the picture below



The balloon's flight is short because the pressure is lost quickly. This handicap could be overcome by pumping air into the balloon so that pressure could be maintained.

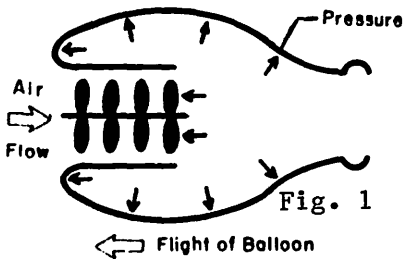


Fig. 1

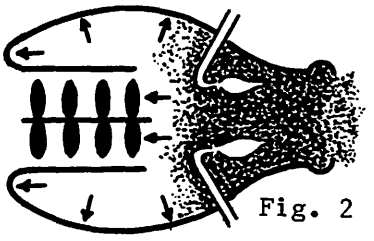


Fig. 2

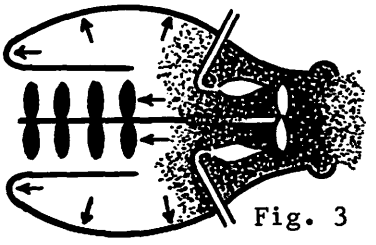


Fig. 3

To transform the balloon apparatus into a self-contained turbojet engine, replace the pump with a series of fans, called a compressor (Fig. 1). Turn the compressor at high speed and huge quantities of air are passed through the engine under pressure.

Now for energy, place a burner in the air stream (Fig. 2). Heat raises air temperature rapidly and increases the volume of the air. The compressor will block the forward flow of air so it will take the less restricted path rearward.

Place a windmill (TURBINE) in the path of the heated air (Fig. 3). Some of the pressure energy can now be used to spin the TURBINE which, in turn, spins the COMPRESSOR by means of a connecting shaft. As the COMPRESSOR spins more air is brought into the engine.

The same type of an <u>ACTION-REACTION</u> principle applies to a jet engine. IT IS NOT THE ESCAPING AIR PUSHING AGAINST THE OUTSIDE AIR THAT MAKES THE ENGINE MOVE.

How is heat energy turned into mechanical energy in the above pictures?

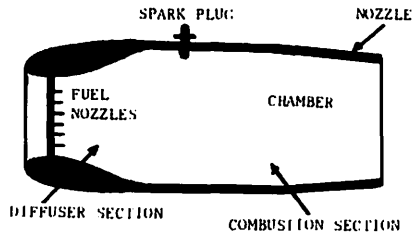
A. By a turbine wheel.

B. By a compressor.

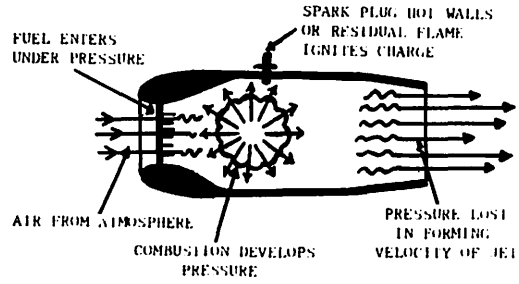
C. By escaping air pushing against outside air.

ANSWER = A

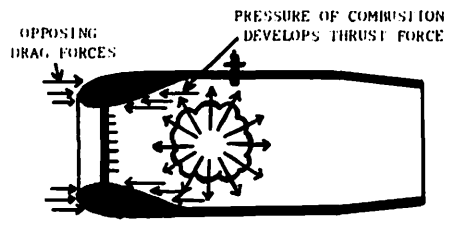
When modern man began toying with the idea of jet propulsion, they found that if they could force enough air into a tube and then provide fuel and ignition that the expanding gases would make the tube move. Air being forced into the tube restricted forward flow of the expanded gases, but the pressure was lost on the opposite end of the tube. Thus when combustion increased the pressure in the tube forward thrust was obtained. Their first efforts resulted in the Ramjet.



POWER UNIT



OPERATION



ANALYSIS OF FORCES

Does the Ramjet employ the principle of Newton's Third Law?

A. Yes

B. No

ANSWER = A

The Ramjet employs Newton's Third Law of ACTION-REACTION to produce thrust. COMBUSTION increases the pressure and on one end of the Ramjet the pressure is lost, on the opposite end it is not.

Next came the Pulsejet. Similiar to the Ramjet, the Pulsejet, like all jet engines, uses the principle of ACTION-REACTION. From the picture below select the two stages when thrust would be produced.

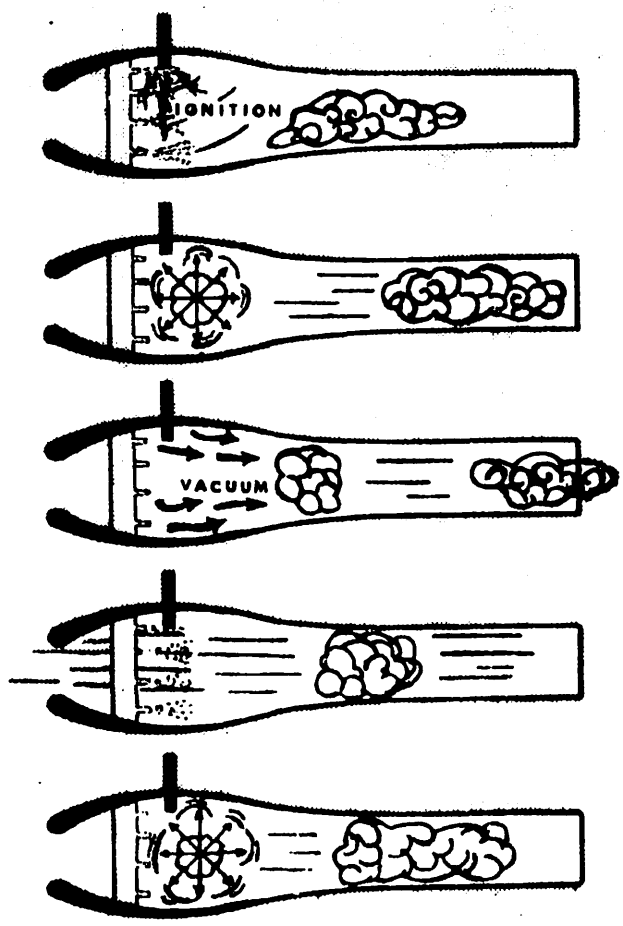
a.

b.

c.

d.

e.



A. "a" and "d"

B. "c" and "e"

C. "a" and "c"

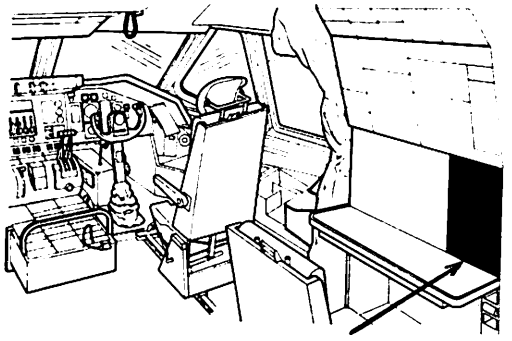
D. "b" and "e"

ANSWER = D

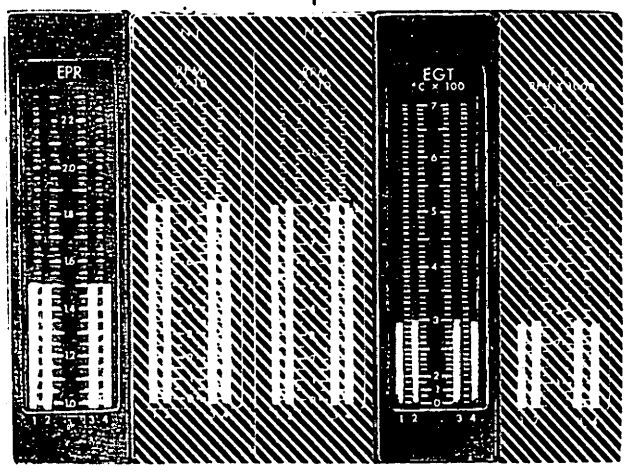
The two (2) combustion stages produce the thrust. Heat is energy. ACTION-REACTION is the key.

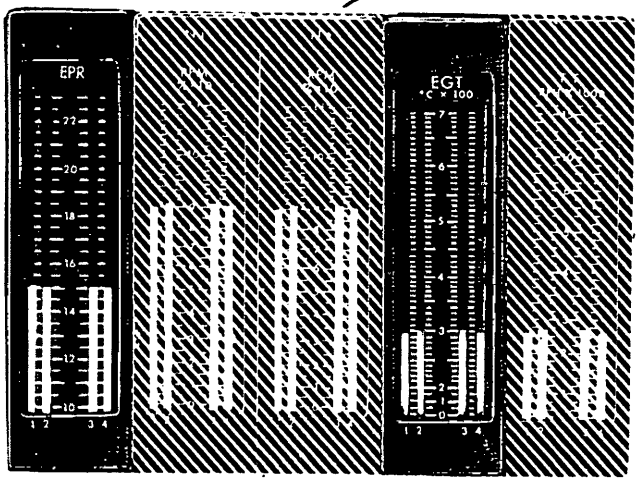
The Jet Engine produces thrust propotional to heat and pressure, therefore it is important for you to understand two terms that you will be using while flying the C-141A. EGT (EXHAUST GAS TEMPERATURE) and EPR (ENGINE PRESSURE RATIO).

PILOTS' CENTER INSTRUMENT PANEL



FLIGHT ENGINEER'S PANEL

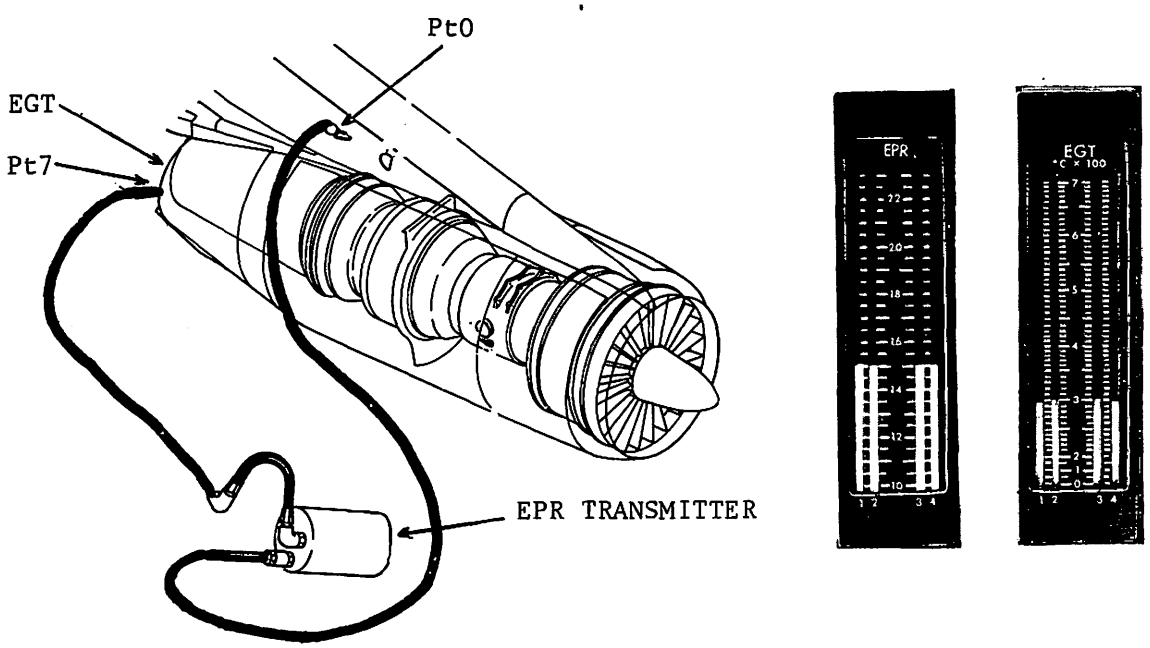




EGT indicators and EPR indicators are located on the Pilots' Center Instrument Panel and the Flight Engineer's Panel. Take a look at them in the above pictures. After looking them over, continue.

Let's look at EPR first.

Engine Pressure Ratio is used as a measurement of engine power and is a ratio between Pt_7 (EXHAUST TOTAL PRESSURE) to Pt_0 (INLET TOTAL PRESSURE). The symbol Pt_7 means TOTAL PRESSURE taken at station number "7" which is at the rear of the engine. Pt_0 means TOTAL PRESSURE taken at station number "0" which, on a C-141, is on the side of the engine pylon. Regardless of where the probe is located it MEASURES pressure as it would be at the air intake. Look at the picture below.



The SECOND term is EGT. Exhaust Gas Temperature is measured by probes mounted aft of the turbine wheels to sense the temperature of the heated air as it leaves the engine.

REMEMBER the EPR is a ratio between Pt_7 and Pt_0 and that EGT is measuring the temperature of the exhaust gases as they leave the engine.

Since EPR is an expression of engine power (thrust) it is important for you KNOW the four (4) THRUST SETTINGS and TIME LIMITATIONS.

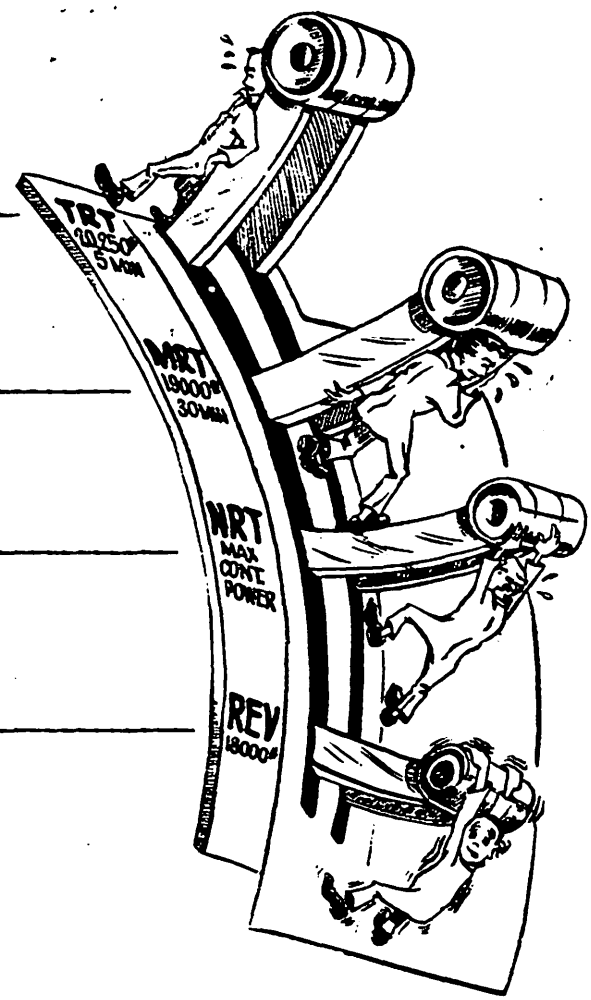
They are:

TRT (Takeoff Rated Thrust)

MRT (Military Rated Thrust)

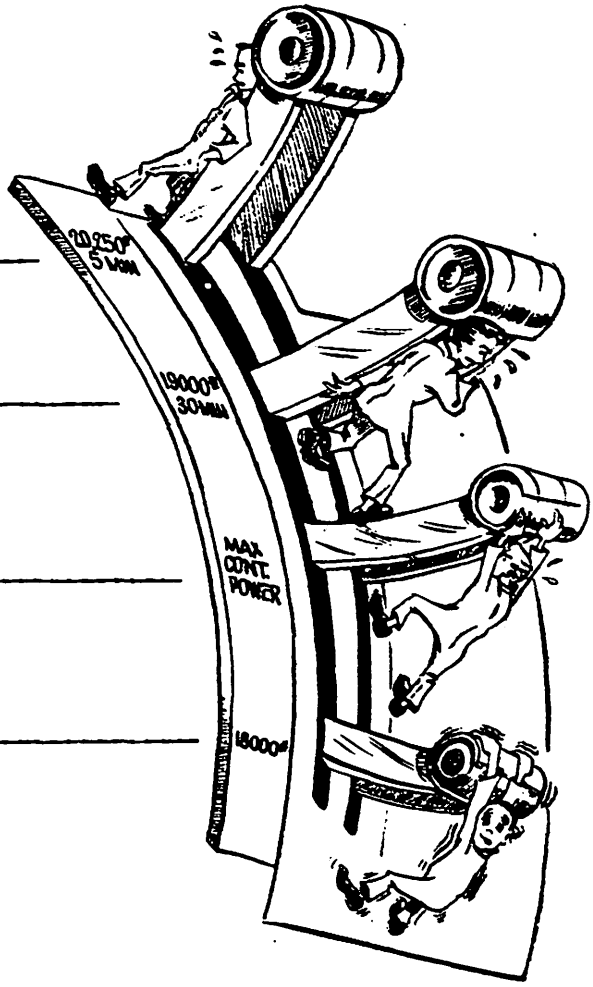
NRT (Normal Rated Thrust)

Full Reverse



Study the picture and learn the settings and the time limits.

In the picture below, write in the THRUST SETTINGS for the TF33-P-7 engine.



_____

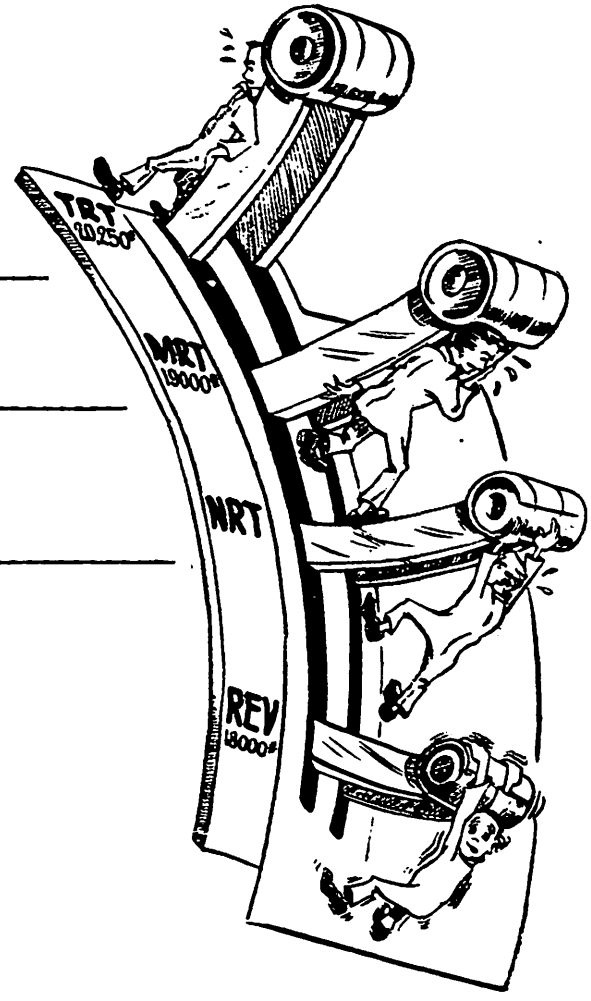
_____

_____

_____

Check your answers on page 10 and make necessary corrections before you proceed.

In the picture below, write in the TIME LIMITS for the thrust settings.

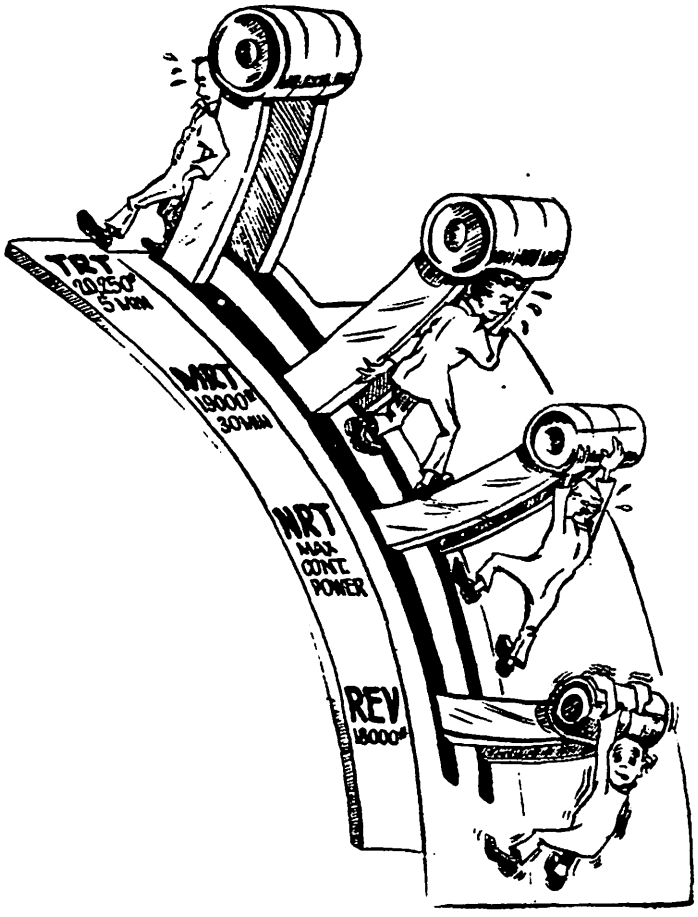


_____

_____

_____

Check your answers on page 10 and make necessary corrections.

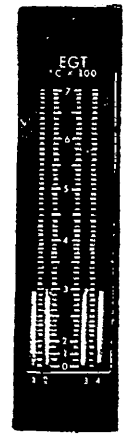


Now that we have the Thrust ratings down pat (we have, haven't we) let's give EGT (Exhaust Gas Temperature) a whirl. To increase thrust we have to add fuel to the engine. And that means HEAT. Obviously we have HEAT LIMITATIONS. Here are the MAXIMUM EGT for given CONDITIONS. KNOW THEM.

CONDITION	EGT
TRT	555° C
MRT	510° C
NRT	488° C
IDLE	488° C
STARTING	455° C
ENGINE ACCELERATION	555° C

In the spaces below write in the EGT for the given condition.

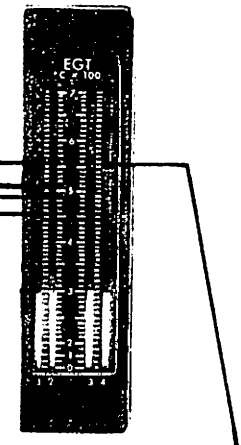
CONDITION	EGT
TRT	_____
MRT	_____
NRT	_____
IDLE	_____
STARTING	_____
ENGINE ACCELERATION	_____



CHECK your answers on Page 13, make any corrections that are necessary.

In the spaces below write in the condition for the given EGT.

CONDITION	EGT
_____	555° C
_____	510° C
_____	488° C
_____	488° C
_____	455° C
_____	555° C



CHECK your answers on Page 13, make any corrections that are necessary.

Before progressing to the engine assemblies, a short review is in order. In the questions below fill in the blank spaces and then check your answers on the next page.

1. Since the jet engine receives its thrust from internal pressures, it is operating on the principle of Newton's Third Law, which says that for every _____ there is an equal and opposite _____.

2. EPR is used as a measure of engine thrust. The reading is obtained by a ratio between _____ and _____.

3. In the spaces below list the time limits.

   a. TRT 20,250 lbs limited to _____ minutes.

   b. MRT 19,000 lbs limited to _____ minutes.

   c. NRT _____.

4. Heat is required to produce thrust. Since there is a heat factor involved in a jet engine, it is necessary for you to know the EGT limits. In the spaces below, list the EGT for the following conditions:

   a. TRT _____

   b. MRT _____

   c. NRT _____

   d. IDLE _____

   e. START _____

   f. ENGINE ACCELERATION _____

CHECK your answers on Page 17, correct if necessary.

1. Action Reaction

2. Pt7 PtO

3. a. 5 minutes

   b. 30 minutes

   c. Maximum Continuous Power

4. a. 555° C

   b. 510° C

   c. 488° C

   d. 488° C

   e. 455° C

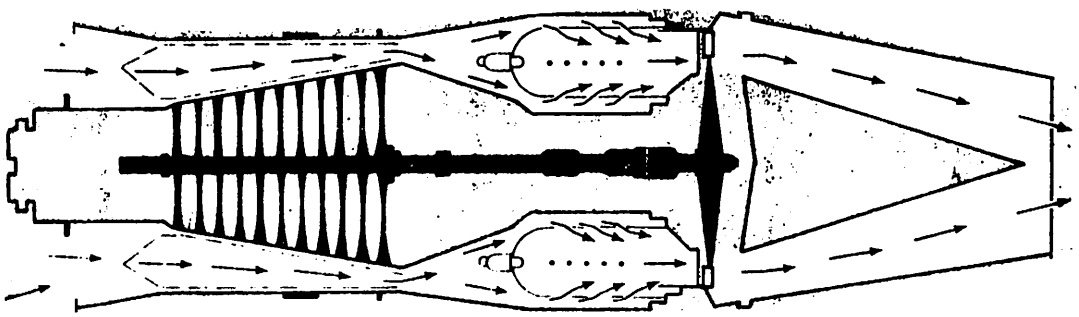
   f. 555° C

Correct any errors.

The C-141 is equipped with four AXIAL FLOW Pratt & Whitney TF33-P-7 FLAT-RATED, FORWARD FAN type engines. AXIAL FLOW means that air flows along the longitudinal axis of the engine. In other words straight through.

The primary purpose of the FLAT-RATED engine is to provide constant thrust over a wide ambient temperature range. Below 15° C the installed engine operating at sea level develops 20,250 pounds of static thrust.

In the picture below, look at the airflow path through the engine. This is AXIAL FLOW.



The TF33-P-7 is:

A. a centrifugal flow engine, flat-rated at 20,250 pounds of thrust.

B. an axial flow engine, variable rated up to 21,000 pounds of thrust.

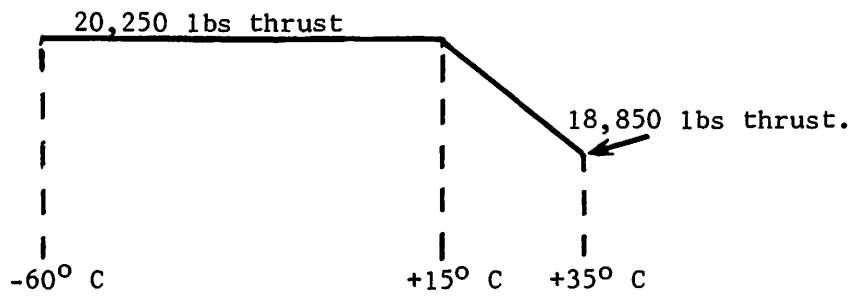
C. an axial flow engine, flat-rated at 20,250 pounds of thrust.

ANSWER = C

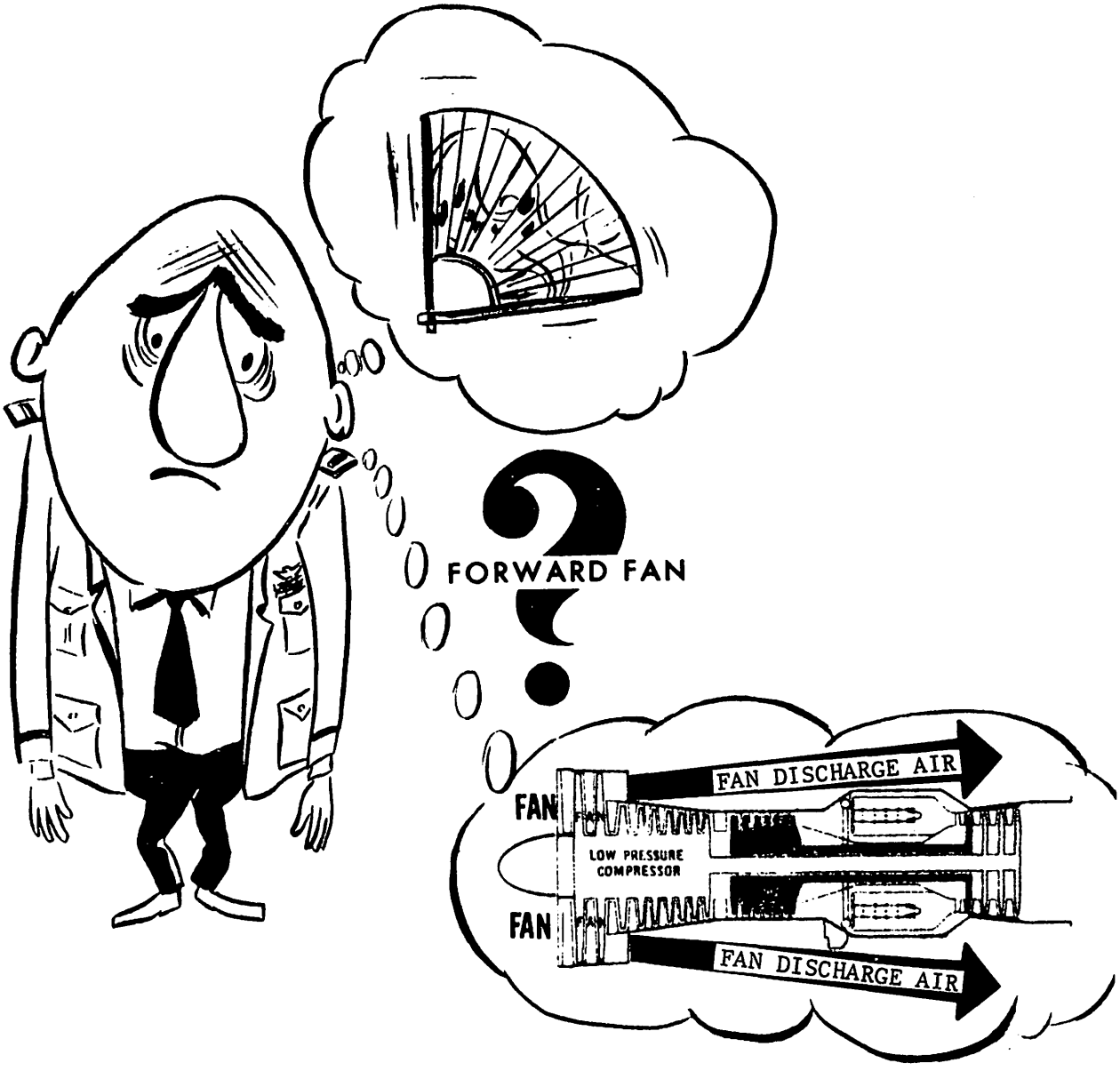
The TF33-P-7 engine IS an AXIAL FLOW type engine and at sea level under static conditions with the temperature below +15° C is FLAT-RATED at 20,250 pounds of thrust.

As the temperature increases above +15° C, the thrust of the engine will decrease. Look at the schematic below.

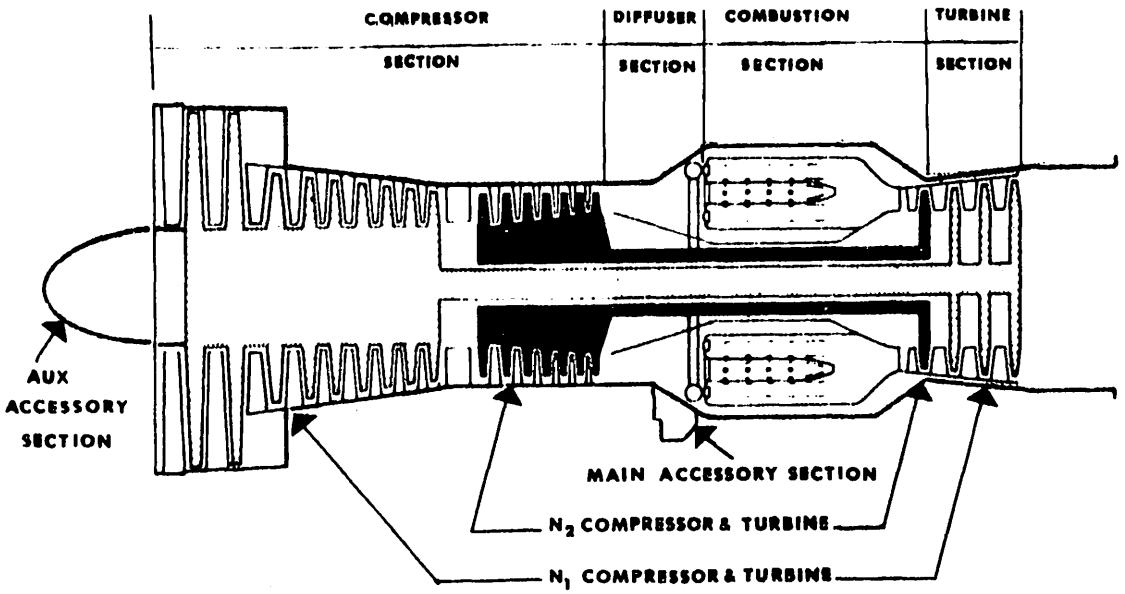
Conditions: Sea Level, static.



The TF33-P-7 engine is a FORWARD FAN type, meaning the FORWARD portion of the low pressure compressor is of a LARGER diameter than the remaining stages of the low pressure compressor. The FORWARD FAN makes up the first two stages of compression. When the engine is operating at Takeoff Rated Thrust the FORWARD FAN produces 49% of the total engine power.



To understand how the jet engine operates, let's divide it into five (5) basic sections; the COMPRESSOR SECTION, DIFFUSER SECTION, COMBUSTION SECTION, TURBINE SECTION and ACCESSORY SECTIONS.



Take a close look at them and notice how the assemblies are arranged. Pay particular attention to each Compressor and Turbine Assembly.

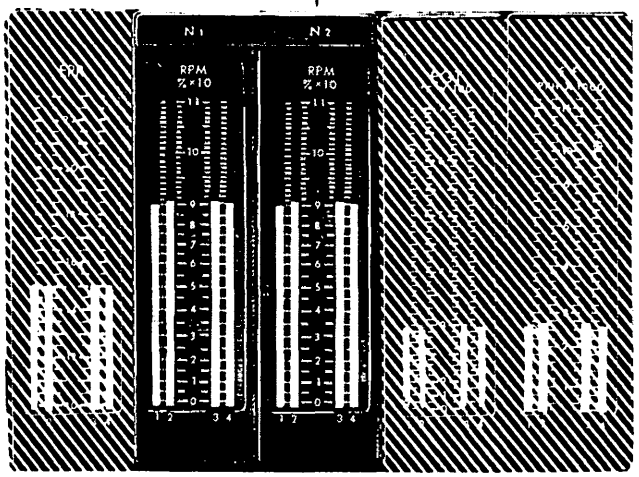
The TF33-P-7 engine has DUAL AXIAL FLOW COMPRESSORS which make up a total of sixteen (16) stages of compression. They are known as N_1 and N_2. "N" is an engineering symbol meaning RPM.

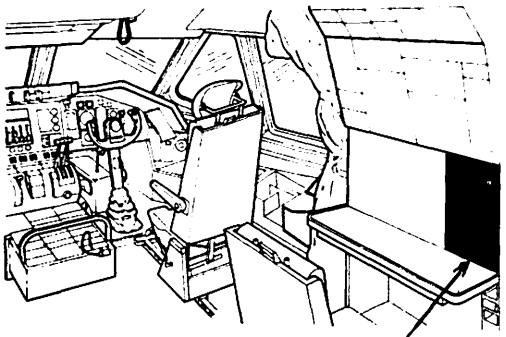
After studying the diagram, does it appear that the N_1 compressor and turbine assembly rotate independently from the N_2 compressor and turbine assembly?

A. Yes.

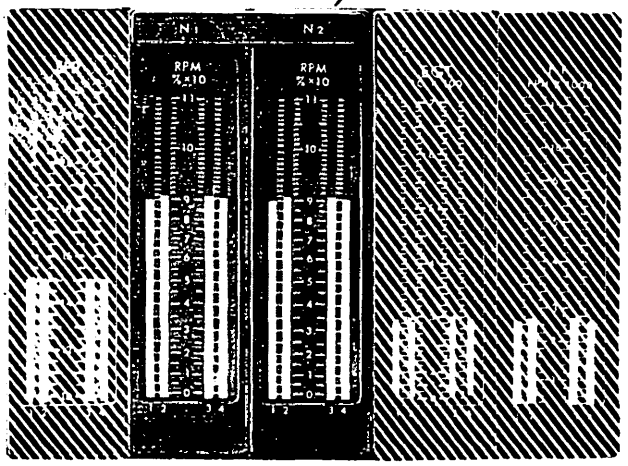
B. No.

PILOTS' CENTER INSTRUMENT PANEL





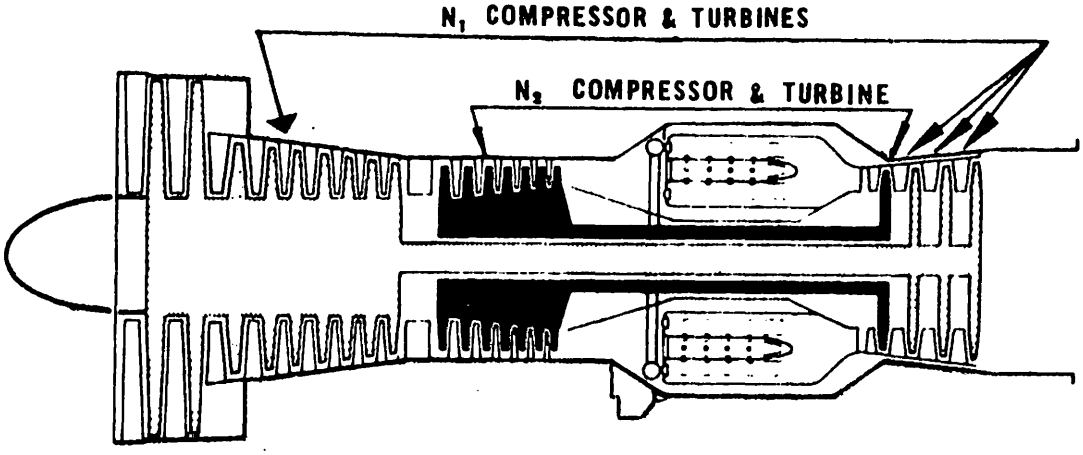
FLIGHT ENGINEER'S PANEL



9

ANSWER = A

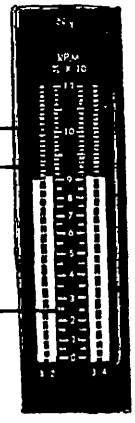
The N_1 and N_2 do rotate independently from each other.



The N_1 compressor is made up of NINE (9) stages of compression. The forward fan is the first two stages. The N_1 is a LOW SPEED, LOW PRESSURE COMPRESSOR.

MAXIMUM LIMIT (N_1) IS 101.1% RPM.

NORMAL OPERATING RANGE (N_1) IS 25 TO 93% RPM.

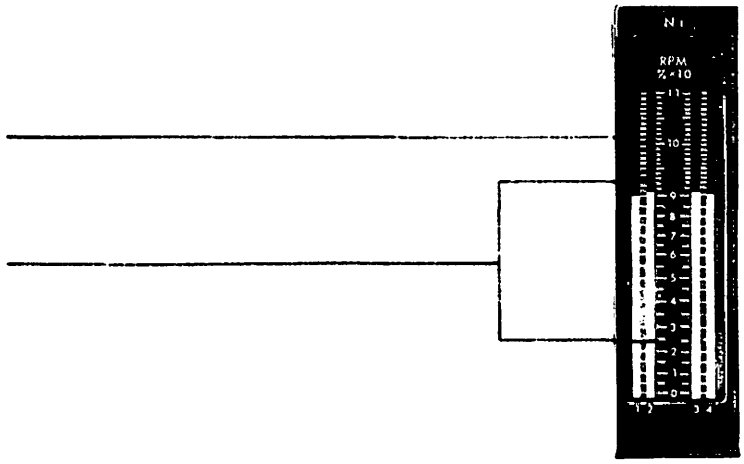


Maximum limit 101.1%?? RPM is indicated in percentage of an engineering reference RPM set by the manufacturer. (The N_1 reference RPM for the TF33-P-7 engine is 6800 RPM.)

The RPM Indicators are located on the Pilots' Center Instrument Panel and the Flight Engineer's Panel as shown on page 22.

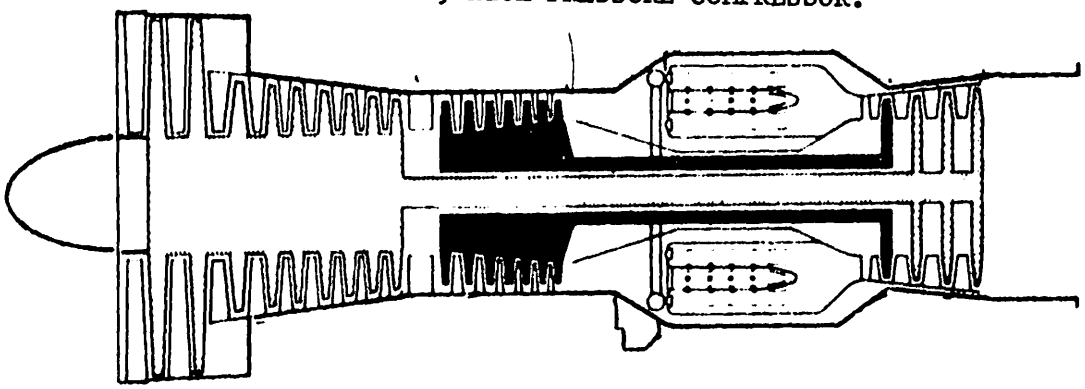
Get the NORMAL OPERATING RANGE and MAXIMUM LIMIT for the N_1 compressor firmly in your mind.

Below is a picture of the N_1 RPM INDICATOR. On the spaces provided write in the NORMAL OPERATING RANGE and the MAXIMUM % RPM.



CHECK your answers on Page 23, make any correction necessary.

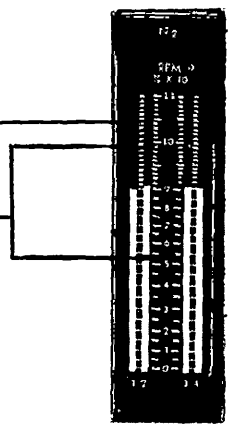
Now let's take a look at the N_2 COMPRESSOR. It has SEVEN (7) stages of compression. It is a HIGH SPEED, HIGH PRESSURE COMPRESSOR.



MAXIMUM LIMIT (N_2) IS 104.5% RPM.

NORMAL OPERATING RANGE (N_2) IS 54 TO 99% RPM.

NORMAL IDLE RANGE IS 54 TO 58% RPM.



(The engineering reference RPM for the N_2 compressor is 9655 RPM.)

Get the N_2 NORMAL OPERATING RANGE and MAXIMUM LIMIT in mind.

Now it is time for a review. In the questions below, fill in the blank spaces and check your answers by TURNING to Page 27.

1. Newton's Third Law states that for every _____ there is an equal and opposite _____.

2. EPR is measured between _____ and _____.

3. In the spaces below, list the time limits.

   a. TRT 20,250 lbs limited to _____ minutes.

   b. MRT 19,000 lbs limited to _____ minutes.

   c. NRT _____

4. List the EGT limits for the given conditions.

   a. TRT _____

   b. MRT _____

   c. NRT _____

   d. IDLE _____

   e. START _____

   f. ENGINE ACCELERATION _____

5. The NORMAL OPERATING RANGE for the N_1 compressor is _____ to _____ % RPM and the MAXIMUM RPM is _____% RPM.

6. The NORMAL OPERATING RANGE for N_2 compressor is _____ to _____ % RPM and the MAXIMUM is _____ % RPM.

7. N_1 is a _____ speed, _____ pressure compressor.

   N_2 is a _____ speed, _____ pressure compressor.

CHECK your answers on Page 27 and correct any errors.

1. action reaction

2. Pt7 PtO

3. a. 5 minutes

   b. 30 minutes

   c. Maximum Continuous Power

4. a. 555°C

   b. 510°C

   c. 488°C

   d. 488°C

   e. 455°C

   f. 555°C

5. 25% 93%

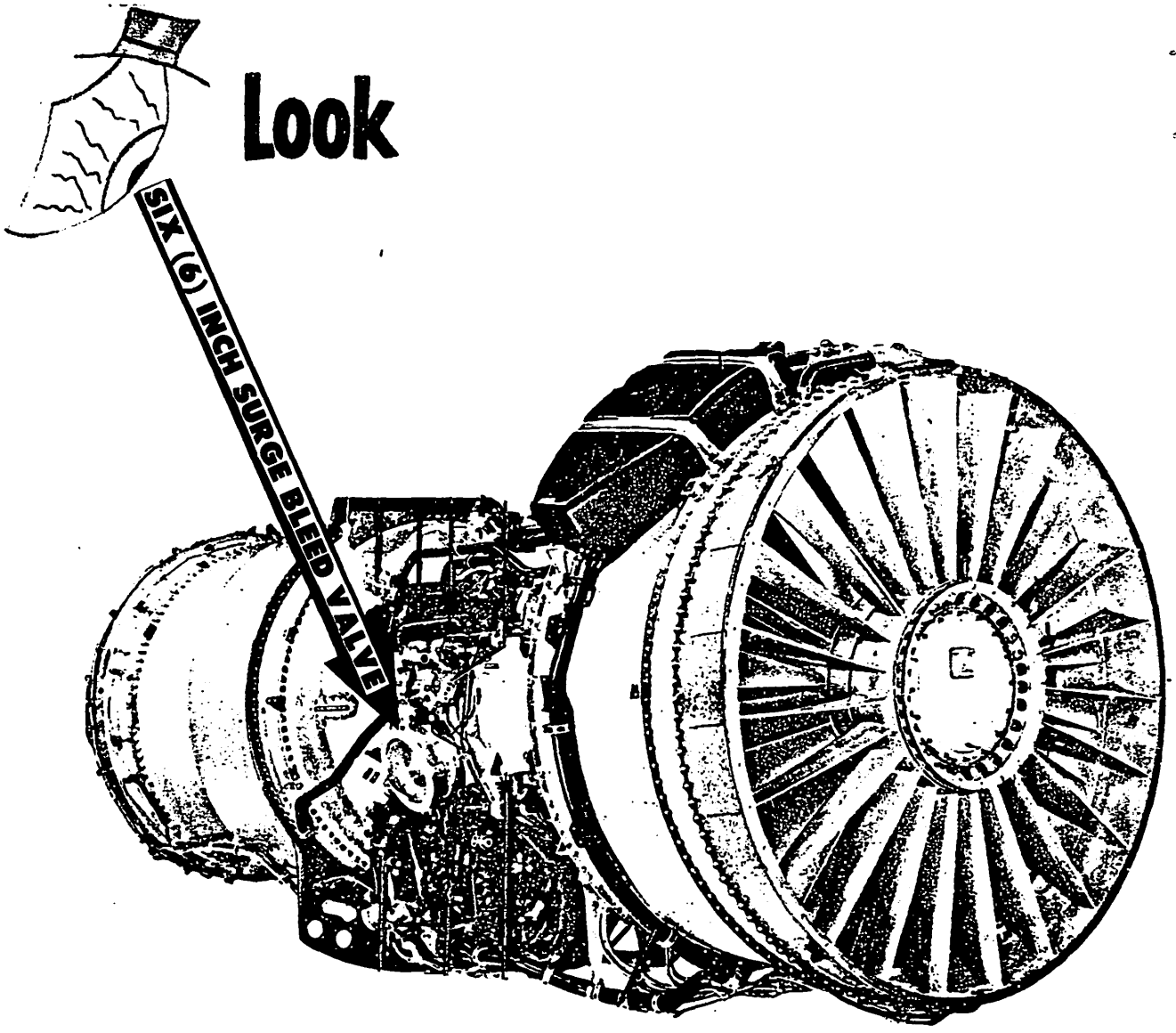
   101.1%

6. 54% 99%

   104.5%

7. low low

   high high


Look
SIX (6) INCH SURGE BLEED VALVE

In the compressor section there is a COMPRESSOR SURGE BLEED System. The purpose of the system is to prevent compressor stalls. Two COMPRESSOR SURGE BLEED Valves installed on the compressor case will bleed out 12th stage air to prevent the compressor from stalling.

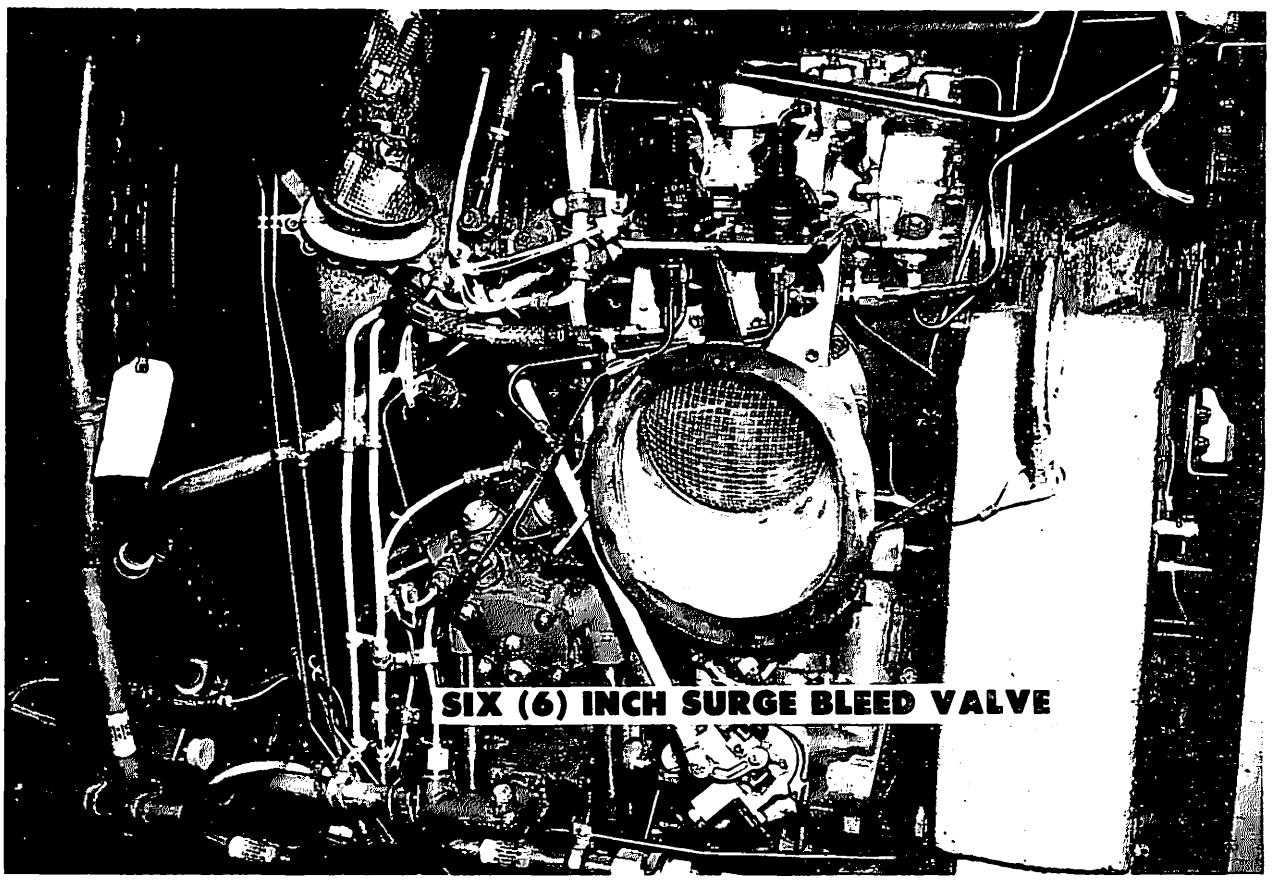
There is a 6-inch valve mounted on the right-hand side of the compressor case and a 4 3/4-inch valve mounted on the left-hand side of the case. These valves are controlled by a differential pressure sensed across N_1 compressor. They will prevent compressor stalls during LOW RPM, ACCELERATION and DECELERATION.

The 4 3/4-inch valve remains closed during all operating conditions except during RAPID DECELERATION, when it opens to assist the 6-inch valve.

The 6-inch valve is open when the engine is NOT operating and remains open until N_2 compressor RPM reaches approximately 80% RPM and then it closes.

Above 80% RPM, the 6-inch valve opens only during a RAPID DECELERATION. When power is reduced normally below 80% of N_2 the 6-inch valve opens.

Both valves port 12th stage air into the fan ducts.



The purpose of the Compressor Surge Bleed System is to prevent compressor stalls or "surges". Two valves have been installed to do this job. When the valves are open they bleed off 12th stage air pressure. The valves are powered by 16th stage air pressure.

During what engine operations does the Compressor Surge Bleed System function?

A. A rapid deceleration only.

B. Low RPM, acceleration and rapid deceleration.

C. Near normal operating RPM and rapid deceleration.

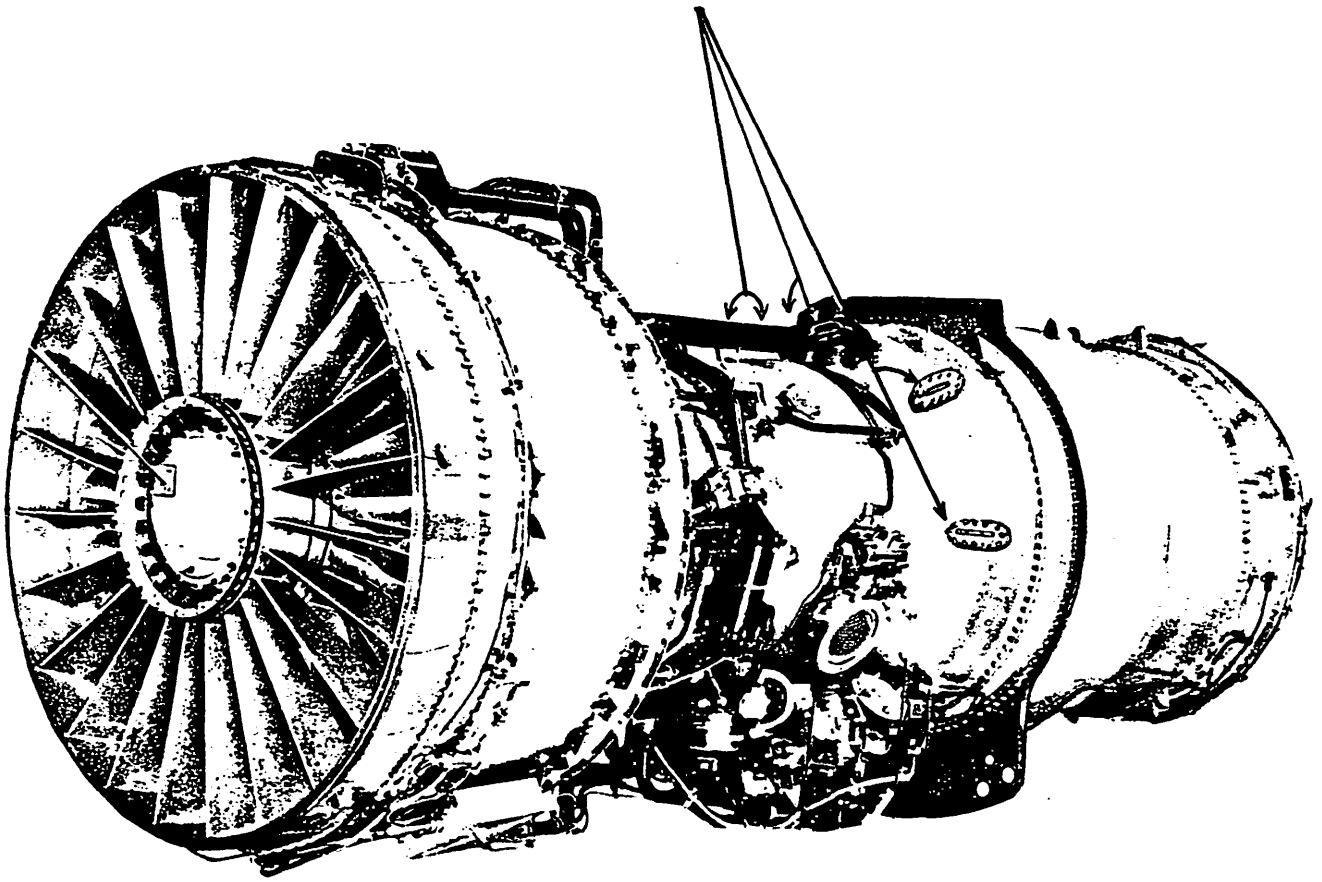
ANSWER = B

12th stage air is bled from the engine during LOW RPM, ACCELERATION, and a RAPID DECELERATION; this will prevent N_2 compressor from stalling out.

Six (6) High Pressure Bleed Ports

on the

DIFFUSER SECTION



Next let's briefly discuss the DIFFUSER SECTION.

The DIFFUSER SECTION, which is secured to the rear flange of the compressor rear case, diffuses the airflow discharged from N2 compressor and adapts the air for entry into the combustion chambers. The DIFFUSER SECTION provides a mount for the Main Accessory Drive and drive shaft at the six o'clock position.

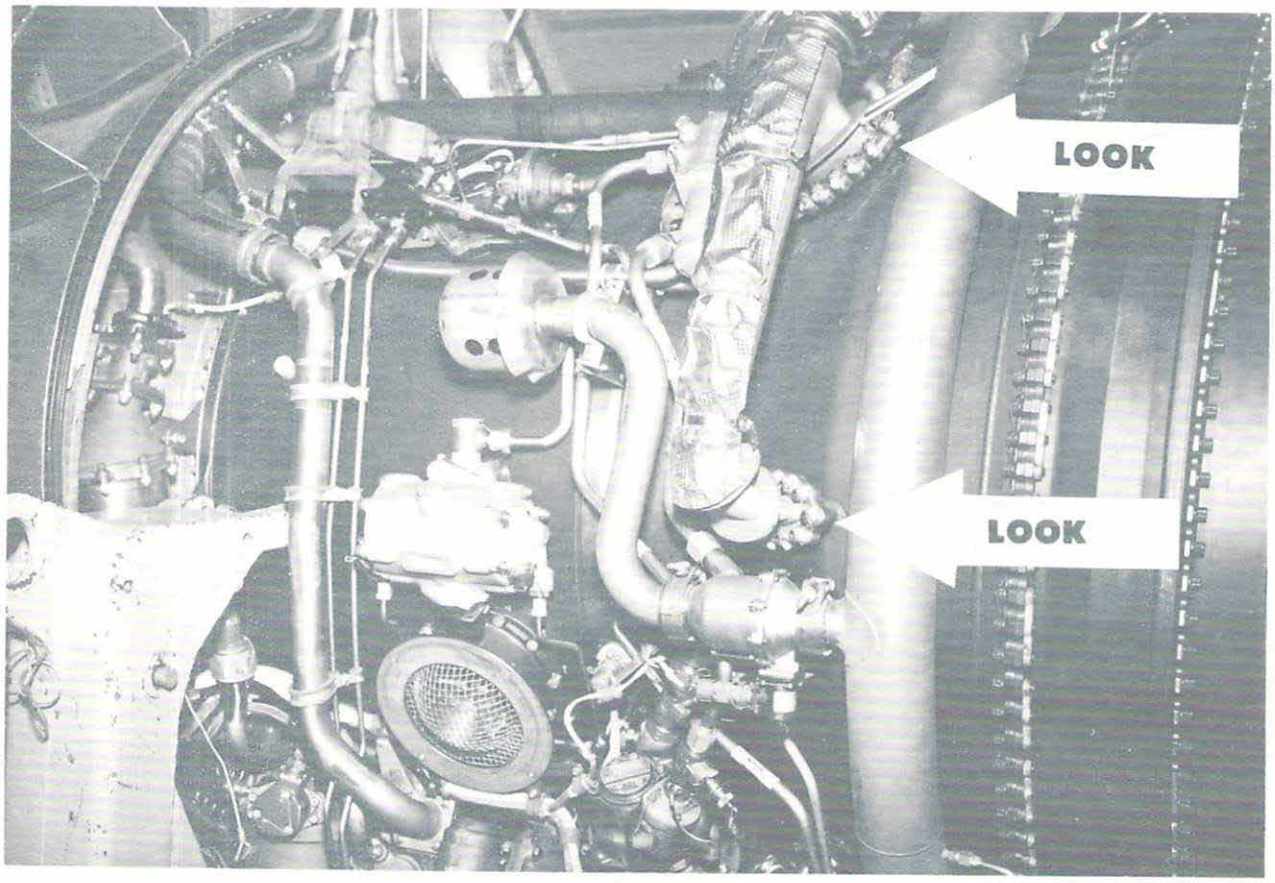
Near the rear of the DIFFUSER SECTION, internally, a split-type fuel manifold and fuel nozzles are installed. Also at this point on the engine (the DIFFUSER SECTION) is the place where air is extracted for pressurization, anti-icing and other jobs.

Pressurization and anti-icing air is extracted from the:

A. Compressor Section.
B. Fan Section.
C. Diffuser Section.

ANSWER = C

The DIFFUSER SECTION is the place where air is extracted. There are a total of six (6) ports for tapping off bleed air. Four (4) of these are struts that extend into the engine to pick up the air and two (2) are on the outer part of the diffuser. All the ports are venturi type to allow only a certain amount of air to be taken out.

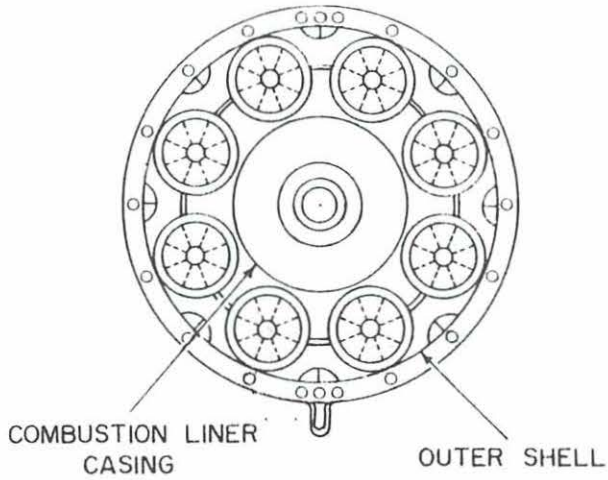


LEFT VIEW

The next area of discussion is the COMBUSTION SECTION. The COMBUSTION SECTION contains the combustion chambers, spark igniters and fuel nozzles. It is designed to burn a mixture of fuel and air, and to deliver the resulting gases to the turbine at a temperature which will not exceed the allowable limit at the turbine inlet.

On the TF33-P-7 engine the type of the COMBUSTION SECTION is called can-annular. It consists of a one piece outer steel shell, a combustion inner casing assembly and eight (8) combustion chambers, mounted so that the airflow completely surrounds them. The air flows into the chambers through various arrangements of holes and out into the turbines. This type of design provides for a high rate of heat release with a short flame length.

The combustion chambers are numbered one (1) through eight (8) clockwise. Numbers 4 and 5 have spark igniters installed.



CANANNULAR COMBUSTION CHAMBER

The next section of the engine is the TURBINE SECTION. The TURBINE SECTION extracts kinetic energy from the expanding gases which flow from the combustion chamber, converting it into shaft horsepower to drive the compressors.

The axial-flow turbine is comprised of two (2) main elements, a set of stationary vanes, usually referred to as a Turbine Nozzle and a set of Turbine Rotors.

Installed in the TF33-P-7 engine is the Multiple-Rotor type turbine. In this type of turbine, the power is developed by two (2) sets of rotors (turbine wheel). The first set has a single turbine wheel which is the driving force for N_2 compressor. The second set has three (3) turbine wheels which is the driving force for N_1 compressor.

Is the following statement TRUE?

Installed in the TF33-P-7 engine is a Multiple-Rotor type turbine. The first turbine wheel is the driving force for the N_1 compressor and the remaining turbine wheels are the driving force for N_2 compressor.

A. Yes.

B. No.

ANSWER = A

Number 1 turbine wheel drives N_2 compressor and the remaining wheels (No. 2, 3 and 4) drive N_1 compressor.

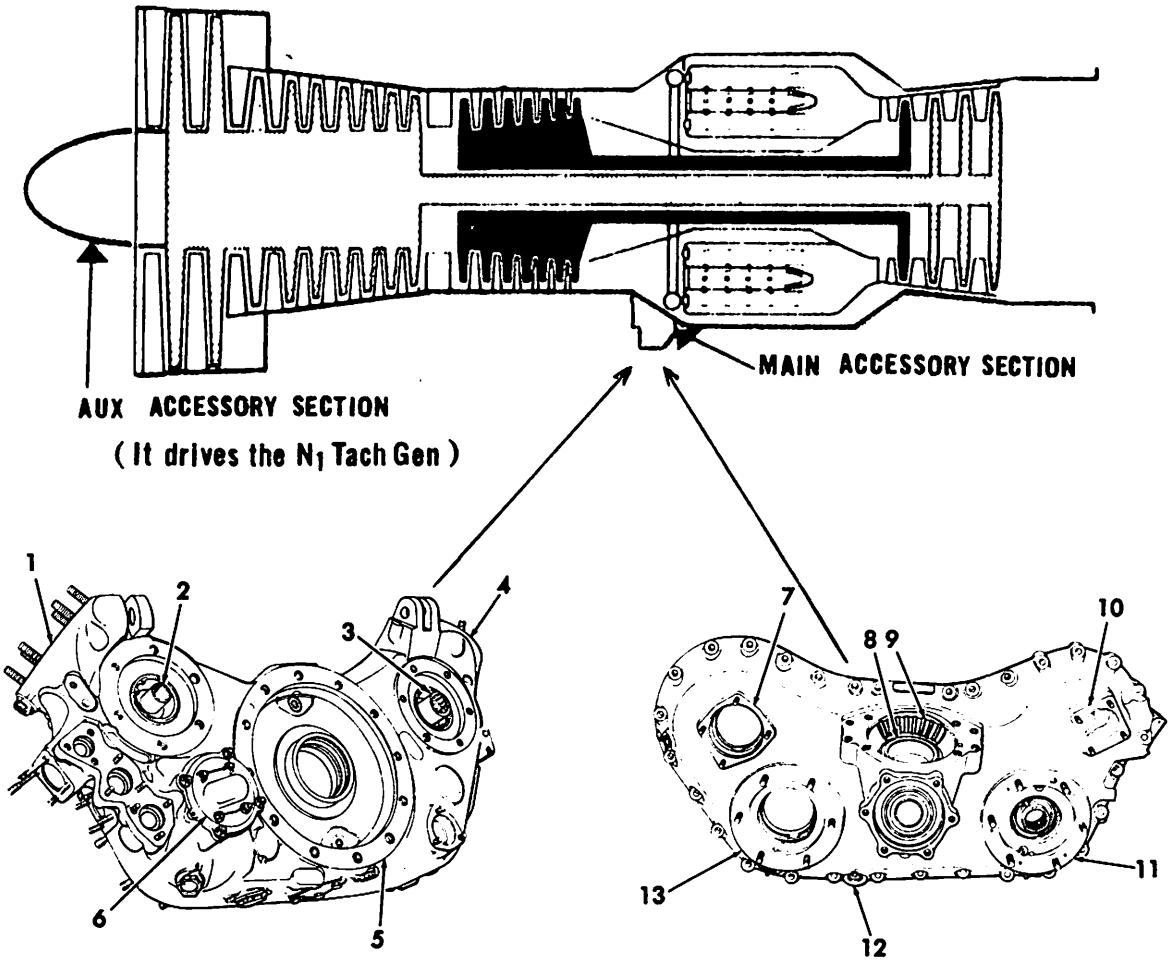
The last of the engine assemblies to be discussed are the ACCESSORY SECTIONS. There are TWO (2) Accessory Sections.

The most important is the MAIN ACCESSORY SECTION which is mounted on the bottom of the Diffuser Case. All engine driven accessories except the N_1 Tachometer Generator are mounted on the Main Accessory Section and are driven by the N_2 compressor.

The second accessory drive section is called the AUXILIARY ACCESSORY SECTION. The only item mounted externally at this point is the N_1 Tachometer Generator.

The Main Accessory Drive Section is mounted on the bottom of the Diffuser Case.

Look at the picture below for a general idea of what is on the ACCESSORY SECTIONS.

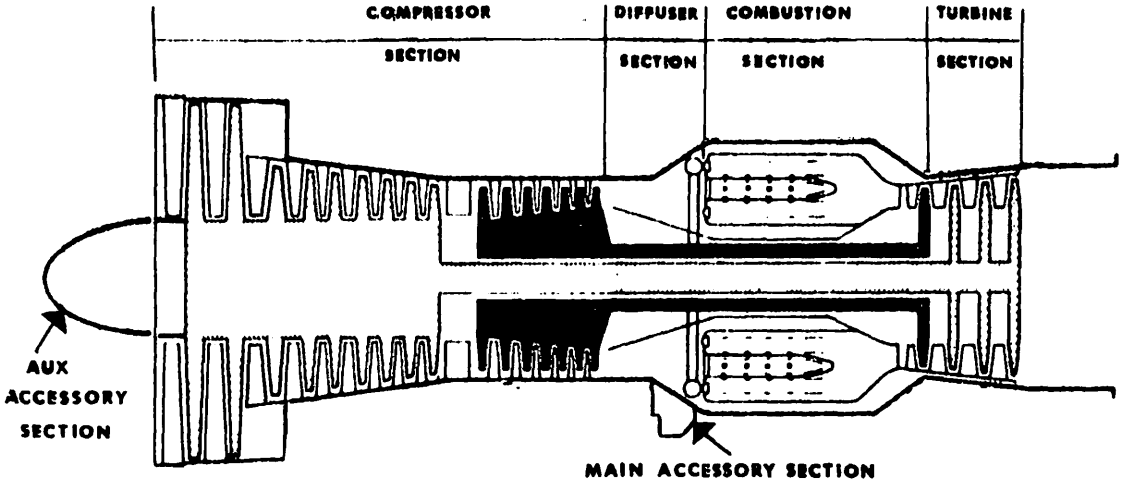


FRONT VIEW

REAR VIEW

1. OIL FILTER
2. FUEL CONTROL DRIVE
3. FUEL PUMP DRIVE
4. THRUST REVERSE PUMP
5. ALTERNATOR DRIVE ADAPTER PAD
6. OIL PUMP ASSEMBLY
7. BREATHER PRESSURIZING VALVE PAD
8. BEARING LINER
9. ACCESSORY DRIVE BEVEL GEARSHAFT
10. TACHOMETER DRIVE PAD
11. HYDRAULIC PUMP DRIVE PAD
12. OIL DRAIN PLUG BOSS
13. STARTER DRIVE PAD

Up to this point we have discussed the five (5) basic assemblies of the TF33-P-7 engine. They were the COMPRESSOR Section, DIFFUSER Section, COMBUSTION Section, TURBINE Section, ACCESSORY Sections. In the picture below the sections are identified, study them.

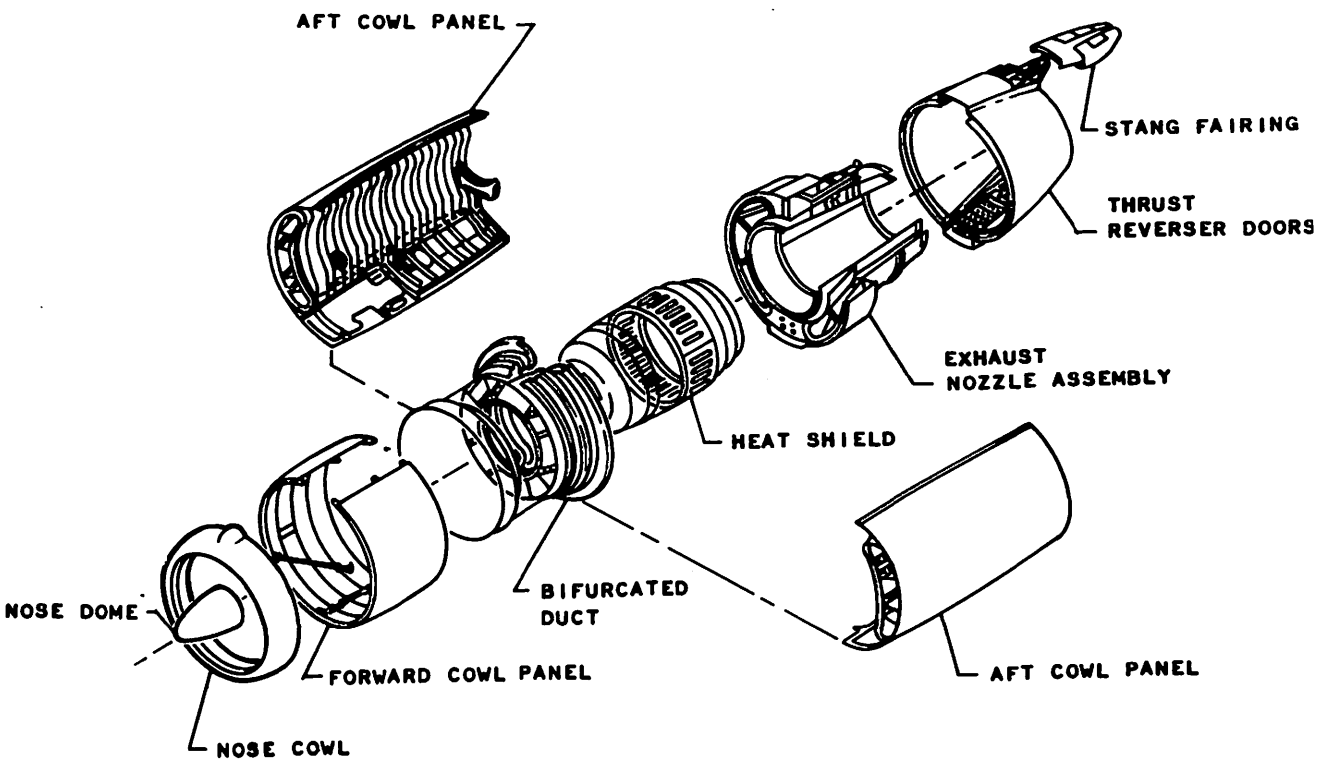


Up to this point we have discussed the COMPRESSOR Section, DIFFUSER Section, COMBUSTION Section, TURBINE Section, and the ACCESSORY Sections. It would be most convenient at this point to have something to wrap around the engine to make it a neat package.

Each engine is contained in an individual power plant NACELLE which provides aerodynamic contour for the engine and the various components related to the engine operation.

The complete power plant consists of the engine and installed accessories, the engine NOSE DOME, NOSE COWLING, FORWARD COWLING, BIFURCATED DUCT, ACCESS DOORS, COWLING SUPPORT STRUCTURE, AFT COWL and DUCT ASSEMBLY, EXHAUST NOZZLE ASSEMBLY and THRUST REVERSER DOORS.

In the picture below are all the items that make up the NACELLE.



It's time for a short review. Fill in the blanks and then check your answers on page 43. (Don't peek until you have answered all the questions - Ivan is watching!)

1. A statement of Newton's Third Law would be, that for every _____ there is an equal and opposite _____.

2. To get an EPR reading it would be necessary to obtain a ratio between _____ and _____.

3. List the EGT limits for the conditions given:

   a. TRT _____

   b. MRT _____

   c. NRT _____

   d. IDLE _____

   e. START _____

   f. ENGINE ACCELERATION _____

4. The TF33-P-7 engine has a:

   a. TAKEOFF RATED THRUST (TRT) of 20,250 lbs and is limited to _____ minutes.

   b. MILITARY RATED THRUST (MRT) of 19,000 lbs and is limited to _____ minutes.

   c. NORMAL RATED THRUST (NRT) _____.

5. The primary purpose of the FLAT-RATED engine is to provide _____ _____ over a wide temperature range.

6. DUAL AXIAL FLOW compressors means there are _____ compressors and the air flows _____ through the compressors.

7. The Normal Operating Range for N_1 compressor is _____ to _____ % RPM.

   The Maximum RPM for N_1 is _____ % RPM.

8. The Normal Operating Range for N_2 compressor is _____ to _____ % RPM.

   The Maximum RPM for N_2 is _____ % RPM.

9. N_1 is a _____ speed, _____ pressure compressor.

10. N_2 is a _____ speed, _____ pressure compressor.

11. The purpose of the Compressor Surge Bleed system is to prevent compressor stalls or "surge" during _____, _____, _____.

12. To do various jobs at the engine and in the aircraft, high pressure air is extracted from the _____ section.

13. The TF33-P-7 engine has a can-annular type _____ section.

14. The TURBINE SECTION has a total of 4 turbine wheels.

    No. one (1) turbine wheel drives the _____ compressor and No. 2, 3 and 4 turbine wheels drive the _____ compressor.

15. All engine driven accessories, except N_1 Tachometer Generator are driven by the _____ Accessory Drive Section.

16. Name the five (5) major sections of the TF33-P-7 engine.

    a. _____

    b. _____

    c. _____

    d. _____

    e. _____

17. On a forward fan type engine the first two stages of the low pressure compressor are of a _____ diameter than the remaining stages.

1. Action Reaction
2. Pt7 Pt0
3. a. 555° C
   b. 510° C
   c. 488° C
   d. 488° C
   e. 455° C
   f. 555° C
4. a. 5 minutes
   b. 30 minutes
   c. Maximum Continuous Power
5. Constant Thrust
6. Two Straight
7. 25 - 93 101.1
8. 54 - 99 104.5
9. Low Low
10. High High
11. Low RPM Acceleration Rapid Deceleration
12. Diffuser
13. Combustion
14. N_2 N_1
15. Main
16. a. Compressor
    b. Diffuser
    c. Combustion
    d. Turbine
    e. Accessory
17. larger

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