RCAF IROQUOIS ENGINE ADVANCE DATA SHEETS DESCRIPTION/MAINTENANCE INSTRUCTION 12.126-59/09

PRELIMINARY TO EO IOB-30A-2

ROYAL CANADIAN AIR FORCE



IROQUOIS

ADVANCE DATA SHEETS DESCRIPTION AND MAINTENANCE INSTRUCTIONS



SUPERSEDE THE SAME PAGES OF PREVIOUS DATE

Insert revised pages into basic publication. Destroy superseded pages.

ISSUED ON AUTHORITY OF THE CHIEF OF THE AIR STAFF

JAN 58

Revised 9 Jan 59

LIST OF RCAF REVISIONS

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22 Aug 58	Table of Contents	1 through 4
22 Aug 58	Low Pressure Thrust Bearing Assembly	1 through 3
		4 added
22 Aug 58	Front Frame Assembly	l through 4
		5 added
22 Aug 58	Internal Gearbox and Oil Tank Assembly	1 through 3
22 Aug 58	Sectioned View of Engine (Figure 3-1-26)	1
22 Aug 58	Fuel System	13
22 Aug 58	Anti-icing System	3A added
22 Aug 58	Fire Detector and Extinguisher Systems	1 and 2
	,	3 added
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PREFACE

The following is a statement of RCAF policy covering the maintenance of the Iroquois powerplant (Arrow). It is published for the guidance of those concerned with the design and logistic support of the powerplant and its associated ground equipment, and in particular for those preparing Iroquois Engineering Orders.

Definition

Powerplant - An engine completely equipped for installation in the appropriate airframe. (Iroquois powerplant (Arrow)).

Weapon System - The weapon (Sparrow), the vehicle (Arrow/Iroquois), and the guidance system (Astra and Sage).

Aircraft - The vehicle, the weapon and Astra.

Scope

This concept is based on approximately twenty operational aircraft located at a prepared all-weather base. The base will be required to maintain four operational aircraft at standby at all times. Fifty percent of the powerplants will normally be undergoing major maintenance although this figure is expected to decrease with experience.

Maintenance

The Iroquois as part of the weapon system requires a new concept of engine

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maintenance and operation, in which all maintenance other than minor servicing and primary inspections will be done with the engine removed from the aircraft.

There will be three main areas of maintenance on each base, namely, readiness, servicing, and repair shop maintenance.

Readiness Area - In the readiness area, very little maintenance will be done to the engine other than replenishment of the lubricating oil system and the hydraulic oil system.

Servicing Area - Maintenance in the servicing area will cover such tasks as primary inspections, unscheduled powerplant changes and minor repairs. No work will be carried out in this area which will take more than three hours to complete. In addition to the above, the servicing organization must be capable of turning round not less than four fully serviceable aircraft in fifteen minutes.

Repair Area - Maintenance in the repair area will cover all scheduled maintenance other than primary inspections and all unscheduled maintenance which cannot be accomplished by the servicing organization.

The base shops will be organized according to the various systems in the aircraft. They will consist of tools, bench equipment, and the technicians necessary to inspect, repair and modify, and test the appropriate system and its components, including the test equipment itself. The scope of work done in the shops will be the maximum commensurate with the capability of shop personnel and shop equipment. As a part of this organization, there will be a powerplant shop responsible for the build-up, repair, inspection, modification, running, testing, inhibiting and storage of powerplants.

Overhaul

In the interests of production improvement, the Iroquois powerplant is to be overhauled by the manufacturer during the first eighteen months of RCAF operational service. Proprietary items may be sub-contracted on specific RCAF/AMCHQ authority.

Ground Support Equipment

Engine Test Facility - The principal piece of GSE will be the facility required for engine testing following build-up, during periodic inspections, and for detailed trouble shooting. To achieve maximum serviceability of the weapon system it is vital that the powerplant, as a component, is fully serviceable at installation.

This facility will be sufficiently instrumented to permit detailed trouble shoot-

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ing and thereby eliminate unwarranted powerplant rejections. In addition, it will be equipped with a noise suppression unit to reduce the excessively high noise levels experienced during engine running at maximum rpm.

Other GSE equipment required for engine maintenance will include:

- (a) Special rigs for pressure filling of the lubrication and hydraulic systems.
- (b) Plug gauges for basic settings and adjustment of the variable nozzle.
- (c) Rig for pressure testing of the afterburner hydraulic system.
- (d) Powerplant stands (work/transport/installation).
- (e) The electrical system will require various pieces of test equipment which will enable checking and trouble shooting of thermocouple circuitry, electronic amplifier, and ignition equipment.
- (f) Small turbojet engines (as compressors) for powerplant starting.
- (g) A mobile engine silencer to enable installed engine running for the purpose of checking flight snags. This would reduce unwarranted engine removals from the airframe.

All this equipment must be maintained in a serviceable condition.

Supply

Normal RCAF supply policy will apply except that 'pipelines' must be much shorter than in the past for high value items. To this end air transport will be used for high value and AOG items.

Amendment

This statement will be amended by AMCHQ as required to conform with changes in AFHQ policy documents.

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INTRODUCTION

GENERAL

The Iroquois is a high performance, axial flow, two-spool turbojet engine with integral afterburner, and is specifically designed for operation under supersonic flight conditions. The engine derives its thrust from the reaction to the increase in momentum of the air mass passing through it. This increase in momentum is produced by burning fuel in the air mass to increase its temperature and volume, and by accelerating the exhaust gases to a high velocity by means of a final nozzle at the rear of the engine.

MECHANICAL ARRANGEMENT

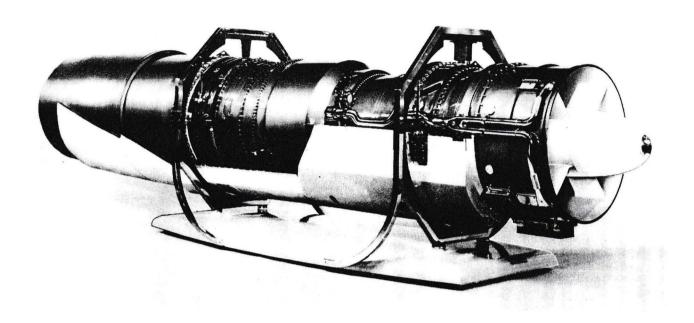
- The engine comprises essentially a two-spool compressor, an annular type combustion system, a turbine section, an afterburner-equipped exhaust system, and the necessary support frames and casings.
- An inlet frame assembly directs the air flow into the three-stage low pressure compressor, from which it is forced into the seven-stage high pressure compressor. Each compressor is individually coupled to its respective turbine by direct shafting, the HP compressor being driven by a two-stage turbine and the LP compressor by a single stage turbine.
- The LP and HP compressor rotor assemblies are mounted in two separate ball thrust bearings supported in the front frame assembly, interposed between the LP and HP compressors. Additional support is provided by a "steadying" roller bearing at the front of the HP rotor assembly. The turbine rotor assemblies are

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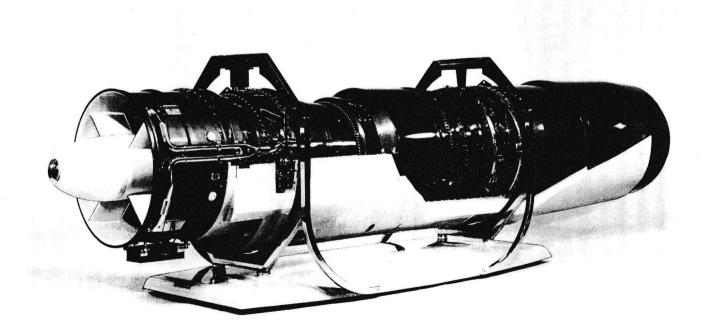


Figure 1-1 Three-quarter Front Views of the Iroquois

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mounted in two separate roller bearings housed in the rear frame assembly located at the rear of the turbine section. In addition to supporting the LP and HP rotors, the front frame and rear frame assemblies distribute the high thrust and tangential flight loadings from the engine casings to the airframe.

- The mid-frame assembly is located between the compressor and turbine sections and accommodates an annular combustion chamber in which the main fuel supply is injected and burned by means of 32 walking stick vaporizer type burners.
- 6 The afterburner assembly, being an integral part of the engine, is mounted aft of the rear frame assembly. It comprises a casing which houses flame stabilizing equipment and fuel spray rings. A variable area final nozzle is attached to the rear of the afterburner assembly.
- Internal gearing located in the hub of the front frame assembly, provides for power take-off points to operate the various accessories necessary to sustain engine operation and meet airframe service requirements. All accessories are mounted around the bottom of the engine forward of the mid-frame. These are enclosed in a sheet metal shroud. Lubrication of internal bearings and gearing, and cooling of the heat producing areas of the engine are provided by self-contained oil and air systems. Protection against the formation of ice at the engine intake under certain operating conditions is by means of a hot air anti-icing system.
- The engine has five mounting points. The front mount located on the top of the front frame transmits the net axial thrust load and side loads, while a side mount takes vertical loads only. Two mounts, one on each side of the rear frame, take vertical loads and a rear mount at the top of the rear frame takes only side loads.

OPERATION

- 9 The Iroquois operating cycle is continuous, whereby a steady supply of air is taken in, compressed, heated and expanded, then exhausted.
- By referring to the gas flow diagram, it will be seen that the air at ambient temperature and pressure is drawn through the inlet frame into the LP compressor where it is progressively compressed at each stage until heated to the temperature indicated on the diagram. The air flow then passes through the annulus provided by the front frame. Struts in the annulus straighten and direct the flow into the HP compressor where further compression takes place until at the compressor outlet, the airflow is heated as indicated. The compressors, being mechanically independent of each other, rotate at speeds up to a maximum of 6000 rpm for the LP rotor and 8150 rpm for the HP rotor. Careful aerodynamic matching of the compressors

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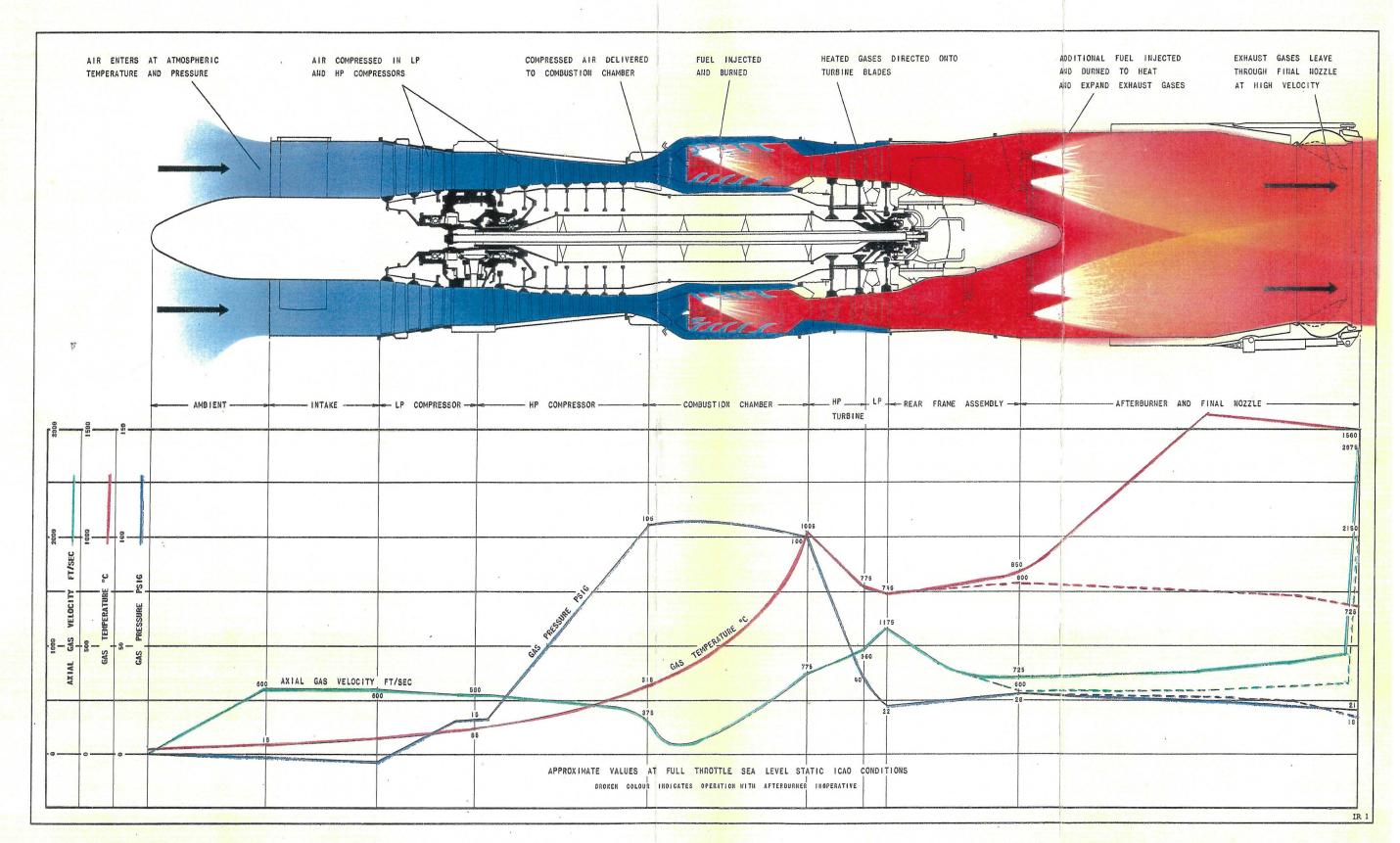


Figure 1-2 Gas Flow Diagram

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provides an overall compression ratio of about 8 to 1 in ten stages of compression. To obtain similar qualities in a single compressor would require a longer rotor with a greater number of stages. Variable incidence fourth stage stator blades improve the aerodynamic qualities and efficiency of the compressor over a wider range of operating conditions.

- 11 The compressor delivery air is forced into the annular combustion chamber where a proportion of the compressed air is diffused and mixed with vaporized fuel. This mixture burns continuously at extremely high temperatures, and expands the main volume of air considerably. The combustion cycle is essentially one of constant pressure, therefore the air flow leaves the combustion chamber at extremely high temperatures and increased velocity.
- In the turbine section, a portion of the total energy instilled in the gases is converted into mechanical work to drive the compressors. Three stages of stator blades increase the velocity of, and direct the gases onto impulse-reaction type blades, which in turn react to the gas loading by causing rotation of the turbine rotors and hence the compressors.
- From the turbine, the gas flow passes through the rear frame assembly to the afterburner where additional fuel is injected and burned in a proportion of the remaining unburnt air in the exhaust stream to further accelerate and increase the momentum of the mass air flow. From the afterburner, the gas stream emerges to atmosphere through a variable area final nozzle. The area of the nozzle determines the temperature and hence the velocity of the exhaust gas stream expelled from the engine.
- For a given set of operating conditions, the thrust of the engine is proportional to engine speed, which in turn is governed by the quantity of fuel burned and the temperature to which the air flow is heated. Engine speed is selected by a manually operated power control lever in the pilot's cockpit. The engine and afterburner fuel flows and the area of the final nozzle are automatically controlled to provide the desired percentage of the available thrust as determined by the pilot"s speed setting.

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LEADING PARTICULARS

GENERAL				
Name of Engine				Iroquois 2
Type of Engine	•••	•••	•••	Two-spool, axial flow, turbojet with integral afterburner
Dry Weight			• • • • • • •	4500 lb (maximum)
				Anti-clockwise as viewed from the rear of the engine
Compressor				G
(LP Section)				3-stage, axial flow
				7-stage, axial flow
				Annular vaporizing type chamber
Turbine	*			
				2-stage, axial flow
(LP Section)	• • • • • • •			Single-stage, axial flow
Afterburner	•••	•••	•••••	Integral design with fully modu- lated, convergent final nozzle
FUEL SYSTEM				
Type of System	•••	•••	•••	Hydromechanical-electronic with single lever control
Fuel Control Unit	•••	•••	•••	Combined main and afterburner controls with manually-selected emergency control (Lucas-Rotax)
HP Fuel Pumps (2 pe	r engine)	•••	•••	Air-driven centrifugal type with automatic pressure control (Lucas-Rotax)

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Fuel Distributor	Sixteen port (Lucas-Rotax)
Hot Streak Igniter Valve	
	type (United Aircraft Products)
Starting Fuel Pump	Hydraulically driven, vane type
	(Vickers)
LP Speed Governor	
HP Speed Governor	
	emergency overspeed governor
Type of Fuel	(Lucas-Rotax)
Type of Fuel	3-GP-22b (MIL-F-5624C, Grade
	JP4)
	*3-GP-25c (MIL-F-5572B, Air-
	craft gasoline)
	MIL-F-5161C (Wide range referee)
Fuel Pressure (At fuel inlet connection)	
Fuel Temperature (At fuel inlet connection)	
	71°C (160°F) maximum
LUDDICATING OIL CYCTEM	
LUBRICATING OIL SYSTEM Type of System	Salf contained dry sump
Type of Oil	
Oil Tank Capacity	
,	gal. (1.2 US gal.) air space
Minimum Oil Pressure (Idling)	
Nominal Operating Pressure across oil jets	
at Normal (Cruise) rpm	30 psi with oil at 71°C (160°F)
Maximum Oil Pressure (During cold weather	
engine starting)	150 psi at the oil temperature regulator
Main Pressure Pump	Single element, Gerotor type (Nichols)
Scavenge Pump	Two element, Gerotor type (Nichols)
Constant Speed Unit Pressure Pump	Single element, Gerotor type
	(Nichols)
Oil Temperature Regulator	9
	hydraulic oil sections using fuel
	as coolant (United Aircraft Products)
Maximum Scavenge Temperature	
Minimum Oil Delivery Temperature	
	regulator by-pass valve
* Maximum allowable temperature of this fuel is 4	• -

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Maximum Oil Consumption (Normal Rated)	
(Military Rated)	3.0 lmp. pt (3.6 US pt)/hr.
STARTING SYSTEM	
Type of System	Pneumatic system supplied with air from a ground starting vehicle
Starter	Air-driven turbine motor with centrifugal type rotor and reduction gearing (Lucas-Rotax) or AiResearch)
IGNITION SYSTEM	
Type of System	Twelve joule, high energy, 14 to 29 volt DC input
Ignition Exciter	denser discharge type (Bendix Scintilla)
Igniter Plugs (2 per engine)	Low voltage, surface gap type (Champion)
Oxygen Injectors (2 per engine)	For altitude relighting only (Lucas-Rotax)
ANTI-ICING SYSTEM	
Type of System	Hot air, surface heating (inter- mittent cyclic operation)
Air Pressure Regulator	F
Maximum Air Pressure	
HYDRAULIC SYSTEM	
Type of System	Self-contained, closed circuit
Type of Oil	MIL-L-7808C
Hydraulic Accumulator	Nitrogen charged, 25 cub. in. nominal capacity (Sprague)
Hydraulic Reservoir	_ , ,
Hydraulic Pump	
Hydraulic Motor (For starting fuel pump)	
Hydraulic Actuators (Final Nozzle)	• • • • • • • • • • • • • • • • • • • •

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Hydraulic Actuator (For variable incidence

** Will vary with aircraft application

guide vanes) Solenoid-operated, piston type

(Dowty)

Nominal Oil Pressure... 3000 psi

regulator by-pass valve

Nominal Oil Temperature 149°C (300°F) continuous

Condition	Minimum Thrust lb.	Rated Measured Exhaust Gas Temp. (Max)		HP Rotor rpm (Nominal)	LP Rotor rpm (Nominal)	Time Limit (Minutes)
		°C	°F			
Maximum with Augmentation	26,000	732	1350	100% (8150)	100% (6000)	5
Maximum	19,250	732	1350	100% (8150)	100% (6000)	5
Military	18,570	707	1305	97.3% (7930)	95.7% (5740)	30
Normal	17,550	667	1233	94.5% (7700)	91.5% (5490)	Continuous
Idle **	600 (Max)	-	_	-	-	Continuous

Table 2-1 Engine Ratings at Standard Sea Level Static Conditions

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		0:	Speed of Rotor Relative to		Direction of Rotation Facing
Accessory	Location	Qty	Compressor Shafts LP HP		Pad on Engine
Aircraft Power Take-off	Front of HP Gearbox	1	LF	0.860	Anti-clockwise
Engine Starter	Rear of HP Gearbox	1		1, 910	Anti-clockwise
Constant Speed Unit Oil Supply Pump	Rear of HP Gearbox	1		0.514	Clockwise
HP Tachometer Generator	Rear Face of C.S.U. Oil Supply Pump	1		0.514	Clockwise
HP Speed Senser	Rear Face of Tachometer Generator	1		0.514	Clockwise
Main Lube Oil Pump	Rear of HP Gearbox	1		0.439	Anti-clockwise
Hydraulic Pump	Rear of HP Gearbox	1		0.797	Anti-clockwise
HP and Emergency Speed Governor	Front of HP Gearbox	1		0.514	Anti-clockwise
Scavenge Oil Pump	Front of HP Gearbox	1		0.541	Anti-clockwise
Constant Speed Unit	Nose Bullet	1	1.000		Clockwise
LP Speed Governor	Rear of LP Gearbox	1	0.699		Clockwise

Table 2-2 Accessories Drives

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DESCRIPTION OF ENGINE AND COMPONENTS

GENERAL

Part 3 of the Iroquois Advance Data sheets deals with a physical description of the engine. Although the basic design of the engine was completed at the time these sheets were being prepared, many changes of a minor nature will take place before the engine design is sealed. Preparing these sheets under such conditions means that much detail will have to be omitted and that where detail has been included, it could quite possibly be changed before the production configuration is reached. If the reader keeps this in mind when using these sheets, he will gain a general idea of the engine while his impression of detail will remain flexible, thus making things easier when the final configuration arrives.

In this section of Part 3, the engine general assembly is divided into major assemblies, these being shown in the order of engine assembly in Figure 3-1-1. For the purpose of clarity, the combustion support frame is shown detached in solid outline and in ghost outline in its assembled position within the mid frame assembly. Accessory components have been omitted, these, and the mounting locations of the fuel system and oil system major components will be shown in a later issue of Figure 3-1-1.

Detailed descriptions covering individual major assemblies and their subassemblies will be issued under separate headings in subsequent advance data sheets. Engine systems, engine mounting and installation details, and the afterburner assembly are described in individual sections of Part 3.

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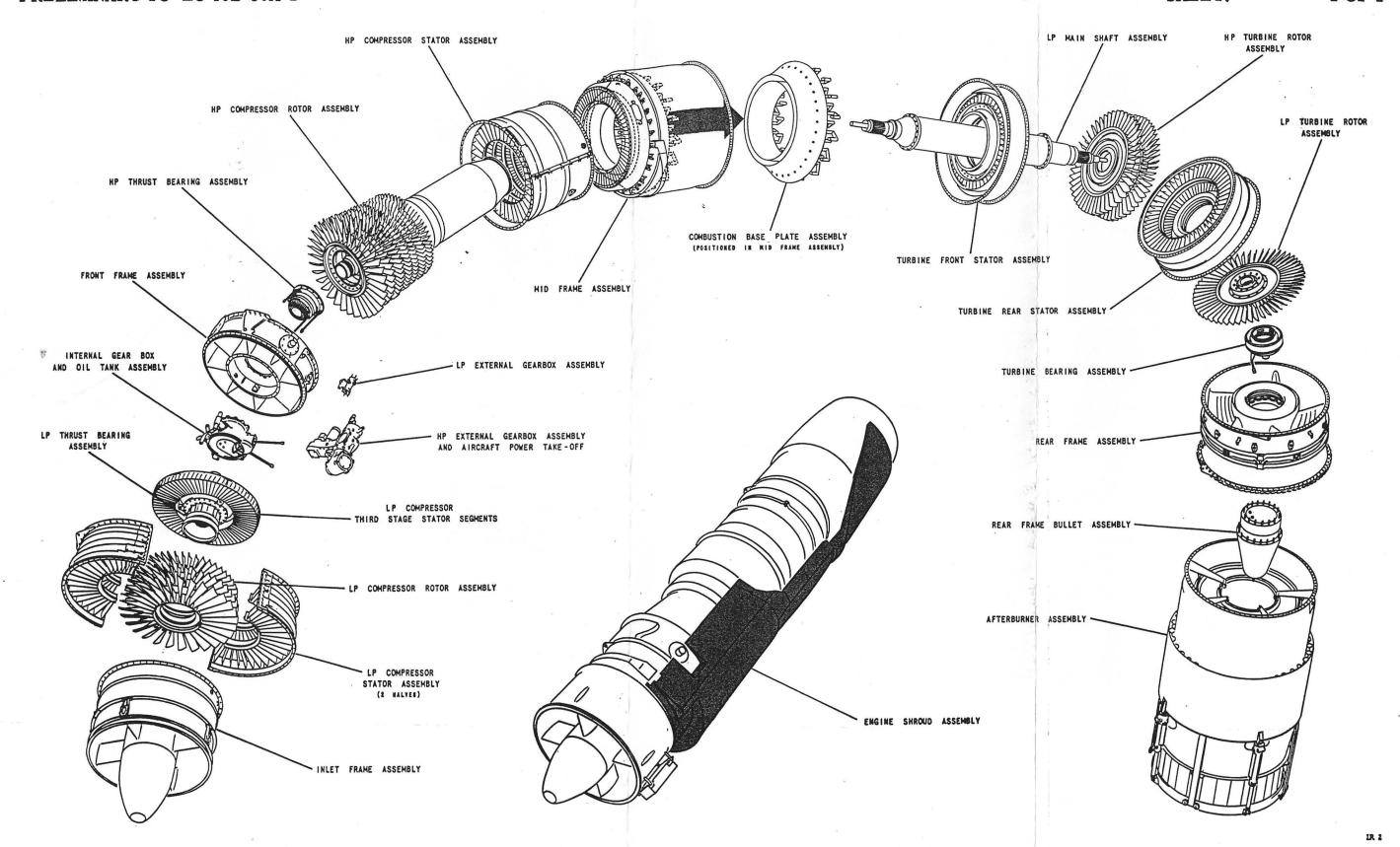


Figure 3-1-1 Exploded View of Engine

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DESCRIPTION OF ENGINE AND COMPONENTS

INLET FRAME ASSEMBLY

The inlet frame assembly is a fabricated structure consisting of a cylindrical outer casing, four aerofoil struts, a cylindrical inner casing, and a nose bullet. The main function of this assembly is to house and support an alternator/constant speed unit combination which is mounted within the inner casing. The drive for these units is provided by suitable shafting extending forward from the LP compressor rotor.

Outer Casing

The outer casing is fabricated from aluminum sheet with a machined aluminum flange ring at the rear, which serves as the mounting attachment to the forward flange of the LP compressor stator casing. Two folding lifting eyes are provided at the top of the casing, and at the bottom provision is made for the inclusion of the ram temperature sensing probe. A dual pressure probe is fitted on the outer casing, just below No. 2 strut for obtaining the PI total pressure and the PI reverse pressure; these probes are connected into the fuel system.

Inner Casing

A magnesium casting shrouded by an aluminum sheet casing forms the inner casing. Four radial, hollow, equi-spaced struts locate the inner casing in the centre of the outer casing. The struts are numbered anti-clockwise, No. 1 strut being at approximately the 10 o'clock position when viewed from the front of the engine. A temperature sensitive thermistor is fitted to the outer skin of the inner casing between No.1 and 4 struts, to sense icing conditions at the engine intake.

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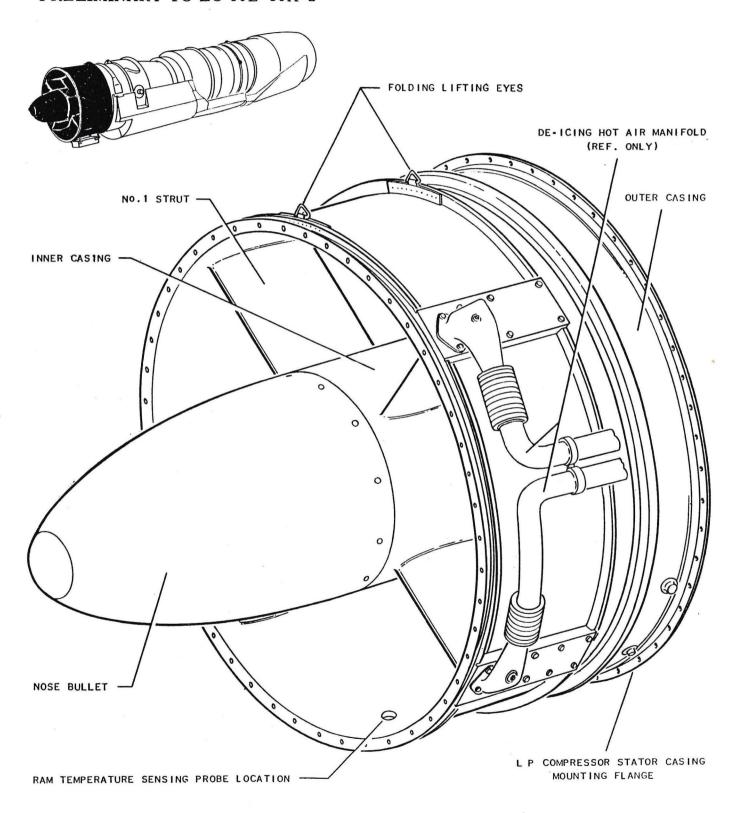


Figure 3-1-2 Inlet Frame Assembly

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Nose Bullet and Struts

- The nose bullet, fitted to the front of the inner casing, the four struts, and the inner casing are all double skinned, thus providing passage for a supply of compressor delivery air for de-icing purposes. The air is piped externally to the outer ends of No. 1 and 4 struts which are interconnected with No. 2 and 3 struts respectively by external manifolds. The warm air passes into the struts, follows a circular path around the inside of the outer skin and enters four passages in the inner casing. From here it flows forward, spills under the outer skin of the bullet, and then flows in a rearward direction under the outer skin of the inner casing to join the air intake stream upstream of the LP compressor first stage rotor blades.
- The hollow struts also carry electrical and thermocouple leads, the oil supply, return, and vent pipes for the aircraft constant speed unit, together with other aircraft services.

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DESCRIPTION OF ENGINE AND COMPONENTS

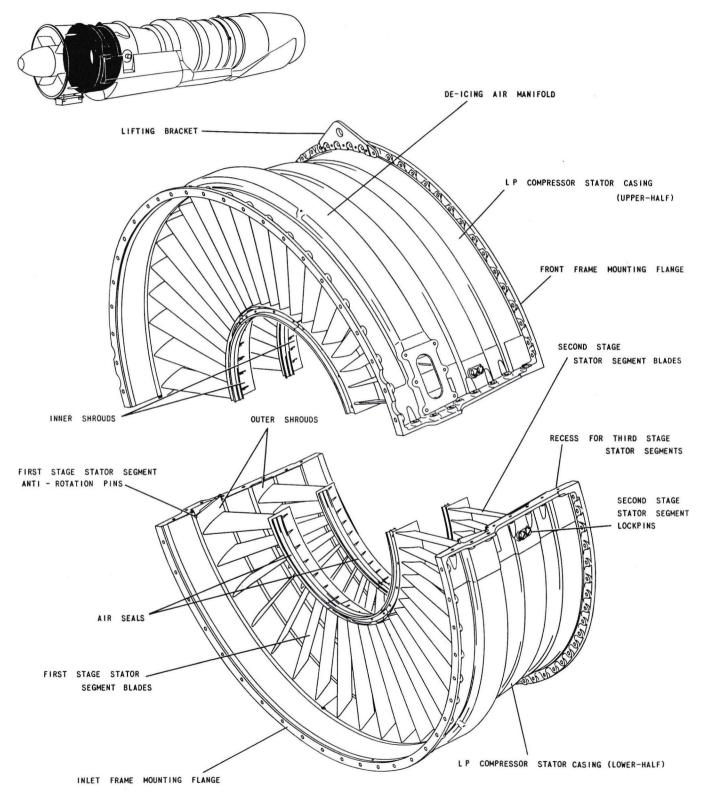
LOW PRESSURE COMPRESSOR STATOR ASSEMBLY

- The LP compressor stator assembly is a horizontally split, magnesium casing containing three stages of stator blades. Recesses and T slots are machined around the inside diameter, the front recess being designed to provide a manifold for the distribution of compressor delivery air for blade de-icing purposes. A coating of friable material is applied to the casing inner surfaces opposite the tips of the compressor rotor blades to minimize damage which may occur should a rotor blade tip rub develop. A machined flange at each end of the casing serves as the mounting attachment to the inlet frame and front frame respectively. Nuts, and bolts with externally splined heads, are used at the split line to secure the two halves of the casing. A lifting bracket is centrally located on top of the casing at the front face of the rear flange. The bracket is secured with the casing joint bolts and by shear pins interposed between the bolts.
- The stator blades are manufactured from stainless steel sheet, and have stainless steel corrugated stiffeners through each blade core. Inner and outer shrouds of stainless steel are brazed to the blades to form stator segments. Each stage has six segments, the first, second and third stage segments having seven, ten and twelve blades respectively.
- The first and second stage stator segments are located in the T slots and are prevented from rotating by anti-rotational pins and lockpins respectively. The third stage segments are mounted on the LP thrust bearing housing outer flange, and are retained and locked against the forward outer and inner flange faces of the front

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Figure 3-1-3 Low Pressure Compressor Stator Assembly

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frame by pins and bolts when the LP thrust bearing assembly is installed on the front frame. When the front frame is attached to the stator casing the segments fit into the rear recess in the stator casing. Stainless steel air seals are riveted to the inner shrouds of the first and second stage stator segments and mate with seal sleeves on the LP compressor rotor spacers.

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE COMPRESSOR ROTOR ASSEMBLY

- The low pressure compressor rotor is composed of three stages of blades, three discs, two spacers, and two peripheral seals, all of which are machined from titanium. The driving flange of the first stage disc is remotely positioned to the rear of the disc hub, the cylinder between the driving flange and the disc hub absorbing the differential strains between the LP mainshaft and the first stage disc. The remaining stages are cantilevered in a rearward direction, with the spacer rings bolted directly to the discs to form a continuous drum.
- A fourteen groove, labyrinth type, peripheral seal is riveted in position in a machined groove in the spacer rings immediately behind the first and second stage blade roots. The mating parts of the seals are fitted to the inner shrouds of the compressor first and second stage stators respectively. Immediately in front of the third stage rotor blades, a machined slot is provided in the spacer ring for the addition of balance weights which may be required during dynamic balancing. At the forward face of the first stage disc, additional weights in the form of strip washers may be added under the disc securing nuts to attain the correct balance.
- The rotor blades are machined from forgings, all three stages having feathered edges on their outer extremities to reduce the possibility of damage to the stator casing if a tip rub should develop due to unforeseen mechanical and/or atmospheric conditions. The first and third stage blades are secured to the disc by a two branch fir tree root while the second stage employs a cylindrical seat dovetail fixing. On the rear face of the blades a positive stop is machined into the blade roots to prevent the blades from being knocked loose should a failure occur in a preceding stage.

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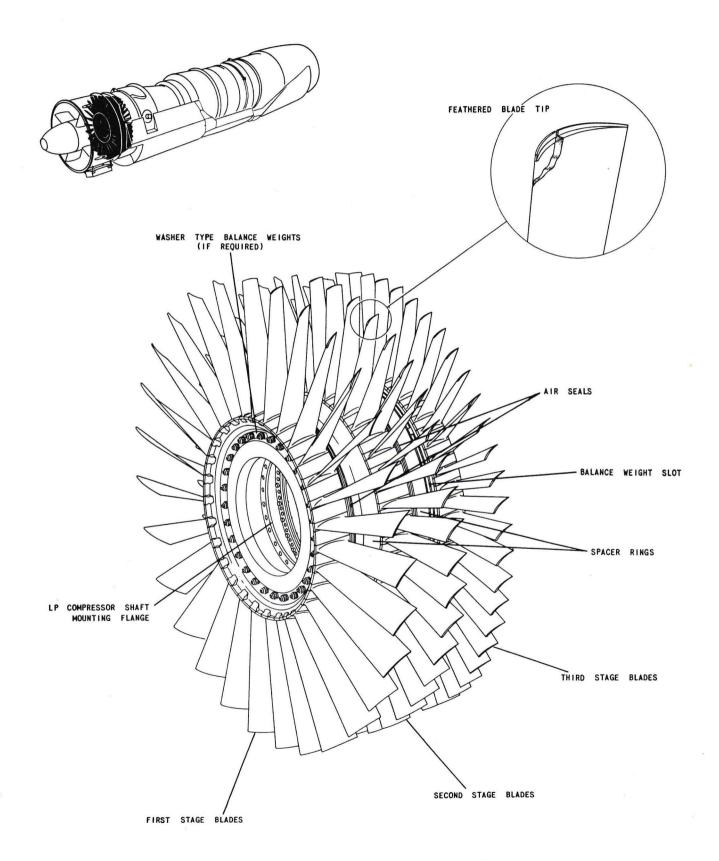


Figure 3-1-4 Low Pressure Compressor Rotor Assembly

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE THRUST BEARING ASSEMBLY

General

1 The LP thrust bearing assembly supports the LP compressor shaft and absorbs the net axial thrust of the LP compressor rotor and LP turbine rotor. The assembly consists of the LP compressor shaft, a bearing housing, a ball thrust bearing, and the LP compressor third stage stator segments.

LP Compressor Shaft

The LP compressor shaft is of nickle-plated steel. Internal splines at the front and rear of the shaft provide the drive for the constant speed unit mounted in the inlet frame, and transmit the torque from the LP mainshaft to the LP compressor rotor respectively. The shaft is bolted to the driving flange of the LP compressor rotor first stage disc during engine build. A seat and shoulder on the external diameter of the shaft, and located immediately forward of the shaft mid-point, accommodates the LP ball thrust bearing.

Bearing Housing

The bearing housing is of magnesium and is mounted on the front inner flange of the front frame. The LP compressor third stage stator segments are mounted on the outer periphery of the housing and are retained by the housing attachment bolts passing through the segment mounting brackets on the inner shrouds. Pins on the front outer flange of the front frame position the outer shrouds of the segments when the bearing assembly is secured to the front frame.

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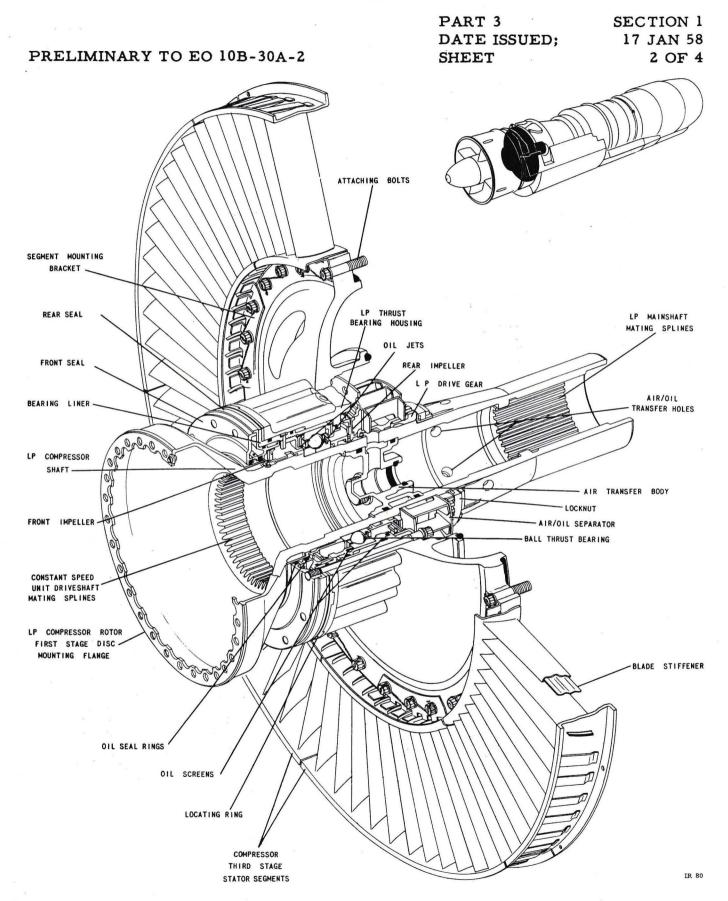


Figure 3-1-5 (Issue 1) Low Pressure Thrust Bearing Assembly

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LP Thrust Bearing and Oil Jets

The bearing is a single row, ball thrust type with a split inner track. It is installed in a steel liner in the bearing housing and is held in position by a locknut. Three screen protected equidistant oil jets are integrally machined in the bearing locknut and spray lubricating oil on the front face of the bearing. Three similar oil jets, integral with the bearing liner are located at the rear of the bearing. The effect of thermal differential expansion between the housing magnesium casting and the steel bearing liner is counteracted by a locating ring with lugs on its rear face, the ring being located in slots on the front inner face of the bearing housing and secured to the liner, thus centralizing the liner.

Air Transfer Body

An air transfer body of cast magnesium is fitted inside the LP compressor shaft at the mid-shaft location. The rear face of the body butts against an internally machined shoulder in the shaft, and is secured at the front by a retaining ring which locates in a machined groove in the shaft. The air transfer body seals the forward end of the internal air vent tube and the internal oil return tube, and cored passages in the six webs of the air transfer body permit the transfer of purified seventh stage scavenge air from the front sump to the internal air vent tube. Six equally spaced holes drilled in the LP compressor shaft aft of the air transfer body give access to the front sump for the seventh stage air/oil mixture passing forward from the rear sump through the internal oil return tube.

Oil Seal

Forward of the bearing a seal sleeve is fitted to the LP compressor shaft, the outer diameter of the sleeve forming a seat for the seal rings. A double floating ring, pressure balance type seal with a spacer between the seal rings, is mounted between the seal front housing and the seal rear cartridge. Compressor seventh stage air is led through drilled passages to pressurize the cavity between the seal rings.

Oil Scavenge Impellers

Two radially vaned impellers, one on either side of the bearing, are each secured by a dowel pin, the head of which is located in a slot machined in the LP compressor shaft. The impellers return scavenge oil from the bearing cavity to the internal oil tank via a cored passage in the bearing housing. The front impeller is shrouded by a rearward extended flange on the rear seal cartridge, and the rear impeller rotates within an annulus ring fitted to the rear of the bearing housing and in front of the air/oil separator.

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Air/Oil Separator and LP Drive Gear

The air/oil separator is mounted on the LP compressor shaft immediately aft of the rear impeller and is retained circumferentially by a dowel located in a slot in the shaft. A LP drive gear splined to the shaft butts against the rear inner face of the separator and is retained axially by a locknut and tanged lockwasher. The drive gear drives the LP external gearbox gear train.

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DESCRIPTION OF ENGINE AND COMPONENTS

FRONT FRAME ASSEMBLY

General

The front frame assembly is the main structural member of the engine and consists basically of a magnesium casing, a single stage of HP compressor variable incidence inlet guide vanes, and hollow struts which are used to carry engine services. The assembly forms the structural connection between the LP and HP compressors and supports the internal gearbox and oil tank assembly, and the LP and HP thrust bearings; the loads of these bearings are transmitted to the airframe through trunnion mounts on the front frame casing.

Outer Casing

The front frame casing is cast in the form of a cylindrical outer casing joined to an inner casing by eight integrally cast struts. The outer casing is provided with front and rear mounting flanges for attachment of the LP and HP compressor stator casings respectively. A mounting is fitted to a pad machined at the top of the outer casing and transmits the net axial thrust load and tangential side loads from the engine to the airframe. Trunnion mounting pads fitted to the outer ends of the horizontal struts transmit tangential vertical loads only. Dependent upon aircraft installation, either one or both of the trunnion side mounts may be used in conjunction with the thrust mount without imposing any undue strains on the front frame casing. The HP and LP external gearboxes are mounted on machined bosses in the outer casing at the ends of No. 5 and 6 struts respectively.

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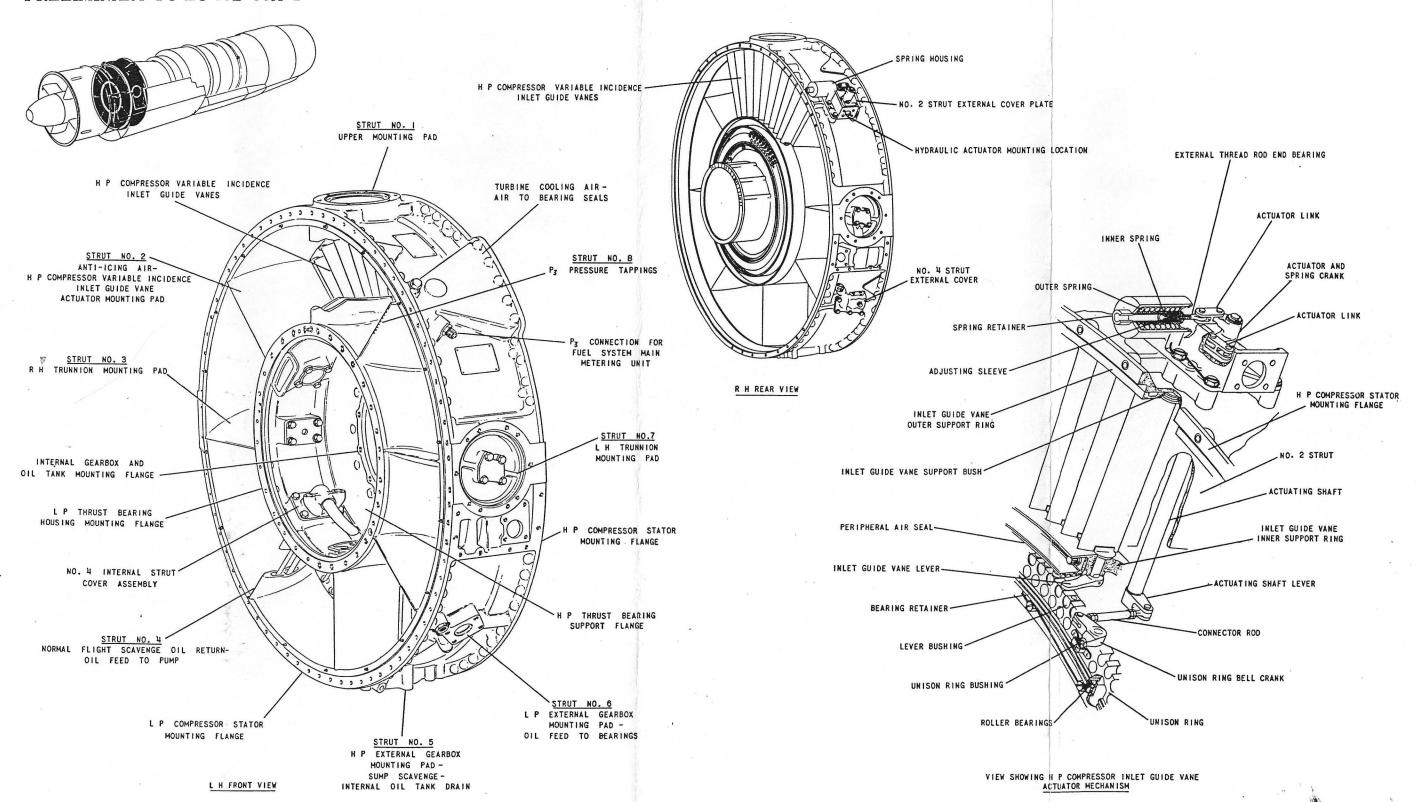


Figure 3-1-6 (Issue 1) Front Frame Assembly

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Struts

3 The eight equi-spaced, hollow struts are aerofoil-shaped and extend radially outwards from the inner casing to the outer casing. Starting with No. 1 strut at the top, the struts are numbered clockwise as viewed from the rear of the engine and carry the following services:

No. 1 Strut - Nil.

- No. 2 Strut Drive from hydraulic actuator to HP compressor variable incidence inlet guide vanes.
 - Anti-icing air (If required).
- No. 3 Strut Nil.
- No. 4 Strut Normal flight scavenge oil return and oil tank overflow (Common line).
 - Oil tank fill pipe.
 - Feed from oil tank to oil pump.
- No. 5 Strut Drive for HP external gearbox.
 - Front sump scavenge oil.
 - Internal oil tank drain.
- No. 6 Strut Oil feed to bearings.
 - Drive for LP external gearbox.
- No. 7 Strut Nil.
- No. 8 Strut Seventh stage air for pressurizing oil seals and turbine cooling.
 - Inter-compressor pressure (P₃) tapping for fuel system main metering unit.

Inner Casing

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A machined flange at the front of the cylindrical inner casing provides a mounting for the LP thrust bearing assembly. The HP thrust bearing housing is

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formed by an inward projecting support flange integrally cast at the rear of the inner casing. A machined flange on the forward face of the bearing housing provides a mounting for the rear of the internal gearbox and oil tank assembly. A cast aluminum cover, embodying three fittings, is attached to the inner end of No. 4 strut. The front fitting is not used, the large centre fitting is the feed to the oil pump, and the rear fitting is the normal flight scavenge oil return. The rear fitting is connected to the internal oil tank by piping; the centre fitting extends downwards to the bottom of the cavity formed by the inner casing.

HP Compressor Inlet Guide Vanes and Actuating Mechanism

- Air flowing from the outlet of the LP compressor passes through the annular duct formed by the inner and outer casings. The outer periphery of the inner casing is slightly concave between the struts to improve the air flow characteristics through the casing. A ring of variable incidence inlet guide vanes at the rear of the duct direct the air into the HP compressor. The outer ends of the hollow stainless steel guide vanes are mounted in steel support bushings located in an outer support ring. This ring is located in a recess in the rear flange of the front frame outer casing and is retained axially when the HP compressor stator casing is assembled to the front frame. Spindles on the inner ends of the vanes locate in an inner support ring which is bolted to the rear face of the inner casing. The bolts retaining the inner support ring also carry a four groove peripheral air seal which mates with the seal ring on the front face of the HP compressor rotor. A small lever, pinned to the inner end of each vane spindle, is located in a bronze bushing carried in a rotatable unison ring. The steel unison ring, which carries sixty-four lever bushings, is supported by twenty caged roller bearings that are held in position by a bearing retainer.
- The unison ring, and hence the guide vanes, are rotated by a hydraulic actuator which is externally mounted on the front frame No. 2 strut cover plate. Linear movement of the actuator push rod is transformed, through a link and crank, into rotary movement of an actuating shaft which passes through the No. 2 strut core. A lever on the inner end of the shaft is linked to a bell crank which, in turn, engages with the unison ring. Internal stops in the hydraulic actuator govern the total rotational movement of the vanes. A spring housing, which is integral with No. 2 strut cover plate, accommodates two concentrically mounted springs. The springs seat on a retainer which bears against a rod end bearing linked to the actuator crank. In the event of failure in the actuator hydraulic circuit, the springs return the guide vanes to their neutral position.

Oil and Air Services

7 Internal passages in the front frame deliver oil to the jets on the fore and aft

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faces of the HP thrust bearing. Similar passages carry oil from the HP thrust bearing scavenge impellers directly to the internal oil tank. A spring-loaded drain valve, which is held closed by pressure oil during engine operation, opens during engine shut-down and allows oil from the scavenge impellers to drain into the front sump. Seventh stage air is piped into No. 8 strut and is tapped off at the front face of the inner casing to supply air pressure to the LP bearing oil seal. The remainder of the air from No. 8 strut bleeds into the interior of the HP compressor rotor to pressurize the HP thrust bearing and LP steady bearing oil seals and to cool the turbine assemblies.

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DESCRIPTION OF ENGINE AND COMPONENTS

INTERNAL GEARBOX AND OIL TANK ASSEMBLY

General

The internal gearbox and oil tank assembly is housed within the front frame inner casing. The assembly consists basically of a gearbox casing, and two gear trains which supply power to the externally mounted LP and HP gearboxes. When installed in the front frame, the gearbox serves as the inner wall of the front sump of the engine lubrication system, with the casing also forming the inner circular wall of the oil tank. The front and rear walls of the oil tank are provided by the LP and HP thrust bearing housings respectively, when the bearing assemblies are installed in the front frame.

Internal Gearbox Casing

The internal gearbox casing is cast from magnesium, with a flange on the front and rear faces. The front flange butts against a flange on the rear face of the LP thrust bearing housing, with an 'O' ring interposed in the joint. The rear flange is bolted to a flange on the forward face of the integrally cast HP thrust bearing housing in the front frame casing. The bottom of the internal gearbox casing seats on the inner end of the front frame No. 6 strut with an 'O' ring interposed at the joint. A sealing flange, which fits over the support housing for the LP driven bevel gear, is bolted to the inner end of the front frame No. 6 strut. An 'O' ring is fitted between the sealing flange and the gearbox casing and also between the sealing flange and the front frame casing.

LP Gear Train

3 A drive gear mounted on the LP compressor shaft meshes with a spur gear

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OF DOUBLE BALL VENT VALVE VENT EXTENSION -NORMAL FLIGHT SCAVENGE OIL RETURN LINE VENT PIPE H P THRUST BEARING SCAVENGE OIL RETURN . LINE -REAR MOUNTING FLANGE VENT VALVE BALLS VENT CASING INTERNAL GEARBOX CASING BALL SUPPORT PIN -OIL JET FOR LP MAINSHAFT FRONT FLANGE -STEADY BEARING H P BEVEL PINION CONSTANT SPEED UNIT-OIL RETURN L P BEVEL PINION OIL JET FOR H P BEVEL GEAR - BEARING CARTRIDGE L P DRIVEN SPUR GEAR L P DRIVEN BEVEL GEAR H P BEVEL PINION BALL BEARINGS SEALING FLANGE > BALL BEARINGS QUILL SHAFT TO L P EXTERNAL GEARBOX LINER LOCKNUT RIGHT-HAND FRONT VIEW OF H P BEVEL PINION QUILL SHAFT TO H P EXTERNAL GEARBOX IR 85

Figure 3-1-7 (Issue 1) Internal Gearbox and Oil Tank Assembly

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within the gearbox casing. A small bevel pinion gear is splined to the hub of the spur gear and is retained by a locknut and lockwasher. The spur gear and bevel pinion gear combination is supported by two, single row ball bearings, the bearing cartridge being housed within an integrally cast boss in the gearbox casing. The drive is turned through ninety degrees by a second bevel gear which is internally splined at its outer end to receive a quillshaft which extends through the front frame No. 6 strut to drive the LP external gearbox. Two single row ball bearings are used to support the driven bevel gear.

HP Gear Train

A bevel pinion gear meshes with the bevel gear splined to the HP compressor front stub shaft, and is supported by two, single row ball bearings in an integral housing in the bottom of the casing. The upper bearing is pressed onto the bevel pinion gearshaft and mounted in a steel liner. The lower bearing is mounted in the liner, and is retained on the gearshaft by a washer and locknut. A flange on the upper end of the liner locates the liner against the inner face of the housing and serves as a retainer when the liner locknut is tightened. Rotational movement of the liner is prevented by a dowel pin which is fitted through the face of the flange into the housing. A quillshaft, splined to the bottom of the gearshaft, carries the drive to the HP external gearbox and aircraft power take-off assembly which is mounted on the outer end of the front frame No. 5 strut.

Lubrication

Two oil jets, located in the rear of the casing, provide lubrication for the LP mainshaft steady bearing and the HP bevel pinion gear respectively. On the right-hand side of the casing, two pipes, connected at the lower ends to the No. 4 strut internal cover in the front frame, carry scavenge oil to the oil tank. The pipes carry constant speed unit scavenge oil and normal flight scavenge oil respectively. When the oil supply is being replenished during ground servicing, these pipes serve as the oil tank fill pipe and overflow pipe respectively. An oil pipe and fitting, mounted on a boss at the top of the casing return scavenge oil from the HP thrust bearing to the oil tank. Air transferred to the tank by the scavenge return system is vented to the front sump by a double ball vent valve. The valve also prevents an oil flow from the tank to the front sump in any flight attitude.

ROYAL CANADIAN AIR FORCE

GP4

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE MAINSHAFT ASSEMBLY

- 1 The LP mainshaft is in three sections. The shaft extends forward from the LP turbine rotor to drive the LP compressor rotor. Two concentrically mounted tubes within the shaft, namely the internal oil return tube and the internal oil vent tube, form part of the engine lubrication system.
- The three sections are of nickel-plated steel, the front to centre section joint and the centre to rear section joint being located by machined spigots on the front and rear sections respectively; stainless steel bolts and nuts secure the joints. The LP compressor rotor shaft is splined to the front section of the main shaft and is locked in position by a locknut. The locknut is internally splined and is retained by a spring-loaded sleeve which slides forward to engage with the locknut splines. The LP turbine rotor shaft is splined to the rear section of the main shaft. Seal rings on the front and rear sections prevent the leakage of oil from the HP compressor rotor 'steady' bearing and the turbine bearing respectively.
- The oil return tube is centrally located inside the mainshaft centre section by five stainless steel disc supports which are silver brazed to the outer diameter of the tube. The inner tube is supported within the outer tube by 12, three point location, 'Z' section, stainless steel supports which are welded to the inside diameter of the outer tube.
- A mixture of air and lubricating oil in the form of froth is returned from the engine rear oil sump to the engine front oil sump via the annular space formed between the inner and outer tubes. The inner tube serves as an engine lubrication system air

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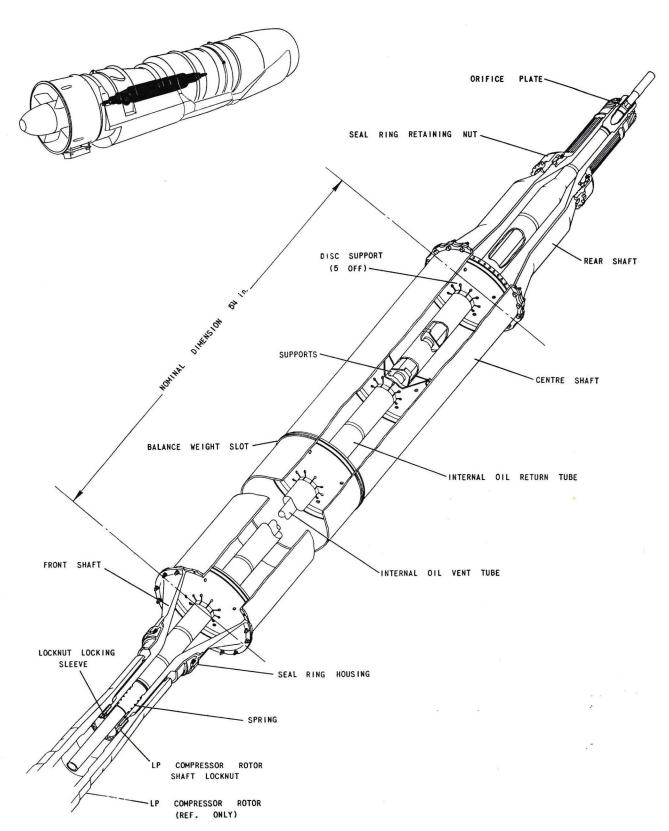


Figure 3-1-8 Low Pressure Mainshaft Assembly

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vent to the rear of the engine. An orifice plate, fitted to the rear end of the inner tube controls the air pressure drop throughout the engine oil scavenge system.

The LP mainshaft assembly and the LP turbine rotor are dynamically balanced as a complete assembly. Correction is made by balance weights at balancing planes located on the mainshaft, the rear face of the turbine disc and on the inner diameter of the turbine bearing outer seal ring.

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DESCRIPTION OF ENGINE AND COMPONENTS

HIGH PRESSURE COMPRESSOR STATOR ASSEMBLY

- 1 The HP compressor stator assembly forms the structural connection between the front frame and the mid frame, and encases the HP compressor rotor drum. The assembly comprises mainly an outer casing, six stages of stator segments and seven spacer rings.
- The outer casing consists of an unsplit, conical, sheet steel shroud with a flange welded to each end for bolting the casing to the front and mid frames respectively. A circular retaining ring, integral with the outer casing, has a machined recess on its inner front face, which mates with a hook-shaped projection on the seventh stage spacer ring. The retaining ring serves as a stiffener for the outer casing to prevent ovality occurring in the stator assembly. Two triangular-shaped instrumentation bosses are located near the bottom of the outer casing immediately aft of the forward mounting flange. A sheet metal flange is welded to each side of the casing, along the horizontal centre line, for attachment of the engine shroud.
- Each stage of stators is composed of six segments which, when assembled in position, form a continuous ring of stator blades. The number of blades per segment in the fourth to ninth stages inclusive is seven, eight, nine, nine, eleven and eleven respectively. The tenth stage stator segments form part of and are dowelled directly to the mid frame assembly. The stator segments are of stainless steel and consist of inner and outer shrouds brazed to the ends of hollow stator blades. Each aerofoil-shaped stator blade is fabricated from two sheet steel pressings strengthened by a corrugated stiffener inserted in the blade core. The outer end of each blade is sealed with a steel plate brazed to the outer shroud; the inner end is left open to vent the blade core. An air seal of the two-groove type is riveted to a flange on the inner

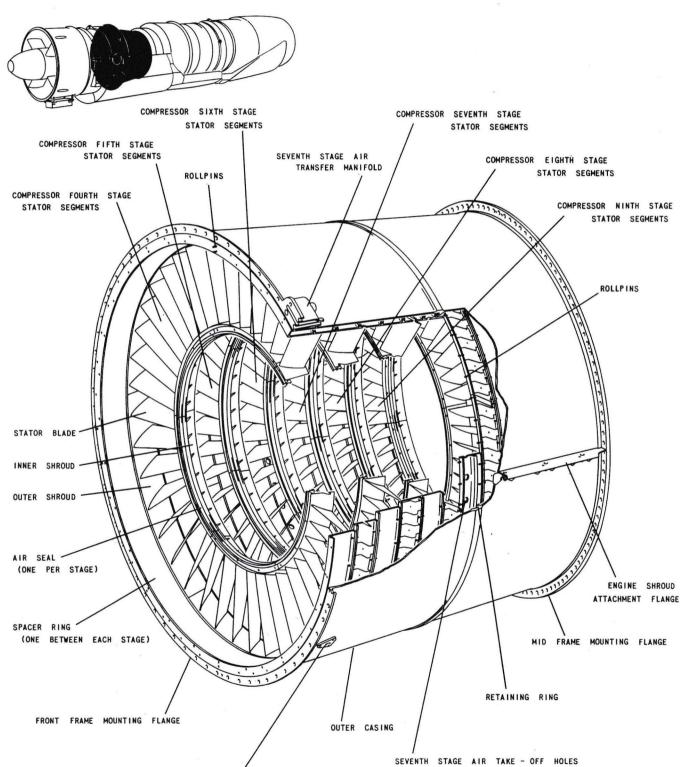
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Figure 3-1-9 High Pressure Compressor Stator Assembly

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shroud of each segment to mate with the inter-stage air seals fitted to the HP compressor rotor spacer rings.

- The circular spacer rings are of stainless steel, and are located intermittently between each stage of stator segments. Like the segment outer shrouds, the spacer rings are channel-shaped to provide maximum rigidity of the assembly. The flanges of the segment outer shrouds and the spacer rings butt together and are retained by single rows of equi-spaced rollpins. The foremost spacer ring is pinned to the rear of the front frame by two rows of equi-spaced rollpins. A coating of friable material is applied to the inner diameter of each spacer ring to minimize damage that may be caused by the development of a tip rub.
- A series of holes in the seventh stage spacer ring, forward of the hook-shaped projection, permits air to be bled off into the annulus formed by the spacer ring and segment assembly, and the outer casing. An air transfer manifold, located on the outer casing adjacent to the front frame mounting flange, transfers seventh stage bleed air from this annulus to the passage provided through the front frame No.8 strut. This flow of bleed air is used for pressurizing oil seals in the main bearing assemblies and for turbine cooling.

NOTE

Although the LP and HP compressors have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

HIGH PRESSURE COMPRESSOR ROTOR ASSEMBLY

- The HP compressor rotor assembly is the front rotating component of the engine HP spool, and revolves around the LP mainshaft assembly. Together with the stator casing, the HP compressor rotor forms a converging annular passage where further compression of the LP compressor delivery air takes place.
- The assembly consists essentially of seven bladed rotor discs and six spacer rings and is supported at the forward end by a stub shaft carried in the HP thrust bearing assembly. The spacer rings and rotor discs are bolted together to form a large diameter drum which transmits axial thrust loadings to the HP thrust bearing. The discs absorb radial loads imposed by the centrifugal blade forces arising from high rotational speeds. The extension shaft and HP mainshaft, extend rearwards from the compressor drum, forming a direct drive from the HP turbine rotor.
- The rotor discs and spacer rings are machined from titanium forgings. Development engines have a steel compressor fourth stage disc, but the use of a titanium disc in this stage is proposed for production engines. The fourth stage spacer ring and disc are cantilevered forward from the fifth stage disc. The fifth stage disc is bolted to the fifth stage spacer ring, which has a conical extension bolted to the front stub shaft.
- The HP compressor rotor blades are titanium forgings and have an aerofoil section, with the blade tips feathered to aid in heat dissipation and to minimize damage should a tip rub develop. Blade stops are machined in the rear portion of the blade roots of stages four to nine inclusive, to prevent axial movement of the blades in a forward direction. Blades in the tenth stage have a stop on the front portion of the root to prevent rearward movement. The fourth and tenth stage blades are secured to the respective discs by two-branch fir tree roots, while the remaining stages employ a cylindrical seat dovetail fixing.

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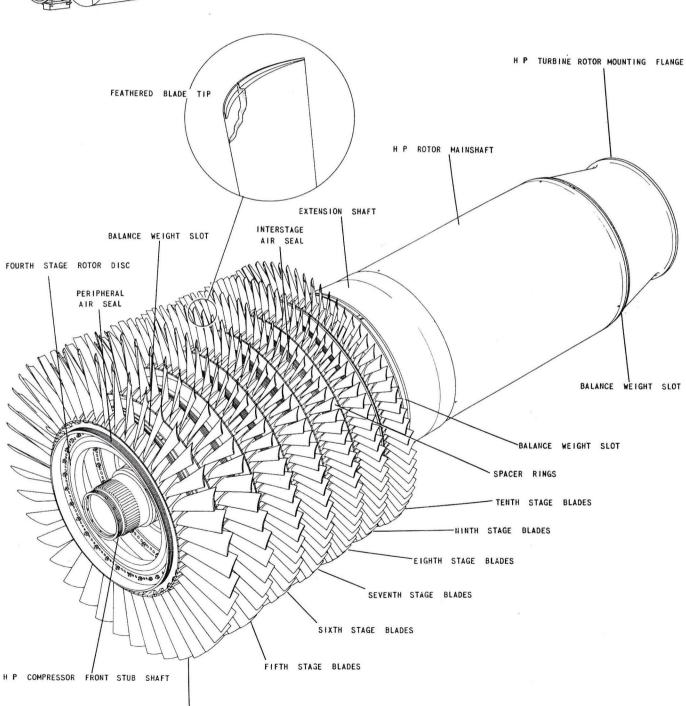


Figure 3-1-10 High Pressure Compressor Rotor Assembly

FOURTH STAGE BLADES

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- Inter-stage air seals of titanium are riveted to flanges on the spacer rings. The forward extending projections on the seal rings butt against the rotor blade roots in the preceding stage and prevent rearward axial movement of the blades. Forward movement of the tenth stage rotor blades is prevented by a similar projection extending from the rear of the ninth stage seal ring. A peripheral air seal is fitted on the front face of the fourth stage disc to prevent excessive air leakage through the clearance between the HP compressor rotor and the front frame.
- The bell-shaped front stub shaft is bolted to the conical extension of the fifth stage spacer ring. A seat and shoulder, machined on the outside diameter of the shaft near the mid-point, provides a location for the HP thrust bearing. The outer diameter of the forward end of the shaft is splined to carry the bevel gear which drives the external gearbox. The bevel gear is retained by a locknut and lock ring, the latter being fitted to the inside of the shaft with a tang protruding through the shaft into the nut. A series of large diameter holes in the conical portion of the front stub shaft, permit the entrance of seventh stage compressor air to the interior of the HP compressor rotor.
- A steady bearing, consisting of a single roller bearing, is mounted inside the front stub shaft. The inner race of the bearing is located against a shoulder on the front section of the LP mainshaft and is retained by the LP compressor shaft and the LP mainshaft locknut. Lubrication of the steady bearing is accomplished by an oil jet located in the rear part of the internal gearbox housing. The jet sprays oil in a rearward direction along the annulus formed between the LP compressor shaft and the HP compressor front stub shaft. Holes in an oil seal sleeve located at the rear of the steady bearing permit scavenge oil from the steady bearing to be centrifuged through oilways in the front stub shaft to the HP thrust bearing scavenge impeller.
- 8 The extension shaft links the compressor drum to the HP mainshaft and the HP mainshaft is secured to the HP turbine rotor by stainless steel tension bolts and a clamp ring fitted to the rear flange of the mainshaft.
- Balancing of the HP compressor rotor assembly is done by the addition of weights installed in three circular grooves, one located on the rear portion of the HP mainshaft, one at the centre of the extension shaft, and another at the fourth stage spacerring. The outer balance weights in each group are secured by peening.

NOTE

Although the LP and HP compressors have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

HIGH PRESSURE THRUST BEARING ASSEMBLY

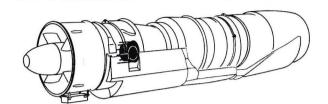
- The HP thrust bearing assembly supports the forward end of the HP compressor rotor, and also absorbs the net axial thrust of the HP compressor rotor and the HP turbine rotor. The assembly consists basically of a single row ball thrust bearing, a bearing liner, the internal gearbox HP bevel gear and locknut, and bearing lubrication system components. When assembled in the front frame it is housed within an inward projecting integrally cast support flange at the rear of the front frame.
- The bearing is retained in the steel liner by a pinned locknut which bears against the rear face of the bearing outer race. The liner is in turn retained within the support flange of the front frame by long steel bolts which also serve to retain the internal gearbox casing in position. The split inner race of the bearing butts against a step machined in the HP compressor rotor front stub shaft, and is held in position by the internal gearbox HP bevel gear. The bevel gear is splined to the front stub shaft and is retained axially by a locknut which is in turn positively locked by the tang of a steel locking ring which engages with holes in the front stub shaft and the locknut.
- A locating plate, with radially disposed teeth machined on its forward face, is fitted between the bearing liner and the rear face of the front frame. The teeth engage with slots in the front frame, and counteract the effects of thermal differential expansion between the magnesium front frame and the steel liner by keeping the liner centralized.
- 4 Lubrication of the bearing is by six oil jets. Three of the jets, located at the front of the bearing, are formed by drillings in the bearing liner while the remaining

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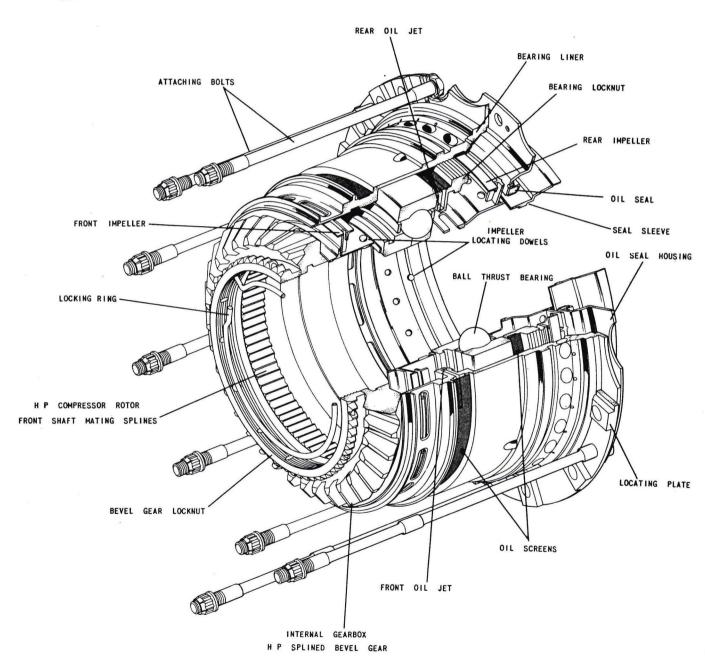
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three, located at the rear of the bearing, are formed by drillings in the bearing locknut. Pressure oil is fed through channelling in the front frame to annular cavities adjacent to each set of oil jets, the front annulus being formed between the front frame and the bearing liner, and the rear annulus between the liner and the bearing locknut. Each annulus is provided with a protective oil screen on the upstream side of the jets.

- Two radially vaned impellers, one fitted on each side of the bearing, scavenge the oil from the bearing assembly by centrifugal action. Holes in the bearing liner admit scavenge oil from the impellers to annular cavities which are formed between the liner and the front frame, and which are interconnected to the internal oil tank by channelling in the front frame. The scavenge oil cavities are isolated from the pressure oil cavities by 'O' ring seals.
- A single carbon ring oil seal is mounted in an oil seal housing located on the rear face of the bearing liner. A steel seal sleeve which butts against a shoulder on the HP compressor rotor front stub shaft, forms a seat for the oil seal. The rear of the oil seal is pressurized with compressor seventh stage air to prevent oil seepage past the seal in a rearward direction.
- Displacement of the seal sleeve and the bearing rear impeller is prevented by a small locating dowel in the front stub shaft. The bearing front impeller is retained by a similar dowel which locates in a slot on the shaft of the internal gearbox HP bevel gear.

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DESCRIPTION OF ENGINE AND COMPONENTS

MID FRAME ASSEMBLY

- The mid frame assembly houses the annular combustion chamber and forms the structural connection between the compressor and turbine HP sections. The assembly comprises mainly the inner and outer casings, the annular combustion chamber liners, the compressor tenth stage stator segments and the primary fuel injectors. The combustion base plate assembly is shown in Figure 3-1-12 for reference purposes only and is fully described in a separate advance data sheet. HP compressor delivery air enters the annular opening at the front of the mid frame and is divided into primary and secondary flows; the primary flow passes through the combustion base plate assembly, and the secondary flow passes into the inner and outer annular spaces formed between the combustion chamber liners and the inner and outer casings.
- The concentrically mounted inner and outer casings are fabricated from stainless sheet steel; the outer casing is of heavier gauge material to withstand structural loadings and the high combustion chamber gas pressures to which it is subjected. The inner casing separates the combustion chamber from the HP compressor mainshaft. The inner and outer casings are joined at the front by 16 hollow, aerofoil section vanes, the trailing edges of the vanes being recessed to accommodate the combustion base plate assembly frame. Machined bolting flanges on the outer casing provide for attachment of the mid frame to the HP compressor stator casing at the front and to the turbine front stator casing at the rear. A similar flange at the rear of the inner casing is used for attachment of the turbine first stage stator segment inner support. Two bosses, at the bottom of the outer casing, accommodate combustion drain fittings.
- 3 An air take-off manifold is located around the periphery of the outer casing

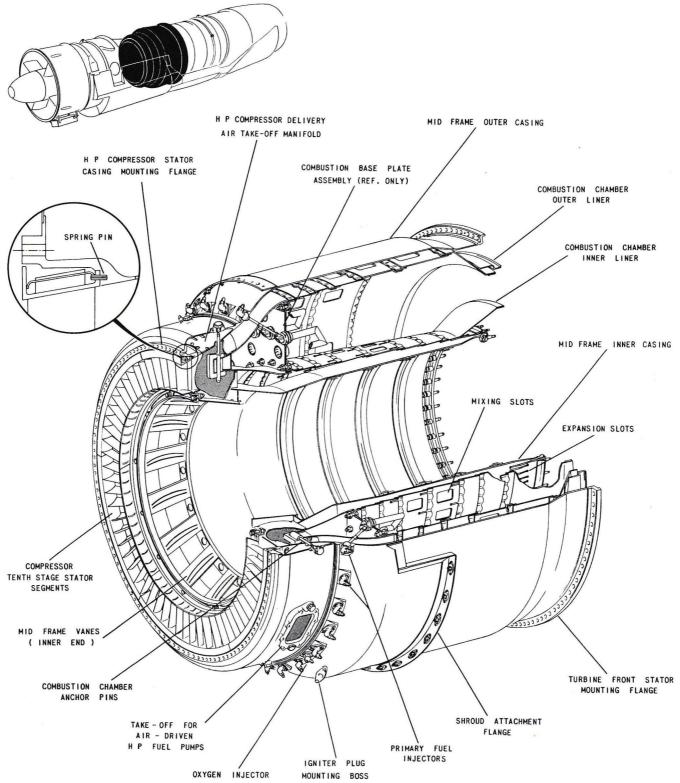
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Figure 3-1-12 Mid Frame Assembly

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immediately aft of the front mounting flange. Holes in the outer casing, at the rear of the tenth stage compressor stators, permit a bleed of HP compressor delivery (tenth stage) air into the manifold. Two take-off pads, one located on each side of the vertical centre line of the manifold, provide compressor tenth stage air for aircraft services; one pad is used, and the other blanked off, dependant upon engine installation requirements. The air take-off pad for the engine anti-icing system is located on the top RH side of the manifold. On the lower LH side of the manifold a pad is provided for an air take-off to drive the air-driven HP fuel pumps. A small take-off pad on the RH side of the manifold provides a P3 pressure tapping for use in the engine fuel and final nozzle control systems.

- Sixteen radially disposed combustion chamber anchor pins engage with holes in channel-shaped supports which are integral with the mid frame vanes. The anchor pins pass through guides on the forward end of the combustion base plate assembly to support and retain the assembly. Access holes in the air take-off manifold are located in line with the outer ends of the anchor pins and are plugged to prevent axial displacement and hence disengagement of the pins.
- The combustion chamber inner and outer liners are fabricated from cylindrical sections of stainless sheet steel which are joined together by spot welded corrugated jointing strips. When assembled in position, the liners form a slightly divergent annulus; a conical section welded to the rear of each liner forms a convergent outlet from the combustion chamber. The openings formed between the corrugations of the jointing strips permit a relatively cool flow of secondary air over the hot surfaces of the liners. Mixing slots in the liners allow a proportion of the secondary air flow to enter the combustion chamber, and mix with and dilute the products of combustion prior to their entry into the turbine. Expansion slots in the inner liner compensate for differential thermal expansion of the cylindrical sections.
- The front end of the inner liner is a sliding fit in a support sleeve on the inner rear flange of the combustion base plate assembly; the rear end of the liner is supported by a welded projection on the turbine first stage stator segment inner support. Axial displacement of the inner liner is prevented by a slotted sheet metal projection which is welded around the rear conical section of the liner. A lip on the projection engages with a recess in the rear bolting flange of the mid frame inner casing and is retained by the bolting flange of the turbine first stage stator segment inner support. The outer liner is bolted at the front, to the outer rear flange of the combustion base plate assembly; a support welded to the rear conical section of the outer liner is a sliding fit on the turbine first stage stator segment outer platforms.
- The compressor tenth stage stators consist of six segments of 11 stainless steel blades each. The blades have a hollow, aerofoil section, with corrugated stiffeners through the core of each blade. The outer ends of the blades are brazed to stainless steel, outer shrouds. Stainless steel plates are fitted between the flanges of

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the outer shrouds, over the ends of the blades. Steel inner shrouds are brazed to the inner ends of the blades; the inner ends of the blades are left open to vent the blade cores.

- The stator segments are pinned to a recess in the front face of the mid frame outer casing by spring pins and retained in position by the rear bolting flange of the HP compressor stator assembly when the engine is assembled. A segment retaining ring is bolted to the inner front face of the mid frame vanes to retain the inner shrouds of the stator segments.
- A primary fuel injector is mounted on each of the 32 bosses located around the mid frame outer casing immediately to the rear of the air take-off manifold. The inner ends of the fuel injectors are centred in flared receptacles at the inlets of the combustion tubes of the combustion base plate assembly. The outer end of each injector is carried in a spherical seating which permits self-alignment of the injectors. A fuel metering orifice in each injector is carefully matched to ensure uniform fuel distribution to the combustion tubes.
- Two bosses, near the bottom of the mid frame casing in line with the fuel injectors, provide a mounting for the oxygen injectors. When assembled to the mid frame, the inner ends of the oxygen injectors engage with the two hemispherical igniter chambers in the combustion base plate assembly. The outer ends are supported in spherical seatings similar to those used for the primary fuel injectors. An igniter plug is fitted to an angled boss on each side of the mid frame casing at the bottom so that the plugs line up with the igniter chambers. During normal ground starting, only the igniter plugs are used to ignite the fuel/air mixture around the combustion tubes. Relight at altitude is assisted by injecting oxygen into the igniter chambers through the oxygen injectors.
- 11 Sheet metal flanges, welded around the lower half of the mid frame outer casing, are fitted with anchor nuts for attachment of the engine shroud assembly.

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DESCRIPTION OF ENGINE AND COMPONENTS

COMBUSTION BASE PLATE ASSEMBLY

- The combustion base plate assembly, which forms the head section of the annular combustion chamber, is located inside the front portion of the mid frame. The assembly consists primarily of a combustion base plate mounted in a support frame, and serves to meter the correct proportion of HP compressor delivery air into the primary zone of the combustion chamber. Combustion tubes and secondary air tubes, extending rearwards from the combustion base plate, create proper conditions for efficient burning of the air and fuel mixture in the combustion chamber.
- The combustion support frame comprises circular inner and outer sheet steel plates, contoured to form a snout-shaped divergent annulus. The support frame divides the incoming HP compressor delivery air into a primary flow and a secondary flow. The primary air flow enters through the snout opening and is diffused in the support frame prior to entering the primary combustion zone. The secondary air flow passes rearwards through inner and outer annular spaces formed between the combustion liners and the midframe casing, and is admitted into the combustion chamber through openings in the liners to assist combustion in the primary zone and cool the burnt gases prior to their entry into the turbine.
- Sixteen streamlined, combustion chamber anchor pin guides are welded equidistantly around the snout opening, between the support frame inner and outer skins. These guides, with the anchor pins, support the forward end of the base plate assembly and keep it concentric with the mid frame casings.
- Flanges at the rear of the support frame provide for attachment of the circular combustion base plate to the support frame, and of the complete base plate assembly

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to the forward ends of the combustion chamber liners. Together with a support sleeve, the base plate is bolted directly to the inner flange at the rear of the support frame, the support sleeve at this location being a sliding fit on the forward end of the combustion chamber inner liner. The base plate is retained to the support frame outer rear flange by the bolts which secure the combustion base plate assembly to the forward end of the combustion chamber outer liner.

An inner and outer circle of stainless steel primary combustion tubes of 16 tubes in each circle, are fitted to the combustion base plate. Each tube is in the form of a "walking stick" which extends rearwards from the base plate, and is angled through two 90° turns so that the outlet of each tube is facing upstream. This configuration produces a flame which passes rearwards over the outer surface of the tubes, resulting in complete vapourization of the fuel as it passes through the heated tubes. Fuel is introduced into the front end of these tubes by means of 32 injectors

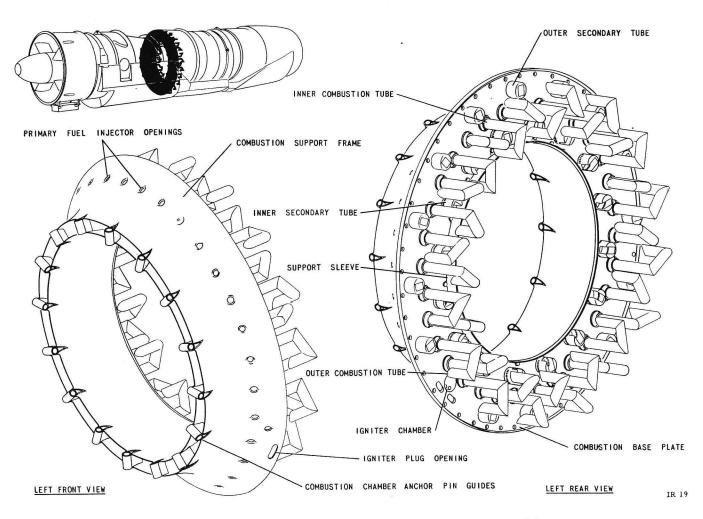


Figure 3-1-13 Combustion Base Plate Assembly

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which pass through dimpled holes in the support frame outer skin and locate in flared receptacles on the tube inlets. The primary air flow through the tubes mixes with and carries the injected fuel to the tube outlets.

- A double circle of secondary tubes, fitted on the rear face of the base plate, are arranged so that the air passing through these tubes meets with the fuel vapour expelling from the combustion tubes, and form vortexes about which the combustion flame stabilizes. Each of the 14 secondary pipes in the outer circle consists of a cylindrical cup-shaped pressing with a slotted opening in the rear end; the 16 tubes of the inner circle are similar except for the inclusion of a row of small holes around the base of each pipe.
- Two hemispherical igniter chambers, each consisting of a slotted dome-shaped pressing, are located on the lower front face of the base plate. Two flared receptacles in each chamber accommodate the inner ends of an igniter plug, and an oxygen and fuel injector. The two igniter plugs are of the low voltage surface gap type, and provide the spark which initiates combustion during the engine starting cycle. The oxygen injectors are provided to improve the re-light characteristics of the engine at altitude.

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DESCRIPTION OF ENGINE AND COMPONENTS

TURBINE FRONT STATOR ASSEMBLY

- The turbine front stator assembly is the structural connection between the mid frame assembly and the turbine rear stator assembly. It consists mainly of an outer casing, inner and outer supports for the turbine first stage stator segments, and a segmented shroud ring for the turbine first stage rotor. An air seal on the stator segment inner support permits a controlled flow of tenth stage cooling air (HP compressor delivery bleed air) to pass over the front face of the turbine first stage rotor disc. The turbine first stage stator blades increase the velocity of and direct the gas stream onto the turbine first stage rotor blades.
- The outer casing is a stainless sheet steel fabrication with machined bolting flanges welded to the front and rear of the casing. The rear flange is stepped to provide support for the front of the turbine second stage stator segments in the rear stator assembly. Twelve holes in the step are fitted with shear pins which engage with slots in the second stage stator segments. In addition, twelve 'T' headed pins are provided on the flange for location of the second stage stator segments. A small spring pin in the rear bolting flange ensures correct positioning of the turbine rear stator during assembly.
- 3 The turbine stator segment outer support is a conical-shaped stainless sheet steel fabrication having a front bolting flange and rear section welded to it, the rear section being channelled to form the outer front support for the stator segments. Five holes are drilled through the channelled section at each segment location and these, in conjunction with five holes drilled at a slightly different spacing pitch in the corresponding segment flange, permit a vernier adjustment to be obtained. A securing pin is inserted through the holes showing the best alignment.

PART 3 SECTION 1 DATE ISSUED: 18 MAR 58 PRELIMINARY TO EO 10B-30A-2 SHEET 2 OF 3 TURBINE REAR STATOR ASSEMBLY MOUNTING FLANGE SPRING PIN TURBINE FIRST STAGE SHROUD SEGMENT STATOR SEGMENT OUTER SECURING PIN COMBUSTION OUTER LINER SUPPORT -SHROUD SEGMENT LOCATING PIN SEGMENT OUTER PLATFORM STATOR SEGMENT INNER SEGMENT INNER PLATFORM SECURING PIN "T" HEADED PIN SHEAR PIN MID FRAME OUTER CASING _ MOUNTING FLANGE STATOR SEGMENT INNER SUPPORT AND AIR SEAL MID FRAME INNER CASING MOUNTING FLANGE TURBINE FIRST STAGE STATOR SEGMENT STATOR SEGMENT OUTER SUPPORT 20.0000000 COMBUSTION INNER LINER SUPPORT STATOR BLADES OUTER CASING

Figure 3-1-14 Turbine Front Stator Assembly

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The turbine stator segment inner support is bolted to the rear flange of the mid frame inner casing, and serves as a support for the inner ends of the stator segments. A welded projection on the inner support provides radial support for the rear of the combustion chamber inner liner; holes in the projection allow a flow of cooling air over the segment inner platforms. The three-gland air seal ring which mates with the front air seal of the HP turbine rotor assembly, is riveted to the inner cylindrical portion of the support.

- Each of the twelve first stage stator segments consists of four hollow aerofoil section blades nicro-brazed between an inner and outer platform. Circumferential ribs on the segment inner and outer platforms ensure an even distribution of the blade stresses. A lip, machined on the foremost rib of the outer platform, mates with and is secured to the channelled section of the stator segment outer support as described in Para 3. The ends of the segment outer platforms overlap to permit expansion and to minimize the escape of hot gases between the joints. A projection on the front face of the segment outer platform provides a support for the rear end of the combustion chamber outer liner. A spigot on the rear face of the outer platform supports the front of the turbine first stage shroud segments.
- The ribs on the stator segment inner platform are slotted and fit over an axially drilled top-hat section welded to the stator segment inner support. A securing pin with flats on each end, locates in the top-hat section holes and engages with the slots in the inner platform ribs to retain the inner ends of the stator segments circumferentially while permitting free radial movement to allow for thermal expansion.
- The twelve turbine first stage shroud segments are arranged circumferentially around the inner diameter of the casing immediately aft of the stator segments. As in the case of the stator segments, the shroud segments overlap each other, to allow for thermal expansion and contraction of the segments without serious effects on the turbine blade tip clearances. The front and rear faces of each shroud segment are channelled and mate with lips on the rear face of the stator segments and the front face of the outer casing rear flange. Circumferential displacement of the shroud segments is prevented by a locating pin passing through each stator/shroud segment joint.

NOTE

Although the HP and LP turbines have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

HIGH PRESSURE TURBINE ROTOR ASSEMBLY

- The HP turbine rotor assembly is of a two-stage design which comprises mainly two bladed rotor discs, separated by a spacer, and mounted on a stub shaft which is supported in the HP turbine bearing. The complete assembly is secured to the rear flange of the HP compressor rotor mainshaft by fifteen stainless steel tension bolts and self-locking nuts. The HP turbine rotor assembly absorbs the required proportion of power from the expanding gases passing from the combustion chamber and transmits it as torque power to drive the HP compressor rotor and external accessories.
- The turbine first and second stage blades are solid cast from heat resistant Inconel material. There are forty-seven blades in the first stage and fifty-three in the second stage. Each blade has a fir tree root for attachment to its respective disc, and an extended neck between the root and the blade platform. The blade tips of both stages are feathered to minimize damage should a tip rub develop. Conventional blade locking strips are used to prevent forward axial displacement of the first stage blades and rearward axial displacement of the second stage blades.
- Nicro-brazed stainless steel air baffles are interposed between the extended necks of the blade roots. The baffles are designed to meter a flow of cooling air between the necks and hence reduce the heat transfer from the blades to the discs. Axial movement of the baffles is prevented by tangs which engage with slots in the rims of the turbine discs. The platform on each blade prevents radial displacement of the baffles under centrifugal loads.
- Both the first and second stage turbine discs are machined from heat resistant Inconel forgings to withstand the high operating temperature at the disc rims. The

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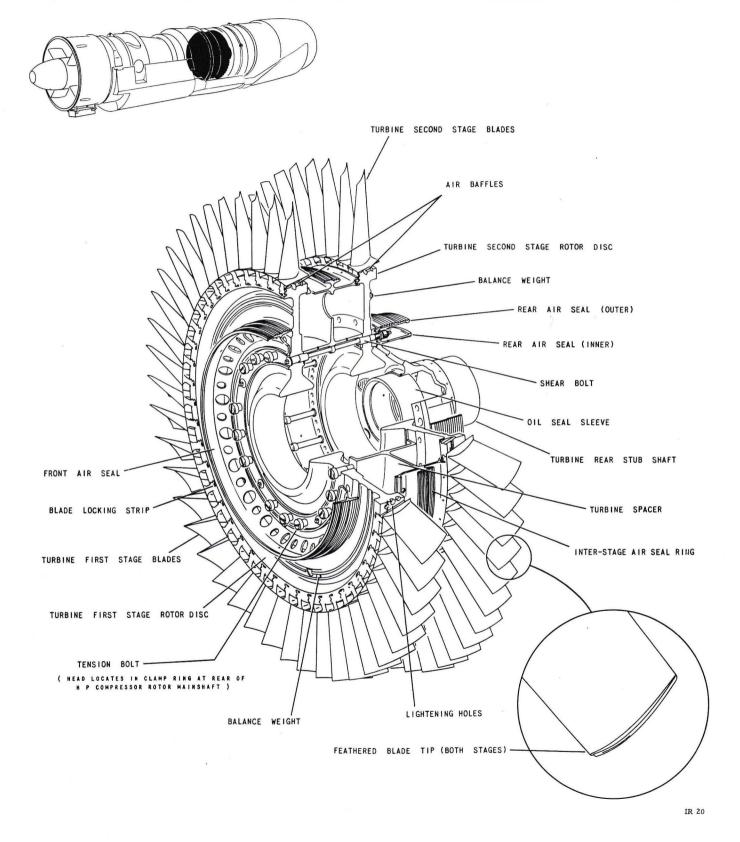


Figure 3-1-15 High Pressure Turbine Rotor Assembly

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discs are of conventional design, and cooling air is passed through holes in each disc web. Lightening holes are drilled in the periphery of the first stage disc between each blade slot.

- A spacer which is in the form of cylindrical inner and outer drums interconnected by an integral web is interposed between the first and second stage turbine discs. The outer drum locates between the rims of the discs and embodies an integral inter-stage air seal ring. The inner drum serves as a spacer shaft between the hubs of the discs. Holes in the web and outer drum provide a passage for cooling air through the inter-disc cavity. A cup-shaped flange at the rear of the outer drum butts against the rim of the second stage turbine disc and forms an annulus around the front face of the blade roots. The flange is drilled to allow cooling air to circulate through the annulus and cool the blade roots. In addition the outer drum portion of the spacer prevents rearward and forward axial displacement of the turbine first and second stage blades respectively.
- The turbine rear shaft is a robustly designed, nickel plated steel forging. The rear external diameter is nitrided and ground to provide the inner race of the HP turbine bearing. Eight holes drilled in the forward conical section of the shaft provide a passage for cooling air. A finely ground oil seal sleeve is riveted to a spigot on the inner front section of the shaft and mates with the carbon seal ring on the rear section of the LP mainshaft assembly.
- In addition to the inter-stage air seal on the turbine spacer, labyrinth-type seals are used at the front and rear of the rotor assembly to separate and apportion the cooling air flows through the turbine assemblies. The front air seal, which butts against the front face of the turbine first stage rotor disc, permits a controlled flow of tenth stage cooling air (HP compressor delivery bleed air) to pass radially outwards over the front face of the disc. Relatively large holes in the web of the front air seal allow the main flow of tenth stage cooling air to pass into the inter-disc cavity. The front air seal is retained in a channel on the rear flange of the HP compressor rotor mainshaft, rotational displacement of the seal being prevented by two lockpins which engage with slots in the mainshaft flange.
- The inner and outer air seals, fitted at the rear of the turbine second stage rotor disc, are retained by the HP turbine rotor shear bolts. The inner rear seal separates the seventh and tenth stage cooling air flows; the outer seal provides a controlled flow of tenth stage air to the front face of the turbine third stage rotor disc.
- With the exception of the front air seal, the components of the HP turbine rotor assembly are bolted together with five stainless steel shear bolts and high temperature self-locking nuts. The heads of the shear bolts locate in mating holes in the rear flange of the HP compressor rotor mainshaft. One bolt head, being of a larger diameter, ensures correct location of the complete turbine assembly on the mainshaft.

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10 Balancing of the HP turbine rotor assembly is effected by the addition of weights installed in two circular grooves, one on the front face of the turbine first stage disc and the other on the rear face of the turbine second stage disc. The outer balance weights in each group are secured by peening.

NOTE

Although the HP and LP turbines have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

TURBINE REAR STATOR ASSEMBLY

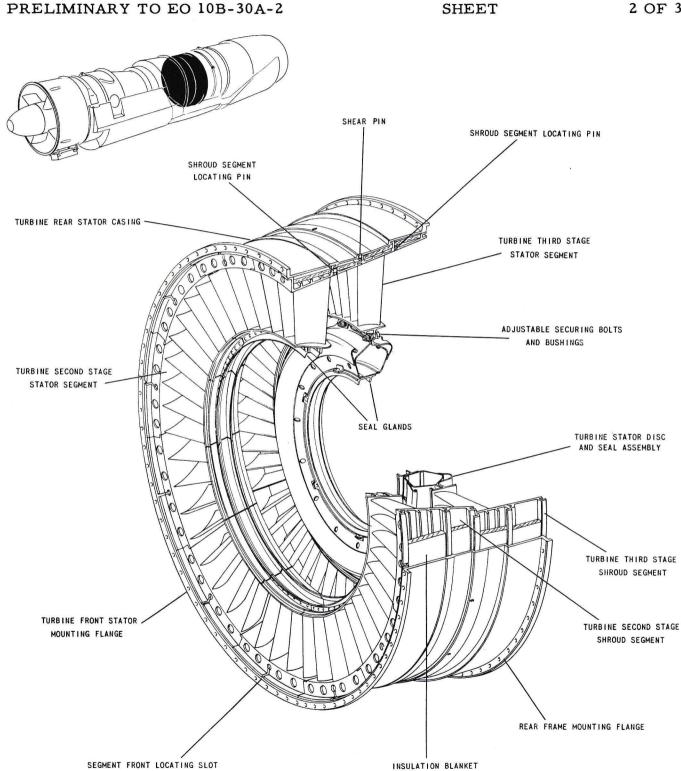
- The turbine rear stator assembly is the structural connection between the turbine front stator assembly and the rear frame assembly. It consists mainly of a machined stainless steel outer casing, the turbine second and third stage stator segments, a turbine stator disc and seal assembly, and segmented shroud rings for the turbine second and third stage rotor blades. The stator blades increase the velocity of, and direct the gas stream onto the turbine second and third stage rotor blades.
- Each of the twelve turbine second stage stator segments and sixteen turbine third stage stator segments consist of four hollow aerofoil section blades, nicrobrazed to inner and outer platforms. Each stage of stator segments is positioned circumferentially around the inner diameter of the outer casing. The ends of the segment outer platforms overlap to permit expansion and to minimize the escape of hot gases between the joints. Circumferential ribs on the segment inner and outer platforms ensure an even distribution of the blade stresses. The outer platforms of the turbine second stage stator segments are located at the front by locating pins positioned around a step machined on the rear face of the turbine front stator casing; shear pins which engage with the slots in the front lip of the segment outer platforms and holes in the rear face of the turbine front stator casing, prevent circumferential displacement of the segments. A machined groove in the outer casing mates with and retains the rear lip of the segment outer platforms. Two sheet metal glands are riveted to the ribs on the stator segment inner platform and mate with the interstage air seal ring which is integral with the HP turbine rotor spacer disc.
- The outer platforms of the turbine third stage segments have forward projecting lips machined on the front and rear faces; these lips engage with retaining

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grooves machined on the inner surface of the outer casing. Circumferential displacement of the turbine third stage stator segments is prevented by shear pins which pass through holes in the outer casing and engage with slots in the segment outer platform front lips.

- The turbine second stage shroud segments and third stage shroud segments are arranged circumferentially around the inner diameter of the casing immediately aft of their respective stator segments. The shroud segments overlap each other to allow for thermal expansion and contraction of the segments without serious effects on the turbine rotor blade tip clearances. The front and rear faces of each shroud segment are channelled; the second stage segment channels mate with lips on the front and rear faces of the turbine third and second stage stator segment outer platforms respectively; the third stage shroud segments locate on lips machined on the rear face of the turbine third stage stator segment outer platforms and on the front bolting flange of the rear frame assembly. Circumferential displacement of the shroud segments is prevented by a locating pin passing through each stator/shroud segment joint.
- The turbine stator disc and seal assembly is bolted to the rearmost rib of each turbine third stage stator segment inner platform. True concentricity is obtained at the seal glands by means of adjustable eccentrically drilled hexagonal bushings. The seal glands are riveted to the stator disc inner diameter and mate with the outer rear air seal of the HP turbine rotor assembly. The stator disc is suitably contoured and ported, and in conjunction with the air seal, apportions the flow of tenth stage cooling air (HP compressor delivery bleed air) over the faces of the turbine second and third stage rotor discs and the third stage stator segment inner platforms.
- 6 Insulation blankets are fitted between the segments and the stator casing, to reduce thermal expansion of the casing and to minimize heat transfer to the aircraft structure.

NOTE

Although the HP and LP turbines have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE TURBINE ROTOR ASSEMBLY

- The LP turbine rotor assembly is a single stage design comprising a bladed disc bolted to the LP turbine shaft which is supported by the turbine bearing assembly. The complete assembly, together with the HP turbine bearing, is splined to the LP mainshaft and is centralized at the front and rear by conical seatings. The assembly is retained by a locknut which seats against the rear face of the turbine shaft cone and locked by the tang of a steel lockring which engages with a hole in the LP mainshaft and a slot in the locknut.
- The LP turbine rotor assembly absorbs power from the gases passing from the turbine second stage, and transmits it as torque power, via the LP mainshaft, to drive the LP compressor rotor, the LP external gearbox, and the constant speed unit in the inlet frame assembly.
- The turbine third stage rotor disc is machined from a stainless steel forging and has fifty-nine solid cast Inconel blades arranged around its outer periphery. The blades are retained in the disc rim by fir tree roots and are retained axially by a tanged locking strip, the tangs being bent outwards against the front and rear face of the disc. The blades have feathered tips to reduce the incidence of damage in the event of blade tip rub. Nicro-brazed stainless steel air baffles are fitted between the extended necks of the blade roots, the baffles being retained axially by tangs which engage in slots in the rim of the disc, and radially by the blade platforms. The function of these baffles is to meter cooling air through the extended necks of the blade roots to reduce the heat transfer from the blades to the disc.
- A dovetail slot machined on the rear face of the rotor disc provides for the addition of balance weights during balancing operations. Using the same point of

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Figure 3-1-17 Low Pressure Turbine Rotor Assembly

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attachment to the LP turbine shaft as the disc, a labyrinth-type rear air seal extends to the rear and mates with a seal extending forward from the turbine bearing assembly. This seal provides a controlled flow of seventh stage cooling air over the rear face of the disc.

- The LP turbine shaft is a nickel plated steel forging with the rear external diameter nitrided to form an integral inner race for the LP turbine bearing. On the outer periphery of the shaft, an integral labyrinth-type front air seal mates with the inner rear air seal of the HP turbine rotor assembly. Oil from the bearing assembly passes forward along the LP shaft splines and is directed by centrifugal force through holes drilled diagonally through the LP shaft forward of the internal splines. The oil is then led via drilled holes in the HP turbine rotor shaft to the front face of the HP turbine bearing. This oil is scavenged to the rear sump by centrifugal force through holes in the reversed section of the LP shaft forward of the bearing, and also as an air/oil mixture through passages in the rear conical section of the shaft.
- Housed within the reversed portion of the LP turbine shaft are the outer race and rollers of the HP turbine bearing. This bearing utilizes, when the engine is assembled, the hardened surface of the HP turbine shaft as an inner race. Also housed in the reversed portion of the LP turbine shaft is a carbon seal ring which, together with the HP turbine bearing, and carbon seal ring seat, is held in place by a spanner nut. A locking pin, which is inserted in one of the nut slots, locates in a drilling in the shaft, and is held by a retaining ring housed in a groove machined in the shaft.

NOTE

Although the HP and LP turbines have been treated as separate units, the numbering of the stages has been consecutive from the front of the engine through the two units. This is to be consistent with the numbering used in the engine functional descriptions.

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE TURBINE BEARING ASSEMBLY

General

The LP turbine bearing assembly is mounted within the rear frame housing and comprises mainly the housing for the LP turbine bearing, and the engine rear sump. The assembly also embodies features for the distribution and scavenging of oil to and from the LP and HP turbine bearings.

Turbine Bearing Housing

The turbine bearing housing is fabricated from three steel parts welded together to form a mounting for the LP turbine bearing and the location for a large diameter carbon ring type oil seal. The part which houses the bearing is drilled and channelled at three equidistant points to accommodate the oil tubes which carry lubricating oil to the front face of the bearing. A machined flange on the oil seal housing, provides for attachment of the housing to the forward bolting flange on the inner diameter of the rear frame housing.

LP Turbine Bearing

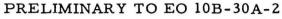
- The LP turbine bearing comprises a single row of crowned rollers spaced evenly in the bearing outer race by a silver-plated cage. The bearing outer race locates against a flange on the bearing housing and is retained in position by a flanged extension on the front of the rear sump. Air holes in the extension and the bearing outer race support flange permit a free circulation of cooling air around the bearing.
- 4 The LP turbine bearing supports the LP turbine shaft which houses the HP

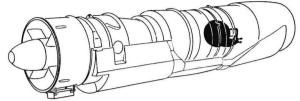
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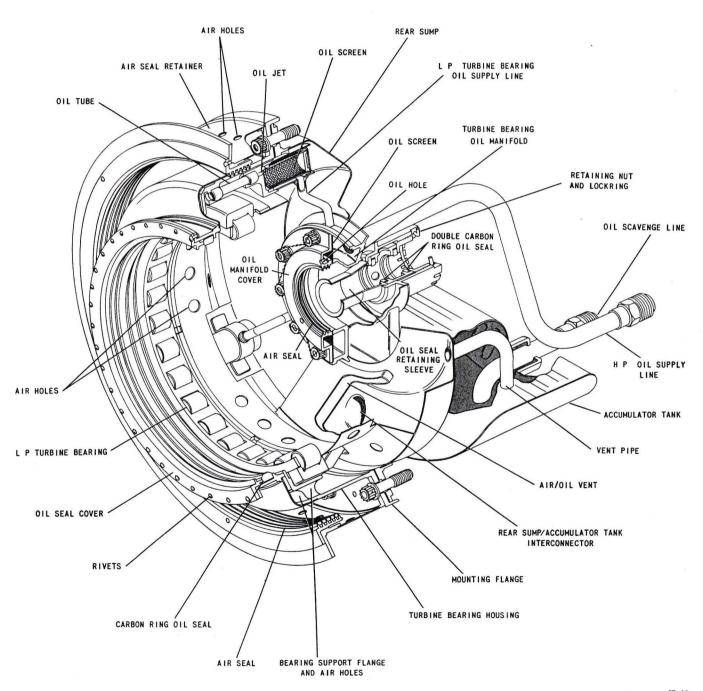
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turbine bearing, see Figure 3-1-17. The HP bearing supports the HP turbine rear stub shaft. The arrangement of mounting the bearings one inside the other in the same transverse plane, reduces the interaction of shaft vibrations and eliminates LP mainshaft deflection.

Rear Sump and Oil Manifold

- The rear sump is a welded stainless steel assembly which forms the rear cover of the turbine bearing chamber and serves as a collector for the scavenge oil from the bearings and the air/oil mist created by the rotation of the bearing rollers. The hub of the rear sump houses the rear end of the LP mainshaft internal vent tube and accommodates an annular turbine bearing oil manifold.
- The turbine bearing oil manifold is supplied through a HP oil line which is connected to the inner section oil tubes in the rear frame bullet assembly. From the manifold, oil is supplied to the LP and HP turbine bearings in two separate flows. The oil flow to the LP bearing passes radially outward from the manifold through supply lines to three oil screen housings spaced evenly on the inside of the rear sump outer cylindrical portion. After passing through the screens, the oil flows through oil jets into the oil tubes which lead to the front face of the LP turbine bearing. The flow to the front face of the HP turbine bearing is delivered from the oil manifold through three screen-protected holes in the manifold cover and thence by centrifugal action through drillings and passages in the HP turbine shafting.
- An interconnector at the bottom of the rear sump allows scavenge oil from the turbine bearings to drain into an accumulator tank which is welded to the lower rear face of the sump. The oil is scavenged from the accumulator tank through a scavenge line which is connected to the inner section oil tubes in the rear frame bullet assembly. A vent pipe between the top of the accumulator tank and the rear sump ensures proper scavenging from the tank in the event that the oil level in the sump rises above the rear sump/accumulator tank interconnector opening.
- Air/oil mist in the bearing cavity is ducted from the bottom of the rear sump, through an air/oil vent, to the annulus formed between the rear sump hub and the internal vent tube. From this annulus the air/oil mist is transferred to the internal oil return tube and thence to the front sump.
- 9 A machined flange welded to the outer cylindrical section of the rear sump is provided to secure the rear sump and turbine bearing housing to the forward flange of the rear frame housing.

Oil Seals

10 The large diameter carbon ring oil seal at the front of the turbine bearing

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housing seats on the reversed portion of the LP turbine shaft and, together with the oil seal rings on the LP turbine shaft and the rear shaft of the LP mainshaft assembly, seals the front of the rear sump. The seal ring is retained by an oil seal cover which is riveted to the front part of the bearing housing. A double carbon ring oil seal in the hub of the rear sump seats on the internal vent tube and is pressurized with compressor seventh stage air to complete the sealing of the rear sump. The double seal is retained in the hub by a retaining nut and lockring.

Air Seals

It wo labyrinth type air seals are provided, one being a small diameter seal integral with the turbine bearing oil manifold cover, the other a large diameter seal which mates with the seal ring bolted on the rear face of the turbine third stage rotor disc. The small seal on the manifold cover seats against the internal oil return tube. The large seal is riveted to the forward end of a cylindrical sheet metal support which uses the same point of attachment as the bearing housing and rear sump. Holes in the seal support apportion the cooling flow of seventh stage air between the rear frame baffle and cover. The seal itself permits a controlled flow of seventh stage air to pass over and cool the rear face of the turbine third stage rotor disc.

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DESCRIPTION OF ENGINE AND COMPONENTS

REAR FRAME ASSEMBLY

General

The rear frame assembly is the main rear structural unit of the engine. It provides a suitable structure for attachment of the engine rear mounts and supports the bearings of both turbine rotors. The assembly consists mainly of an outer casing, a rear frame housing which forms the hub of the assembly, five struts, and the rear frame fairing.

Outer Casing

- The outer casing comprises a cylindrical front section and a conical rear section which are welded to a channel section main support ring. The support ring provides three points of suspension, one at the top and one on each side, for mounting the rear of the engine. The top mounting is an aircraft fitting which is bolted through holes in the flanges of the support ring, while the side mounts, located above the horizontal centre line of the engine, are used for the attachment of the rear mounting struts. Each side mount comprises a rear mounting pin which is supported in lined drillings in the support ring flanges. Displacement of the mounting pin is prevented by a cotter pin which passes through holes in the head of the mounting pin and a retaining clip. The support ring also carries the outer ends of the rear frame housing support struts.
- Machined bolting flanges welded to the front and rear of the outer casing, provide a mounting for the turbine rear stator assembly at the front and the after-burner assembly at the rear. A spigot on the front mounting flange supports the rear of the turbine third stage shroud segments when the turbine rear stator and rear

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frame assemblies are bolted together. Flanged pads spaced around the periphery of the casing front section provide a mounting for the eight probe, dual thermocouple system used for exhaust gas temperature measurement. Two additional pads on the lower right-hand side of the casing provide alternative mounting positions for the afterburner hot streak relay jet; a third pad at this location accommodates the P7 pressure probe. At the bottom of the casing immediately aft of the main support ring are two bosses, the foremost of which accommodates the oil supply and scavenge lines for the turbine bearing assembly, the rearmost being a mounting for the fuel supply line to the afterburner primary fuel manifold. Provision is made at ten points on the rear section of the casing for attachment of the internally mounted afterburner spray and stabilizer group.

Rear Frame Housing

The rear frame housing encases and supports the turbine bearing assembly and associated sub-assemblies. The housing is a stainless steel machined forging, secured centrally and axially by the struts. The turbine bearing assembly is bolted to a flange machined on the inner diameter of the housing. A collector box for seepage oil and waste air is riveted to the lower outside surface of the housing. The collector box is vented to the gas stream through a vent pipe which is attached to the front of the box and passes through an opening in the fairing hub. Four insulation blankets, which serve as a heat shield for the turbine bearing assembly, are positioned and wirelocked around the periphery of the housing between the struts; the fifth space is occupied by the collector box.

Struts

The five struts are designed to transmit bearing loads to the main support ring, and are arranged to compensate for differential thermal expansion of the casting and rear frame housing. Each strut comprises a solid front leg and a tubular rear leg welded at their outer ends to a shouldered and threaded stub which forms the outer support for the strut, and is secured to the rear frame casing by a castellated nut locked by a cotter pin. The inner ends of the legs are welded to plates which are mounted tangentially on the rear frame housing. Serrations machined on the mating faces of the strut plate, an adjusting strip, and the rear frame housing, permit location of the housing concentrically within the rear frame casing. Elongated holes in the adjusting strip permit it to be moved axially along the bolts to obtain correct bedding of the mating serrations. The adjusting strips compensate for variations between the strut and housing due to tolerance stack-up or service distortion of the parts. An eccentric hexagonal-headed stop pin which is positioned through the housing, adjusting strip and strut plate, is held in position by a cover plate and a retaining ring. The pin absorbs axial loads between each strut and the housing.

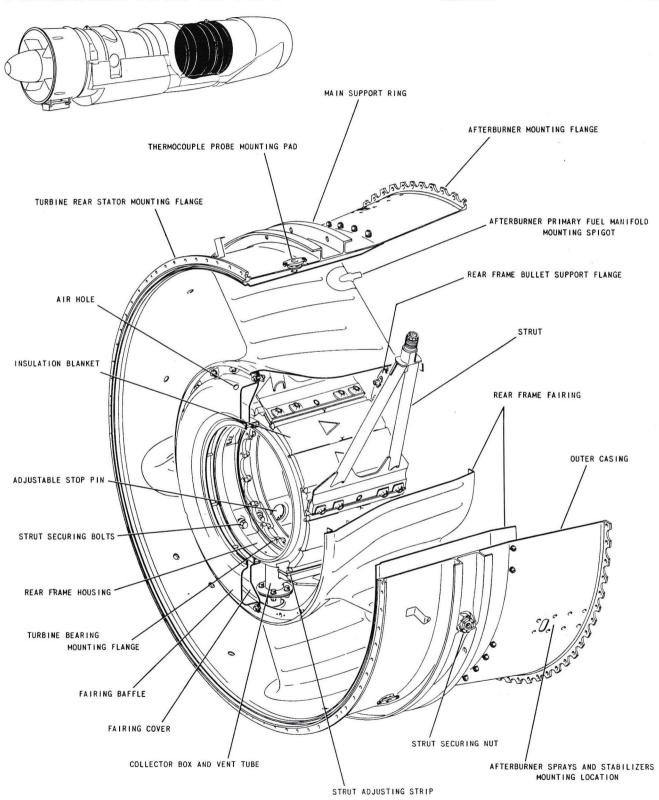
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Rear Frame Fairing

- The rear frame fairing provides a smooth passage for the exhaust gases passing through the rear frame by streamlining the struts and smoothly contouring the inner surface of the casing and the outer surface of the rear frame housing. The five aerofoil-shaped vanes of the fairing form streamlined housings for the struts and are integrally formed with the hub of the fairing. The outer ends of the vanes are welded to the cylindrical outer portion of the fairing which is secured to the casing rear section by forty-five mushroom-headed screws, locking nuts, and washers. The hub of the fairing is supported at the front by the fairing cover and the fairing baffle, which in turn are supported at their inner diameters by a spigot machined on the front face of the rear frame housing.
- An opening at the bottom of the fairing hub accommodates the vent pipe from the rear frame collector box. Holes in the outer cylindrical portion of the fairing provide openings through which pass the thermocouple probes, the outer ends of the struts, the turbine bearing oil supply and scavenge lines, the afterburner hot streak relay jet, and the P7 probe. A boss is welded on the trailing edge of each vane to support the afterburner primary fuel manifold. Welded around the front flange and riveted to the rear lip of the fairing hub is a series of self-locking anchor nuts. The nuts are used for attachment of the front cover and baffle, and the rear frame bullet assembly respectively. The fairing is strengthened by embossed fluting on the surfaces of the vanes and hub.

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DESCRIPTION OF ENGINE AND COMPONENTS

REAR FRAME BULLET ASSEMBLY

General

The rear frame bullet assembly is located at the rear of the inner housing of the rear frame. The main function of the assembly is to provide a smoothly transitioned passage for the engine exhaust gases leaving the rear frame, and to seal the rear end of the rear frame hub cavity into which the internal air vent tube exhausts. In addition, the bullet assembly forms the rear supporting member of the rear frame fairing and houses the inner section of the rear bearing oil tubes. The assembly comprises mainly a fairing support cylinder and ring, a rear frame housing cover, a bullet, and the inner and outer sections of the rear bearing oil tubes.

Fairing Support Cylinder and Ring

The fairing support cylinder is a stainless sheet steel fabrication with machined flanges welded to the front and rearfaces, the front flange being used to attach the fairing support cylinder to the rear bolting flange of the rear frame housing. The fairing support ring consists of an angled circular collar, which locates in the extended portion of the fairing support cylinder rear flange. Together with the rear frame bullet, the support ring is bolted to the inward projecting rear flange of the rear frame fairing. An insulation blanket is wrapped around the periphery of the fairing support cylinder to minimize the transfer of heat to the rear frame hub cavity. A drain, located at the bottom of the fairing support cylinder and immediately forward of the rear flange, removes any residual oil which tends to collect in the rear frame hub cavity. The oil is drained forward into a collector box in the rear frame, from which it is vented into the engine exhaust stream.

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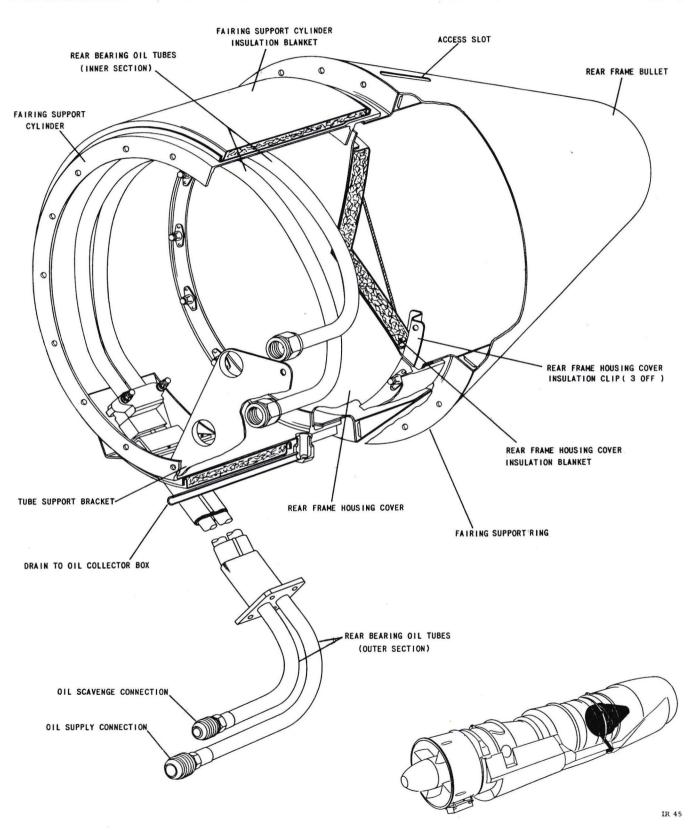


Figure 3-1-20 Rear Frame Bullet Assembly

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Rear Frame Housing Cover

The rear frame housing cover, comprising a concave stainless steel plate, is bolted to the inward projecting rear flange of the fairing support cylinder and is covered on the rear face by an insulation blanket. The rear frame cover and insulation blanket separate the rear frame hub cavity from the relatively high temperatures inside the rear frame bullet. The insulation blanket consists of a pad of insulation sandwiched between two layers of Inconel foil and is positioned by three equi-spaced insulation clips which are bolted to the rear face of the cover. The blanket is firmly retained against the rear frame housing cover by locking wire which passes between the three insulation clips.

Rear Frame Bullet

The rear frame bullet is a conical steel pressing with a mounting flange welded to the front face for bolting the bullet to the rear flange of the rear frame fairing. Access to the mounting bolt heads is gained through slots in the bullet skin immediately behind the front face. An inner skin adjacent to the slots minimizes the entry of hot exhaust gases into the bullet cavity. A small vent hole in the inner skin maintains equal gas pressure loads on each side of the bullet skin.

Rear Bearing Oil Tubes

The rear bearing oil supply and scavenge tubes both consist of an outer section which passes inward from two external connections, through the bottom vane of the rear frame, and an inner section which is housed within the fairing support cylinder. The outer section is secured to a mounting boss at the bottom of the rear frame outer casing and terminates at a junction on the bottom of the support cylinder. The inner section passes from the junction and terminates immediately behind a bracket which supports the oil tube connections of the turbine bearing assembly.

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DESCRIPTION OF ENGINE AND COMPONENTS

LOW PRESSURE EXTERNAL GEARBOX ASSEMBLY

- The LP external gearbox assembly is located on a mounting pad at the outer end of the front frame No. 6 strut, the drive to the gearbox being supplied by shafting from the internal gearbox. The cast magnesium gearbox casing is T shaped in section with a flange at each end of the T head for mounting the LP tachometer generator and the LP speed governor. The tachometer generator and the speed governor measure and limit respectively the rpm of the LP compressor rotor.
- The drive is transmitted from a radially positioned shaft to one parallel to the engine axis by means of a pair of case hardened, phosphated, steel, bevel gears. The bevel drive gear on the radial axis is centrally located by two ball bearings in a flanged, steel cartridge, which in turn is retained in the gearbox casing by two machine screws. The screws also locate and retain the steel shim between the flanges of the gearbox casing and the bearing cartridge.
- The driven gear is dowelled to a hollow gearshaft and meshes with the drive gear on the radial axis. The shaft and gear combination is mounted in two ball bearings located in bearing cartridges in the gearbox casing. The front and rear ends of the driven gearshaft are machined to accommodate the square-ended driveshafts of the LP tachometer generator and the LP speed governor respectively.
- 4 Lubrication of the bevel gears is by a screened oil jet positioned in the outer casing, which supplies a spray of oil to the contact point of the gears. The ball bearings in the gearbox are splash lubricated. External piping delivers pressure

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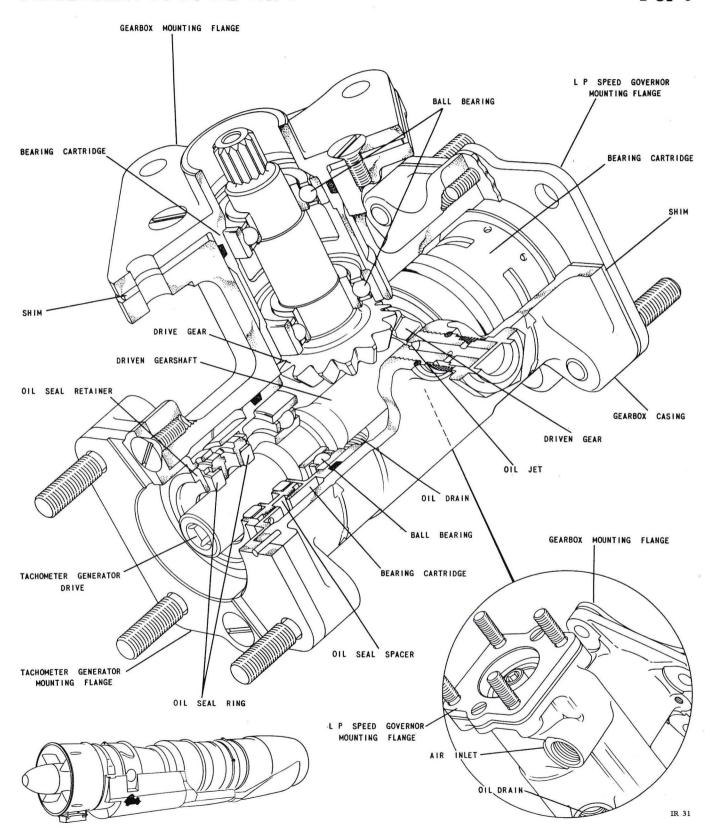


Figure 3-1-21 Low Pressure External Gearbox Assembly

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oil to the gearbox and carries scavenge oil to the HP external gearbox sump. A pair of oil seal rings, separated by a steel spacer, are fitted at each end of the driven gearshaft to prevent oil seepage from the gearbox. The cavity between the oil seal rings is pressurized with HP compressor air supplied through an external fitting and channelling in the gearbox casing.

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DESCRIPTION OF ENGINE AND COMPONENTS

HIGH PRESSURE EXTERNAL GEARBOX

General

- The HP external gearbox assembly is located on the mounting pad at the outer end of No. 5 strut in the front frame casing. When viewed from the rear, the gearbox follows the contour of the front frame, through approximately 40 degrees, up the right-hand side of the engine. The drive for the gearbox is transmitted from the HP compressor front stub shaft to the HP gear train in the internal gearbox assembly and then by a quillshaft to the external gearbox. The assembly consists of a gearbox casing and front cover, together with the gear train required to drive an aircraft power take-off assembly and engine auxiliary components mounted on the gearbox.
- The front face of the gearbox has three pads which accommodate the aircraft power take-off assembly, the engine oil scavenge pump, and the HP speed governor. The rear face has four mounting pads to which are mounted the engine starter, the hydraulic pump, the oil lubrication pump, and the tachometer generator and HP speed senser.

Gearbox Casing and Front Cover

The gearbox is a crescent shaped magnesium casting with drillings to supply lubricating oil to the gears and bearings. Forward of the rear face, an integral inner wall houses the bearing cartridges supporting the rear ends of the gearshafts. The cavity formed between the rear face and the inner wall is sealed and serves as an air gallery for compressor seventh stage air which is used to pressurize the oil seals. The front cover, which is bolted to the front face of the gearbox with an 'O' ring interposed in the joint, is also of cast magnesium. The cover supports the

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MOUNTING FACE LUBRICATION PUMP GEAR -LOWER BEARING MOUNTING FRONT COVER GEARBOX MOUNTING FACE SCAVENGE PUMP GEAR AIRCRAFT POWER TAKE-OFF OIL JET STARTER MOUNTING FACE HYDRAULIC PUMP GEAR STARTER SPLINES ANGLED OIL JET SCAVENGE PUMP MOUNTING FACE COMPOUND IDLER GEAR -OUTPUT SHAFT ACCESS PLUG VIEW SHOWING ALTERNATIVE MOUNTING POSITION OF AIRCRAFT POWER TAKE-OFF AND LOCATION OF OIL JETS AIRCRAFT POWER TAKE-OFF-AIR INLET FITTING OIL SEAL RINGS OUTPUT GEARSHAFT STARTER SHAFT CARTRIDGE OIL SEALS STARTER SHAFT MOINIS STATE PINION AIRCRAFT POWER TAKE-OFF CASING POWER TAKE-OFF BEVEL PINION INPUT BEVEL PINION SHAFT INPUT BEVEL BEARING CARTRIDGE OUTPUT SAFETY SHAFT PINION POWER TAKE-OFF BEYEL PINION SHAFT OUTPUT GEARSHAFT BEARING LOCKNUT OUTPUT SHAFT BEARING CARTRIDGE IR 39 AIRCRAFT SPLINED COUPLER LOCKNUT

Figure 3-1-22 High Pressure External Gearbox

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forward end bearings of the hydraulic pump gear, the scavenge pump gear and the lubrication pump gear, and provides a mounting flange for the oil scavenge pump. When the gearbox is installed on the engine it is steadied by a bracket fitted on a mounting boss at the upper right-hand end of the casing, the bracket in turn is secured to the front frame No. 4 strut cover. Four bosses located on the left-hand side of the casing below the gearbox mounting face accommodate the engine oil cooler mounting brackets. The mounting pads for the engine auxiliaries are machined so that their axes are parallel to the engine axis.

Input Bevel Gear Assembly

The input bevel gear assembly consists of a bevel gear supported by two single row angular contact bearings installed in bearing mountings. The upper mounting is screwed into the lower mounting, and retained in position by a tanged, steel locking ring. The lower mounting is retained in position on the gearbox mounting face by two fillister head screws.

Power Take-off Input Shaft and Bearing Cartridge

- The power take-off input shaft assembly comprises three concentrically mounted shafts with integral gears supported by two ball bearings housed in a flanged steel cartridge. The bearing cartridge mounting flange is fitted between the gearbox casing and the mounting flange of the aircraft power take-off casing with the forward end of the cartridge extending into the aircraft power take-off casing. The three gears comprise an auxiliary drive pinion, an input bevel pinion, and a power take-off bevel pinion. The input bevel gear meshes with the power take-off bevel pinion, the shaft of which extends forward and is supported by a ball bearing at each end. The power take-off bevel pinion shaft is hollow with rows of lightening holes drilled round the circumference. Internal splines at the rear of the shaft, inside the pinion, mate with splines on the input bevel pinion shaft and the auxiliary drive pinion shaft.
- The input bevel pinion shaft is hollow and drilled with lightening holes. A close tolerance diameter at the rear of the input bevel pinion teeth locate the shaft centrally inside the forward end of the power take-off bevel pinion shaft. The input bevel pinion delivers the drive to the aircraft power take-off bevel gear.
- The auxiliary drive pinion shaft is the inner member of the three concentrically mounted shafts. It has a spur gear at the rear and threads with a locknut and washer at the forward end to secure the three shafts together. Internal splines at the rear of the shaft mate with the splines on the forward end of the starter shaft.

Aircraft Power Take-off Assembly

8 The aircraft power take-off assembly is bolted to the front face of the mounting

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pad on the front of the HP external gearbox, see Figure 3-1-22. The assembly consists of a casing, an output shaft assembly, an output safety shaft, a power take-off drive oil seal and an output shaft access plug.

- 9 The aircraft power take-off casing is of cast magnesium and is installed on the front face of the HP external gearbox in either one of two positions, approximately 180 degrees apart, dependent upon the engine installation.
- The output shaft sub-assembly consists of an output bevel gear bolted to the flanged end of the output gearshaft. The gear meshes with the input bevel pinion. The output gearshaft and bevel gear are supported by two single row ball bearings mounted in a bearing cartridge. The output gearshaft has splines machined on the inner diameter of the forward end which mate with the splines on the rear of the output safety shaft. Three rows of lightening holes are drilled round the body of the shaft. A blanking plug is installed at the rear of the internal splines and is retained by an internal circlip. Threads on the shaft accommodate a special type of sleeved locknut which has a grease packed ball bearing fitted at the forward end of its inner diameter to support the output safety shaft; a circlip at the front of the bearing retains the bearing and safety shaft in position. The forward outer diameter of the locknut is smooth and provides the seat for a double carbon ring oil seal.
- The output safety shaft, which is hollow except for the centre waisted section, fits into the internal splines in the forward end of the output gearshaft. The shaft is located axially by its shoulder, which butts against the front grease packed bearing and is clamped to the bearing by the aircraft splined coupler. The waisted section is to provide a shear spot which, in the event of overload conditions, will shear and thus prevent damage to the gearbox and/or engine.
- An oil seal housing is screwed into the forward end of the output gearshaft bearing cartridge. Slots in the forward face of the housing accommodate a wrench for tightening, and a row of holes drilled in the large diameter of the housing provide passage for compressor seventh stage air for pressurizing the oil seals.
- Access to the output gearshaft is provided by a plug installed in the casing at the rear of the bevel gear. The plug is of cast magnesium and is a sliding fit in the casing. It is retained by a ring and an 'O' ring forms an oil seal between the plug and the casing. Three equi-spaced integrally cast lugs are provided for withdrawing the plug.

Starter Shaft

14 The starter shaft is a steel forging which is bored out from the front and rear with a small section left solid near the forward end. External splines on the forward end of the shaft mate with the internal splines at the rear of the auxiliary drive

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pinion. The shaft is supported by a ball bearing mounted at the front end of a bearing cartridge at which point the shaft is retained by a washer and locknut. The bearing is retained in the cartridge by a circlip. A double, carbon ring oil seal is mounted in the rear of the cartridge, the shaft outer diameter providing the seat for the seal rings. Compressor seventh stage air passes through slots in the cartridge to pressurize the cavity between the seal rings. A flinger on the starter shaft between the bearing and the oil seal ring deflects incoming sealing air and prevents oil starvation of the bearing. The flinger also serves to induce oil mist through the bearing. Both the oil mist and the sealing air are exhausted through slots in the starter shaft cartridge into the gearbox sump. Internal splines at the rear of the shaft are for mating with the engine starter driveshaft.

Compound Idler Gears

The compound idler gears consist of two integral spur gears mounted on a hollow shaft, the larger gear meshing with the auxiliary drive pinion and the smaller one with the hydraulic pump gear. Each end of the idler shaft is supported by a ball bearing mounted in a cartridge which is an interference fit in the external gearbox casing. At the front of the shaft, a plug and an 'O' ring are fitted in the gearbox casing and retained by an internal circlip. At the rear, the bearing and cartridge are located in position by an air gallery plug, the flange of which butts against a shoulder in the gearbox casing. The air gallery plug is of magnesium and has a flange with four cross grooves to permit air circulation.

Hydraulic Pump Gear

- The hydraulic pump gear consists of two spur gears integral with a shaft. The larger gear meshes with and is driven by the smaller of the compound idler gears, whilst the smaller gear meshes with and drives the scavenge pump gear. The gearshaft, which is hollow, is mounted on two ball bearings; the inner races butt against shoulders on the gearshaft. Internal splines towards the rear end of the gearshaft, mate with those on the hydraulic pump driveshaft, which fits inside the gearshaft and is retained by a circlip.
- 17 The bearing at the rear of the hydraulic pump gearshaft is carried in a steel cartridge which is an interference fit in the gearbox casing. The front bearing is mounted in a steel cartridge fitted to the gearbox front cover. Immediately behind the rear bearing cartridge is an oil seal cartridge and oil seal. The oil seal is of the double ring type and the hydraulic pump driveshaft serves as the seat for the seal rings. Compressor seventh stage air from the air gallery is fed through slots in the cartridge to pressurize the cavity between the seals.

Scavenge Pump Gear

18 The scavenge pump gear is a single spur gear with an integral hollow shaft. It

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is supported at the front by a ball bearing mounted in a cartridge housed in the gearbox front cover, and at the rear by a bearing mounted in a cartridge fitted into the inner wall of the gearbox. Internal splines at the front of the shaft provide the drive for the oil scavenge pump, and the spur gear meshes with and drives the lubrication pump gear.

Lubrication Pump Gear

The lubrication pump gear is a single spur gear with an integral hollow shaft which is supported by a ball bearing at each end. At the rear, the shaft passes through a steel air gallery liner which is installed between the inner wall and the rear face of the gearbox to prevent oil leakage into the air gallery. Internal splines at the rear end of the shaft provide the drive for the oil lubrication pump, and the spur gear meshes with and drives the HP compressor speed governor gear.

HP Compressor Speed Governor Gear

- The governor spur gear has an integral hollow shaft and is supported by two ball bearings. The rear bearing is mounted in a steel flanged cartridge which is housed in a bearing support installed in the gearbox rear face. The forward section of the shaft is necked and a double carbon ring type oil seal, mounted in a cartridge, seats on this portion of the shaft. Compressor seventh stage air is fed through holes in the cartridge to pressurize the cavity between the seal rings.
- 21 Internal splines at the front and rear of the shaft transmit the drive to a HP compressor speed governor, and a tachometer generator and a HP speed senser respectively.

Lubrication

- Lubrication of the gearbox is effected by oil jets directed at gear meshes, and the oil mist created by the gear action serves to lubricate the bearings. Two oil jets, positioned at the top of the casing, approximately six inches apart, spray oil onto the spur gear train. A third oil jet of the angled type is located near the top of the gearbox just forward of the gearbox mounting pad, and sprays oil at the meshing point of the input bevel gear and the power take-off bevel pinion. A fourth jet is mounted in the aircraft power take-off for lubrication of the bevel gears. Each oil jet is screened to protect the jet orifices from blockage by foreign matter.
- Two oil bobbins are positioned in the oil feed and return passages at the joint between the HP external gearbox and the aircraft power take-off. The bobbin at the top of the joint is in the oil feed passage to the aircraft power take-off, and the one at the bottom is in the oil return passage.

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DESCRIPTION OF ENGINE AND COMPONENTS

ENGINE FIREWALL ASSEMBLY (Engine Shroud)

General

The engine firewall assembly, which comprises a front and rear section, isolates the engine nacelle from auxiliary equipment and piping located round the underside of the engine. The assembly was originally named the engine shroud. A flow of air through the auxiliaries compartment formed by the front section, vapourizes and carries away any fuel and oil leakage which may occur during engine running, and hence reduces the risk of fire. Waste air from the auxiliaries compartment and exhaust air from the HP fuel pumps is expelled to atmosphere through ducts in the rear section. The air flows are induced rearward by the action of an airframe-mounted ejector casing located round the engine final nozzle. All openings in the firewall are covered with screens which serve as flame traps in the event of fire.

Front Section

The front section of the firewall comprises a panelled framework which extends along the lower half of the engine from the inlet frame rear bolting flange to approximately the mid point of the mid frame outer casing. The framework formers and stringers are made from stainless sheet steel and are bolted to supports on the engine casings. Corrugated stainless steel panels are bolted to anchor nuts riveted on the framework, and the panels and framework are detachable to facilitate engine maintenance. Doors on the underside of the firewall provide access to the engine starter, engine controls, and systems installation connections; the starter access door is supplied by the airframe manufacturer.

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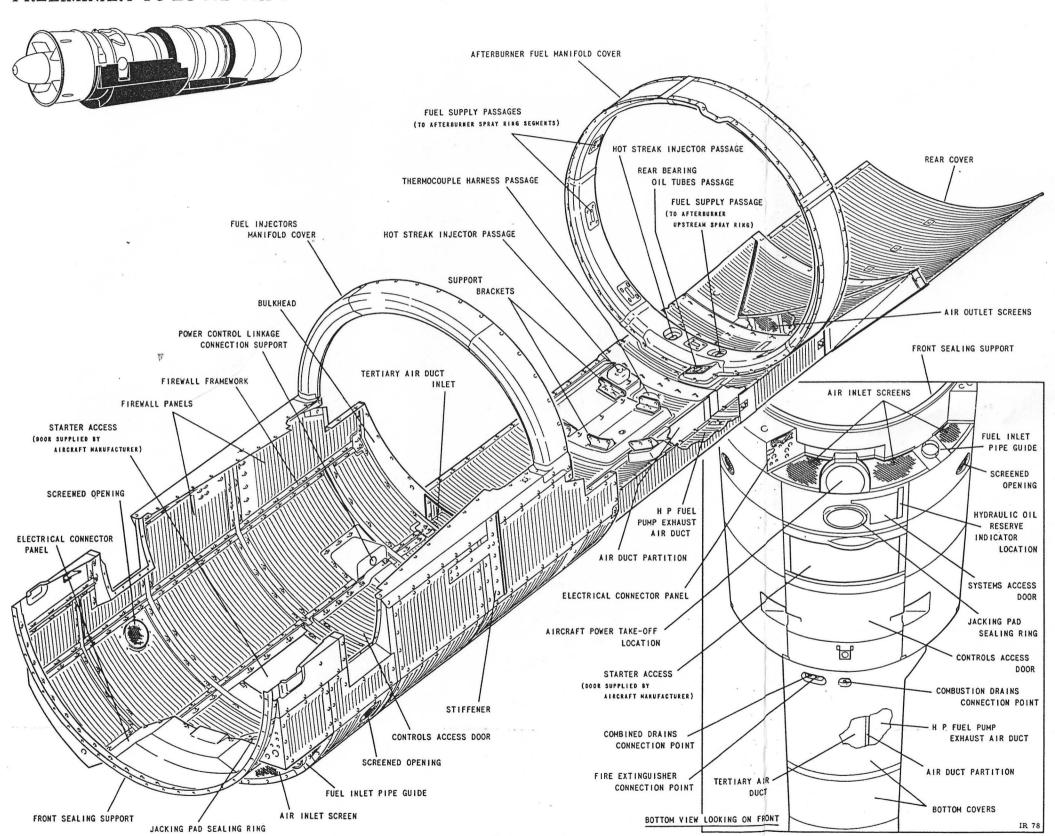


Figure 3-1-23 Engine Firewall Assembly

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Screened openings in the front face of the firewall permit a proportion of the nacelle (secondary) air flow to enter the auxiliaries compartment; air entering the compartment is termed tertiary air. In addition, a small screened opening in each side of the firewall permits fire extinguisher fluid to be sprayed into the auxiliaries compartment in the event of fire during ground running. Other openings in the front section of the firewall accommodate the hydraulic oil reserve indicator and the power control linkage connection as well as fuel, oil and electrical connections.

Rear Section

- The rear section of the firewall comprises an air duct casing which extends from the rear bulkhead of the front section to the afterburner shroud. The casing is made up of corrugated panels in the form of an inner platform which is supported by brackets bolted to the engine casings, and a channel section outer platform which is bolted to anchor nuts riveted along the edges of the inner platform. Sliding sections in the platform allow for differential thermal expansion between the firewall and the engine casings, and facilitate removal of the afterburner assembly during ground maintenance.
- An axial partition between the inner and outer platforms divides the space into two air ducts. The large right-hand duct carries tertiary air rearwards from the auxiliaries compartment and also serves as a channel for fuel, oil and electrical service lines to the rear of the engine. The smaller left-hand duct carries the relatively hot exhaust air from the HP fuel pump air turbines to the rear of the engine. The common outlet from the ducts is screened to prevent rearward flame propogation in the event of fire. A rear cover bolted to the bottom of the afterburner shroud, directs the outlet air from the ducts to the rear of the engine where it joins the secondary air stream being expelled to atmosphere through the airframe ejector casing.
- Openings in the inner platform provide passages for the afterburner and hot streak injector fuel supply lines, the rear bearing oil tubes and the thermocouple harness. Small openings in the outer platform accommodate the combined drains and combustion drains connections, and the fire extinguisher connectors.

Manifold Covers

- A manifold cover, which encloses the upper half of the primary fuel injector supply pipes, is vented into the auxiliaries compartment so that any fuel leakage and vapour from this region is exhausted to atmosphere by the tertiary air stream. The cover engages with a machined groove immediately ahead of the injector mounting bosses on the mid frame outer casing and is bolted at the rear to a semi-circle of anchor nuts riveted round the periphery of the outer casing.
- 8 A similar cover for the afterburner fuel manifold is vented into the tertiary air duct. It is proposed to delete the outer panels of this manifold cover on later engine models.

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DESCRIPTION OF ENGINE AND COMPONENTS

NACELLE AIR RESTRICTOR ASSEMBLY

General

- The nacelle air restrictor assembly is designed to obtain the best matching of the intake, engine, and ejector over the operating envelope of the aircraft. In order to achieve this, the restrictor assembly is composed of two parts. These are a fixed restrictor, and a variable restrictor which is made up of four automatically operated flaps.
- The flow area provided by the fixed restrictor and the flaps has been chosen to give the highest possible thrust augmentation from the secondary flow at high Mach numbers, and to limit the by-pass flow at low Mach numbers, in order to keep the inlet flow distortion within limits. Because of the pressure drop across the restrictor, it has been possible to stress the portion of the engine tunnel aft of the restrictor assembly for a lower pressure differential across the tunnel wall, and thereby save weight in the aircraft structure. The fixed restrictor assembly is attached to the rear flange of the LP stator casing using the casing attachment bolts.
- 3 Detailed information regarding the secondary airflow through the engine tunnel and the ejector action of the final nozzle will be found in the relevant Arrow 2 Engineering Order.

Fixed Restrictor Sections

4 The one large and two small fixed restrictor sections, which are fabricated from stainless steel sheet, extend round the upper half of the LP stator casing interposed by the two upper variable flap sections. Fusion welded, laminated construction

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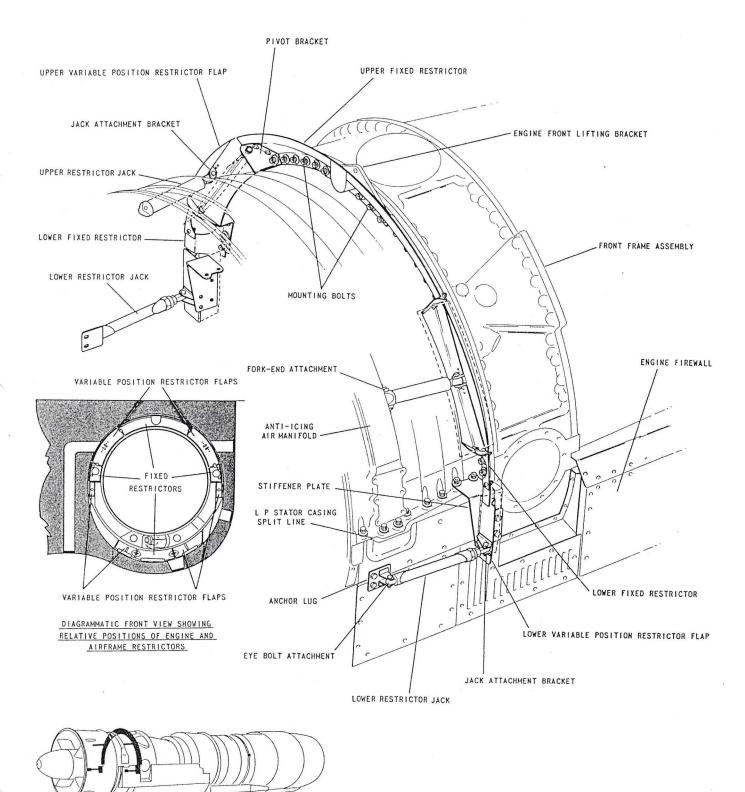


Figure 3-1-24 Nacelle Air Restrictor Assembly

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provides strength and rigidity to the fixed sections. A 'U' shaped housing formed in the upper fixed restrictor section adjacent to the engine front lifting bracket, provides clearance for the attachment of the engine lifting sling to the bracket.

The two lower fixed restrictor sections are cut away to permit the anti-icing air supply line to pass through them. The outer member of each restrictor section is detachable to facilitate removal of the anti-icing air supply line during engine maintenance.

Upper Variable Position Restrictor Flaps

- Two variable position restrictor flaps of aerofoil section are located on the upper half of the LP stator casing and follow the contour of the openings provided by the fixed restrictor sections. Each flap is fabricated from stainless steel sheet and is brazed to a centre tube which acts as a pivot for the flap assembly. Pivot brackets, bolted to the fixed restrictor sections retain the flaps, allowing them to pivot about their axes.
- The degree of opening of the upper variable position restrictor flaps is determined by two spring-loaded jacks, the forward ends of which are retained by fork ends bolted to the anti-icing air manifold of the LP stator casing. The jack plungers are pinned to attachment brackets riveted to the flaps.

Lower Variable Position Restrictor Flaps

The two lower variable position restrictor flaps are hinged to angular stiffener plates, which are bolted to the LP stator casing split line and the engine firewall assembly forward of the rear flange of the casing. Each flap is fabricated in two sections from fusion welded stainless steel sheet. The rear section forms an integral stiffener which also serves as a stop for the flap when in the fully open position. Two brackets brazed to the forward face of the flap, provide a fork for the pin attachment of the lower jack. The forward end of the jack is retained by an anchor lug bolted to the engine firewall.

Restrictor Jacks

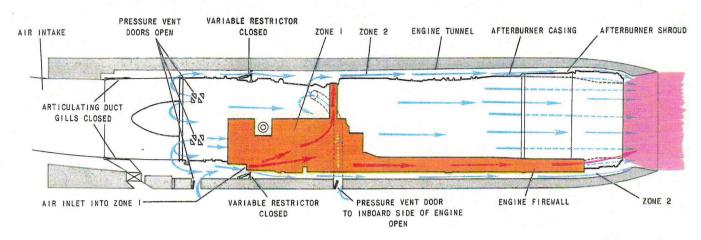
- 9 The upper and lower jacks, although differing in size, are of the same general construction. The stainless steel jacks each comprise a tubular casing, housing a plunger and a spring.
- An internal stop is incorporated in the two upper jacks in the form of a free floating sleeve on the plunger. When the spring is compressed, the sleeve contacts the outer casing end cap, thus preventing further travel of the plunger and determining the maximum open position of the restrictor flap.

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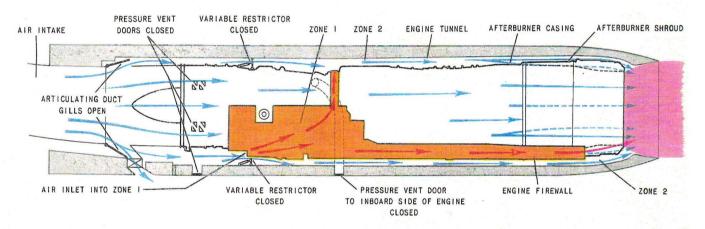
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AIR FLOW FROM PRESSURE VENT DOORS



AIR FLOW FROM ARTICULATING DUCT GILLS

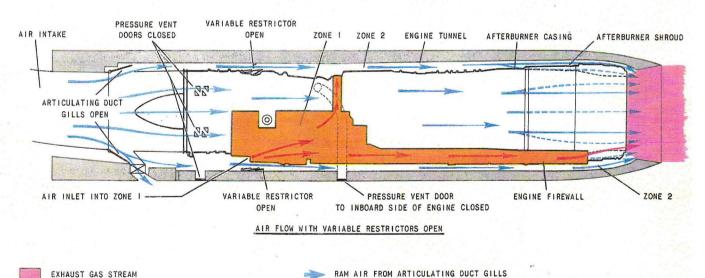


Figure 3-1-24A Engine External Cooling

COOLING AIR FROM PRESSURE VENT DOORS

COOLING AIR STREAM THROUGH ZONE I

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Operation

During ground running and at aircraft speeds below Mach 0.55 a depression exists in the air intake, and the variable position flaps of the restrictor remain in the closed (vertical) position.

- The intake depression causes spring-loaded duct gills, located in the articulating duct forward of the engine, to close to prevent reverse flow into the duct. Under these conditions, the ejector effect of the final nozzle induces a small depression in the compartment between the engine and the engine tunnel (designated as Zone 2), and also at the aft section of the engine accessories compartment (designated as Zone 1).
- This depression causes spring-loaded pressure vent doors to open and allow air from atmosphere to enter the engine tunnel. The vent doors are located in the side of the nacelle wall adjacent to the engine front frame, and in the engine access door on the underside of the nacelle. A percentage of the incoming air is drawn into the accessories section due to the depression in the rear section of the compartment.
- 14 The remainder of the air flow from the pressure vent doors passes over the front section of the engine, through the relatively small air gap provided by clearance between the restrictor and the contour of the engine tunnel, and is drawn to the rear of the engine to cool and vent the external engine surfaces and aircraft structure.
- 15 The cooling and venting air flows eventually combine and pass through the final nozzle ejector. Above Mach 0.55 a small percentage of additional thrust is provided by the air flows due to heat from the afterburner casing being passed into the engine cooling airstream.
- Above aircraft speeds of Mach 0.55 the pressure in the air intake duct becomes greater than ambient due to the ram effect. Under these conditions the intake duct gills open, allowing the pressure in the bay to rise above ambient and thereby causing the pressure vent doors to close.
- The variable position restrictor flaps are designed to open at a specific pressure differential, and thus the time at which they open is dependent on aircraft speed, altitude, and the amount of by-pass flow. The point of opening also depends on whether the afterburner is on or off since this has a marked effect on the ejector action of the final nozzle and thus the amount of by-pass flow.

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DESCRIPTION OF ENGINE AND COMPONENTS

AUXILIARY AND ACCESSORY DRIVES

General

1 The auxiliary and accessory drives consist of an HP gear train and an LP gear train, the power to drive both gear trains being drawn from the HP compressor and the LP compressor respectively.

HP Gear Train

- A bevel gear (2) is splined to the HP compressor shaft (1) and drives a bevel pinion (3) which turns the drive through 90 degrees. A quill shaft (4) which is splined to the bevel pinion extends down through No. 5 strut of the inlet frame, and transmits the power from the bevel pinion to an input bevel gear (7) mounted in the HP external gearbox (5). The drive is then turned through 90 degrees by a power take-off bevel pinion (8) mounted on a shaft in the input shaft assembly. This assembly comprises three concentrically mounted shafts with integral gears. Internal splines at the rear of the power take-off bevel pinion shaft, inside the pinion, mate with the splines on the input bevel pinion shaft and the auxiliary drive pinion shaft. The input bevel pinion shaft accommodates an input bevel pinion (9) which drives an output bevel gear (10) in the aircraft power take-off gearbox (6). The auxiliary drive pinion shaft accommodates an auxiliary drive pinion (11) which transmits the drive to a series of spur gears which in turn drive the auxiliary components through internally splined integral shafts.
- 3 The initial drive for the gear trains is provided by the engine starter through internal splines in a starter shaft which is in turn splined to the auxiliary drive pinion shaft.

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H P COMPRESSOR SHAFT 7 INPUT BEVEL GEAR 8 POWER TAKE-OFF BEVEL PINION 2 H P BEVEL GEAR 9 INPUT BEVEL PINION 3 H P BEVEL PINION IO POWER TAKE-OFF OUTPUT BEVEL GEAR 4 H P QUILL SHAFT 5 H P EXTERNAL GEARBOX II AUXILIARY DRIVE PINION 12 COMPOUND IDLER GEAR 6 AIRCRAFT POWER TAKE-OFF ASSEMBLY 13 HYDRAULIC PUMP GEAR 14 HYDRAULIC PUMP 15 SCAVENGE PUMP GEAR 16 SCAVENGE PUMP 17 LUBRICATION PUMP GEAR 18 LUBRICATION PUMP 19 H P SPEED GOVERNOR GEAR 20 H P SPEED GOVERNOR 21 H P TACHOMETER GENERATOR 22 H P SPEED SENSER 23 ENGINE STARTER 24 L P COMPRESSOR SHAFT 25 L P DRIVE GEAR 26 L P DRIVEN SPUR GEAR 27 L P BEVEL PINION 28 L P DRIVEN BEVEL GEAR 29 L P QUILL SHAFT 30 L P EXTERNAL GEARBOX ASSEMBLY 31 L P EXTERNAL GEARBOX BEVEL GEARS 32 L P TACHOMETER GENERATOR 33 L P SPEED GOVERNOR 34 CONSTANT SPEED UNIT DRIVESHAFT 35 STARTER SHAFT

Figure 3-1-25 Auxiliary and Accessory Drives

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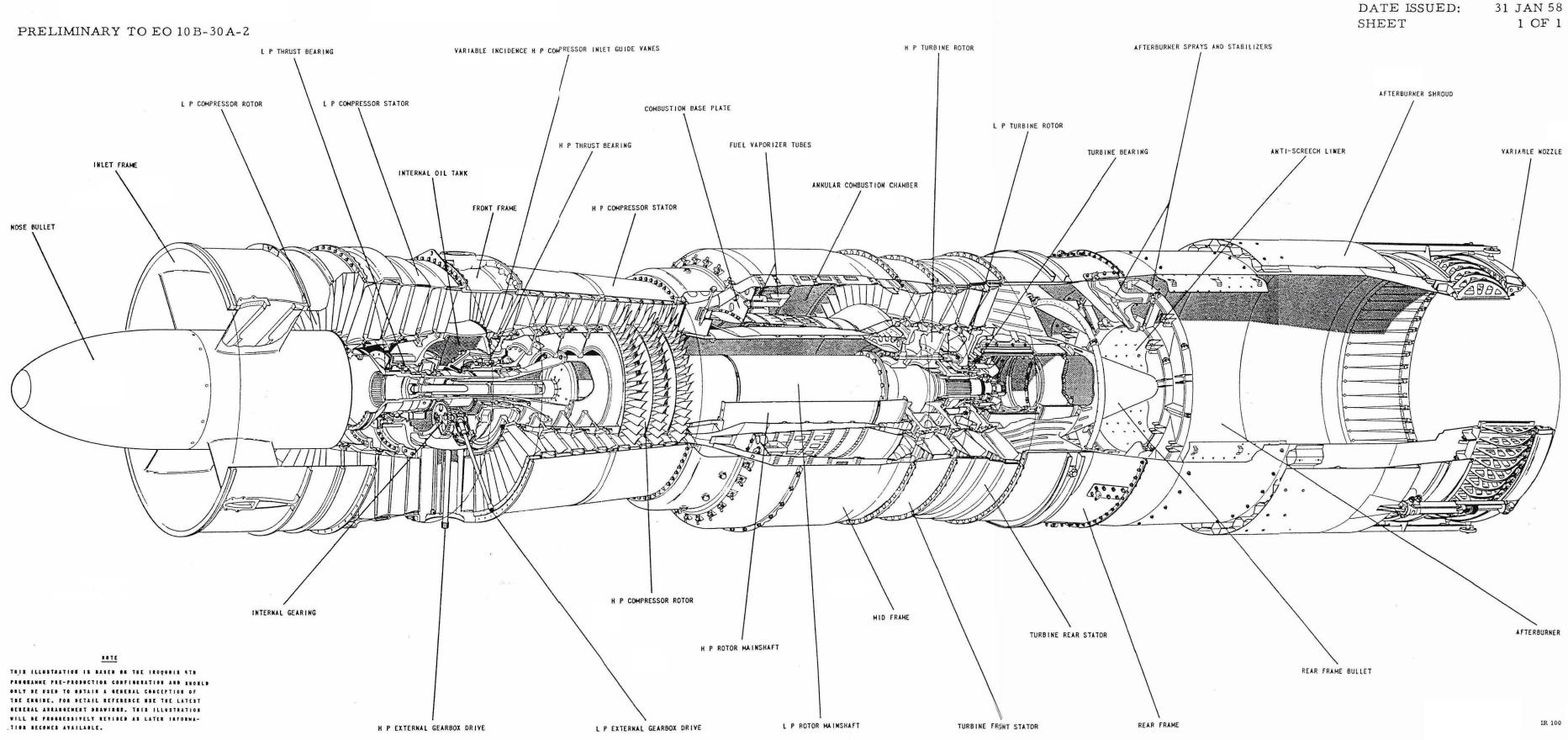
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LP Gear Train

- A drive gear (25) is mounted on the LP compressor shaft (24) and drives a spur gear (26) mounted co-axially with a bevel pinion (27) which meshes with a driven bevel gear (28). A quill shaft (29) engages with internal splines in the driven bevel gear and transmits the drive through the inlet frame No. 6 strut to a pair of bevel gears (31) in the LP accessories gearbox (30). The driven member of the two bevel gears is mounted on a shaft which is machined to accommodate square-ended driveshafts of auxiliary components.
- 5 A drive for an alternator/constant speed unit combination is taken forward of the LP compressor shaft. Internal splines in the shaft mate with the splines on the constant speed unit driveshaft (34).
- 6 Lubrication of the gearboxes is effected by oil jets directed at gear meshes, and the oil mist created by the gear action serves to lubricate the bearings.
- Refer to the Advance Data Sheets for the HP and LP external gearboxes for complete construction details of the gears and shafts in the HP and the LP gear trains and to Part 2 for details of rotational direction and relative speeds.



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SECTION 1

Figure 3-1-26 (Issue 1) Sectioned View of Engine (Excluding Engine Firewall and External Accessories)

ROYAL CANADIAN AIR FORCE

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FUEL SYSTEM

INTRODUCTION

General Principles of Engine Control

- As described in Part 1, the thrust of a turbojet engine is related to the increase in momentum of the gases passing through it, this increase being brought about by burning fuel in the air flow passing through the engine. Thus, air and fuel are the two essential substances consumed by the engine in its operation. Therefore, basic control of the engine power output can be effected by regulating either the mass air flow through the engine or the fuel supply to the engine combustion chamber.
- The complex mechanical arrangement and resultant performance losses and weight penalties necessary to effect control of the large quantities of air consumed by a turbojet engine, renders this method of engine control impracticable in aircraft applications, thus, regulation of the engine fuel flow is selected as the most suitable method of control.
- In addition to regulating the engine fuel flow, it is desirable to control the area of the final (propelling) nozzle of the turbojet to obtain maximum performance from the engine. A detailed description of the variable area final nozzle used on the Iroquois, and the control principles involved, will be issued later.

Basic Control Variables

4 Certain engine conditions vary as a result of changing the quantity of fuel burned in the engine. For example, when the pilot's power control lever is advanced to obtain a higher thrust output, the fuel flow to the engine is increased. This in turn results in higher gas temperatures in the combustion chamber and an increased

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acceleration of the gases through the turbine causing an increase in engine rpm and mass airflow. In addition, corresponding increases in gas pressure occur throughout the engine. Thus, any one of these variables, - engine thrust, gas pressures and temperatures, or engine rpm, could be used as a basis on which to establish fuel schedules.

- Engine rpm is ideally suited as the primary controlled operating variable in that it bears a definite relationship to thrust output and the method of cockpit indication of engine rpm is relatively simple. The rpm indicator in the cockpit readily provides the pilot with an indication that the engine is satisfactorily responding to his power setting.
- The graph in Figure 3-2-1 shows the linear relationship between the position of the power control lever (throttle angle) and thrust. The graph also shows a typical

engine rpm curve required to produce the desired thrust/throttle angle relationship. The relationship between rpm and thrust is generally consistent throughout the entire operating range of the engine and is relatively unaffected by the changing set of conditions encountered during engine operation. If, for example, 75% rpm produces 50% of the available thrust output at sea level conditions, the same engine rpm will produce approximately 50% of the available thrust at altitude. Thus, the setting of the power control lever establishes a demand for a certain percentage of the available thrust. The fuel control units interpret this setting as a request for the engine rpm which will deliver the desired thrust output and, in

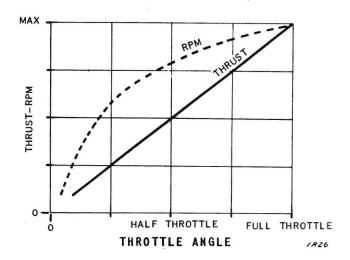


Figure 3-2-1 Typical Thrust - RPM/Throttle Angle Relationship

turn, schedule the exact fuel flow required to produce this rpm.

Temperature and pressure sensing devices are used extensively in the Iroquois fuel system to apply trims on the basic fuel schedule. These "override" controls modify the fuel flow to keep the engine within its operating requirements and limitations. Figure 3-2-2 shows the source and terminology of the control variables used on the Iroquois engine.

Fuel Control Requirements

8 It is essential that the engines in modern high performance aircraft be automatically controlled to provide the thrust output determined by the setting of the power control lever. Furthermore, it is desirous to have a single control lever per engine which enables the pilot to request thrust modulation over the entire engine

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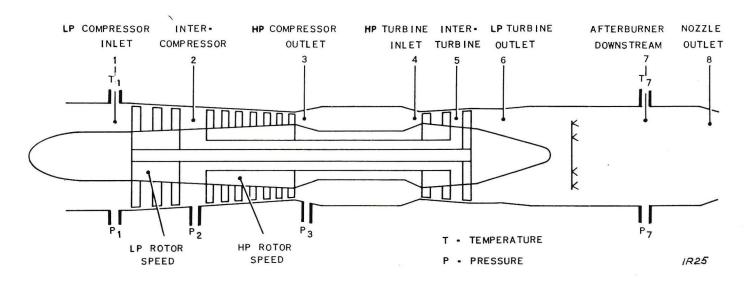


Figure 3-2-2 Engine Control Variables and Pick-up Points

and afterburner operating range, and which can be used to effect engine shutdown.

- As the turbojet engine is frequently operated at or near its maximum operating conditions, a system of controls is necessary which will override and modulate the basic fuel schedule when maximum rotor speed or structural and temperature limitations are reached or exceeded. On the Iroquois engine these trimming controls are fully automatic and protect the engine from damage under normal "steady state" operating conditions, during accelerations and decelerations, or as a result of inept handling of the power control lever. In addition, the control units are capable of maintaining the air/fuel ratio at the correct values to sustain safe and efficient combustion of the fuel under all operating conditions. Compensation is also made for changes in altitude and aircraft forward speed to maintain a constant engine speed for a given power control lever setting over the complete range of aircraft operation. The minimum idling fuel flow to the engine is modulated to produce a rising idling speed schedule as altitude increases, and hence maintain sufficient compressor pressure for adequate cabin pressurization and other aircraft services at altitude.
- 10 As an added safety feature, provision is made for an emergency system which provides the pilot with full manual control of the fuel flow to the engine should malfunctioning of the normal control units develop.

OUTLINE OF IROQUOIS FUEL CONTROL SYSTEM

General

Il The Iroquois fuel control system is specifically designed to schedule the engine and afterburner fuel flows according to the varying fuel requirements encountered under all operating conditions. The system is essentially hydromechanical in nature

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and includes adequate provision to fulfil the general control requirements discussed in the preceding paragraphs.

12 For the purpose of description the system can be sub-divided into four major groups, namely, an HP fuel supply system, main and emergency control systems for the engine fuel supply, and a control system for the afterburner fuel flow. A brief description of each group is contained in the following paragraphs; more detailed accounts of the components and their functions will be issued in subsequent advance data sheets.

HP Fuel Supply

- 13 The supply of pressurized fuel required for engine and afterburner operation is provided by two air-driven centrifugal type pumps. Referring to Figure 3-2-3, the fuel at boost pump pressure is supplied from the aircraft tanks to the HP pumps where it is pressurized to the required operating pressure. From the pumps, the fuel is delivered at high pressure to the appropriate control system units.
- The pump pressure control unit depicted in the diagram, controls the pressure output of the pumps by regulating a bleed flow of HP compressor delivery air (P₃) used to drive the air turbines which in turn drive the centrifugal impellers in the pumps. Regulation of the air flow is effected by a hydraulic actuator which receives signals from the pump pressure control unit and which is mechanically linked to a barrel valve in the air inlet duct of the pumps. The pump pressure control unit primarily senses the pressure rise across the engine compressor, this being a measure of the mass air flow through the engine, and hence regulates the pump delivery pressure according to changes in engine speed, aircraft forward speed and altitude.
- The pump output is controlled by the control unit at a value above the discharge pressure required at the burners. The excess pressure delivered by the pumps provides for initial acceleration of the engine, compensates for the pressure losses in the system components, and supplies a small controlling pressure drop across the metering orifices located elsewhere in the system. The principle advantage of this type of control system over a by-pass system is that the demand on the pumps is decreased, resulting in an extension of their effective life. Under most operating conditions, a by-pass type of system is continuously over-pressurized, resulting in a large proportion of pump delivery pressure being wasted during the return of excess fuel to the inlet side of the pumps. In addition, extensive overheating of the fuel is commonly associated with the by-pass system.
- The fuel discharge pressure required for vaporizer type burners is relatively low in comparison to other types of fuel burners and the maximum operating pressure required in the Iroquois fuel system is about 1150 psi. Fuel pump delivery pressure at ground idling is approximately 200 psi.

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FROM AIRCRAFT TANKS BOOST PUMP PRESSURE DRIVEN H P PUMPS H P PUMP DELIVERY METERED FUEL PUMP PRESSURE CONTROL UNIT AUXILIARY STARTING PUMP AFTERBURNER . OIL COOLER FUEL FLOW MAIN FLOW AFTERBURNER EMERGENCY BY . PASS FLOW METERING UNIT -PRESSURE DROP UNIT - MAIN METERING UNIT AND TRIM CONTROLS PRESSURE DROP UNIT AND TRIM CONTROLS SERVO THROTTLE VALVE SERVO THROTTLE VALVE SHUT OFF VALVE -- SELECTOR VALVE FLOW TO AFTERBURNER -FUEL MANIFOLDS EMERGENCY THROTTLE SELECTOR VALVE VALVE SHUT OFF VALVE - IGNITER VALVE - FLOW DISTRIBUTOR AFTERBURNER FUEL MANIFOLDS BURNERS

Figure 3-2-3 Simplified Diagram of the Fuel System

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- 17 As described later in this Section, the actual flow rate of the fuel delivered by the pumps is determined by the metering orifice sizes in the various control units and the pressure drop across these orifices.
- As seen in Figure 3-2-3, an auxiliary starting pump is provided in the system to produce sufficient delivery pressure during the initial stages of the starting cycle until the value of compressor delivery pressure is sufficient to drive the HP pumps. The starting pump is hydraulically driven and is automatically cut out as the main pumps become self-sustaining during completion of the starting cycle.

Main Control System

- The main control system comprises the units which under normal circumstances provide automatic regulation of the fuel flow to the burners in the engine combustion chamber. Referring to Figure 3-2-3, the main flow of pressurized fuel delivered by the HP pumps passes through the main metering unit and a servo throttle valve. The servo throttle valve is positioned by a servo control pressure originating in the pressure drop unit and trim controls depicted in the diagram.
- The servo control pressure acting on the servo throttle valve is modulated by the pressure drop unit which in turn operates primarily according to the setting of the pilot's power control lever and signals received from the HP and LP rotor speed governors and a minimum idling flow valve. A proportional fuel valve included in the pressure drop circuit controls the fuel flow to avoid excessive exhaust temperatures and to provide safe engine accelerations. The servo throttle valve establishes the pressure drop across the metering valve in the main metering unit. The opening of the metering valve is dependent on inter-compressor pressure (P₂), (see Figure 3-2-2) this being a measure of the mass air flow through the engine. Thus the system is altitude compensated.
- 21 From the servo throttle valve the fuel flows unrestricted to the flow distributor, and thence to the burners, via a selector valve which is fully open when the engine is operating on NORMAL. A shut-off valve located upstream of the flow distributor closes when the cockpit power control lever is retarded to the CLOSED position and cuts off the fuel flow to the burners during engine shut-down. The shut-off valve is fully closed between 0° and 3° throttle angle. Above 3° throttle angle, the valve opens sufficiently to allow fuel flow with negligible pressure drop. An igniter valve, located in parallel to the flow distributor, supplies fuel to the torch igniters for starting purposes. The igniter valve will be deleted from later engines.

Emergency Control System

The emergency control system provides an alternative route for the engine fuel flow should malfunctioning of the automatic control units develop. When the pilot selects EMERGENCY, the selector valve in the main control system closes and simultaneously one in the emergency system opens. This allows pump delivery fuel

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to by-pass the main control units and pass directly to a manually operated emergency throttle valve.

The emergency throttle valve, being mechanically linked to the power control lever, provides the pilot with full manual control of the fuel flow during emergency conditions. With the automatic control inactive, the pilot must exercise extreme care during the throttle handling and when necessary, must modulate the throttle setting to protect the engine from adverse operating conditions. However, a degree of altitude compensation is provided by the nature of the pump pressure control unit which as previously described, reduces or increases pump delivery pressure as a function of the engine mass air flow. In addition, overspeed protection for the HP rotor is provided by an emergency governor which applies a trim on the pump pressure control.

Afterburner Control System

- The fuel supply to the afterburner is automatically regulated to the exacting flow values required for safe and efficient operation of the afterburner under the wide range of operating conditions encountered by the engine. During operation of the afterburner, a flow of HP pump delivery fuel passes through a series of afterburner control units, including a metering unit and a servo throttle valve, which are located in parallel to the main control system. The mechanical configuration and operation of the afterburner metering unit and servo throttle valve are similar to those in the main control system with the exception that the valve in the afterburner metering unit is positioned as a function of the HP compressor delivery pressure (P3), which, like P2, is a measure of the mass airflow through the engine. Thus, the afterburner fuel flow is also altitude compensated.
- The pressure drop unit establishes the servo control pressure, and hence the fuel flow to the afterburner, primarily, according to the setting of a miniature throttle valve located in the proportional flow by-pass circuit. This throttle valve, being mechanically linked to the power control lever, is opened and closed according to movement of the power control lever in the afterburning range, thus providing full thrust modulation of the afterburner. In addition, a small pressurizing valve in the proportional by-pass circuit establishes the minimum fuel flow required to obtain afterburner light-up and sustain combustion. HP compressor delivery pressure (P3) is used also in the pressurizing valve as the controlling variable.
- 26 Thus it is seen that the afterburner fuel flow is regulated according to power control lever setting in the afterburning range, and as a function of P₃ and hence altitude.
- A normally closed, solenoid-operated shut-off valve located downstream of the servo throttle valve, opens to permit the passage of fuel to the afterburner manifolds when the power control lever is advanced into the afterburning range (93° to 110°)

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throttle angle). Afterburner ignition is accomplished by a hot streak igniter system. Premature opening of the shut-off valve and operation of the hot streak system is prevented by a speed lock-out switch which breaks the electrical circuits involved until the minimum safe HP rotor speed is reached. Closing of the shut-off valve, and hence shutdown of the afterburner, is accomplished by retarding the power control lever to a setting below 78° throttle angle.

OPERATING PRINCIPLES OF HYDROMECHANICAL FUEL CONTROL UNITS

Principles of Flow Control

- The quantity of fluid flowing through any passage is dependent primarily on the value to which the fluid is pressurized and secondly on the cross sectional area of the passage. Other factors such as fluid viscosity, have a marked effect on flow values, however, these are not considered in the following simplified examples. Thus, there are two primary means of controlling the flow through a passage; that of varying the pressure of the fluid, or, varying the cross sectional area of the passage.
- 29 By placing a restriction in a passage, see Figure 3-2-4, the effective cross sectional area (A1) upstream of the restriction is reduced. Thus, with applied pressure constant, the flow through the passage is reduced and since the flow rate on both sides of the restriction is obviously equal, and the cross sectional area (A2) downstream of the restriction is larger than A1, then the downstream pressure is at a reduced value. This process is termed "throttling" whereby

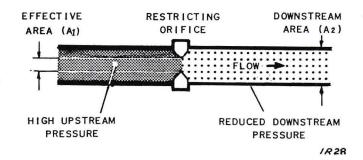


Figure 3-2-4 Throttling Effect of a Restriction

the pressure and hence flow of a fluid is reduced by varying the area of the passage by the use of a valve or other form of restriction. It will now be seen that one possible means of controlling the flow through a passage is to vary the area of a restriction in the passage.

On the other hand, with a constant upstream pressure and constant area restriction, control of the flow can be effected by varying the pressure downstream of the restriction and hence the pressure drop across the restriction. If by some means the downstream pressure is reduced, this will create a larger pressure drop across the restriction, and result in increased flow. From the relationship between pressure and area, it will be seen that an increase or decrease in the downstream pressure can be brought about by decreasing or increasing respectively the effective cross

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sectional area of the downstream passage. This is effected by introducing a second restriction downstream of the first restriction, see Figure 3-2-5. With the effective area of the passage downstream of the first restriction now dependent on the size of the second variable area restriction, the pressure drop across the first fixed area restriction, and hence the flow through the entire passage, can be regulated by varying the area of the second restriction.

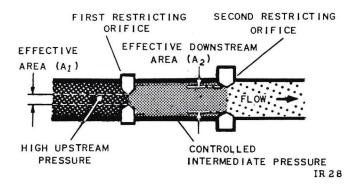


Figure 3-2-5 Flow Control Using Two Restrictions

Both the main control system and afterburner control system in the Iroquois fuel control adopt this principle of controlling the fuel flow, the metering units and servo throttle valves being the equivalent of the first and second restrictions respectively in the example previously described. The valve openings in these units are determined by the position of servo actuated plungers operating in orifice sleeves. This brings about another operating principle used in the Iroquois type of control units, the servo motor, which is described in the following paragraphs.

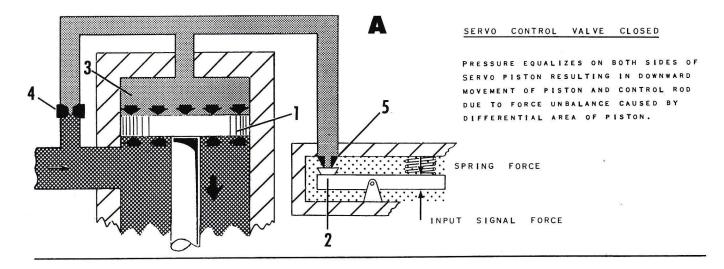
Servo Motors

- Servo motors are used extensively in the Iroquois fuel system as a means of actuating metering valves in the control units. A typical servo motor (see Figure 3-2-6) comprises essentially a control rod and piston(1), and a servo control valve (2), linked by suitable channelling to the chamber (3) above the piston. One side of the servo piston is subjected to high pressure fuel while a servo pressure derived from a small fixed area restriction (4) in a high pressure tapping upstream of the motor is applied to the opposite side of the piston.
- A second restricting orifice (5) is placed in the servo circuit downstream of the fixed orifice and is made variable by the action of the servo control valve (2). Thus, the arrangement of these orifices is similar to that previously described, where the second orifice is made variable to regulate the pressure downstream of the first orifice. This regulated or intermediate pressure is termed "servo control pressure" and being applied to the upper face of the servo piston can be used to create a pressure differential across the piston.
- When the servo control valve closes, the pressure in the servo circuit and hence on the upper face of the piston equalizes with the upstream pressure applied on the underside of the piston. The differential area of the piston (caused by the control rod reducing the effective area on the underside of the piston) results in an unbalance of the pressure forces applied to the piston and a downward movement of the piston and hence the control rod results. In certain applications this movement is assisted or opposed, depending on the configuration, by applying appropriate

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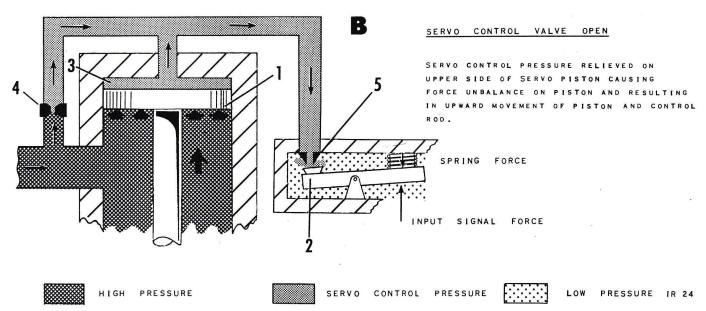


Figure 3-2-6 Operating Principles of a Servo Motor

spring forces to the piston. Movement of the piston ceases when balance is restored between the forces applied to the piston.

- When the servo control valve opens, a flow occurs in the servo circuit and as previously described, the pressure downstream of the fixed orifice is relieved. This upsets the pressure balance of the servo piston and results in an upward movement of the piston and control rod in the direction of lower pressure. Thus, the pressure in the servo circuit is established by the effective area of the servo control valve.
- 36 The degree of opening of the control valve generally varies in proportion to an input signal. The spring-loaded rocker lever type of servo control valve is commonly used in the system, whereby one end of the lever carries the sealing member

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of the control orifice while a signal force is applied to the other end of the lever. Other types of servo control valves used in the Iroquois fuel system include manually selected valves, slide type valves, diaphragm-operated plate valves, solenoid-operated valves, and valves operated by an arrangement of pressure sensitive bellows.

37 The piston control rod in a servo motor can be used as an actuator in many different applications. In the main metering unit for example, the end of the control rod is equipped with a profiled plunger which moves up and down in an orifice plate to form a variable area metering valve. A second application of the servo motor in the Iroquois fuel system is the hydraulic actuator used to position the barrel valve located in the inlet of the air duct to the HP fuel pump turbines.

Proportional Flow Control

- As previously mentioned, the flow through the fuel system is established by the orifice size of the servo throttle valve which controls the pressure drop across, and hence the fuel flow, through the metering unit. The orifice in the servo throttle valve is made variable by a servo motor which moves according to servo pressure signals originating in a proportional flow circuit. The underlying principle of the proportional flow type of control is to regulate a small by-pass flow in exact proportion to the fuel flow requirements of the engine, and to establish the main fuel flow at some multiple of the by-pass flow by proper calibration of the control units involved.
- 39 Referring to Figure 3-2-7, the proportional by-pass flow in the Iroquois fuel system originates from the HP side of the metering unit and passes through two restrictions in series and located in parallel to the main flow. This arrangement of two restricting orifices is again similar to the general configuration previously described whereby the effective areas of the restrictions establish the flow rate of fuel passing through the circuit and regulate the pressure between the orifices.
- In the proportional flow circuit, the intermediate reference pressure between the restrictions is applied on the pressure drop unit which converts the pressure signal into a servo control pressure. The servo control pressure varies inversely to the reference signal to suit the configuration and operates the servo-operated plunger in the servo throttle valve, which in turn regulates the main flow as previously described.
- Thus, the main flow is established in proportion to the small by-pass flow by regulating the areas of the restricting orifices (A1 and A2) in the proportional flow circuit. It will be seen that a demand for an increase in the main fuel flow can be fulfilled by increasing the effective area of the first restricting orifice (A1). Enlarging the area of the first restriction results in an increased reference pressure which via the pressure drop unit increases the opening of the servo throttle valve. This in turn increases the pressure drop across and hence the fuel flow through the

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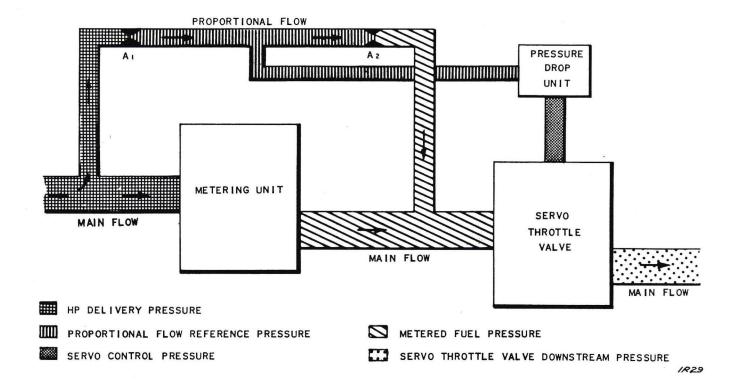


Figure 3-2-7 Proportional Flow Control

metering unit. Conversely, increasing the area of the second restriction (A2) reduces the reference pressure and hence reduces the main flow.

In the main control system, for example, the area of the first restriction corresponds in effect to the combined areas of a miniature throttle valve which is opened or closed by direct mechanical linkage as a function of power control lever movement, and a control orifice in the minimum idling flow valve which opens when an increase in fuel flow is required with an increase in altitude. The effective area of the second orifice corresponds to the size of a fixed area restriction together with the combined areas of the control orifice in the LP and HP rotor speed governors. The fixed area restriction is used in calibrating the proportional system to establish the desired main fuel flows. The governor control valves act essentially as override controls which increase the effective area of the second restriction only when necessary to stabilize or reduce the main flow when the required rotor speeds are reached or exceeded.

Continuation Pages

The preceding pages give but an introduction to the Iroquois fuel system and a brief description of the basic principles contained therein. Continuation pages to be issued later, will treat the system in greater detail and explain how the units operate to obtain optimum performance from the engine over its full range of operating conditions.

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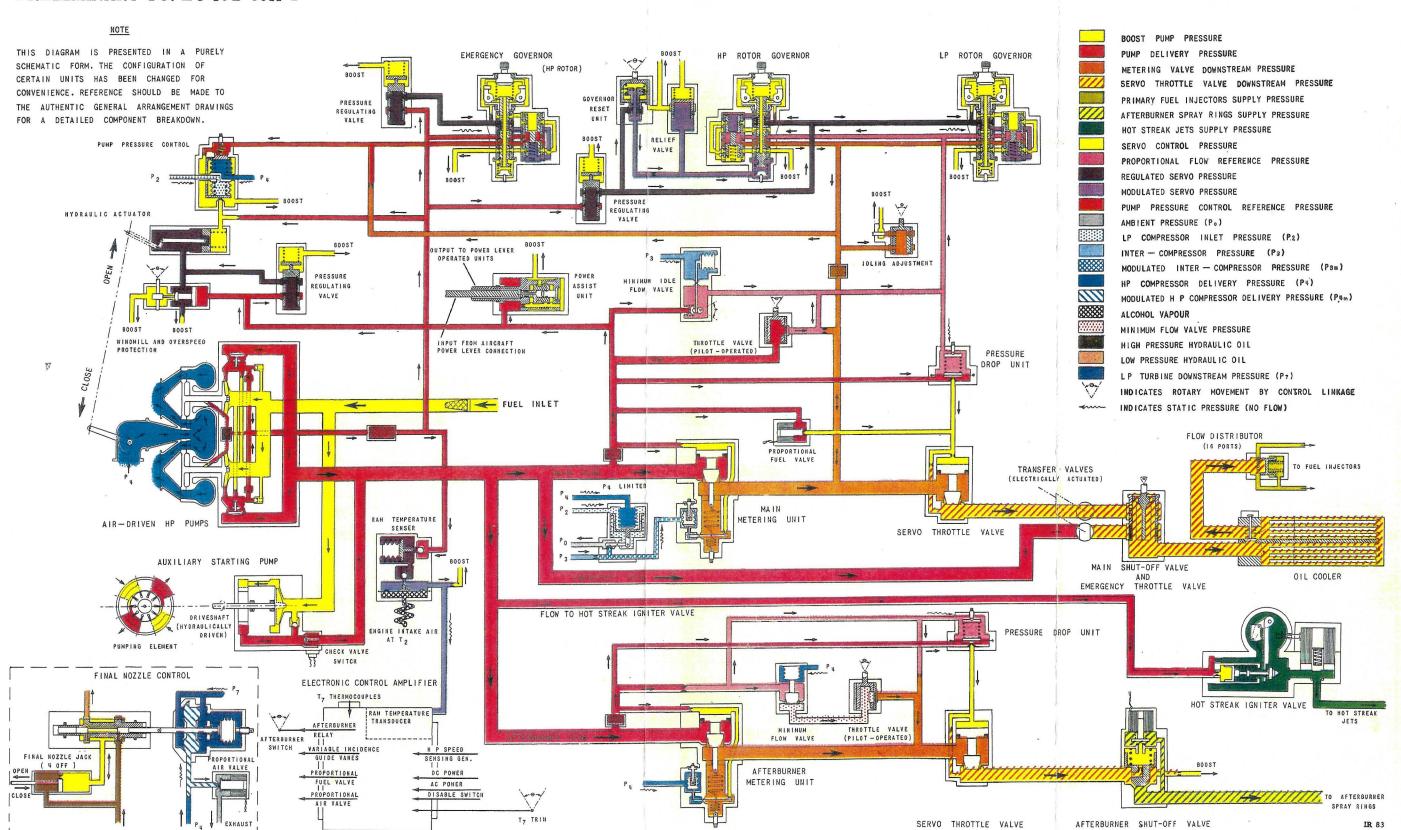


Figure 3-2-8 (Issue 1) Schematic Diagram of Fuel System

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THESE DATA SHEETS BEAR THE AUTHORITY OF REGULAR EO'S INTO WHICH THE INFORMATION IN ITS REVISED FORM WILL EVENTUALLY BE INCLUDED.

FUEL SYSTEM

HIGH PRESSURE FUEL SUPPLY SYSTEM

The HP fuel supply system provides the engine and afterburner combustion systems with fuel pressurized to the required operating values. The system comprises essentially two air turbine driven HP fuel pumps with attendant air ducting and a rotary air valve; a fuel pump hydraulic actuator and pressure control unit, which together with the pressure regulating valve, controls the pressure output of the pumps. A small auxiliary pump, operating in parallel with the HP pumps, supplies fuel to the engine during starting. The HP fuel pump group is mounted on the lower left-hand side of the HP compressor casing adjacent to the fuel control unit. The unit is enclosed by the engine firewall assembly.

HIGH PRESSURE FUEL PUMPS

General

- The pump pressure output is controlled by regulating the air flow through the turbines which drive the HP pumps. The air flow is regulated by a rotary air valve which is incorporated in the air ducting and positioned by the hydraulic actuator as a function of signals received from the fuel pump pressure control unit.
- The HP fuel pumps are of the centrifugal type and are designed for high speed operation with a high capacity output to more than meet the maximum fuel requirements of the engine and afterburner. Each pump consists of a single entry centrifugal impeller connected by direct shafting to a single stage axial flow air turbine, these components being housed in appropriate body casings.
- Both HP pumps are capable of peak speeds in excess of 45,000 rpm, and they

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have an exceptionally high pressure output capacity in relation to their size and weight. In addition, the air turbine and centrifugal pump combination is carefully matched to respond rapidly to meet increased fuel demands during engine accelerations and to provide sufficient fuel at low engine speeds and low values of HP compressor delivery pressure.

- An important feature of the pumps, due to their centrifugal design, is their relative insensitivity to contaminated fuel. This is due to the absence of critical clearances in the pumping element, which also eliminates the necessity of micronic filtration of the fuel. Since a micronic filter with sufficient capacity to handle the maximum fuel flow of the system would be exceedingly large, a considerable saving of space and weight is realized. However, to protect the pumps and metering units from the entry of foreign material large enough to affect their operation, a screen type strainer is installed in the engine/airframe fuel inlet connection.
- As previously described in the introduction to this section, the method of pump control used in this system avoids needless pumping of excess fuel and resultant overheating of the fuel as is often the case in by-pass fuel systems. In the Iroquois system, practically all the fuel delivered by the HP pumps is consumed by the engine.

Air Turbine

The air turbine of each pump consists of a ring of stationary nozzle guide vanes located at the rear of the pump casing, and a bladed turbine wheel secured to one end of the fuel impeller shaft. A flow of P4 air, bled from the HP compressor air take-off manifold, and directed by suitable ducting through the pump turbine, results in high speed rotation of the impeller shaft.

Fuel Impeller Shaft and Bearings

- 8 Each end of the impeller shaft is supported in a carbon bush type bearing located in an insert retained in the pump casing. Channelling in the insert provides a passage for fuel to the bearings for lubrication and cooling purposes. This fuel is returned to the fuel pump inlet. A spring-loaded seal at the turbine end of the impeller shaft prevents the escape of excessive quantities of fuel through the bearing clearances. Fuel leakage past the seal goes through an internal channel in the pump casing and is dumped overboard via an external piping.
- 9 The self-lubricating qualities of the fuel pumps renders them entirely independent of the engine lubricating system, thus eliminating the possibility of fuel contamination in the lubricating oil causing failure of other engine auxiliaries.

Fuel Impeller

10 The radially vaned fuel impeller is located in the pump inlet manifold so that fuel supplied from the aircraft tanks at boost pump pressure enters directly into the eye of the impeller. The centrifugal action of the rotating impeller accelerates

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the fuel passing radially outwards through the impeller. Pressure recovery of the fuel takes place in a ring of diffuser vanes located in the pump casing round the periphery of the impeller. From the vanes the high pressure flow is directed into an annulus adjacent to the impeller and then to the pump outlet port.

Fuel Pressure Relief Valve

A pressure relief valve located between the inlet and delivery ports of the pump, prevents the build up of excessive fuel delivery pressures which, for example, may occur on afterburner and/or engine shut down. The spring-loaded ball type valve opens at delivery pressures exceeding 1500 psi and relieves excess pressure to the low pressure inlet side of the pump.

Fuel Outlet Manifold

- The pump outlet ports are interconnected by a common manifold which houses a non-return valve at the HP outlet of each pump. The main supply of pump delivery fuel passes directly from the outlet manifold to the engine and afterburner metering units.
- Two crossbleeds in the fuel outlet manifold maintain a small circulatory flow of fuel between the HP outlet of each pump to the LP inlet of the other; this is to reduce the possibility of impeller operation in the stalled condition and resultant overheating of the fuel. This adverse condition would likely occur during engine operation at low fuel requirements when one pump tends to assume a larger proportion of the pumping load than the other.
- Suitable channelling in the outlet manifold provides a separate supply of HP delivery fuel originating from the upstream side of the pump outlet non-return valves. These channels are fitted with smaller non-return valves to avoid loss of pressure should a pump failure occur. A tapping from this source supplies HP fuel through a small micronic filter to a HP inlet port on the fuel pump hydraulic actuator, and to the pressure regulating valves for the speed governors and the ram temperature senser which are located elsewhere in the system. A second tapping protected by a screen strainer, directs HP fuel to the pump impeller shaft bearings and seals, and to the rear face of the pump impellers, for cooling and lubrication purposes.

Dual Pump Installation

As a safety measure, the two HP pumps operate in parallel, each pump being individually capable of satisfying the maximum fuel supply requirements likely to be encountered during engine operation without afterburning. Parallel operation, together with the use of non-return valves in the pump outlets, prevents the loss of

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HP delivery pressure should one pump fail. The arrangement of the main non-return valves in the HP outlets also prevents reverse flow occurring from HP to LP through the crossbleed and the small subsidiary HP fuel supply passages, during the initial stages of the starting cycle. This avoids unnecessary loading of the auxiliary starting pump.

Both HP pumps are basically identical in design; the external ports and connections are positioned RH and LH for installation purposes. The RH pump is driven in a clockwise direction and the LH pump in an anti-clockwise direction, as viewed from the rear of the pumps.

AIR DUCTING

General

The supply of high pressure compressor delivery air (P4) required to drive the HP pump turbines is directed from an air take-off on the mid frame assembly to the pumps by suitable air ducting. The air ducting comprises an inlet manifold incorporating a rotary air valve, a casing for the pump turbines, and two exhaust ducts leading to a common outlet manifold. The ducting is assembled from a group of fabricated sheet metal weldments to form a simple and compact unit.

Air Inlet Manifold and Rotary Air Valve

- The air inlet manifold serves to duct the flow of P4 air from the outlet of the HP compressor to the pump turbine casing. The flanged end of the manifold is bolted directly to the mating boss on the P4 air take-off manifold located round the periphery of the mid frame diffuser. The elbow in the manifold accommodates a rotary air valve which serves both pumps. Downstream of the air valve the manifold is shaped to provide proper entry conditions to the pump turbine casing. Cross members in the manifold serve to strengthen the assembly.
- The rotary air valve is of the barrel type and controls the quantity and pressure of the air flow entering both pump air turbines and hence the pressure output of the pumps. The valve spindle is mechanically linked to the hydraulic actuator. The degree of valve opening, and hence the airflow through the turbines of both pumps, is in proportion to signals received from the pump pressure control unit via the hydraulic actuator.
- The design of the air valve offers only one controlling edge to determine the effective area of the air inlet passage and the change in area of the valve opening is a linear function of the rotating movement of the valve. This characteristic simplifies control design. In a butterfly type valve, there are two controlling edges and rotary

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movement of the valve results in a non-linear change in area, particularly near the closed position.

Fuel Pump Air Turbine Casing

The air flow through the inlet manifold passes into the pump turbine casing where the flow is divided into two equal parts and is diffused in an annular chamber located upstream of each pump turbine. From the annulus, the air passes through a ring of nozzle guide vanes which impart a whirl velocity into the air and directs the flow onto the turbine blades, causing high speed rotation of the turbine wheel and hence the pump impeller. Machined flanges on the turbine casing at the outlet of each turbine provide mountings for the exhaust ducts.

Air Exhaust Ducts and Outlet Manifolds

- Two air exhaust ducts, each comprising a conical outer casing and a bullet supported by radially disposed vanes, are secured to the turbine casing outlet flanges by special clamps. These ducts serve to collect and expel the air from the pump turbines into two outlet manifolds.
- 23 The outlet manifolds dump the exhaust air, through two circular openings in the firewall rear bulkhead, into the fuel pump exhaust air duct from which the air escapes to atmosphere with the secondary air flow from the engine nacelle.

FUEL PUMP HYDRAULIC ACTUATOR

General

- The fuel pump hydraulic actuator assembly, which controls the rotary air valve, is a hydromechanical device operating on the servo motor principle. The actuator, which is a sub-assembly of the fuel control unit, transforms error signals, in the form of pressure changes from the pump pressure control unit, into movement of the rotary air valve. Modulation of the servo control pressures acting on the actuator results in linear movement of the actuator piston. This movement is transformed, through suitable mechanical linkage, into rotary movement of the air valve. Hence the position of the actuator piston, as determined by the pump pressure control unit, directly controls the degree of opening of the air valve, which in turn governs the speed and pressure output of the fuel pumps.
- A secondary feature of the hydraulic actuator assembly is a small valve which protects the fuel pumps from adverse operating conditions during engine windmilling and shutdown. This valve also prevents overspeeding of the pumps in the event of an interruption in the boost pump supply.

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The engine idling adjustment valve is also included in the hydraulic actuator assembly. However this valve is functionally independent of the pump control circuit and will be dealt with separately in the description of the main control system.

27 The hydraulic actuator, being a sub-assembly of the fuel control, is located on the underside of the HP compressor stator casing, adjacent to the HP fuel pumps.

Actuating Mechanism

- The rotary air valve actuating mechanism comprises essentially a spring-loaded actuator piston operating in a cylinder, and pinned to one end of a control rod. The other end of the rod is connected to a link which in turn is keyed to a rotary shaft extending through the actuator housing. A lever attached to the outer end of the rotary shaft transmits piston movement to the rotary air valve lever through a series of push rods and intermediate levers. Rod-end bearings are used at the lever connections to minimize wear and friction, and hence reduce the amount of torque required to move the linkage. Micrometer type adjustments are provided on two of the levers to facilitate adjustment of the linkage.
- The relationship between the rotary air valve angular travel and hydraulic actuator piston movement is established to provide a wide margin of stability over the entire range of engine and afterburner operation. As the linear travel of the hydraulic actuator piston increases towards the 'open' position, the degree of opening of the rotary air valve also increases but at a declining rate.
- The spring-loaded side of the actuator piston is subjected to a servo control pressure which originates through pump delivery fuel passing through a small restricting orifice in the pump delivery passage to the assembly. This pressure also communicates with the servo control valve in the pump pressure control unit; opening and closing of the control valve results in relief and build-up of the pressure acting on the actuator piston. It will be noted that the arrangement is similar to that shown in Figure 3-2-6 of this section.
- The opposite side of the actuator piston is exposed to a regulated servo pressure which originates in a pressure regulating valve incorporated in the assembly. During steady state operation this pressure is essentially constant to ensure stable operation, and balances the opposing servo control pressure and spring force. When the servo control valve in the pump pressure control opens, the servo control pressure acting on the piston is relieved, resulting in piston movement against the spring. When the control valve closes, the servo control pressure increases and, assisted by the spring force, overcomes the regulated servo pressure force.

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Pressure Regulating Valve

- The regulated servo pressure is maintained at a constant value above boost pump pressure by the pressure regulating valve to make the actuator sensitive to dynamic variations in pump delivery pressure. If, during steady state operation, pump delivery pressure drops, an immediate decrease in the servo control pressure acting on the actuator piston results and the rotary air valve opens to restore delivery pressure. This action is further assisted and controlled by the fuel pump pressure control unit which simultaneously senses the drop in pump delivery pressure and opens the servo control valve to augment the decrease in the actuator servo control pressure. Thus the actuator/pump pressure control combination responds rapidly to make a stable recovery when pump delivery pressure deviates from the exact requirements.
- 33 The pressure regulating valve is of the spring-loaded spindle type which operates in a drilled sleeve. Movement of the spindle covers and uncovers drillings in the sleeve which communicate with pump delivery pressure. The valve is spring-loaded to rest in the open position so that the initial pressure builds up in the valve until it is sufficient to balance the opposing spring force and boost pump reference pressure. Any tendency for a further increase in the regulated servo pressure moves the valve spindle to reduce the opening of the valve and hold the pressure at a constant value. A continuous bleed of regulated servo pressure to boost pump pressure, through a restricting orifice located in the windmill and overspeed valve assembly, creates the required pressure drop to ensure proper functioning of the regulating valve. Leakage past the valve spills into the spring chamber at the end of the spindle.

Windmill, Shutdown and Overspeed Protection

- A dual purpose valve, operating in parallel with the actuating mechanism and pressure regulating valve, prevents prolonged operation of the HP fuel pumps in the stalled condition (impeller rotation with little or no flow) during, for example, engine windmilling in flight and on engine shutdown from high rpm. As described in Para 25, the valve also provides overspeed protection for the pumps.
- When operating to provide windmill and shutdown protection, the valve, being spring-loaded to rest in a closed position, is opened by a cam and plunger arrangement which is mechanically linked to the power control linkage. The linkage is actuated as a function of power control lever movement, and the valve is fully open from 0 to 4 degrees and fully closed above the 12 degree position. The maximum opening of the valve, being larger than that of the pressure regulating valve, enables it to override the latter. Hence when the valve opens, regulated servo pressure is bled to 'boost' and the fuel pump hydraulic actuator piston moves in the direction which closes the pump rotary air valve and shuts down the pumps. Thus, when the

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power control lever is retarded to the closed position during engine shutdown or during engine windmilling in flight, rotation of the fuel pumps in the stalled condition is prevented.

Overspeeding of the HP pumps is a result of excess torque being available at the pump turbines, when, for example, a loss of boost pump pressure, combined with high fuel temperatures, results in vapourization (boiling) of the fuel in the inlet manifold and disrupts the pumping action of the impellers. A piston exposed to pump delivery pressure acts, against a spring, to hold the valve closed during normal conditions. Should pump delivery pressure fall below 80 psi, pressure is relieved on the piston, allowing the valve, through spring pressure, to open and bleed off the regulated servo pressure. This results in closing of the rotary valve and shutdown of the pumps as described in Para 35. Reset action of the pump control system is obtained by carrying out the normal relight procedure.

FUEL PUMP PRESSURE CONTROL UNIT

General

- 37 The fuel pump pressure control unit is a hydropneumatic device which regulates the pressure output of the HP pumps at values which are sufficient to meet the requirements of the fuel control and distribution systems at all operating conditions. The pump pressure control unit comprises essentially a bellows and cage assembly, a pressure sensing piston and the hydraulic actuator servo control valve. This unit, like the fuel pump hydraulic actuator, is embodied in a sub-assembly of the fuel control unit.
- A satisfactory pump pressure schedule is obtained, through proper calibration, by comparing the pressure rise across the compressor (P4 P2) against a feedback reference pressure which is a function of pump delivery pressure. The selected schedule avoids needless overpressurization of the fuel system and reduces the work load on the pumps. When deviations from the established schedule are detected, the pump pressure control corrects this condition by altering the position of the rotary air valve. This is accomplished by transmitting the error signals developed in the pump pressure control, to the fuel pump hydraulic actuator in the form of servo control pressure variations, thus positioning the rotary air valve.
- Since the pump pressure control primarily senses the pressure rise across the compressor, the pump delivery pressure is regulated according to changes in engine speed, aircraft forward speed and altitude. Thus during operation in EMERGENCY, with the automatic control inactive, a degree of altitude compensation is provided by the pump pressure control. In addition, overspeed protection for the HP rotor is provided by the action of the emergency governor influencing the pump pressure control.

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Bellows and Cage Assembly

The bellows assembly comprises two bellows which are anchored at their inner end to the bellows housing. The bellows are internally spring-loaded, and channelling in the housing vents the lower bellows to LP compressor inlet pressure (P2) and the upper bellows to HP compressor outlet pressure (P4). The free ends of the bellows are attached to a common cage so that movement of the cage occurs when the pressure forces acting on the assembly are unbalanced. Thus the bellows and cage arrangement is made directly sensitive to the pressure rise (P4 - P2) across the compressor.

Pressure Sensing Piston

Movement of the bellows cage is also dependent on a spring-loaded pressure sensing piston. The piston, being integral with the upper end of the cage, is subjected to a reference pressure which is derived in a fuel potentiometer circuit comprising two restricting orifices in series. The first orifice, located upstream of the piston chamber, is supplied with fuel at pressure downstream of the main metering valve, while the downstream orifice connects the piston chamber to boost pump pressure in the bellows chamber. Thus the reference pressure, which is termed pump pressure control reference pressure, is at a reduced level which is directly proportional to metering valve downstream pressure which in turn is related to pump delivery pressure. Therefore, as the resultant downward pressure force on the piston is in opposition to the upward bellows force, a comparison between compressor pressure rise and pump delivery pressure is obtained.

Servo Control Valve

The servo control valve comprises a variable area restricting orifice, the sealing member of which is carried by the lower end of the bellows cage. Upward movement of the cage moves the valve in the open direction and bleeds servo control pressure from the spring-loaded side of the hydraulic actuator piston. This results in actuator movement to increase the opening of the rotary air valve and hence the pressure output of the pumps. Conversely, when the cage moves downward, the opening of the control valve is reduced, resulting in a decrease in pump delivery pressure and hence fuel flow.

Operation in NORMAL

The effective areas of the bellows and the pressure sensing piston, and the spring forces acting on the bellows and piston are calibrated to maintain the servo control valve, and hence the hydraulic actuator, in a stabilized position when the desired relationship between compressor pressure rise and the pump delivery pressure is being maintained. During steady state operation, the forces acting on



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the cage are balanced and the degree of opening of the servo control valve is dependent on the system operating conditions.

If for any reason, the compressor pressure rise increases, the resultant force unbalance on the bellows cage moves the cage upward to increase the opening of the servo control valve. As previously explained, this results in an increase in the pressure output of the HP pumps. Corrective action continues until the consequent increase in pump pressure control reference pressure is sufficient to restore the force balance on the bellows cage. At this time the pump pressure control stabilizes and steady state operation ensues.

Operation in EMERGENCY

- During EMERGENCY operation or in the event of a failure in the normal HP governing system, overspeed protection is provided for the HP rotor by the action of the emergency governor on the pump pressure control. The emergency governor is connected in parallel to the pump pressure control reference pressure circuit and when an overspeed condition occurs, the governor uncovers a port which connects the reference pressure circuit with the pump delivery pressure. The resultant build-up in reference pressure is sensed by the pressure sensing piston and holds the servo control valve closed until the pump delivery pressure drops sufficiently to reduce engine rpm to the 'on speed' condition. The overspeed protection provided by the emergency governor and the pump pressure control unit is also effective during NORMAL operation in the event of a failure in the HP rotor governor control circuit.
- The character of the pump pressure control unit also provides a degree of altitude compensation during EMERGENCY operation in that the pump delivery pressure is increased or decreased according to corresponding changes in compressor pressure rise as sensed by the bellows assembly.

AUXILIARY STARTING PUMP

General

The auxiliary starting pump is provided in the HP fuel supply system to produce sufficient fuel flow during the starting cycle to obtain a light-up and engine acceleration. The pump continues to operate until the value of HP compressor delivery pressure (P4) is sufficient to drive the HP pump air turbines at the required rate for self-contained operation. The starting pump is driven by a hydraulic motor which, in turn, is energized by selection of the START or RELIGHT switches in the cockpit. On completion of the starting cycle, the HP pumps become self-sustaining and the starting pump is automatically cut out by a check valve switch which deenergizes the drive motor solenoid valve.

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The starting pump which operates in parallel with the HP fuel pumps, comprises two pumping elements mounted on a common driveshaft; the first element serves as a booster for the main pumping element. The driveshaft is supported by two ball bearings which are fuel lubricated to render the pump independent of the lubricating oil system. A pressure relief valve in the pump controls the pressure in the starting pump circuit.

Booster Element

The booster element is a radially vaned, shrouded impeller mounted on the forward end of the pump driveshaft. Fuel at boost pump pressure passes through a strainer installed in the pump inlet and is centrifuged outward by the impeller into an annulus surrounding the periphery of the impeller. The centrifugal action of the impeller pressurizes the fuel, and channelling in the pump casing directs the delivery from the impeller to the inlet ports of the main pumping element.

Main Pumping Element

- The main pumping element consists of a slotted cylindrical rotor which accommodates ten radially disposed vanes operating in a Carboloy liner which is more or less elliptical in shape. The vanes, being a sliding fit in the radial slots, are held in continuous contact with the hardened face of the liner to form fluid-tight pockets.
- 51 Referring to Figure 3-2-8, the contour of the liner provides two diametrically opposed pumping sections in the element. The element is therefore hydraulically balanced and no appreciable radial loads are imposed on the shaft, hence enabling a lighter bearing design. As the pump rotor turns, the pockets progressively increase to provide suction on the inlet sides of the element, then decrease to pressurize the fuel in the outlet passages. During the suction cycle, the vanes are forced outward against the liner by a supply of HP fuel which is directed to the key-hole cavities at the inner end of each vane. Outward movement of the vanes is also assisted by centrifugal force arising from rotation of the shaft. To reduce wear, the ends of the vanes are chamfered to 'scoop' fuel past the contact faces and thus prevent direct rubbing between the vanes and the liner. The chamfers also expose a large area of the vane ends to HP fuel to assist the inward return of the vanes during the pressure cycle. As the vanes enter the pressure cycle, the key-hole cavities are vented to the LP side of the element and the resultant force unbalance on the vanes assists in returning them inwards. The maximum speed of the auxiliary starting pump is set at approximately 6200 rpm.

Pressure Relief Valve

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and outlet of the pump. The relief valve opens when the pressure rise across the pump exceeds a pre-set value, and spills excess delivery fuel into the inlet.

Check Valve Switch

- A spring-loaded check valve, installed in the auxiliary starting pump outlet, closes when the delivery pressure of the main fuel pumps exceeds the starting pump delivery pressure. When the valve closes, a magnetic Glaswitch-type relay breaks the electrical circuit to the hydraulic motor solenoid valve and shuts down the starting pump.
- The relay comprises two overlapping reed type contacts hermetically sealed in a glass enclosure. This enclosure, being housed in a separate assembly bolted to the check valve housing, is isolated from the fuel chamber in the housing. The switch is operated by the influence of a permanent magnet which is carried, adjacent to the reed contacts, by the check valve spindle on which it is mounted. Polarity is induced into the contact ends of the reeds by the magnet; as the check valve opens, the magnet is carried to a position which induces unlike polarity in the contact ends of the reeds and hence holds the reeds closed; when the check valve is closed, the magnet is positioned to induce like polarity in the contact ends of the reeds and hold the reeds open. Complete details of the electrical circuitry of the check valve switch and the hydraulic motor solenoid are contained in Section 6 of this part.
- 55 Small grooves cut in the face of the valve allow a small circulatory flow of fuel from the HP to the LP side of the starting pump when the check valve is closed. This flow avoids stagnation and resultant overheating of the fuel when the starting pump is inoperative during normal engine running.

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THESE DATA SHEETS BEAR THE AUTHORITY OF REGULAR EO'S INTO WHICH THE INFORMATION IN ITS REVISED FORM WILL EVENTUALLY BE INCLUDED.

FUEL SYSTEM

MAIN FUEL CONTROL SYSTEM

NOTE

The following paragraphs should be read in conjunction with Figure 3-2-8. Units written in capitals are called up in this figure. Information will be issued later giving further details of these units.

General

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- The pressure generated by the HP FUEL PUMPS must be scheduled into a controlled flow rate before it is fed to the engine combustion system. The flow is primarily scheduled as a function of the setting of a PILOT OPERATED THROTTLE VALVE and is corrected to maintain a basic relationship with the mass air flow delivered by the compressor. Provision is made for modulating the basic fuel schedule to avoid undesirable conditions which may be encountered during engine operation. SHUT-OFF VALVE action is also provided during movement of the power control lever.
- The basic fuel flow rate is established by the metering valve in the MAIN METERING UNIT (hereafter referred to as the metering valve) and the pressure drop control circuit. As explained later, the fuel flow through any valve is primarily dependent on two factors, the area of the valve opening, and the pressure drop across the valve. The metering valve opening is made proportional to intercompressor pressure (P3) and the pressure drop across the valve is regulated by

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a pressure drop unit and the SERVO THROTTLE VALVE primarily as a function of the setting of the PILOT OPERATED THROTTLE VALVE.

- 3 The required modulating trims on the fuel flow are applied either on the pressure drop across the main metering valve or on the opening of the valve. A brief description of the function of the modulating controls and limiting devices incorporated in the system follows:
- (a) The HP ROTOR GOVERNOR controls the HP compressor rotor rpm at a value corresponding to the required setting over the complete range of power lever movement. This control also provides overspeed protection for the HP compressor rotor.
- (b) The LP ROTOR GOVERNOR controls the maximum rpm of the LP compressor rotor. As this unit controls only the maximum rpm, it is frequently termed the LP rotor speed limiter.
- (c) The PROPORTIONAL FUEL VALVE regulates the rate of increase of the fuel flow during starting and acceleration to avoid surge and overtemperature conditions.
- (d) The MINIMUM IDLE FLOW VALVE maintains a flow schedule which gives a rising idling speed as altitude increases.
- (e) The P4 LIMITER functions to reduce the metering valve area, and hence the fuel flow when the delivery pressure of the HP compressor becomes excessive.
- The combination of basic scheduling units and the modulating controls, enables the pilot to advance the power control lever and obtain an engine thrust percentage corresponding to the lever setting. If, for example, the power control lever is positioned at a 75% opening, an rpm is obtained such that the thrust produced by the engine will be approximately 75% of the available thrust for the conditions under which the engine is operating. However, should the engine performance exceed any of the imposed limitations, the applicable modulating control will override the lever setting and reduce the fuel flow to avoid the unsafe condition.

MAIN METERING UNIT

General

The MAIN METERING UNIT controls the fuel flow by varying the metering valve area and/or by altering the pressure drop across the valve. If the pressure drop across a given area is maintained constant and the area is increased, the fuel flow will increase. On the other hand, if the area is fixed and the pressure drop is increased or decreased, a corresponding change in fuel flow will result.

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During fixed power control lever flight operation at constant inlet temperature conditions, the MAIN METERING UNIT operates in the variable area/fixed pressure drop category. The pressure drop control circuit maintains a fixed pressure drop across the valve and the valve area is made variable as a function of intercompressor pressure (P3).

Should one of the modulating controls sense a required increase in fuel flow, the PRESSURE DROP UNIT responds through the SERVO THROTTLE VALVE to increase the pressure drop across the metering valve, thereby increasing the fuel flow. In this instance, the MAIN METERING UNIT operates in the fixed orifice/variable pressure drop category.

Description

The metering valve, located in the main body of the unit, comprises a variable area restriction provided by a profiled plunger operating in a circular orifice. The profiled plunger is integral with a servo piston, and is connected through a tension spring to a rocker lever. An additional spring is provided for fine adjustment to the spring load applied to the plunger. One end of the lever is connected to an evacuated bellows housed in the metering unit, and the other end operates the metering unit servo control valve.

Operation

- Fuel at pump delivery pressure passes through a small fixed area restricting orifice into the chamber above the servo piston. The servo chamber is connected by internal channelling to the servo control valve which is opened and closed by movement of the rocker lever. Thus, the plunger is positioned according to the difference between servo control pressure acting on one side of the servo piston and pump delivery pressure on the other side. Since both pressures are derived from the same source, the metering unit is insensitive to changes in pump delivery pressure.
- However, repositioning of the plunger in the orifice is by the servo control system operating as a function of inter-compressor pressure. The intensity of the inter-compressor pressure signal varies with the different values of compressor intake temperature and pressure, and compressor rotor speed. Thus, the metering orifice area is varied according to changes in the engine rpm, aircraft forward speed, and altitude.
- If, for example, inter-compressor pressure (P3) increases, the resultant contraction of the bellows moves the rocker lever to open the servo control valve orifice. Servo control pressure bleeds off, increasing the pressure differential across the servo piston to which the plunger is attached. The piston moves in the direction of lower pressure, hence enlarging the metering valve aperture. As the

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resistance offered by the metering valve reduces, the pressure drop across it tends to decrease. The change in pressure drop is sensed by the PRESSURE DROP UNIT which repositions the servo throttle valve to a larger opening. This action tends to restore the pressure drop across the metering valve and permits an increase in fuel flow to the engine. Movement of the metering valve plunger continues until the tension force in the spring is sufficient to balance the increase of inter-compressor pressure and return the rocker lever, and hence the servo control valve, to a position of force equilibrium. The metering valve then stabilizes in its new position, the fuel flow having been corrected to a higher level to meet the increased engine requirements.

PRESSURE DROP CONTROL CIRCUIT

General

- As previously stated, the second factor in regulating the fuel flow through the main metering unit is control of the pressure drop across the metering valve. The pressure drop control circuit maintains the pressure drop across the metering valve constant for any fixed power control lever setting excluding trim action. Assume, for example, that a hydraulically operated potentiometer, which is located in parallel with a metering valve, consists of a fixed orifice in series with a variable orifice. By keeping the pressure drop across the variable orifice constant, it will be seen that an increase in the variable orifice area increases the flow rate through the potentiometer and results in an increased pressure drop across the fixed orifice. The total pressure drop across the potentiometer is thus increased and a corresponding increase in the pressure drop across the metering valve, and hence an increase in the main fuel flow rate, will result.
- 13 The pressure drop control circuit consists of a hydraulic potentiometer, a PRESSURE DROP UNIT and a SERVO THROTTLE VALVE. A small by-pass flow of fuel at pump delivery pressure is in parallel with the main metering valve and passes through the potentiometer.

Hydraulic Potentiometer

- 14 The hydraulic potentiometer consists of a group of restricting orifices located in the units of the pressure drop control system, which, for purposes of description, can be considered equivalent to two variable orifices in series. The areas of these orifices are designated A_1 and A_2 respectively.
- Area A₁ is, in effect, the combined area of two variable orifices located in parallel. The first orifice consists of a small rotary-type sleeve valve termed, for this description, the potentiometer throttle valve (see PILOT OPERATED THROTTLE VALVE, Figure 3-2-8). This valve is connected to the power control linkage,

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and is actuated as a function of power control lever movement. The second orifice is incorporated in the MINIMUM IDLE FLOW VALVE. As described later, this orifice opens when the inter-compressor pressure (P3) falls below the required value in accordance with the preset schedule. Area A2 consists of one fixed and four variable area orifices. The fixed area orifice is located downstream of the potentiometer throttle valve. The four variable area orifices are located in the HP and LP ROTOR GOVERNORS and open as a function of engine speed deviations sensed by the governors.

Pressure Drop Unit

Pump delivery pressure upstream of, and the reference pressure downstream of the potentiometer throttle valve (area A1), are applied to opposite faces of a flexible diaphragm in the PRESSURE DROP UNIT. Attached to the centre of the diaphragm is a plate valve which seats on a small servo control orifice. A calibrated spring provides a reference pressure on the upper face of the plate valve. During engine running, the differential fuel pressures applied to the PRESSURE DROP UNIT result in the plate valve assuming a 'floating' position, and regulation of the fuel passing through the servo throttle valve relative to the pressure drop across area A1 in the potentiometer.

Servo Throttle Valve

- The SERVO THROTTLE VALVE consists of a profiled plunger which is positioned in a circular metering orifice as a function of the pressure differential across an integral servo piston. When the pressure drop across area A1 increases beyond the set value, the plate valve and diaphragm in the pressure drop unit move against the spring load, and open the servo control orifice. Fuel at pump delivery pressure bleeds through the orifice, thus increasing the pressure in the servo chamber. The resultant pressure differential across the piston repositions the SERVO THROTTLE VALVE to reduce the flow rate, and hence the pressure drop across the metering valve, until the pressure drop across area A1 is restored to its set value. The pressure drop plate valve returns to an equilibrium position and the SERVO THROTTLE VALVE stabilizes.
- 18 From the preceding description it is seen that the fuel flow is scheduled by the pressure drop control circuit as a function of the pressure drop across area A_1 . Since this pressure drop is also dependent on area A_2 , decreasing area A_1 and/or increasing area A_2 will result in a reduction in the main fuel flow or vice versa.

CONTROL OF ENGINE ACCELERATION

General

When the pilot moves the power control lever rapidly to the fully open position, the PRESSURE DROP CONTROL requests an immediate increase in the fuel flow

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schedule to provide engine acceleration in the minimum possible time. The HP ROTOR GOVERNOR is then operating in the underspeed condition. As a result, the governor valves do not interfere with the request and the fuel supply remains a function of inter-compressor pressure (P₃). However, if the fuel flow is allowed to increase at an uncontrolled rate, rich flame-out, overtemperature or surge conditions may be encountered.

- To prevent this happening, engine acceleration is controlled by a solenoid-operated PROPORTIONAL FUEL VALVE which functions when impulse signals are received from the ELECTRONIC CONTROL AMPLIFIER. The control amplifier senses the engine exhaust temperature (T7) by means of an electrical signal and compares the signal with a desired reference schedule which has been set up in the amplifier. This reference schedule is established as a function of HP rotor speed and engine intake temperature (T1) so that at any given speed during acceleration, the fuel flow will be established according to the desired ratio of exhaust temperature to intake temperature $\left(\frac{T7}{T1}\right)$. If the sensed exhaust temperature (T7) exceeds the reference schedule at any time during the acceleration, an amplified signal proportional to the error is transmitted to the PROPORTIONAL FUEL VALVE.
- The amplifier reference schedule is arranged so that a relatively high temperature is permitted for starting. As the engine approaches idling speed, a signal from the amplifier switches the reference voltage to a lower value, in order to provide a lower temperature limit immediately on accelerating from idling. In the intermediate operating range, an even lower temperature reference is provided until the critical stall range is passed. At this point the temperature reference is once again increased to permit rapid acceleration to the high rpm range.
- As the engine enters the high rpm range, the divergence between the operating line of the engine and the surge line increases and the need for acceleration control no longer exists. Therefore a speed switch transfers the amplifier output from the PROPORTIONAL FUEL VALVE to the PROPORTIONAL AIR VALVE of the FINAL NOZZLE CONTROL, thus changing exhaust temperature trim from fuel flow to final nozzle area. Simultaneously the switch prepares the afterburner circuit, and afterburning may be accomplished if the power control lever is advanced beyond 93 degrees. Further details of the electronic aspects of engine acceleration control are contained in Section 6 of this part.

Ram Temperature Senser

The intermediate range speed signals to the amplifier are biased by engine intake air temperature $\left(\frac{1}{T_1}\right)$ in order to compensate for a shift in the surgeline that results from variation in intake temperature. (The exhaust temperature signals



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are biased by $\left(\frac{1}{T_1}\right)$ for the same reason). The bias is provided by the RAM TEMP-ERATURE SENSER which transmits a pressure signal proportional to T1 to a RAM TEMPERATURE TRANSDUCER in the ELECTRONIC CONTROL AMPLIFIER.

Essentially, the RAM TEMPERATURE SENSER consists of a pressure balancing device downstream of a bellows-operated pressure regulating valve. Because the bellows is evacuated, the pressure developed by the regulating valve is always constant. The pressure of the regulated servo fuel is then varied by the action of a diaphragm and ball valve assembly; the diaphragm is sensitive to the pressure derived from an alcohol vapour filled helix located in the intake duct. The fuel pressure applied to the transducer is therefore proportional to ram temperature. Within the transducer, this pressure input is converted into electrical signals proportional to $\left(\frac{1}{T\,1}\right)$ and $\left(\frac{1}{\sqrt{T\,1}}\right)$ which are applied to the speed and temperature input signals.

Proportional Fuel Valve

Control of engine acceleration is effected by means of the solenoid-operated, PROPORTIONAL FUEL VALVE. When energized by the electronic control amplifier, the valve overrides the PILOT OPERATED THROTTLE VALVE setting (area A1) to retard the rate of increase of fuel flow during acceleration. If, for example, the pilot advances the power control lever to accelerate the engine, area A1 is increased by the corresponding movement of the PILOT OPERATED THROTTLE VALVE. The decreased pressure drop across area A1 is sensed at the PRESSURE DROP UNIT which closes, and results in opening of the SERVO THROTTLE VALVE. This produces an increased pressure drop, and hence fuel flow, through the MAIN METERING UNIT. The engine begins to accelerate and, as a result of increasing inter-compressor pressure (P3), the metering valve is repositioned to a larger opening. However during acceleration, certain limitations such as exhaust temperature may be exceeded and the electronic control amplifier transmits error signals to the PROPOR-TIONAL FUEL VALVE solenoid. The valve opens in varying degrees according to the intensity of the signal received and allows fuel at pump delivery pressure to bleed into the SERVO THROTTLE VALVE servo chamber, hence controlling the rate at which the valve opens. This tends to reduce the pressure drop across the MAIN METERING UNIT and hence the fuel flow rate to the engine. This cycle of operation continues, until the error signal is eliminated and the pressure drop across area A₁ is restored to the set value.

CONTROL OF ENGINE DECELERATION

When the pilot retards the power control lever to a lower setting, it may be desirable to have the fuel flow and hence the engine speed reduced as quickly as

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possible to meet the request for lower thrust. However, because of rotor inertia and resultant maintenance of mass air flow, a sharp decrease in fuel flow would result in loss of combustion (flameout). Thus it is seen that, in order to maintain combustion, the fuel flow must be scheduled during deceleration at a minimum flow rate based on mass air flow.

The MAIN METERING UNIT establishes the desired relationship during deceleration. Although the pressure drop control circuit immediately reduces the metering valve pressure drop to a minimum value, the metering valve closes in relation to the decreasing inter-compressor pressure (P₃). Thus the rate of decrease of the fuel flow is dependent on the rate at which the rotor speed and the air flow is decreasing.

HP ROTOR GOVERNING SYSTEM

General

28 The HP rotor governing system is designed to control the HP rotor speed at any power control lever setting and to prevent overspeeding beyond the designed maximum rotor speed. The HP governing system comprises an isochronous HP ROTOR GOVERNOR UNIT which incorporates an EMERGENCY GOVERNOR, and a GOVERNOR RESET UNIT with pressure regulating valves and a relief valve. The GOVERNOR RESET UNIT varies the setting of the HP ROTOR GOVERNOR as a function of power control lever position so that an approximately linear relationship is produced between power lever angle and thrust. The HP rotor governor responds to each engine overspeed error and simultaneously varies the pressure drop signal sensed at the pressure drop unit, thereby rescheduling the fuel through the metering unit until the set engine speed is restored. The unit has a high rate of response and provides fast corrective action. The EMERGENCY GOVERNOR limits the maximum speed of the HP rotor during operation in EMERGENCY, and it also automatically prevents HP rotor overspeed should the NORMAL HP rotor governor fail. The operation of the EMERGENCY GOVERNOR is described in the Emergency Control System Advance Data Sheets.

HP Rotor Governor

The HP ROTOR GOVERNOR consists of a flyweight mechanism, a spindle valve and a floating valve. The governor drive is taken from the HP external gearbox at a speed directly proportional to HP rotor speed. As the flyweights rotate they are thrown outward by centrifugal force. This outward movement is transformed into axial movement of the spindle valve which operates in a fixed sleeve. A constant circulation of fuel is provided through the unit for cooling and lubricating purposes.

Governor Reset Unit

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UNIT is used to position the governor spindle valve, relative to the power lever position and the fuel schedule. The unit consists of a profiled cam, a variable pressure regulating valve, fed by a constant pressure regulating valve, and a relief valve.

The cam profile is cut to produce the desired engine rpm/power lever angle relationship. It is connected to the power control lever linkage and actuates the variable pressure regulating valve. As the valve is actuated a variable fuel pressure, termed modulated servo pressure, is fed to the HP governor spindle valve trim spring chamber. The pressure decreases as the power lever angle increases. This in effect, raises the rpm at which the governor will control by decreasing the pressure on the end of the spindle valve. When the governor reset pressure is decreased the force required to move the spindle valve against the governor rate spring increases. Hence a high engine rpm and increased centrifugal force are required, before the spindle valve is raised to the controlling position. Thus for each power control lever setting the governor system is reset to maintain continual speed control.

Relief Valve

32 The maximum pressure acting on the spindle valve is determined by the setting of a spring-loaded RELIEF VALVE. When a preset value of modulated servo pressure is exceeded, the valve opens and bleeds off the excess pressure to boost. The setting of the valve, combined with the idling adjustment valve described in Para 40 of this section, determines the minimum ground idling speed of the engine.

LP ROTOR GOVERNOR

- 33 The LP ROTOR GOVERNOR controls at one speed only. The point at which the governor control takes place is preset and determines the maximum LP rotor speed. Except for the following differences both the HP and LP isochronous governor systems are similar. No reset unit is included in the LP ROTOR GOVERNOR. The spindle valve is exposed to boost pump pressure at each end, the valve being drilled through the centre to provide a boost passage to each end of the valve. The drive to the governor is taken from the rear mounting pad of the LP external gearbox.
- Operation of the governor unit and the controlling cycle is exactly the same as that of the HP ROTOR GOVERNOR, except that control of the LP rotor speed is not variable. Due to the settings used in the LP and HP rotor governors, the HP governor normally controls engine speed before the LP governor controlling position is reached. However, under certain engine air intake conditions, the reverse action takes place and the LP ROTOR GOVERNOR enters the controlling range first.

P4 LIMITER

General

35 The P₄ LIMITER protects the engine from excessive values of HP compressor

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delivery pressure which may occur under certain combinations of altitude and high forward speed. Excessive delivery pressure imposes high gas pressure loadings on the compressor casing, combustion chamber, and turbine, and may stress these components beyond limitations.

As described in Para 10 of this section, the orifice area of the metering valve and hence the fuel flow through the valve is increased according to increases in inter-compressor pressure (P₃) which is sensed by the bellows in the MAIN METERING UNIT. The P₄ LIMITER, by artificially reducing the intensity of the P₃ signal to the MAIN METERING UNIT when the maximum compressor pressure limit is reached, provides a reduction in fuel flow and hence compressor speed.

POWER ASSIST UNIT

General

- The POWER ASSIST UNIT is included in the control system to reduce the torque required to move the power control lever. The unit consists basically of a servo-operated power piston which is positioned hydraulically by a pilot valve mechanically linked to the power control lever. Thus during normal operation the only load at the power control lever is the torque required to operate components which are mechanically linked to the power lever gearbox, mainly the MAIN SHUT-OFF VALVE and EMERGENCY THROTTLE VALVE, and the linkage to the power assist input. Loads imposed on the output side of the power assist unit are not felt at the power control lever.
- The unit is bolted to the main engine control and incorporates a concentric input and output shaft arrangement. The inner shaft which is mechanically linked to the power lever gearbox operates a pilot valve. Movement of the pilot valve alters the servo pressure acting on the right-hand side of the power piston and causes it to move in the same direction, and by the same amount, as the pilot valve. The outer shaft, which forms part of the power piston, actuates all the mechanical linkages on the control. The input shaft is connected to the pilot valve; a machined tee and matching tee slot arrangement allows for eccentricity between the components. The valve slides freely in a fixed sleeve located in the bore of the power piston. 'O' ring seals are used on all static and sliding joints to prevent internal fuel leakage which could affect operation.

POWER LEVER GEARBOX

39 The power control lever input signal actuates the power assist unit by means of a reduction gearbox located on the main fuel control unit. The gearbox input shaft is splined at each end and extends through the sides of the gearbox, to provide a common drive for either left or right-hand engine installations. The drive to the

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output shafts is transmitted by means of a spur and bevel gear arrangement. A bevel gear on the input shaft drives a similar gear on the end of the combined main shut-off valve and emergency throttle valve spindle. The drive to the power assist unit pilot valve is through spur gears and a layshaft. If for some reason the power assist unit cannot move the main control linkage and seizes in one position, sufficient torque can be exerted at the power control lever to shear a small 'fail safe' pin incorporated between the layshaft and the spur gear. This isolates the main fuel control unit. However if EMERGENCY is selected, manual control of the engine can be effected as the drive to the EMERGENCY THROTTLE VALVE remains intact. Adjustable travel stops and a graduated indicator plate are provided to enable accurate setting up of the control linkage.

IDLING CONTROL

Idling Adjustment Valve

- A ground IDLING ADJUSTMENT VALVE is provided in the fuel control system in order that the fuel control unit can be matched to any engine. As each engine varies dimensionally, the idling adjustment provides the correction needed to eliminate idling speed deviation at sea level static conditions. The remaining fuel control components are pre-adjusted.
- The valve is located in the system between the MAIN METERING UNIT and the SERVO THROTTLE VALVE. It comprises a rotary shut-off valve in series with an adjustable needle valve and, being connected to the fuel control linkage, is operated by power control lever movement. The outlet side of the valve is connected to a boost return line.
- When the power control lever is in the 'idle' position, the idling valve is open, thus allowing excess scheduled fuel from the metering unit to bleed to boost. The needle valve setting determines the quantity of fuel bled to boost, hence by adjusting the setting, the idling speed can be varied. As the power control lever is advanced beyond the idling setting the rotary valve cuts off the bleed to boost.

Minimum Idle Flow Valve

43 The minimum engine speed must provide sufficient compressor air pressure to supply cabin pressurization and cooling of certain aircraft components. The rpm obtained by the ground idling speed setting will not normally fulfil the requirements mentioned as altitude increases. Therefore a MINIMUM IDLE FLOW VALVE is provided to reschedule the fuel flow and obtain higher rpm and increased HP compressor delivery pressure (P₄) as altitude increases.

MAIN SHUT-OFF VALVE

Shut-off action for the fuel flow to the engine is provided by a valve located

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downstream of the SERVO THROTTLE VALVE. The SHUT-OFF VALVE is fully closed between 0 degrees and 4 degrees power control lever position. The valve also serves as an EMERGENCY THROTTLE VALVE, the functioning of which is fully described in the Advance Data Sheets for the Emergency Control System.

FLOW DISTRIBUTOR

General

- The flow distributor ensures that an equal quantity of scheduled fuel is supplied to each of the 32 primary fuel injectors. It also acts as a minimum pressure valve, which opens at a pre-set fuel delivery pressure that is most suitable for satisfactory operation at low fuel pressures. The distributor prevents fuel leakage to the injectors when the engine is inactive.
- 46 Fuel pump delivery pressure passes through the scheduling units and is supplied to the distributor inlet by way of the oil cooler. As the fuel pressure rises, it acts on a distributor piston head, and two pre-set springs are gradually compressed. At 75 psi the piston is depressed sufficiently to uncover the distribution ports and a small fuel flow is delivered to each injector. As engine speed and fuel pressure increases the piston is further depressed and larger fuel flows result as more of each distribution port is uncovered. A description of the oil cooler is contained in Section 3 of this part.

ROYAL CANADIAN AIR FORCE

IROQUOIS ADVANCE DATA SHEETS

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FUEL SYSTEM

EMERGENCY CONTROL SYSTEM

GENERAL

- The emergency control system provides the pilot with an alternative means of controlling engine speed and power output should malfunctioning of the automatic controls develop. An EMERGENCY selector switch located on the cockpit control panel can be selected at the discretion of the pilot.
- When the control system is switched to EMERGENCY, the automatic control of fuel flow during acceleration is cut-off, also are the HP and LP rotor governors and the minimum idle flow control valve. This means that the pilot must exercise great care in handling the power control lever while in EMERGENCY. However, overspeed protection for the HP rotor is provided by the emergency governor; power modulation is provided by the emergency throttle valve and the fuel pump pressure control unit. A degree of altitude compensation is also provided by the pump pressure control unit.
- 3 The emergency control system provides a very basic means of controlling the fuel flow and comprises essentially a changeover valve assembly operated by a rotary actuator, an emergency throttle valve, and the emergency governor.

EMERGENCY CHANGEOVER VALVE ASSEMBLY

General

4 The emergency changeover valve assembly comprises two rotary type transfer

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valves, one of which is normally held in the open position and the other in the closed position. The valves are located in the NORMAL and EMERGENCY fuel passages upstream of the emergency throttle valve and main shut-off valve, and are positioned by the rotary actuator. Transfer of the fuel flow from NORMAL to EMERGENCY and vice versa, is effected smoothly and without interruption by rotating the valves simultaneously through 90 degrees so that as one closes, the other opens.

Transfer Valves

- Each transfer valve is in the form of a suitably ported cylinder which, when in the closed position, completely shuts off the passage in which it is located. The port in the NORMAL transfer valve is of such an area that little or no restriction is offered to the fuel flow when the valve is open. The port in the EMERGENCY valve is however of a considerably reduced area to provide a restriction in the passage upstream of the emergency throttle valve.
- The transfer valves are located side by side in a common housing and the outlets from the valves lead directly to the emergency throttle valve and the main shut-off valve. The ends of each valve are sealed with 'O' rings to prevent the leakage of excessive quantities of fuel past the valves. Small cross bleeds in the valves and the valve housing permit a circulatory flow from the high pressure to the low pressure side to prevent stagnation and overheating of fuel in whichever system is inactive.

Actuating Gears

Two gears, one keyed to the outer end of each transfer valve, are in mesh with a common drive gear splined to the output shaft of the rotary actuator. The rotational relationship between the three gears is such that clockwise movement of the drive gear through 90 degrees angular displacement results in a similar displacement of the NORMAL transfer valve in the clockwise direction and of the EMERGENCY valve in the anti-clockwise direction.

ROTARY ACTUATOR

General

8 The rotary actuator is an electromechanical device which converts electrical energy into mechanically controlled rotary motion of an output shaft. The actuator is mounted in line with the transfer valves and comprises a limit switch assembly, a reduction gearbox and a motor and brake assembly.

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Limit Switch Assembly

The limit switch assembly controls the electrical supply to, and the direction of rotation of, the motor. A cam arrangement on the rotary actuator output shaft actuates two micro-switches which determine the direction of current flow through the motor and hence its direction of rotation. The micro-switches also supply current to the magnetic brake until the 90 degree travel limit of the output shaft is reached. The leads from a five-pin electrical receptacle mounted externally on the rotary actuator, are routed via the limit switch assembly and channelling in the actuator housing to the brush block of the electric motor.

Reduction Gearbox

10 The reduction gearbox transmits the drive from the motor armature, at reduced speed, to the rotary actuator output shaft. The gearing is a planetary system with a reduction ratio of approximately 1000:1.

Motor and Brake Assembly

The motor and brake assembly is mounted on the outer end of the reduction gearbox and provides the drive to the reduction gearing. The motor is a 28 volt DC, series wound, reversible type, the armature of which is supported at each end by ball bearings. An electromagnetic brake on the end of the armature shaft comprises a spring-loaded plunger which is held against a brake anvil. The electromagnet is energized simultaneously with the motor and attracts the plunger away from the anvil to release the armature. When the output shaft reaches its 90 degree travel limit, the electromagnet is de-energized and the spring returns the plunger against the anvil to lock the armature in place. Simultaneously the electrical supply to the armature windings is cut off and rotation of the shaft ends. The total elapsed time for actuation through the travel limit is approximately 1.5 seconds under normal operating conditions.

EMERGENCY THROTTLE VALVE

General

- 12 The emergency throttle valve provides the primary means by which the pilot can control the fuel flow to the engine during EMERGENCY operation. The throttle valve is geared directly to the power control lever input shaft on the fuel control unit so that movement of the control lever results in positive movement of the throttle valve.
- 13 As previously described, the emergency throttle valve also functions as the main shut-off valve for both the NORMAL and EMERGENCY fuel flows to the engine.

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Description

- The emergency throttle valve consists of a simple, rotary-type plunger which rotates in a fixed sleeve as a function of power control lever movement. The sleeve and plunger arrangement are assembled into a bore in the emergency changeover valve housing in a position immediately downstream of the transfer valves. The housing and sleeve are machined to form two separate annular chambers around the periphery of the sleeve. 'O' ring seals are fitted to the sleeve to prevent fuel leakage from the chambers. The upper annulus communicates with the NORMAL fuel supply passage and the lower annulus with the EMERGENCY fuel supply passage.
- A series of large drillings in the sleeve communicate with the upper annulus. The holes are covered and uncovered by rotary movement of the plunger; from 0 to 4 degrees (shut-off position) the holes are completely covered; above 4 degrees the holes are sufficiently uncovered to offer negligible pressure drop and minimum restriction to the NORMAL fuel flow passing to the engine through the throttle valve outlet.
- A second series of smaller drillings allows the EMERGENCY fuel supply to pass from the lower annulus to the throttle valve outlet. These holes are also covered and uncovered by rotary movement of the plunger in such a way that all are covered from 0 to 4 degrees (shut-off position) and progressively uncovered from 4 degrees upwards. Thus when operating in EMERGENCY, a given power control lever setting always uncovers a given number of holes. Hence modulation of fuel passing through the valve when in EMERGENCY, is a direct function of power control lever movement.

HP ROTOR EMERGENCY GOVERNOR

General

17 The HP rotor emergency governor functions to control the maximum permissible rpm and prevent serious overspeeding of the HP rotor during operation in EMERGENCY. This governor provides the same protection during operation in NORMAL should a malfunction develop in the NORMAL governing system. Emergency overspeed protection for the LP rotor, although indirect, is provided through direct control of the HP rotor.

Description

18 The HP rotor emergency governor, which is an isochronous device similar in design and operation to the normal LP and HP governors previously described, comprises essentially a flyweight mechanism, a proportional valve and a floating valve. The normal HP governor and the emergency governor are located side by

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side in a common housing which is mounted on the outermost mounting pad on the front of the HP external gearbox. The drive from the gearbox governor gear is taken through a splined driveshaft to the spindle of the emergency governor. A spur gear on this spindle meshes with and drives a similar gear mounted on the normal HP rotor governor spindle.

19 The spring load on the emergency governor spindle is adjusted to give a governing speed of 50 rpm higher than the maximum setting of the normal HP governor. This avoids hunting between the governors and consequent unstable engine operation at maximum rpm.

Operation

- When governing, operation of the emergency governor is essentially the same as that previously described for the normal LP and HP governors except that the emergency governor acts directly on the fuel pump pressure control unit rather than on the pressure drop unit. A detailed description of the operation of the fuel pump pressure control unit during EMERGENCY governing is contained in the description of the HP Fuel Supply System.
- Like the normal governors, the emergency governor is supplied with fuel at a constant value above boost pump pressure by means of a separate pressure regulating valve. The position of the governor floating valve is controlled by modulating this constant pressure supply. The upstream side of the proportional and floating valve control orifices communicates with pump delivery pressure while the downstream side communicates directly with the pressure sensing piston in the fuel pump pressure control unit. Thus when the governing speed of the emergency governor is reached or exceeded, the governor control orifices open, and high pressure fuel is applied to the pressure sensing piston. This results in a reduction in the fuel flow rate to the engine as previously described in the HP Fuel Supply System.

ENGINE OPERATION IN EMERGENCY

General

When EMERGENCY is selected, the NORMAL control system is rendered inoperative and fuel passes directly from the HP fuel pump outlet to the emergency throttle valve. Basic control of the fuel flow to the engine is then effected by the emergency throttle valve. The pressure output of the HP fuel pumps for a given operating condition is established by the fuel pump pressure control unit. The flow rate through the emergency throttle valve is solely a function of the pressure drop across it, and its degree of opening. Therefore by opening or closing the valve

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through movement of the power control lever, the pilot can effect adequate control of the fuel flow to the engine.

Provided that the final nozzle control system is operative and the DC supply is uninterrupted, operation of the afterburner during EMERGENCY is possible.

Power Control Lever Handling

Since EMERGENCY operation isolates the electronic control amplifier, a complete loss of automatic control associated with exhaust temperature, acceleration, and the variable inlet guide vanes results. HP rotor range governing, LP rotor overspeed protection, altitude idling control, and maximum compressor pressure limiting are also eliminated. The pilot must be very observant of engine operating characteristics under these conditions and all accelerations and decelerations must be carried out by careful movement of the power control lever. 'Slam' openings, which cause rapid movement of the emergency throttle valve, are dangerous, as compressor surge and stall, or overtemperature conditions, may result.

Altitude Operation

Normally, when flying at altitude, control of the engine idling speed is automatic. However, in EMERGENCY, the loss of the minimum idle flow valve may necessitate manual repositioning of the power control lever to obtain the desired idling conditions. High rpm operation at low altitudes should be avoided due to the inactivity of the P4 limiter. A degree of altitude compensation is provided by the fuel pump pressure control unit which, as previously described, reduces or increases pump delivery pressure as a function of the pressure rise across the compressor. This results in a corresponding reduction or increase in the pressure drop across, and hence the fuel flow through, the emergency throttle valve.

Sea Level Idling Control

The sea level idling setting for EMERGENCY operation is 30 degrees as opposed to 13 degrees in NORMAL. This lessens throttle sensitivity at low fuel flows and thus provides a wider range of power control lever movement at altitude. In addition, this facilitates selection of idling speeds at altitude.

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FUEL SYSTEM

AFTERBURNER FUEL CONTROL SYSTEM

NOTE

The following paragraphs should be read in conjunction with Figure 3-2-8. Units written in capitals are called up in this figure. Information will be issued later giving further details of these units.

General

- The fuel supply to the afterburner spray rings is scheduled by the afterburner fuel control system to the flow values required for efficient operation of the afterburner, over the wide range of operating conditions encountered by the engine. The afterburner fuel control system is mechanically linked to the power control lever, and operates automatically as the lever is moved into the afterburning range. Provision is made for automatic modulation of the fuel schedule with varying altitude and forward speed.
- The afterburner control system includes units which are similar in design and operation to those used in the main fuel control system, namely: the AFTERBURNER METERING UNIT, SERVO THROTTLE VALVE, PILOT OPERATED THROTTLE VALVE and PRESSURE DROP UNIT. In addition, the afterburner control system incorporates a MINIMUM FLOW VALVE, AFTERBURNER SHUT-OFF VALVE and HOT STREAK IGNITER VALVE, these units being described in subsequent paragraphs.

AFTERBURNER METERING UNIT

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AFTERBURNER METERING UNIT. The description of the MAIN METERING UNIT explains that two factors govern the fuel flow through any valve namely: the valve orifice area and the pressure drop across the valve. The AFTERBURNER METER-ING UNIT differs from the MAIN METERING UNIT in that the bellows assembly is subjected to HP compressor delivery pressure (P4) in place of inter-compressor pressure (P3). The calibration of the units also differs. As P4 is a measure of the engine mass air flow, the valve orifice area is automatically positioned relative to the forward speed and altitude at which the aircraft is operating. Control of the pressure drop across, and hence the fuel flow through the valve, is effected by the afterburner pressure drop control circuit, which repositions the SERVO THROTTLE VALVE primarily as a function of power control lever movement. The SERVO THROTTLE VALVE forms a variable area fuel restriction, which controls the fuel pressure downstream of the metering valve and hence the pressure drop across it. Therefore, the metering unit regulates the afterburner fuel flow to give the thrust output selected by the pilot, and continuously compensates for changes in engine mass air flow caused by varying altitudes and forward speeds.

AFTERBURNER PRESSURE DROP CONTROL CIRCUIT

General

The pressure drop control circuit maintains the pressure drop across the AFTERBURNER METERING UNIT constant for any fixed power control lever setting excluding trim action. The circuit consists of a hydraulic potentiometer, the PRESSURE DROP UNIT, and the SERVO THROTTLE VALVE. The basic principle of operation of these units is the same as that described in Para 12 of the Main Fuel Control System Advance Data Sheets.

Afterburner Servo Throttle Valve and Pressure Drop Unit

The SERVO THROTTLE VALVE and PRESSURE DROP UNIT used in the afterburner pressure drop control circuit resemble, both in construction and operation, the equivalent units used in the main fuel control system; refer to the Main Fuel Control System Advance Data Sheets for a description of these units.

Afterburner Hydraulic Potentiometer

The afterburner hydraulic potentiometer comprises two fixed orifices and two variable orifices namely, the potentiometer throttle valve (see PILOT OPERATED THROTTLE VALVE Figure 3-2-8) and the MINIMUM FLOW VALVE. The orifices are inter-connected and located parallel to the AFTERBURNER METERING UNIT. A small by-pass fuel flow taken upstream of the metering unit is filtered and fed to the circuit. The pressure signals required to reposition the SERVO THROTTLE VALVE are produced across the orifices, and sensed at the PRESSURE DROP UNIT.

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The orifice areas are equivalent to two orifices (area A1 and A2) in series. Area A1 is a fixed area restricting orifice and area A2 is the combined areas of a fixed orifice downstream of area A1 and the variable area potentiometer throttle valve. The MINIMUM FLOW VALVE also forms part of area A2 when, under certain conditions, it operates to override the throttle valve setting. Its operation and purpose in the potentiometer is fully described in Para 9.

Operation of Pressure Drop Control Circuit

- Fuel at pump delivery pressure enters the pressure drop control circuit through the fixed restriction (area A1). This restriction establishes a reference fuel pressure at a value below pump delivery pressure. The flow passes through the MINIMUM FLOW VALVE to the potentiometer throttle valve (area A2). When the power control lever is at or below the 93 degree quadrant position, the potentiometer throttle valve is fully open. The fuel passes through the throttle valve and enters the main fuel flow downstream of the AFTERBURNER METERING UNIT. A pressure tapping between area A1, and the MINIMUM FLOW VALVE connects the reference fuel pressure to the spring side of the PRESSURE DROP UNIT and also the fixed orifice (area A2). This reference pressure is at a higher value than metering valve downstream pressure. Hence a small flow of fuel occurs through the fixed orifice (area A2).
- When the power control lever is advanced beyond 93 degrees, the potentiometer throttle valve gradually closes. The increased restriction formed by the throttle valve increases the reference fuel pressure and hence reduces the pressure drop across the fixed orifice (area A1). The increase in reference pressure together with the spring force acting against the diaphragm plate valve in the PRESSURE DROP UNIT, force the plate valve against its orifice seat. This prevents fuel at pump delivery pressure from entering the SERVO THROTTLE VALVE servo chamber. As the pressure in the servo chamber is relieved, the high pressure fuel downstream of the metering unit forces the SERVO THROTTLE VALVE piston upward. The SERVO THROTTLE VALVE orifice area is enlarged, and the pressure drop across, and hence the fuel flow through the AFTERBURNER METERING UNIT increases. Thus the control circuit regulates the pressure drop across the AFTERBURNER METERING UNIT primarily as a function of the setting of the potentiometer throttle valve.

AFTERBURNER MINIMUM FLOW VALVE

General

9 The MINIMUM FLOW VALVE establishes the minimum fuel flow required to sustain afterburner combustion when the fuel schedule set at the potentiometer throttle valve is too lean. It operates throughout the afterburning range within set

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mass air flow pressure limits. As engine speed and mass air flow varies, the afterburner fuel controls are automatically rescheduled to provide the most suitable combustion mixture.

Description

The valve comprises a variable area fuel restriction, provided by a profiled plunger operating in a circular orifice. The plunger is connected to one end of an evacuated bellows, the other end of the bellows being fixed. The bellows assembly is enclosed in a sealed chamber which is subjected to compressor delivery pressure (P4). Hence the plunger is actuated by expansion or contraction of the bellows due to changes in the compressor delivery pressure. The unit is located in the pressure drop control circuit between the fixed entry orifice (area A1) and the potentiometer throttle valve (area A2). The valve is closed until P4 pressure rises to 13.3 psi and is fully opened at 66.4 psi.

Operation

- When the power control lever is retarded between 93 and 78 degrees, the potentiometer throttle valve is fully open, and hence does not modulate the fuel flow. Without the MINIMUM FLOW VALVE in the circuit, the afterburner SERVO THROTTLE VALVE would tend to close. However, the MINIMUM FLOW VALVE senses the mass air flow through the engine and is positioned accordingly. This produces a variable choke action in the hydraulic potentiometer. The resultant decrease in the pressure drop across area A1 is sensed by the PRESSURE DROP UNIT, which simultaneously repositions the SERVO THROTTLE VALVE, to maintain the correct fuel flow required to match the gradually reducing engine speed and mass air flow.
- As the power control lever is advanced between 93 and 110 degrees, the potentiometer throttle valve gradually closes. Hence in this range the fuel flow can be modulated by both the potentiometer throttle valve and the MINIMUM FLOW VALVE, depending upon the power control lever setting and the value of P4 pressure. If the fuel flow scheduled by the potentiometer throttle valve results in a lean combustion mixture, the MINIMUM FLOW VALVE increases the fuel schedule to the minimum flow required for satisfactory afterburner combustion.

AFTERBURNER SHUT-OFF VALVE

General

13 The AFTERBURNER SHUT-OFF VALVE provides a positive means of cutting off the afterburner fuel supply when afterburning is not required. The unit is located in the tertiary air duct of the engine firewall assembly. A sliding mounting arrangement is used to allow for differential thermal expansion.





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Description

14 The unit basically consists of an integral piston and shut-off plunger, a fixed sleeve, a spring-loaded orifice plate valve and an electrical solenoid. The inlet and outlet ports are interconnected through orifices in the fixed sleeve. The waisted section between the piston and plunger contains a small fixed area restricting orifice and strainer which connects the inlet port to a servo chamber formed in the piston head. The piston head is spring-loaded to hold the plunger in the closed position when the engine is stopped. The plate valve seats across a control orifice in the servo chamber. When it is raised by means of the electrical solenoid, the chamber is connected to the shut-off valve outlet port through internal drillings. The shut-off plunger seats against the outlet orifice in the fixed sleeve. A small port in the side of the valve body connects the inlet port to boost. Hence a continuous circulatory fuel flow is provided during engine running to prevent the unit and supply lines from overheating.

Operation

When the afterburner is not operating, fuel from the SERVO THROTTLE VALVE enters the AFTERBURNER SHUT-OFF VALVE and passes through the fixed orifice and strainer to the servo chamber. As the solenoid is not energized the fuel cannot escape and the pressure in the chamber builds up until it is equal to the fuel supply pressure. The internal servo chamber diameter is greater than the external exposed piston diameter, hence the pressure in the servo chamber prevents the shut-off plunger from opening. When the solenoid is energized, the orifice plate valve is raised and pressure in the servo chamber is relieved to the valve outlet port. Thus a pressure drop is formed in the servo chamber, and the piston moves upward in the direction of lower pressure to open the valve. Fuel is then supplied to the afterburner combustion manifold.

AFTERBURNER IGNITION SYSTEM

General

The 'hot streak' ignition method is used to ignite the afterburner fuel flow. A separate flow of fuel at pump delivery pressure is supplied to a HOT STREAK IGNITER VALVE which introduces metered pulses of fuel into the flame area of the engine combustion chamber. Each pulse of fuel ignites and produces a long streak of relatively hot gases through the turbine section and through the rear frame to the region of the afterburner fuel spray rings. The hot streak is augmented by additional fuel injected through a relay jet installed in the rear frame outer casing. The scheduled fuel flow passing simultaneously through the spray rings is thus ignited as the power control lever is advanced into the afterburning range.

Hot Streak Igniter Valve

17 The HOT STREAK IGNITER VALVE is a pulsating type of fuel injector which

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introduces measured quantities of fuel into the hot streak system in pulses of approximately 0.75 seconds duration. The pulsating action continues at intervals of approximately three to four seconds during a 15 second time cycle. Normally no more than two pulses are required to ignite the afterburner fuel flow.

- 18 The igniter valve comprises a servo-operated timing piston, a micro switch and lever assembly, a safety shut-off valve, and a solenoid-operated shut-off valve.
- 19 As the power control lever is advanced into the afterburning range, the power supply to the valve solenoid passes through a timer set for 15 seconds. The power control lever must be retarded and readvanced before the valve solenoid can be re-energized to repeat the light-up procedure.
- The valve is supplied with fuel at pump delivery pressure. When the solenoid is energized, the shut-off valve opens and fuel passes through the unit to the hot streak fuel injectors. As this occurs the timing piston in the valve is displaced by fuel pressure, and travels against a micro switch lever which trips the electrical contacts to de-energize the valve solenoid. Simultaneously the shut-off valve closes to prevent fuel delivery to the injectors. Hence the fuel pressure in the unit builds up and the timing piston and micro-switch lever return to their original position. The valve solenoid is re-energized and the pulsating cycle repeated until the timer isolates the power supply to the valve solenoid. Should the solenoid-operated shut-off valve fail to close, the servo-operated timing piston moves to the right until the safety shut-off valve closes.

AFTERBURNER ELECTRICAL CONTROL CIRCUIT

- To operate the AFTERBURNER SHUT-OFF VALVE and HOT STREAK IGNITER VALVE and thus bring the afterburner in operation, two electrical circuits must be closed to energize the appropriate solenoids. One circuit is closed when the power control lever is moved past 93 degrees into the afterburning range. The second circuit is closed when the rising engine speed actuates a speed switch. In this way premature afterburner operation is prevented until the engine rotor speed is beyond the surge range and until the dry engine thrust is near its maximum value.
- If the engine speed switch is closed, afterburner light-up will occur at 93 degrees power control lever position. However when retarding the lever, the afterburning range extends to 78 degrees power lever angle. Further details of the electrical circuits are detailed in Section 6 of this part.

FINAL NOZZLE CONTROL

During afterburning, the final nozzle area is automatically increased to allow the additional volume of exhaust gases to escape. Control of the final nozzle area is

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described fully in Section 12 of this part.

AFTERBURNER SPRAY RINGS AND STABILIZERS

The scheduled afterburner fuel flow is delivered to the afterburner through a series of spray rings and stabilizers which evenly distribute the fuel into the combustion zone. Full details of these components will be found in Section 9 of this part.

ROYAL CANADIAN AIR FORCE

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LUBRICATING OIL SYSTEM

General

- I The engine lubricating oil system is self-contained and operates basically on the dry sump principle. The system consists mainly of an internal tank, two oil pressure supply pumps and a scavenge pump, an oil temperature regulator, and the necessary components for oil distribution.
- The quantity of oil supplied to the various components considerably exceeds that normally required for lubrication; this is to ensure that such items as bearings and gears are effectively cooled. The oil flow is controlled by jet orifice size and line resistance to the various outlets.
- A feature of the lubricating system is the use of steel-backed carbon ring seals with air at high pressure applied to the seals to prevent oil leakage; the pressurizing effect is a major factor in the efficient scavenging of the oil system. Inverted flight is not a normal military requirement and no special provision is made for anti-g conditions. However, the engine will function inverted without detriment for periods up to one minute should the oil supply to the bearings and gears be interrupted.

Oil Tank

An annular shaped oil tank is provided, using the inner hub of the front frame as the tank outer wall. The internal gearbox casting forms the inner circular wall of the tank, the front and rear walls being provided by the LP and HP bearing housings respectively, see Figure 3-3-1. The oil tank is vented to the front sump through a double ball vent valve, in order to exhaust air transferred by the scavenge return system to the tank. The double ball vent valve also prevents oil flow from the tank

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to the front sump in any flight attitude. Refilling is carried out by attaching a pressure oil supply to a quick disconnect fitting located near the oil filter on the underside of the engine. An adjacent quick disconnect fitting connects to an overflow pipe from the tank and indicates when the correct oil level has been reached. The tank is drained by means of a cock at the bottom of the front frame No.5 strut. The capacity of the tank is five Imperial gallons (six US gallons), four-fifths of which is occupied by oil.

Pumps

5 The oil pumps are of the positive displacement type employing a special form

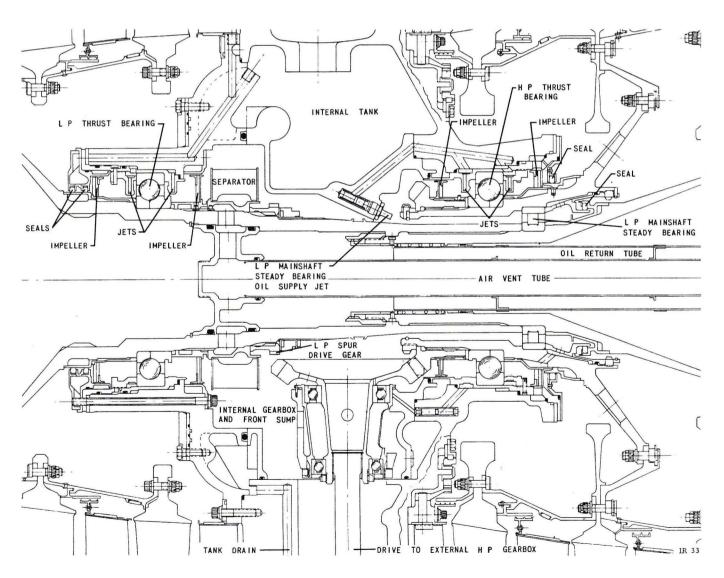


Figure 3-3-1 View Showing Front Frame Internal Details

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of internal-external gear system known as the Gerotor mechanism. The pumping action of this mechanism is described in detail in Part 4 of EO 15-25HA-2 and EO 15-25HB-2. The three pumps employed in the engine lubricating system are mounted on the HP external gearbox. The larger of the two single element pressure pumps supplies the main engine requirements whilst the smaller unit provides a pressure oil supply solely for the aircraft alternator drive constant speed unit. The scavenge pump unit, composed of two elements in a single casing, returns oil to the tank from the engine main circulating system. An oil flow indicator is provided in the pilot's cockpit. The indicator is actuated by a switch which senses the pressure differential across the main pressure pump.

Filter and By-pass Valve

The filter has a re-usable 33 micron element of the stacked disc type, formed from calendered wire cloth. A by-pass valve incorporated in the filter assembly opens at 30 psi pressure difference and prevents undue restriction of the oil flow should the element become clogged by foreign matter. The filter body is retained to its housing by a single self-locking bolt, and access for servicing is provided by a panel on the underside of the engine shroud. A check valve located on the filter adaptor prevents oil drainage from the tank into the circulating system through the pressure pump element when the engine is inoperative.

Oil Temperature Regulator

The engine oil is cooled by circulation through a conventional heat exchanger through which fuel is passed as the cooling medium. A pressure relief valve operating at 150 psi protects the oil temperature regulator from excessive pressure. A combined thermal and by-pass valve opens at temperatures below 15°C (59°F) or pressure differences above 40 psi, allowing oil to by-pass the cooling element to achieve minimum warm up time.

Rotary Valve

A rotary valve, interconnected with the engine throttle linkage, is interposed in the pressure oil supply immediately downstream of the oil temperature regulator. The purpose of this valve is to divert the flow of pressure oil from the engine main circulation to the tank during engine rundown, when the engine throttle is closed. This prevents the possibility of oil accumulating in the engine bearings, and leaking into the turbine or compressor casing after the engine has stopped. The valve has a single inlet and two outlets, and to prevent interruption of the flow, the valve is ported so that from 0 degrees to 10 degrees throttle angle the outlet to the tank is open, and from 5 degrees to 110 degrees throttle angle, the outlet to the engine circulation is open. An overlap when both outlets are open together is therefore obtained between 5 and 10 degrees throttle angle. This porting ensures that the full



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pressure supply is delivered to the engine before the idling position of 13 degrees throttle angle is reached.

Internal Gearbox Lubrication

Pressure oil is supplied through an oil jet to the meshing point of the spiral bevel gears which transmit the drive from the HP rotor shaft to the internal gearbox; pressure oil is also fed to the driven gear support bearings. The gear train from the LP rotor, being lightly loaded, is lubricated by oil mist. The lower portion of the internal gearbox casting forms the front sump. Oil from the separator and internal gearbox components collects in the front sump, and gravitates to the external gearbox sump, through No.5 strut of the front frame.

External LP and HP Gearbox Lubrication

Pressure oil is supplied by external connections to both the LP and HP gear-boxes for jet lubrication of the gear trains. The oil seals are of the double floating ring type, the space between the seals being supplied with high pressure air tapped from the HP compressor. Drainage from the LP to the HP gearbox is by an external gravity line. The HP gearbox sump is scavenged by the main scavenge pump element.

Oil Seals

The main oil seals used in the Iroquois are each composed of a steel-backed carbon ring located in a housing. The housing locates the ring axially and permits it to float with minimum clearance on the surface of the adjacent rotating component. As the pressure oil supply to the bearings and gears is by jets, no appreciable internal pressure head need be contained by the seals, thus a supply of high pressure air tapped from the HP compressor and applied to the seal, is sufficient to prevent oil leakage. It should be noted here, that a limited flow of air escapes through the seal to mix with the oil, as detailed later.

Engine Main Bearing Lubrication

The HP and LP thrust ball bearings, the LP mainshaft steady roller bearing, and the HP and LP turbine roller bearings, comprise the main engine bearings. Each of these bearings is supplied with oil through the main pressure line. In the case of the LP thrust bearing, oil is fed from a tapping in the front frame through screens to six jets, three equally spaced on each side of the bearing to ensure, in addition to lubrication, adequate cooling and heat distribution. A radially vaned scavenge impeller is mounted on either side of the bearing and these discharge the oil through passageways leading directly into the tank. The air on the front of the LP bearing housing is at third stage LP compressor pressure. At this point a double carbon

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ring oil seal is fitted, and to maintain an efficient sealing effect, the space between the two seals is pressurized by seventh-stage HP compressor air.

The feed arrangements, jets, and impellers used on the HP thrust bearings are similar to those described for the LP bearing. Scavenge oil in the passages from the impeller to the tank can, however, drain to the front sump by means of a drain valve operated by pressure oil. As the main supply pressure falls during engine rundown, the valve opens to drain away oil accumulating in the HP thrust and steady bearings, which might otherwise leak through the seals into the compressor casing. A single carbon ring oil seal is fitted at the rear of the HP bearing, the air at the exterior of the bearing housing being at seventh stage HP compressor pressure.

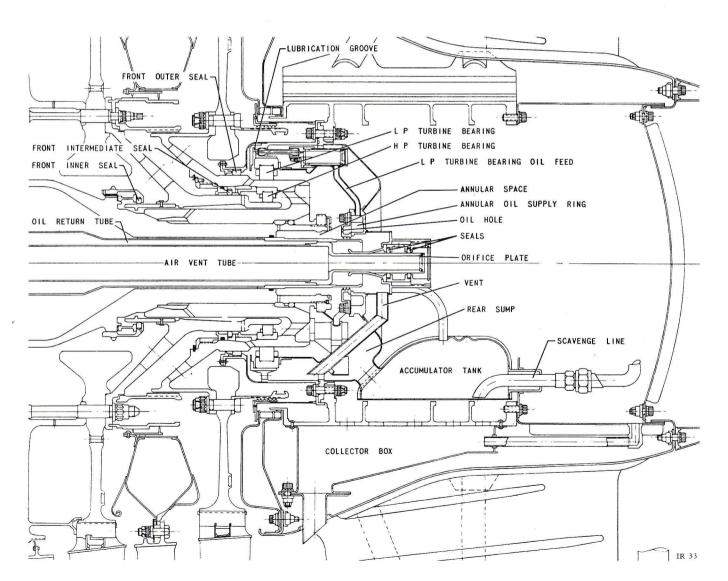


Figure 3-3-2 View Showing Rear Frame Internal Details

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14 The oil supply for the LP mainshaft steady roller bearing is conveyed by drillings in the internal gearbox casting to a single screened jet discharging into the annular space between the LP compressor shaft and the HP compressor front shaft. After flowing through the bearing, the oil passes through drillings in the HP compressor front shaft to the HP bearing impeller and is scavenged to the tank. A single carbon ring oil seal is fitted at the rear of the bearing, the ambient air being at seventh-stage HP compressor pressure.

The LP and HP turbine roller bearings are each supplied with pressure oil fed into an annular ring on the inner face of the rear sump, see Figure 3-3-2. Three equally spaced holes in the forward face discharge oil into the annular space between the oil return tube and the LP shaft. This oil, by centrifugal force, makes its way through drillings and spline clearances to the forward face of the HP bearing. Oil for the LP bearing is piped from the annular ring to the concentric lubrication groove immediately forward of the bearing. In both cases the oil flows rearward through the bearings and drains into the rear sump. The front inner, front intermediate and front outer oil seals on the HP and LP turbine assemblies are all pressurized by seventh stage compressor air, and single carbon ring oil seals are fitted at these locations.

Oil Circulation

- The circulation of pressure oil from the internal tank to the various engine components is indicated in Figure 3-3-3. A large portion of the oil collected in the rear sump is in the form of an oil air mist due to air leakage through the seals and the churning action of the bearings. This mixture flows through the rear sump vent into the rotating oil return tube, as the rear sump air pressure is always slightly higher than that at the separator in the front sump. This flow is assisted by the forward air flow from a double floating ring seal pressurized by seventh stage compressor air, located at the rear of the oil return tube. At extreme altitude when the air flow is reduced, the oil may tend to separate from the air in the oil return tube. To accommodate this condition the diameter of the oil return tube outer member increases in two increments, from rear to front. These local conical sections impel the oil forward due to centrifugal effect.
- 17 On emerging from the oil return tube the air and oil flows through radial holes in the LP rotor shaft into the separator, which centrifuges all oil droplets of 10 microns and greater into the front sump. The air flows inward through the separator vanes into the air vent tube, then rearwards into the space behind the rear sump in the exhaust bullet. Air returned by the scavenge pumps to the tank is vented to the front sump, and passes through the separator to the exhaust bullet in the same manner. An orifice plate located at the rear of the air vent tube restricts the flow, and therefore controls the overall air pressures throughout the system to the required proportions. The air discharges through a collector box on the underside of

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the exhaust bullet into the main exhaust gas stream. Any oil accumulating in the exhaust bullet drains into the collector box and is expelled with the outgoing air.

Oil collecting in the rear sump, drains into a small accumulator tank to which the auxiliary scavenge pump is connected. The purpose of this tank and pump is to ensure continuous scavenging of the rear sump during engine rundown, when the air pressure may be inadequate for efficient scavenging of the sump through the oil return tube.

Alternator Constant Speed Unit Drive Oil System

The alternator, constant speed unit, and drive is provided by the airframe contractor, however, the oil supply required to operate this equipment is drawn from the internal tank by a pressure pump mounted on the HP external gearbox. The pump suction line extends only to the half-full level in the tank so that an adequate oil reserve for engine lubrication is always maintained, should loss from the constant speed unit drive system occur. A separator incorporated in the return system discharges both oil and air into the internal tank.

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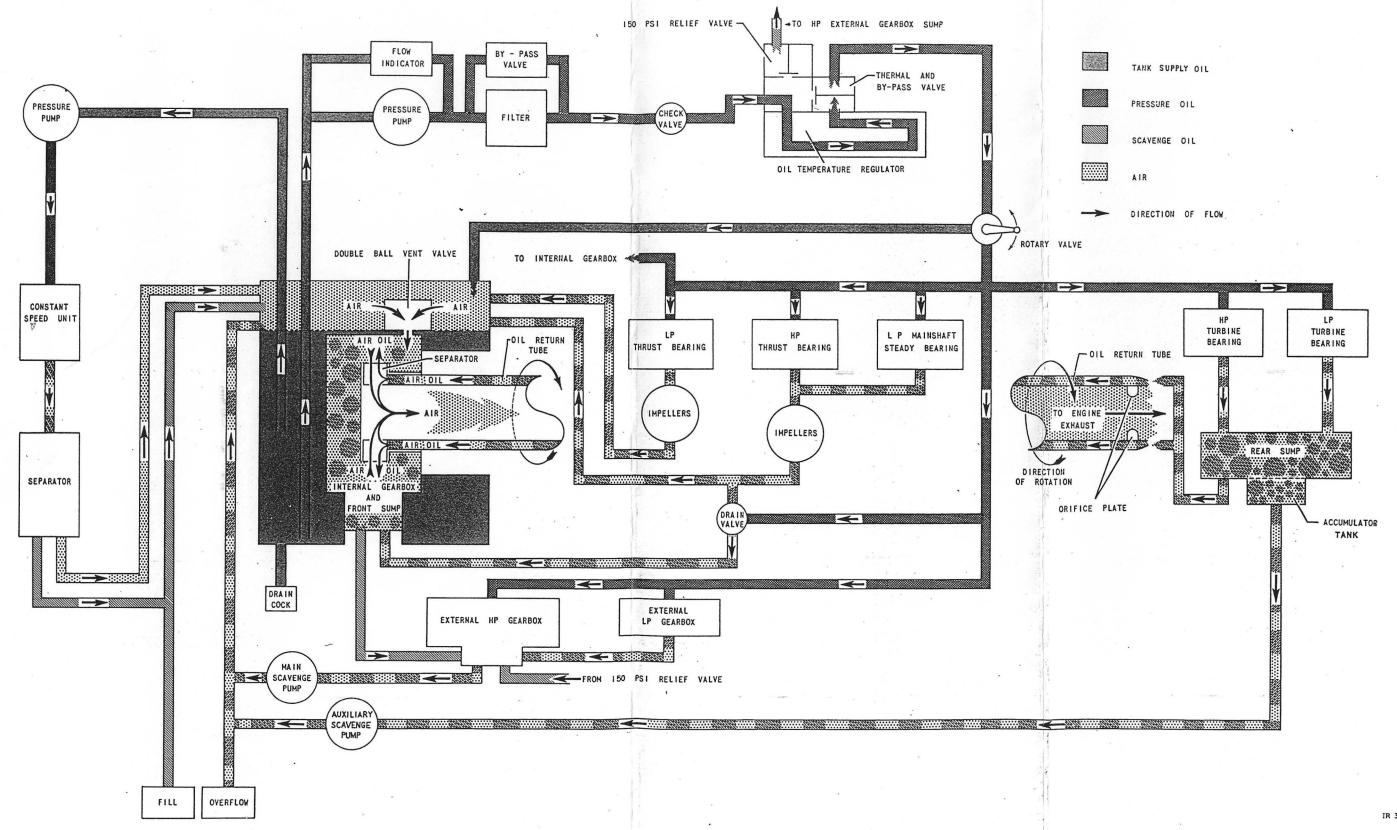


Figure 3-3-3 Schematic Diagram of Lubricating Oil System

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ENGINE HYDRAULIC SYSTEM

General

- The engine hydraulic system provides a supply of oil at high pressure which is used primarily to actuate the variable area final nozzle, and the variable incidence HP compressor inlet guide vanes. The high pressure oil is also used, during engine starting, to drive a hydraulic motor to which the auxiliary fuel pump is coupled. The system operates on a closed circuit and consists basically of a reservoir to maintain a reserve of oil at low pressure, an accumulator, filters, and a variable output hydraulic pump. Provision is made to bleed the HP side of the system. A schematic arrangement of the system is shown in Figure 3-4-1.
- A section of the lubricating oil temperature regulator is used to regulate the temperature of the hydraulic oil as it flows through the LP return line to the hydraulic pump; fuel passing through the regulator is used as the cooling medium. A thermal valve in this section of the regulator opens at oil temperatures of 85°C (185°F) and below allowing LP oil to by-pass the cooling element. This is to ensure rapid warm-up to normal operating temperatures on initial engine start.

Hydraulic Pump

The supply of pressurized oil required for the operation of the system is provided by a variable stroke, axial piston type pump which is mounted on the HP external gearbox. The pump embodies an integral control which is made sensitive to pump output pressure, and which maintains a pressure of 3000 psi in the high pressure side of the system by adjusting the effective stroke of the pump. If, for example, the output pressure tends to drop due to the opening of the actuator control valve or a decrease in engine rpm, the pump control increases the stroke of the pump to maintain the pressure. Conversely, when a valve in the system closes, or when an

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increase in engine rpm occurs, the pump stroke is reduced to prevent an excessive build up of pressure beyond the required value. When the full HP line pressure is attained, the pump delivers only sufficient oil to compensate for loss through the bleed holes in the final nozzle actuator pistons.

Filters

Two 10 micron filters are provided in the system; one is located on the inlet and the other on the outlet side of the hydraulic pump. The filter elements are of the re-usable type and are formed of sintered wire cloth. Each filter is fitted with a by-pass valve which operates at 50 psi pressure difference, to prevent excessive flow restriction in the event of the filter element becoming clogged with foreign matter.

Accumulator

A 25 cub. in. capacity piston type accumulator is fitted in the HP side of the system. The accumulator provides a reserve supply of HP oil and tends to stabilize the system when, for example, a sudden change occurs in the demand for HP oil as a result of a control valve opening or closing. The accumulator is pre-charged with nitrogen gas to a pressure within 1500 to 2000 psi. A connection is provided for pressure checks, and for recharging the accumulator should this be found necessary during ground servicing.

Reservoir

- A 90 cub. in. capacity self-energizing oil reservoir is provided in the system. The reservoir consists of a piston and rod assembly which is free to move in a cylinder. HP oil acting on the small area of the piston rod is balanced by LP oil acting on the larger area of the piston outer face. The ratio of these areas is arranged so that the 3,000 psi HP oil at the rod end exerts a pressure of 45 psi on the LP oil in the system. Unlike the conventional spring-loaded reservoir, the self-energizing type maintains an almost constant pressure at the pump inlet, irrespective of the volume of oil in the reservoir, or atmospheric pressure variations. Provision is made on the reservoir for the installation of a magnetic type switch which operates a warning light in the pilot's cockpit should the volume of oil fall below a predetermined minimum value.
- A LP relief valve is incorporated in the reservoir to prevent excessive pressure build-up of the LP oil due to thermal expansion effects and overfilling. This valve is located in the reservoir piston and is operated mechanically when the valve stem contacts the inner face of the cylinder end wall. Oil passing through the valve to the space behind the piston is drained overboard.

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8 For servicing purposes the volume of oil in the reservoir is indicated by a pointer and suitably graduated scale which is visible when the adjacent engine panel is removed. The pointer is connected to the reservoir piston by a flexible cable.

HP Relief Valve

A HP relief valve protects the HP side of the system from excessive pressure which might result from malfunctioning of the system components. The valve operates at pressures in excess of 3,300 psi to by-pass HP oil to the LP side of the system.

Pressure Filling Connection

A quick-disconnect fitting for the attachment of pressure filling equipment is located on the underside of the engine. This fitting is positioned in close proximity to the oil reservoir volume indicator for ease of servicing, and is designed to prevent the entry of air during the filling operation.

Auxiliary Fuel Pump Drive Motor

- It is auxiliary fuel pump which provides the initial fuel supply to the engine during starting, is driven by a hydraulic motor of the fixed displacement, axial piston type. The hydraulic motor is operated by a supply of HP oil which is conveyed to the motor inlet through a solenoid-operated valve; the motor outlet is connected to the LP oil return to the hydraulic pump. The speed of the motor is controlled by a maximum flow valve which senses the volume of oil flowing through the motor.
- When the engine starting button is pressed, a relay simultaneously energizes the solenoid which opens the valve and hence the HP oil line to the hydraulic motor. As the engine begins to rotate, pressure builds up rapidly in the hydraulic system, thus driving the hydraulic motor. The speed of the hydraulic motor increases until the oil flow through the motor approaches the maximum value established by the maximum flow valve. At this point the flow valve restricts the HP oil supply to the motor and stabilizes the motor speed.
- As the engine speed increases, the main fuel pumps build up sufficient pressure in the fuel control supply line to close a check valve in the outlet of the auxiliary fuel pump. A switch on the check valve opens and de-energizes the hydraulic motor solenoid, thus cutting off the supply of HP oil to the hydraulic motor, stopping the motor and auxiliary fuel pump.

Final Nozzle Actuator and Control

14 Four hydraulic actuators, equally spaced around the engine final nozzle, are

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used to vary the final nozzle area to suit changing engine operating requirements. Each actuator consists basically of a piston and cylinder mechanism, the linear piston movement being transmitted to the final nozzle unison ring by direct mechanical linkage.

- Movement of the piston in the actuator cylinder is regulated by an actuator control which is positioned as a function of the ratio of HP compressor delivery pressure (P3) to afterburner downstream pressure (P7), by means of a pressure ratio actuator. The pressure ratio actuator maintains a constant trim of the final nozzle area at all flight conditions, to suit the varying engine requirements. Referring to "A" of Figure 3-4-1, it will be seen that variations in the P3 and P7 pressure ratio regulate the position of a valve in the actuator control, to direct HP oil or LP oil to the space on the left of the final nozzle actuator piston. HP oil is fed to the space on the right of the final nozzle actuator piston at all times. When the actuator control valve is positioned as shown, HP oil is fed to both sides of the final nozzle actuator piston. Due to the difference in piston areas subjected to pressure, the piston will move to the right and increase the area of the engine final nozzle.
- When an increase in the P₃ and P₇ pressure ratio occurs the actuator control valve moves to the right, and reduces the HP oil supply to the control. Simultaneously the LP port is uncovered and the pressure acting on the left side of the final nozzle actuator piston is relieved, causing the actuator piston to move to the left and reduce the engine final nozzle area.
- A bleed through each of the actuator pistons maintains a continuous circulation of oil through the actuators for cooling purposes. A hydraulic clutch which locks the actuator in the event of failure of the engine hydraulic system is also embodied in each of the final nozzle actuators.

HP Compressor Inlet Guide Vanes Control

- The angle of incidence of the HP compressor inlet guide vanes is changed from minus 15 degrees to plus 25 degrees by means of three hydraulic actuators equally spaced around the periphery of the LP thrust bearing housing. (Later model engines will have one actuator located externally). The control and actuator details shown in "B", Figure 3-4-1, consist of a solenoid-operated valve which controls the supply of HP and LP oil from the engine hydraulic system to the guide vane actuators. Adjustable stops in the actuators limit the range of movement. The supply of electric current to the solenoid is controlled by a switch in the engine amplifier unit as a function of HP compressor rotor speed.
- 19 On engine start, the speed switch in the amplifier unit energizes the solenoid to move the valve to the right, as shown. HP oil is fed to the space on the left of the actuator piston, the space on the right of the piston being opened to LP oil. The

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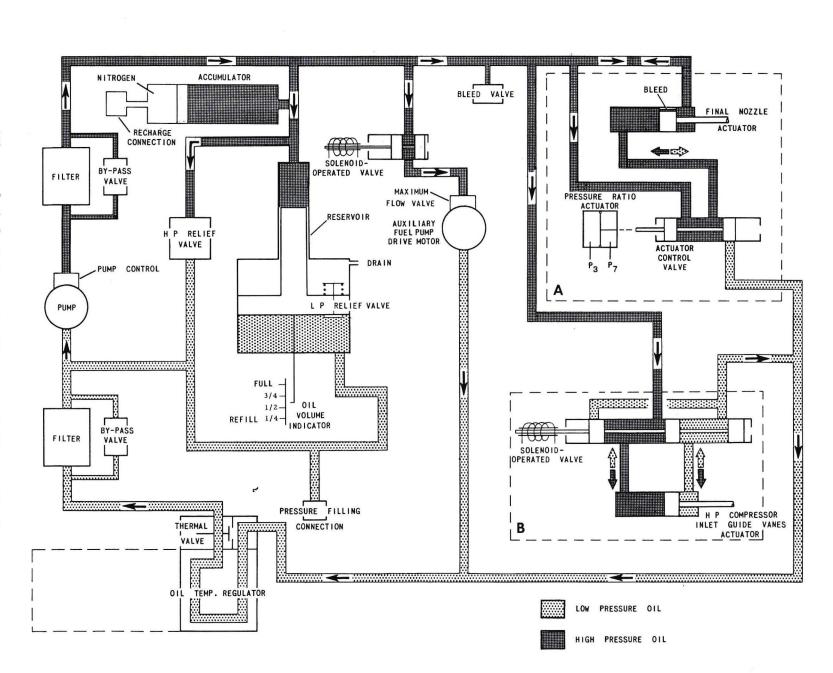


Figure Schematic Diagram of Hydraulic System

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actuator piston therefore moves to the right and rotates the guide vanes to the plus 25 degree position. The guide vanes remain at this setting until the HP compressor exceeds the speed at which the switch in the amplifier is set. The switch then opens to break the supply of current to the solenoid, and the valve moves to the left. HP oil is now fed to the space on the right of the actuator piston, the space on the left of the piston being open to LP oil. The actuator piston therefore moves to the left and rotates the guide vanes to the minus 15 degrees position. The guide vanes remain at the minus 15 degrees position until the HP compressor speed falls below the speed switch setting, when the switch closes to energize the solenoid, and return the guide vanes to the plus 25 degrees position.

A spring mechanism incorporated in the linkage for each actuator, acts in opposition to the actuator travel from 0 degrees to plus 25 degrees guide vane angle. In the event of failure of the engine hydraulic system, the springs ensure that the guide vanes return to the 0 degree position, at which setting the engine will continue to operate satisfactorily under all conditions.

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AIR SYSTEM

General

The Iroquois air system is divided primarily into two distinct internal flows, the air supply being bled from the compressor seventh and tenth stages. Seventh stage air is used to pressurize the carbon ring oil seals in the front and rear oil sumps, and in the LP and HP external gearboxes; this air also scavenges oil mist from the rear sump to the front sump through an internal oil return tube. The tenth stage air is used to cool the turbine rotor discs and blades, and tappings on the HP compressor delivery air take-off manifold supply tenth stage air for the engine anti-icing system, the air driven fuel pumps, and aircraft services.

Seventh Stage Air

- Seventh stage air is bled through holes in the compressor seventh stage spacer ring immediately upstream of the seventh stage rotor blade tips, and passes forward through an annulus formed in the HP compressor stator casing, to a manifold cast on the front frame outer casing at the No. 8 strut location. The air then flows radially inwards through the hollow core of the strut and divides into two flows. A drilled passage in the LP compressor bearing housing permits one flow to pass to the annulus formed between the double carbon ring oil seal at the front of the LP thrust bearing. Some of this air leaks through the rearmost seal into the front sump, thus preventing oil seepage past the seal ring; the remainder leaks forward through the front seal into the cavity formed by the LP bearing housing and LP compressor rotor.
- 3 The second flow, which is the main stream of seventh stage air, is ducted

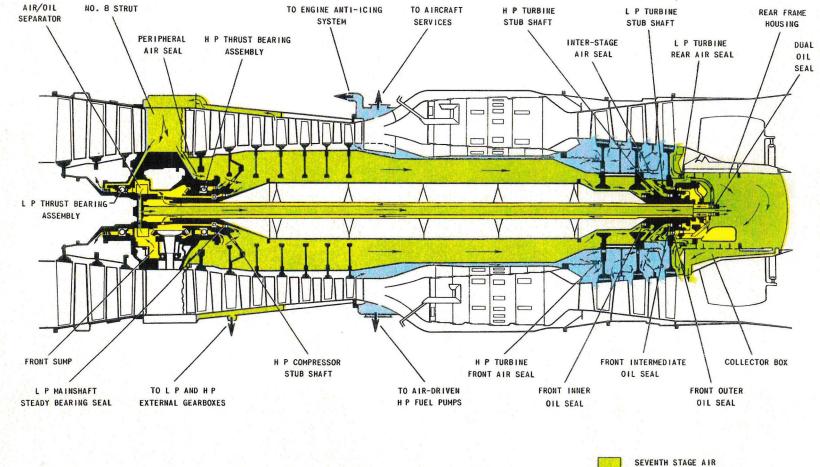
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TO AIRCRAFT

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NO. 8 STRUT

Figure

3-5

Schematic

Diagram

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Air

System

SEVENTH STAGE AIR OIL MIXTURE

TENTH STAGE AIR

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from the base of No. 8 strut, through cored passages in the HP thrust bearing support flange on the rear of the front frame inner casing, into the cavity ahead of the HP compressor rotor stub shaft. This air pressurizes the carbon ring oil seal at the rear of the HP thrust bearing assembly; a small portion of the air leaks through the seal to the front sump. A further small quantity of air leaks out past the peripheral air seal at the rear of the variable incidence HP compressor inlet guide vanes. The main seventh stage air flow continues rearward through holes in the HP compressor stub shaft and completes the sealing of the front sump by pressurizing the LP mainshaft steady bearing seal.

4 The remainder of the air flows to the rear of the engine through the annulus formed between the HP and LP mainshafts to the front inner oil seal of the HP turbine rotor assembly, where it divides, some to pressurize and leak past this seal to the rear sump, the remainder passing through holes in the HP turbine shaft to the space between the HP and LP turbine shafts. At this point a proportion of the air pressurizes and leaks past the front intermediate oil seal to the rear sump, while a second flow passes radially outwards through an air seal to combine with tenth stage air and cool the front face of the turbine third stage rotor disc; this air is exhausted to the main gas stream at the rim of the disc. The remainder flows through holes in the LP turbine shaft where some of the air pressurizes and leaks through the front outer oil seal to the rear sump. The flow continues past the hub of the LP turbine disc to the LP turbine rear air seal where some air flows through a tube at the rear of the bearing housing to pressurize the double carbon ring oil seal at the rear of the rear sump, the remaining air passing through the LP turbine rear air seal to cool the rear face of the turbine third stage rotor disc. This flow joins that which passes through the space formed between the rear frame baffle and cover and is exhausted to the main gas stream immediately aft of the turbine third stage rotor disc rim. The air which pressurizes the rear sump seal rings passes forward into the sump and rearward into the rear frame inner housing.

Seventh Stage Air/Oil Mixture

The engine lubricating oil system uses seventh stage air to return scavenge oil mist from the rear sump to the front sump where the oil is separated from the air by a centrifugal air/oil separator. Seventh stage air leaking past the oil seal rings to the rear sump carries oil mist, through a sump vent, to the annulus formed between the internal air vent tube and the internal oil return tube. The air/oil mixture is carried forward to the front sump, where it joins the front sump air/oil mixture. The mixture is vented to the centrifugal air/oil separator and the purified air flows through holes at the base of the vanes in the separator to the internal air vent tube, thence rearwards to the space formed by the rear frame inner housing and the rear frame housing cover. The air cools the housing inner surfaces and, together with any oil vapour that may be present in this region, passes through a series of

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holes at the bottom of the housing into a collector box from which it is vented to the main gas stream.

External Gearboxes Air Supply

Air is tapped from the seventh stage air take-off annulus and is externally piped to the LP and HP external gearboxes. In the LP external gearbox, the double carbon ring oil seals at each end of the LP external gearbox driven gearshaft are pressurized. In the HP external gearbox, the double ring oil seals on the aft end of the starter shaft, on the aircraft splined coupler end of the power take-off, and on the forward end of the governor gear are pressurized. Seventh stage air is also bled into the hollow shaft of the hydraulic gear to pressurize the outer faces of the hydraulic gear bearings. Some of this air leaks outward past the seals into the engine nacelle, the remainder passing inward to the gearboxes to mix with the oil and be scavenged by the main scavenge pump to the oil tank where the air/oil mixture is vented to the front sump.

Tenth Stage Air

- Tenth stage air is bled immediately aft of the roots of the tenth stage rotor compressor blades and flows rearward through the annulus formed by the HP rotor mainshaft and the mid frame inner casing. When the flow reaches the HP turbine front air seal, some air passes through the seal and cools the front face and rim of the first stage HP turbine disc and the roots of the turbine rotor blades before exhausting to the main gas stream. The remainder flows through axial holes in the turbine first stage rotor disc into the space formed by the turbine spacer disc and the first and second stage turbine discs. From the first chamber some air flows radially outward over, and cools, the rear face of the first stage disc, and is exhausted to the main gas stream through holes in the forward rim of the spacer. The remainder passes through axial holes in the spacer disc web to a second chamber where it again divides into two streams; one flows radially outward through the annulus formed around the rear rim of the spacer to the main gas stream. This annulus is adjacent to the front face of the turbine second stage rotor disc rim and air is permitted to flow through clearances between the blade roots and the disc slots to carry heat away from the area.
- The second stream continues to flow rearwards through axial holes in the turbine second stage rotor disc where the flow divides three ways; one stream flows radially outward across the rear face of the second stage turbine disc, the second through holes in the turbine stator disc assembly, and the third through the interstage air seal where it joins a portion of seventh stage air, flows radially outward over the front face of the third stage turbine disc, and exhausts into the main gas stream.

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Engine Services

Tenth stage air supplied to the engine anti-icing system, and the air driven fuel pumps is drawn from the HP compressor delivery air take-off manifold which forms an integral part of the mid frame assembly. This manifold is supplied with tenth stage air bled into it through holes in the mid frame outer casing. The take-off point for the anti-icing system is at the upper right-hand side of the manifold; for the fuel pumps it is at the lower left-hand side of the manifold.

Aircraft Services

Aircraft services, including air conditioning of the equipment bays, cockpit heating and pressurizing, windshield de-frosting, pressurizing of rocket pods, fuel tanks, and anti-g suits, are supplied with tenth stage air from one of two take-off pads situated at either side of the top manifold centre line, depending on the installation.

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THESE DATA SHEETS BEAR THE AUTHORITY OF REGULAR EO'S INTO WHICH THE INFORMATION IN ITS REVISED FORM WILL EVENTUALLY BE INCLUDED.

ELECTRICAL SYSTEM

GENERAL

- All the power required for operation of the engine electrical system is obtained from the aircraft electrical system. The engine system operates on 28 volts DC and 110 volts 400 cycle AC; the latter is required for the electronic control amplifier and the anti-icing magnetic amplifier.
- The main aircraft-to-engine electrical connector is of the quick release type locked by a latch mechanism and is mounted on the electrical connector panel on the lower right-hand side of the engine firewall assembly. All connections between the engine and airframe circuits are routed through this connector except for the fire detector and thermocouple circuits which are individually harnessed. The fire detector and thermocouple connectors are mounted on the panel adjacent to the main connector.
- 3 The operation of the engine electrical system is almost entirely automatic; the only pilot-operated controls are the START-MOTOR switch, the RELIGHT switch and the NORMAL-EMERGENCY switch, and indirectly, switches in the power lever switch box which are actuated by movement of the power control lever.
- A schematic wiring diagram of the engine electrical system and associated details of the aircraft electrical system is shown in Figure 3-6-3.

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STARTING SYSTEM

Power Supply

The electrical power required to operate the engine starting circuit is drawn from the aircraft emergency DC supply. For ground starting, a starting trolley supplies 28 volts DC and 110 volts AC to the aircraft electrical system, and provides the compressed air required to drive the engine air turbine type starter. The compressed air supply is controlled by a solenoid valve which is connected to the aircraft electrical system, but which is controlled by the engine starting circuit.

Ignition System

A 12 joule high energy ignition system, consisting of a dual input ignition exciter box, two lead assemblies, and two surface discharge type igniter plugs, is used. The plugs are located one on either side of the combustion chamber. The voltage supplied to the exciter box is stepped up within the box by a contact breaker mechanism and transformer, and stored in a capacitor. The stored energy is discharged to each igniter plug through a sealed spark gap in the exciter box at the rate of approximately one discharge in one second. A separate circuit is provided from the DC supply source to each plug, thus ensuring that the failure of one circuit will not impair the functioning of the other.

Ground Starting Circuit

The ground starting circuit is arranged so that an engine start is obtained only if the prescribed operating sequence is followed. It is impossible to energize the circuit by accidental selection of the START-MOTOR switch only, as the starting system is open circuited until the power control lever is advanced beyond the four degrees position.



Although the engine cannot be started on the ground by selection of the RE-LIGHT switch, this action does energize the ignition system. Serious injury or death might result if personnel are handling the HT section of the ignition system at the time the RELIGHT switch is selected.

8 An oxygen system control valve solenoid is connected to the engine starting circuit; as the oxygen system is not required during ground starting, the solenoid is

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held in the CLOSED position by the contacts of a scissors switch relay on the aircraft undercarriage when the aircraft is on the ground.

Ground Starting Sequence

NOTE

The starting sequence given here is only for descriptive purposes. For operational use, the Aircraft Operating Instructions must be followed.

- The power control lever is advanced from the SHUT-OFF position to the IDLE position, closing a micro-switch in the power lever switchbox as it passes the four degrees position. The START-MOTOR switch is then held in the START position; this completes a circuit from the emergency DC supply through the Kl relay solenoid, the HP compressor 2500 rpm switch on the starter motor, and the four degree switch in the power lever switchbox to ground. The Kl relay closes and the START-MOTOR switch can be released as the relay is held closed by its own hold-in circuit. When the Kl relay closes, current flows from the emergency DC supply to energize the ground starting equipment air valve solenoid, which opens to supply compressed air to the engine air turbine starter. The starter in turn rotates the HP compressor shaft through the HP external gearbox.
- A second switch on the starter closes when the HP compressor speed is about 200 rpm, thus causing relay K2 to close. Closure of the K2 relay energizes both the ignition exciter box and the solenoid which controls the starting fuel pump drive motor; the oxygen supply valve solenoid is not energized. The starting fuel pump must remain in operation until the main HP fuel pumps are supplying enough fuel to sustain the engine during the starting cycle, therefore a hold-in circuit, independent of the K2 relay, is provided for the starting fuel pump drive motor solenoid. This hold-in circuit is energized when the flow from the starting fuel pump is sufficient to operate a starting pump check valve switch.
- When the HP compressor reaches a speed of approximately 2500 rpm, the associated starter speed switch opens, thus de-energizing relay Kl which deenergizes the ground starting equipment solenoid valve, and relay K2 which deenergizes the ignition exciter box. The check valve hold-in circuit retains the starting fuel pump in operation however, until the output from the main HP fuel pumps reduces the flow through the check valve switch to a predetermined value; the check valve switch then opens to de-energize the starting pump drive motor solenoid. This completes the starting cycle, and the engine will accelerate to idling speed.

Failure to Start

12 Should light-up not occur during the starting cycle, the starting circuit is

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reset by returning the power control lever to the OFF position. The micro-switch in the power lever switchbox opens at the four degrees position thus de-energizing relays Kl and K2, and the starting fuel pump drive motor control solenoid.

13 Failure to reset the circuit can cause overheating and damage to this solenoid and an unnecessary drain of electrical power. Furthermore the open circuit safety feature of the starting system referred to in Para 7, is no longer effective.

Engine Motoring Circuit

In order to permit the engine to be rotated with the remainder of the starter circuit inoperative for inspection and servicing purposes, the START-MOTOR switch is selected to MOTOR. This action energizes the ground equipment air valve solenoid only. The switch is held in this position throughout the motoring operation.

Engine Relighting in Flight

- The engine is relit in flight by advancing the power control lever past the four degrees position, whilst the RELIGHT switch is held in the closed position and the engine windmilling speed is controlled within the appropriate rpm range. The RELIGHT switch directly energizes and closes the K2 relay which in turn energizes the ignition exciter box, the starting fuel pump drive motor solenoid, and the oxygen supply valve solenoid (the contacts on the undercarriage scissors switch relay close when the aircraft is airborne). The RELIGHT switch is held closed until a rise in engine exhaust temperature is observed, indicating that combustion is taking place.
- 16 The use of oxygen helps to promote rapid engine relights in flight and extends the range of altitudes at which relights can be successfully accomplished.

Failure to Relight

17 If an engine fails to relight, the relight switch is released and the power control lever returned to the OFF position. When further attempts to relight are made, they should be as specified in the Aircraft Operating Instructions.

CONTROL SYSTEM

General

18 The engine control system is basically hydromechanical in operation, but some of the engine control variables are more easily sensed and applied electrically. These are used to provide trims and interlocks on the operation of the basic system.

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- 19 The functions which are controlled electrically are as follows:
- (a) Maximum exhaust temperature during start.
- (b) Engine acceleration.
- (c) HP compressor variable incidence inlet guide vane actuation.
- (d) Exhaust temperature control during steady state operation in the upper power range.
- (e) Prevention of afterburner light-up below a minimum engine speed.

Operating Principles

The components which provide the trims and interlocks are controlled by the electronic control amplifier. Control variables sensed at various points on the engine are transmitted to the control amplifier as input signals. These signals are inlet temperature (T₁), exhaust temperature (T₇), HP compressor rotor speed (N_H), and the power lever angle through the four degree switch and the afterburner switch. Within the amplifier this data is assimilated into output signals for system operation. The underlying principle behind the operation of the control amplifier is the use of circuits to compare voltages proportional to actual and desired values of various control variables. Where the actual value exceeds the desired value, the difference between the two is used to actuate a control device. Since the power level of input and error signals is generally small, the signal used to actuate the control device is amplified. In the case of modulated control signals amplification is achieved electronically; in the case of interlocks, relays are used.

Power Supply

The control amplifier is powered by 400 cycle AC and 28 volt DC from the aircraft primary power supply. To minimize the number of switches and to maintain the amplifier in a state of readiness, the amplifier is energized when the aircraft master switch is ON. When the aircraft is on the ground with the engine stopped, and it is necessary to energize the amplifier, the AC and DC power is supplied from an external source. A warm-up period of approximately 30 seconds is required for the amplifier to become operational.

Power Lever Switchbox

The engine mounted power lever switchbox contains three micro-switches and a potentiometer; the switches are actuated by a rotary shaft, in the switchbox, which is interconnected with the power control lever. Only two of the three micro-

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switches are utilized in the electrical system at present; the third switch is provided to accommodate possible future requirements. The central controlling member of the potentiometer is coupled to the end of the rotary shaft, thus the two microswitches and the potentiometer operate as a function of power control lever travel.

One of the micro-switches is connected into the engine starting circuit and the other into the afterburner circuit; the potentiometer forms part of the exhaust temperature control circuit. The functions and settings of these three controls are detailed in the paragraphs describing the operation of the engine starting and control system.

Exhaust Temperature Control During Engine Start

- During engine start the exhaust temperature must not be allowed to rise above a predetermined maximum value, in order to prevent damage to engine components. However, to ensure that the starting time is as brief as possible, it is desirable to provide the richest fuel/air ratio consistent with safe temperature limits, so that maximum torque is available for acceleration to idle.
- When engine light-up takes place, the exhaust temperature, as sensed by the thermocouples, is transmitted to the control amplifier as a voltage signal. This signal is compared to a reference voltage, within the amplifier, which is at a level corresponding to the maximum permissible exhaust temperature during starting; the starting reference temperature is represented by Ta in Figure 3-6-1. When the sensed temperature exceeds the reference temperature, the voltage error, amplified to the required power level, actuates a solenoid controlled proportional fuel valve in the fuel system, to reduce the rate of increase of the engine fuel flow. The solenoid opens the valve to an extent proportional to the degree of excess temperature.
- Reference to Figure 3-2-8 in Part 3, Section 2, shows that when the proportional fuel valve opens, the servo control pressure acting above the piston in the servo throttle valve tends to increase. The servo throttle valve reduces the fuel flow rate to the engine, with resultant reduction in the exhaust temperature.
- As the engine approaches idling speed, a signal from the HP speed sensing generator switches the reference voltage (temperature) in the amplifier to a lower value Tb (see Figure 3-6-1). It should be noted that the exhaust temperature at idle does not normally approach the value represented by Tb. The prime purpose of the Tb reference setting is to control acceleration from idle to prevent low speed surge.

Factors Determining Maximum Permissible Rate of Acceleration

Acceleration is controlled by scheduling engine fuel flow as a function of exhaust temperature (T₇) and HP compressor rotor speed (N_H). If the exhaust



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temperatures obtained at different engine speeds during steady state operation of the engine are measured and plotted, a curve known as the engine operating line is produced. It can be shown that as compressor inlet temperature (T₁) varies the curve is displaced in both the vertical and horizontal planes while still maintaining the same general shape. Similarly if the exhaust temperatures which just produce compressor surge at various engine speeds are plotted, a curve defining the surge area is obtained. This too is displaced by variation in inlet temperature, in the same

FIXED VALUES - TA TO N₁ N₄

TEMP.

(17)

T1 STASED VALUES TO TO N₂ N₃

SURGE AREA

SURGE AREA

TEMP.

T1 STASED VALUES TO TO N₂ N₃

TO N₃

TO N₄

TO N₄

TO N₄

TO N₄

TO N₄

TO N₅

TO N₄

TO N₄

TO N₅

TO N₄

TO N₅

TO N₄

TO N₄

TO N₅

TO N₄

TO N₄

TO N₅

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TO N₅

TO N₅

TO N₆

TO N₆

POWER LEVER ANGLE

H P ROTOR SPEED (N₆)

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Figure 3-6-1 Exhaust Temperature Reference Diagram

SWITCHING SPEEDS FOR

29 An indication of the general shape of the surge area and associated operating line are given in Figure 3-6-2 for two

manner as the engine operating line.

line are given in Figure 3-6-2 for two differing compressor inlet temperature conditions. Surge area A and operating line A provide an indication of the curve obtained at the same relatively high inlet temperature, whereas surge area B and operating line B represent the curves obtained at the same relatively low inlet temperature. The general direction of curve displacement with varying inlet temperature is indicated by the arrows to the right. It is possible however to produce a single basic curve defining surge area and a similar basic curve defining the engine operating line, which cover all varying inlet temperature conditions, if T_7/T_1 versus N_H/T_1 are used as the co-ordinates instead of simply T_7 and N_H . The manner in which this T_1 bias is sensed and applied

T₁ = INLET TE T₇ = EX. TEMP.

> ть N₂

is described later.

- The margin between the engine operating line and the surge area is a measure of the excess torque, in terms of exhaust temperature, available to accelerate the engine. Maximum rate of acceleration is achieved when the exhaust temperature approaches, but does not enter the surge area.
- 31 An acceleration control which generates a reference temperature curve conforming precisely to the shape of the compressor surge characteristic is difficult to provide. A stepped approximation

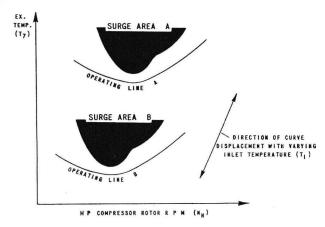


Figure 3-6-2 Surge Area and Operating Line Relationship

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can however be readily produced by providing a series of fixed reference temperatures to which the engine can be controlled during acceleration, while maintaining a safe margin from the compressor surge area. This is illustrated in Figure 3-6-1; the four reference temperatures, Ta, Tb, Tc, and Td are selected automatically in the control amplifier.

Engine Control During Acceleration

- 32 When the power control lever is advanced from the IDLE position, an increase in fuel flow to the engine takes place, and a corresponding increase in exhaust temperature is sensed by the exhaust thermocouples. As previously described, if the sensed exhaust temperature exceeds the reference temperature (in this case Tb) the proportional fuel valve reduces the rate of increase of the fuel flow to maintain the required temperature limit. When N2 switching speed is reached, a signal from the HP speed sensing generator switches the reference temperature to Tc. This reduction in reference temperature results in a reduced rate of engine fuelling while skirting the critical surge area. When N3 switching speed is reached, the reference temperature is switched to a higher value Td, and the rate of fuelling is accordingly increased. At the same time the solenoid valve controlling the HP compressor variable incidence inlet guide vanes is de-energized causing the guide vanes to move to their high speed position, as described in Part 3, Section 4. The reference temperature remains at the Td value until N4 speed is reached at which point the margin between the engine operating line and surge area increases and acceleration fuel flow is therefore no longer restricted.
- The Tb, Tc, N2 and N3 reference values are based on thermodynamic considerations and are biased by T1 in order to compensate for shift in the surge area with inlet temperature; Tb and Tc are biased by $1/T_1$, and N2 and N3 are biased by $1/T_1$. The T1 bias is provided by the ram temperature senser which transmits a pressure signal proportional to T1 to the control amplifier. Within the amplifier this pressure input is converted to electrical signals proportional to $1/T_1$ and $1/T_1$ and applied to these temperature and speed input signals respectively.
- Temperature references Ta and Td are established by temperature limits of the engine structure. Since these limits are absolute values, they are not biased by T₁. Switching speeds N₁ and N₄ are not critical, and are therefore not T₁ biased.

Exhaust Temperature Control in the Upper Power Range

35 When N₄ speed is reached, a speed switch in the control amplifier transfers the amplifier output from the proportional fuel valve to the proportional air valve; the exhaust temperature trim is then applied to the final nozzle area control instead

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of to the fuel flow.

36 As described in Part 3, Section 4, the engine final nozzle area is controlled by the pressure ratio actuator to maintain a constant turbine pressure ratio (P_3/P_7) . When the exhaust temperature sensed by the thermocouples exceeds the temperature reference, an output signal (voltage) from the control amplifier proportional to the degree of overtemperature, is applied to the proportional air valve, causing it to open. The extent of the valve opening is proportional to the applied voltage. When the valve opens, air is bled from the P3 chamber of the pressure ratio actuator, thus the sensed P3 pressure at the pressure ratio actuator will be less than the true P3 pressure. This artificial reduction of P3 pressure causes the pressure ratio actuator to reposition the actuator control valve in order to restore the original P3/P7 pressure ratio. The final nozzle actuators therefore move to increase the final nozzle area in order to reduce P7. This also causes a proportional reduction in exhaust temperature (T_7) .

When the exhaust temperature trim is transferred to the proportional air valve, the reference temperature (voltage) with which the sensed exhaust temperature is compared, varies with power control lever position. As the power control lever is advanced, the reference temperature is raised progressively through the 70 degrees to 90 degrees power lever range, and then remains constant to 110 degrees power lever angle. This provides automatic exhaust temperature control during both cruise and maximum speed operation in order to maintain high engine efficiency and ensure long engine life. The variable temperature reference is provided by the potentiometer in the power lever switchbox, which produces a variable voltage in the error detecting network of the control amplifier.

Afterburner Operation

- Afterburning is initiated by advancing the power control lever beyond the 93 degrees position which closes a micro-switch in the power lever switchbox. A speed switch incorporated in the circuit to the afterburner electrical control delays light-up while the engine is still accelerating until a predetermined minimum speed is reached, in order to achieve minimum acceleration times and reduce the risk of surge. This speed switch closes when N₄ speed is attained. The afterburner control circuit is therefore energized causing a relay in the afterburner electrical control to close. This relay in turn energizes the solenoid-operated afterburner shut-off valve which opens and permits fuel to flow to the afterburner spray rings.
- A second circuit in the afterburner control is energized simultaneously with the shut-off valve, and, after a two second delay, to allow for priming of the afterburner fuel manifold, energizes the hot streak igniter valve continuously for fifteen seconds. This time circuit is voltage compensated to ensure that variation in supply

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voltage will not affect the time cycle.

- The hot streak igniter valve has a pulsating action, and injects a metered quantity of fuel at intervals of about three to four seconds into the combustion chamber, with a second injection point downstream of the turbines to serve as a relay. Fuel from the first jet ignites in the combustion chamber and passes through the turbines as a burning stream. This flame, augmented by the relay jet downstream of the turbine, is used to ignite the fuel being supplied to the afterburner spray rings. At the end of the fifteen second period, the hot streak circuit is de-energized; the shut-off valve solenoid, however, remains energized continuously while the afterburner is in operation.
- The afterburner fuel flow is varied with power lever position to modulate afterburner thrust. To provide continuity to the thrust versus power lever position curve for certain operating conditions, such as formation flight, a hysteresis loop is provided which causes the shut-off valve to remain energized down to the 78 degree power control lever position. Afterburner fuel flow remains constant between 93 and 78 degrees power lever position and thrust is varied by varying engine basic fuel flow only. When the power lever is retarded below 78 degrees the micro-switch in the power lever switchbox opens. The shut-off valve solenoid is then de-energized and the valve closes to cut off the fuel supply to the afterburner manifold.

Emergency Change-over Control

- As described in Part 3, Section 2, fuel is supplied to the engine through either the NORMAL or EMERGENCY fuel system. Change-over from one system to the other is by means of motorized valves which are controlled by a two position selector switch in the pilot's cockpit. The switch is connected to the aircraft emergency DC supply so that fuel system transfer can be achieved in the event of failure of the main DC supply.
- When the selector switch is moved from NORMAL to EMERGENCY or viceversa, it energizes a rotary actuator in the engine control system. The rotary actuator embodies an electric motor and reduction gear which drive two rotary flow transfer valves in the emergency control. These rotary valves are geared so that as one valve closes the other opens. The position of these valves determines whether the fuel flows through the NORMAL or EMERGENCY fuel system. The actuator incorporates cam-operated limit switches to de-energize the motor at the limits of travel and to reverse the direction of motor rotation. Accurate positioning of the transfer valves is ensured by an electromagnetic brake on the electric motor shaft. Current supply to the brake is controlled by the limit switches.

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Engine Operation in EMERGENCY



When EMERGENCY is selected the acceleration control is rendered inoperative as well as a number of hydromechanical components in the fuel control system. Automatic control of engine speed and accelerations, and possibly exhaust temperature trim, are no longer in effect, therefore great care must be exercised in handling the power control lever and rapid changes of power lever setting must not be attempted.

- Provided the amplifier control is serviceable, operation of the HP compressor variable incidence inlet guide vanes and the final nozzle area control and its associated temperature trim, will continue normally. Afterburning could also be carried out subject to the observance of exhaust temperature limitations.
- 45 If the amplifier is unserviceable, the inlet guide vanes move to the high speed position irrespective of engine speed. The engine is therefore more susceptible to surge on accelerating from low speed, and demands particular care in power lever handling. The final nozzle area control will function normally except that exhaust temperature trim is not applied.

NOTE

If the amplifier is unserviceable, afterburning when EMERGENCY is selected is not recommended.

ANTI-ICING SYSTEM

Anti-icing System Operation

The engine anti-icing system uses hot air piped from the HP compressor outlet to prevent ice accumulation at the engine air intake under adverse weather conditions. When icing conditions are encountered, a detector circuit in the aircraft operates a relay which supplies DC current to a solenoid-operated shut-off valve integral with the air pressure regulator, and allows hot air circulation to commence. The magnetic amplifier is simultaneously energized through the relay by the 400 cycle AC supply.

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A temperature sensing element senses the inlet frame skin temperature and this temperature signal is amplified into an electrical output by the magnetic amplifier. The temperature control valve converts this output into a pneumatic control signal which modulates the hot air flow through the air pressure regulator as a function of inlet frame skin temperature.

- 48 The aircraft ice detector system operates on a time cycle; when icing conditions no longer exist, the relay opens to de-energize the engine anti-icing circuit, causing the flow of hot air to cease.
- 49 A detailed description of the engine anti-icing system is provided in Part 3, Section 7, of this Engineering Order.

Serviceability Test of the Anti-icing System

The serviceability of the engine anti-icing system can be checked on the ground by supplying a false ice detection signal to the anti-icing magnetic amplifier. Provision is made in the engine anti-icing circuit for this check, which entails the removal of the flight connector from the engine firewall electrical connector panel and the plugging in of a specially instrumented test connector.

INDICATORS AND INSTRUMENTATION

General

The engine and airframe instrumentation requirements are not yet finalized. However, a projected arrangement, which may not be fully representative of the final layout, is shown in Figure 3-6-3. The following paragraphs describe the proposed instrumentation details.

Exhaust Temperature Indication

- The engine exhaust temperature is indicated continuously in the cockpit, and, as already described, is also one of the signals used to vary the area of the final nozzle. Two separate thermocouple circuits are therefore provided for these two functions.
- An eight probe dual thermocouple system senses the exhaust temperature; the probes project radially through the rear frame casing into the exhaust gas stream, downstream of the turbine. Each probe contains two chromel/alumel thermocouples, one of which connects to the cockpit engine performance indicator circuit, and the other to the control amplifier circuit. Each circuit transmits the average temperature sensed by its set of eight thermocouples. The thermocouple leads are shielded and incorporated in a separate harness to prevent induced interference from external

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electrical sources. The harness is routed forward to the airframe connector and control amplifier.

Nozzle Area Transducer

54 The incorporation of a nozzle area transducer is proposed as part of the engine performance instrumentation. Detailed information on this equipment is not yet available, but will be supplied at a later date.

RPM Indicator and Overspeed Detector

It is anticipated that an rpm indicator will be installed in the cockpit for the HP compressor, together with an overspeed warning for the LP compressor. To meet these requirements, and to ensure that a ready means of determining HP and LP compressor rotor speed is available when the engine is test run, provision is made for the mounting of tachometer generators on both the HP and LP external gearboxes.

Minimum Hydraulic Oil Reserve Warning

A magnetic switch mounted on the hydraulic oil reservoir operates a warning device when the minimum safe hydraulic oil reserve is reached. This warning enables the pilot to take precautionary measures before serious damage to the engine occurs, caused by loss of final nozzle area control.

Minimum Oil Pressure Detector

57 A pressure switch senses the pressure differential across the lubricating system supply pump. The switch operates a warning device in the cockpit when the pressure difference across the pump falls below a minimum value.

400 Cycle AC Power Failure Warning

The power failure warning equipment and circuit is part of the aircraft AC electrical system. For details refer to the applicable Arrow 2 Engineering Order. Failure of the 400 cycle AC supply results in the loss of acceleration control and exhaust temperature trim of the final nozzle area. Engine control can still be maintained satisfactorily in either NORMAL or EMERGENCY provided the pilot appreciates the effect of the AC supply failure on engine control, and acts accordingly.

Fuel Low Pressure Warning

59 If the fuel supply pressure to the fuel pumps falls below a predetermined value, a pressure switch, located on the inlet side of the engine fuel pumps, trans-

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mits a signal to an indicator in the pilot's cockpit. This pressure switch is incorporated in the aircraft electrical system.

Emergency System Indicator

When the NORMAL-EMERGENCY selector switch is in EMERGENCY a circuit is energized through one of the limit switches in the rotary actuator to operate an indicator in the pilot's cockpit.

FIRE DETECTION AND AIR BLEED VALVE CIRCUITS

Fire Detection Circuit

Two connectors on the engine firewall electrical connector panel are fitted to the end of the fire detector loop and connect into the aircraft fire detector system. A detailed description of the engine fire detector system is contained in Part 3, Section 8 of this Engineering Order.

Air Bleed Valve

- Prior to installation of the engine in the airframe, a solenoid-operated air bleed valve is mounted on one of the upper two air take-off pads located on the mid frame assembly air take-off manifold. The particular pad to which the valve is fitted is dependent on whether the engine is to be a port or starboard installation. The purpose of the valve is to control the supply of compressor tenth-stage air used for aircraft services such as cabin pressurization, fuel tank pressurization and air conditioning.
- 63 The valve is actuated by a control in the aircraft electrical system. This control circuit is routed to the main engine to aircraft connector on the engine firewall electrical connector panel. From this point a lead in the engine harness extends to a connector mounted on the firewall horizontal support member adjacent to the left-hand side of the compressor casing.
- A separate harness containing the current supply lead and ground return, extends from the firewall support to the solenoid valve. The length of this harness varies with the disposition of the valve on either the LH or RH air take-off pad.
- 65 The only engine supply item in this circuit is the lead from the engine and airframe main electrical connector to the firewall horizontal support. The solenoid valve and harness are supplied by the aircraft contractor.

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DATE ISSUED: 13 JUN 58 PRELIMINARY TO EO 10B-30A-2 SHEET 15 OF 15 CONTROL SYSTEM FIRE DETECTION AND STARTING SYSTEM INDICATORS AND INSTRUMENTATION ANTI-ICING SYSTEM AIR BLEED VALVE CIRCUTS PROPORTIONAL INLET GUIDE AIR VALVE VANE SOL. PROPORTIONAL AIR BLEED VALVE AFTERBURNER FLIGHT CONNECTOR SOLEHOID O SKUT-OFF IGHITER PLUGS UNIT N P SPEED SENSING HOT STREAK IGHITER VALVE GERERATOR TEMP. SENSING AFTERBURKER SWITCH [AIR TURBINE STARTER **₹EXMAUST** EXMAUST TEMP. CHROMEL CONTROL AMPLIFIER THERMOCOUPLES TEMP. OPERS AT ENGINE SHROUD REFERENCE ANTI-ICING
MAGNETIC AMPLIFIER CONNECTOR POTENTIONETER FIRE DETECTION SENERATOR IGNITION EXCITER BOX CLOSES AT EXHAUST THERMOCOUPLES 200 RPM POWER LEVER MOZZLE AREA TRANSDUCER INLET TEMP. TEMP. CONTROL SIGNAL DEGREE P.L. (T,) SIGNAL SWITCH ENGINE SHROUD CONNECT W. KIDDE CO. RECEPTACL STARTING FUEL PUMP STARTING AIR PRESSURE SMITCH REGULATOR EMERGENCY CHANGE-OVER VALVE VALVE SOL. AND SHUT-OFF VALVE ENGINE DISCONNECT ENGINE (8) A)-(23)(22)(21)(20)-(58)----(57)-(28)---(25)(19)(10)(11) AIRFRAME ANTI-ICING RELAY AIRCRAFT CONTROLLED BY A C REUTRAL D C GROUND AIRFRANE DE-ICING SYSTEM TO AIRCRAFT FIRE DETECTION SYSTEM EMERGENCY - HORMAL MASTER WARNING BOX SELECTOR SWITCH TO 110V CONTACTS ON UNDERCARRIAGE AC SUPPLY SCISSORS SWITCH RELAY R P M STARTER SOL. ON GROUND STARTING TROLLEY ENGINE PERFORMANCE INDICATOR K2 RELAY SOL. TO AIR BLEED TO DE-ICING DC SUPPLY TO ITOY AC SUPPLY RELIGHT START DIS MOTOR I I OV AC POWER FUEL L P START-HOTOR SWITCH FAILURE SIGNAL WARNING CIRCLES NUMBERED BETWEEN 1 AND 58 REPRESENT PIN NUMBERS ON THE ENGINE TO AIRFRAME MAIN CONNECTOR. MAIN DC SUPPLY SEPARATE CONNECTORS ARE PROVIDED FOR THE FIRE DETECTOR AND THERMOCOUPLE CIRCUITS, AND ALSO IN THE ANTI-ICING AND AIR BLEED VALVE CIRCUITS. EMERGENCY DC SUPPLY

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ANTI-ICING SYSTEM

General

- During engine operation in weather conditions conducive to icing, the formation of ice at the engine air intake is prevented by a hot air, surface heating, anti-icing system. The system is fully automatic in operation and is designed to operate at air pressures up to approximately 45 psi.
- A supply of air, bled from the delivery side of the HP compressor, is supplied to the LP compressor hollow first stage stator blades, and to the inlet frame assembly where the air heats the outer skins of the nose bullet and frame struts. Since the temperature and pressure of the tapped air increase with engine speed, only a small proportion of the available supply of air is required during high speed operation. Provision is made to compensate for these variations in temperatures and pressures.

External Piping and Ducting

3 The supply of air is piped externally from the upper right-hand side of an air take-off manifold immediately downstream of the HP compressor to an air manifold formed around the LP compressor stator casing, thence to air ducts at the outer ends of the four inlet frame struts.

Compressor Stator Blade Heating

The compressor first stage stator blades are heated by a flow of air from the LP compressor stator casing air manifold. As each blade is hollow and open-ended, the air flows through the blades and is expelled inwards to the engine air stream.

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Nose Bullet and Inlet Frame Strut Heating

The flow of air delivered to the air ducts of the inlet frame struts passes into the struts through a cavity at the front of each strut. Holes in the strut inner skin direct the air flow against the leading edge inner surface and into the annular space formed between the inner and outer skins. The air flows rearward through the annular space and is then led through a cavity at the rear of each strut into the inlet frame internal air manifold.

The air is then piped from the internal air manifold to the front of the nose bullet and flows into the annular space formed by the double skin of the bullet. The air flows rearward through the annular space to a corresponding annular space in the inlet frame inner casing and is exhausted to the engine air stream immediately upstream of the compressor first stage rotor blades.

Air Pressure Regulator and Shut-off Valve

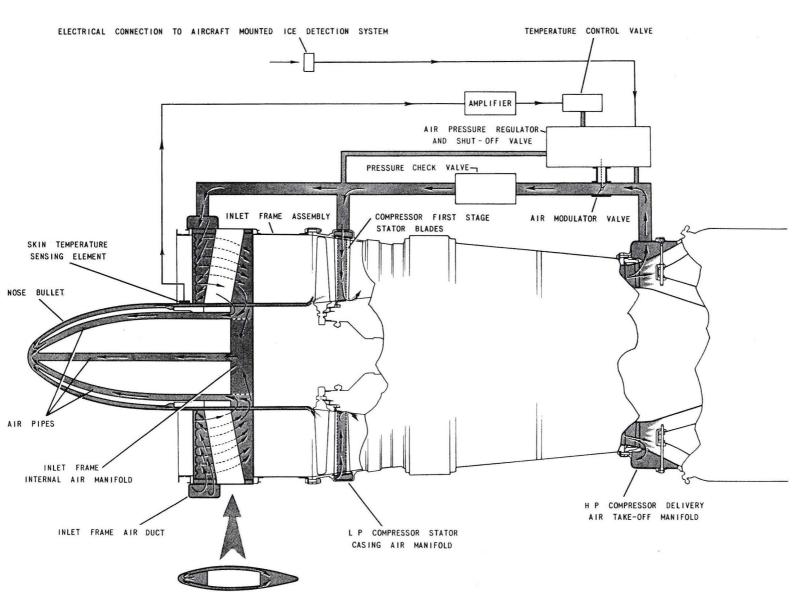
- The quantity of air required for adequate anti-icing protection is controlled by the air pressure regulator and shut-off valve. The valve is comprised mainly of a spring-loaded, pressure sensitive diaphragm which opens and closes a butterfly type air modulator valve located in the main air supply pipe, together with a solenoid-operated shut-off valve which is electrically connected to an aircraft mounted ice detection system. Opening and closing of the modulator valve regulates the amount of air passing into the anti-icing system.
- When the system is inoperative, pressure derived from a tapping upstream of the air modulator valve is applied to the spring-loaded side of the actuator diaphragm to hold the valve closed. When icing conditions are detected, the normally closed, solenoid-operated shut-off valve is energized by the aircraft mounted ice detection system, and the pressure on the underside of the actuator diaphragm is transferred to the upper side of the diaphragm. The air modulator valve opens and the air flow to the system begins. The shut-off valve remains energized, and hence the air flow continues, until the end of a pre-determined cycle which is timed by the ice detection system. If the icing condition is still sensed by the ice detection system at the end of the cycle, the cycle is repeated.
- A maximum pressure limiter, which is integral with the air pressure regulator, is sensitive to the air pressure at the LP compressor stator casing air manifold. A rise in manifold pressure above calibrated limits unseats a valve in the pressure limiter and permits this pressure to be applied to the spring-loaded side of the actuator diaphragm in the air pressure regulator, thus moving the air modulator valve towards the closed position to reduce the air flow pressure.

Temperature Control Valve

10 As high engine speeds result in a higher bleed air temperature, less air is

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H P COMPRESSOR DELIVERY AIR



SECTION THROUGH STRUT

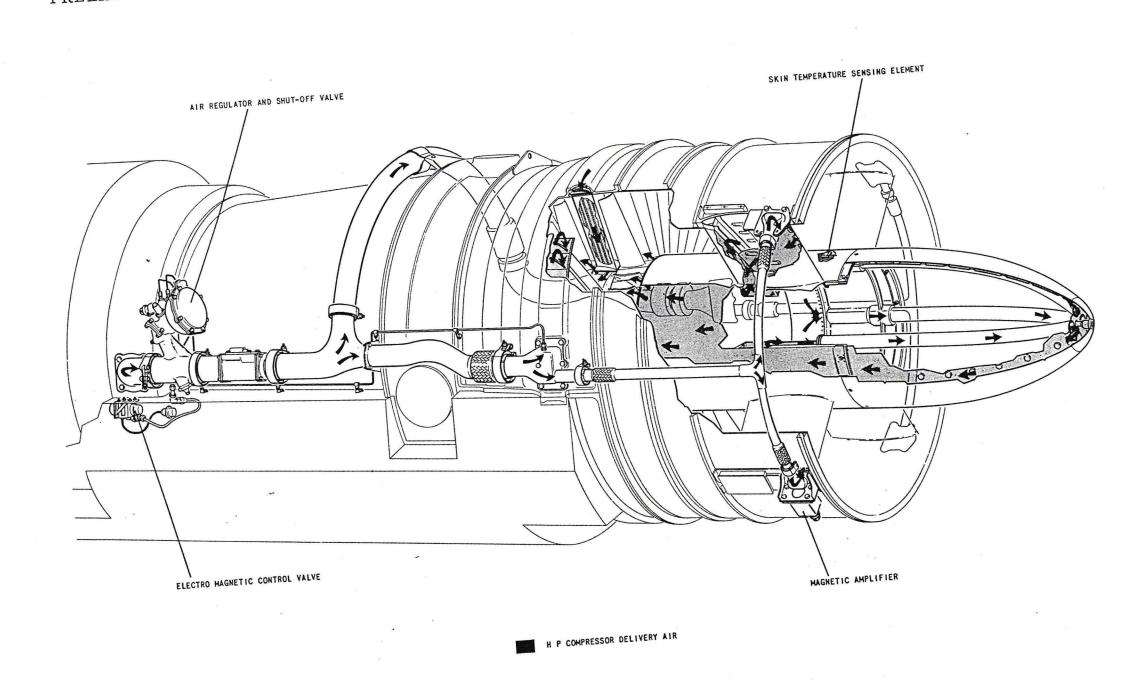
Figure 3-7-1

Schematic Diagram of Anti-icing System

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required to maintain adequate anti-icing protection. To prevent excessive usage of air, a trim is applied to the degree of modulator valve opening, as a function of the actual skin temperature of the engine intake components, by an electro-magnetic temperature control valve.

A skin temperature sensing element, comprising a thermistor mounted at the front of the inlet frame inner casing, varies the current output from the magnetic amplifier as a function of its change in resistance; the thermistor resistance decreases with a rise in temperature. The amplifier in turn transmits an amplified signal in the form of current flow to the temperature control valve in proportion to the skin temperature. The control valve regulates a bleed-off of the pressure acting on the air pressure regulator valve actuator diaphragm. If a low temperature is sensed by the thermistor, the control valve reduces the bleed-off, and the pressure acting on the actuator diaphragm increases. This results in an increased opening of the air modulator valve and a corresponding increase in the air flow. As the skin temperature of the intake components rises to the set value, the temperature signal to the control valve increases and the opening of the air modulator valve is reduced until the air flow is at the value which maintains the desired skin temperature.

Pressure Check Valve

A pressure check valve, which is installed in the main supply pipe downstream of the air modulator valve, cuts off the hot air supply in the event of a failure in the air pressure regulator and shut-off valve.

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FIRE DETECTOR AND EXTINGUISHER SYSTEMS

General

I The fire detector system for the Iroquois is of the continuous-wire, heat and fire detection type consisting of heat sensing elements, a control unit and two coloured cockpit warning lights. The fire extinguisher system comprises a network of lines which carry extinguisher fluid to the forward region of the engine accessories compartment. A threaded connector on the engine firewall assembly connects the lines to a supply line from the aircraft mounted fire extinguisher bottles.

Fire Detector System

- Three heat sensing elements together with a fire resistant cable, form a continuous loop inside the engine firewall assembly, passing near the top of the engine firewall assembly on the right-hand side of the engine, down towards the bottom centre at the mid-frame, and then rearwards along the bottom of the firewall to the rear frame. The element assembly returns along the left-hand side of the engine in a route opposite to the right-hand route, with the exception that at the front of the firewall assembly it is routed under the engine to the right-hand side. Each end of the element assembly is connected to a socket receptacle on the engine firewall electrical connector panel located near No. 4 strut of the front frame; the receptacles are connected to mating plugs in the aircraft fire detector system. Two elements are also positioned around the engine nacelle. These, together with the fire detector control unit, are included in the aircraft part of the system; refer to the applicable Arrow 2 Engineering Order for details.
- 3 The three heat sensing elements are identical and consist of a semi-flexible

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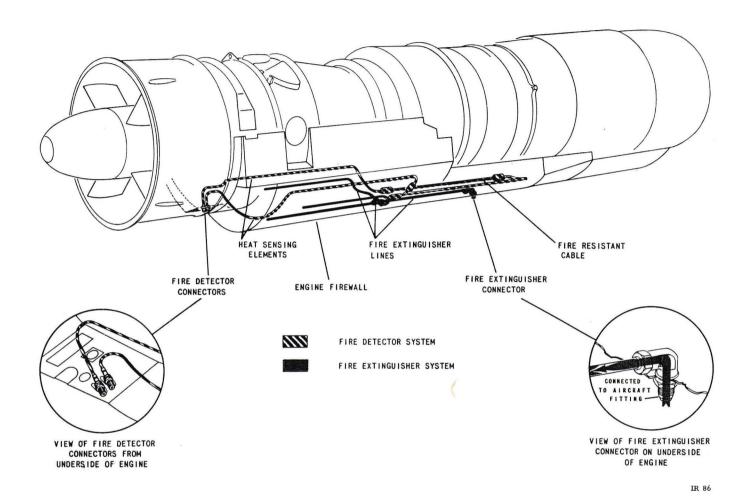


Figure 3-8-1 (Issue 1) Fire Detector and Extinguisher System

Inconel tube enclosing a ceramic thermistor core and one internal wire. Each element is fitted with a plug at one end and a receptacle at the other. A short length of fire resistant cable, with a socket at each end, connects the elements at the rear section of the engine firewall. As the temperature coefficient of resistivity of the thermistor material is negative, the resistance between the wire and the Inconel tube varies inversely with the temperature of the element. The system monitors the resistance variations of the sensing element to provide an amber light overheat signal at 205°C (400°F) and a red light fire signal at 288°C (550°F). No signal is given for normal temperature changes up to the average maximum ambient temperature of 177°C (350°F).

The system also incorporates an averaging temperature sensing control which ensures that the total length of the detector element must be subjected to the preceding temperatures before an alarm is given. Since a fire would probably not affect the complete element at one time, the temperature necessary to cause an alarm is

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inversely proportional to the length of the element in the fire. An excessive rate of heat rise, above the normal ambient temperature, illuminates the red light instead of the amber light to indicate an abnormal temperature increase due to a fire hot spot. Upon elimination of the hazard, the high resistance of the thermistor reestablishes itself, and the system is ready to detect any further hazards. The existence of a break in the sensing element can be established by a continuity check. However, the system continues to function as a detector in spite of a break.

Fire Extinguisher System

- The engine portion of the fire extinguisher system, when operating, is supplied with extinguisher fluid through a connection located on the underside of the engine firewall assembly, adjacent to the combustion drains fitting. Inside the engine firewall a short length of pipe extends forward from the connector to a cross fitting from which three open-ended lines carry the fire extinguisher fluid to the region between the outer ends of the front frame No. 5 and 6 struts, and to the regions fore and aft of the HP external gearbox. For details of the fire extinguisher bottles and controls, refer to the applicable Arrow 2 Engineering Order.
- In the event of fire during an engine ground run, provision is made for a manual fire extinguishing procedure. Two fire traps, each consisting of a screened opening, are located one on either side of the engine firewall centre section, near the bottom of the engine. The screened openings line up with openings in the aircraft nacelle structure which permit the insertion of hand or mobile fire extinguisher nozzles.

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AFTERBURNER ASSEMBLY

General

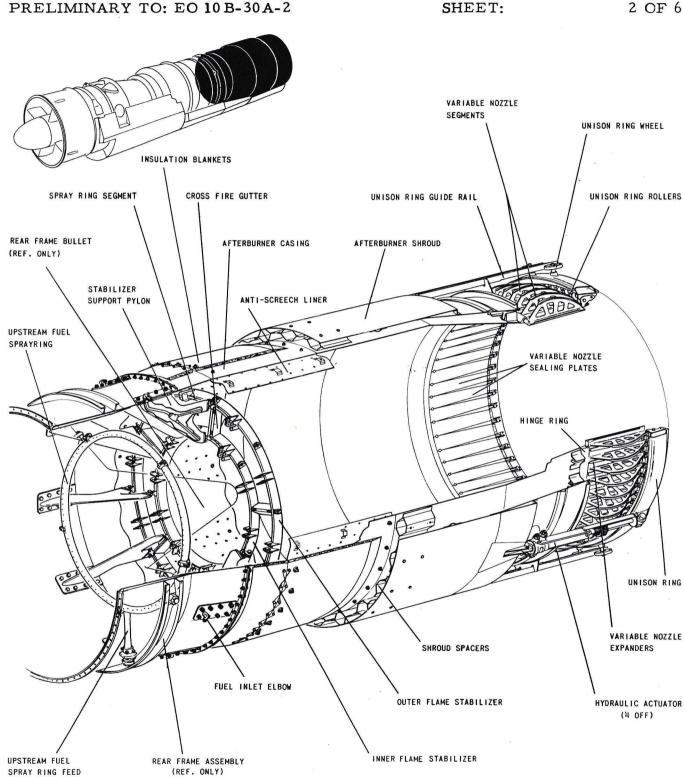
- Afterburning is a method of thrust augmentation used primarily to improve the performance of an aircraft under take-off, climb or combat conditions. Since only a proportion of the total air entering the combustion chamber is used in the engine combustion cycle, a considerable amount of oxygen is available in the exhaust gas stream to assist further combustion. Fuel is injected and burned in the exhaust gas stream at a point between the turbine and the final nozzle thus increasing the temperature and exit velocity of the exhaust gases which results in an increase in thrust. The mixture must be easy to ignite under all flight conditions and altitudes, and a stable flame which will burn steadily over a wide range of mixture strengths and gas flows is necessary to ensure smooth and efficient operation of the after-burner.
- The Iroquois afterburner assembly is integral with the engine and is designed to fulfil the general requirements detailed in the preceding paragraph. In addition to the final nozzle, spray, and stabilizer group, the afterburner consists of a casing, an anti-screech liner, and a shroud. A hot streak ignition system is used to start combustion of the afterburner fuel flow.
- Due to the increased volume of exhaust gases when the afterburner is in operation, an increase in final nozzle area is required to avoid excessive exhaust gas temperature and high turbine back pressure. To meet this and other requirements, the engine is equipped with a variable area final nozzle, operated by four automatically controlled hydraulic actuators. The fuel supply to the afterburner is also automatically controlled to provide full thrust modulation over the entire range

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Figure 3-9-1 Sectioned View of Afterburner Assembly

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of afterburner operation. Details of the final nozzle control system and afterburner fuel control system will be issued at a later date.

Afterburner Casing

The afterburner casing is a hollow cylinder of stainless steel sheet which extends rearward from the engine rear frame assembly. The casing is fabricated from five circular sections which are overlapped and welded together. The divergent conical front section of the casing has a machined bolting flange welded to the forward edge for attachment of the complete afterburner assembly to the engine rear frame. The convergent conical rear section of the casing has a circular hinge ring welded to its rear edge. A contoured groove machined on the rear face of the hinge ring accommodates the forward ends of the variable nozzle segments. At approximately the centre of the afterburner casing, a circle of shroud spacers is welded to the outside of the casing for attaching the forward end of an afterburner shroud. The stainless steel spacers have a hexagonal section, and are designed to accommodate the differential thermal expansion between the afterburner casing and the shroud, and to transmit the axial loads of the final nozzle hydraulic actuators attached to the rear of the shroud. The front portion of the afterburner casing is covered by insulation blankets which minimize heat radiation to the adjacent airframe structure.

Anti-Screech Liner

Forward of the mounting spacers, two circles of holes around the casing accommodate the attaching bolts of an anti-screech liner. The anti-screech liner comprises a perforated stainless steel sheet with axial corrugations, and is located round the inner wall of the afterburner casing. The liner prevents high amplitude resonant vibrations in the afterburner casing by absorbing and dissipating the high frequency gas pressure fluctuations which originate in the region of the flame stabilizer during afterburner operation.

Afterburner Shroud

- The afterburner shroud encases the rear half of the afterburner casing, and is fabricated from circular spotwelded sections of stainless steel sheet. The front of the shroud is bolted to hexagonal shroud spacers fitted to the afterburner casing, whilst at the rear, the shroud is supported by a circle of guides which engage with 'M' section spacers welded on the rear of the afterburner casing forward of the final nozzle. The guides permit free axial displacement of the rear section of the shroud resulting from the differential thermal expansion of the shroud and casing.
- A flow of relatively cool air is directed over the exterior of the afterburner casing by the shroud. The cooling air flow dissipates and carries away heat from

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the afterburner casing and thus maintains the temperature of the casing at a safe value during afterburner operation. From the shroud, the air is then directed over the variable nozzle segments to cool the final nozzle outer surfaces and reduce heat radiation to the final nozzle actuators.

Final Nozzle

- The final nozzle, fitted to the rear of the afterburner casing, is of the segmented, variable area type. The final nozzle area is varied by four hydraulic actuators, the forward ends of which are retained by fork-ends at the rear of the afterburner shroud. The actuators are equi-spaced round the final nozzle at 45 degrees from the vertical, and are designed for operation in the relatively high ambient temperatures at the final nozzle. The rear ends of the actuators are eyebolted to a unison ring. Four double-sided roller guide rails, welded to the rear of the afterburner shroud and equally spaced between the actuators, accommodate four pairs of rollers that are mounted on and carry the unison ring. The rollers ensure that the unison ring is centrally located during fore and aft movements.
- The unison ring is a rectangular sectioned ring, fabricated from stainless steel sheet. Four brackets, spaced at 45 degrees from the vertical on the outer diameter of the unison ring, mate with eye bolts on the rear of the actuators. Inward projecting brackets, welded to the inner face of the unison ring, carry sixty stainless steel unison ring rollers which bear against hardened cam faces on the outer edges of the final nozzle segments.
- The forward ends of the sixty cast stainless steel final nozzle segments are located round the rear of the afterburner casing in the contoured groove of the hinge ring. A braided Inconel tape is spotwelded in the hinge ring groove and locates the segment ends securely while cushioning the movement of the segments and forming a gas tight seal. Sealing plates and flexible metal expanders are interposed between the nozzle segments to form a closely knit, gas tight, fully expandable nozzle. Insulation is packed in each expander and is retained in position by covers which are pinned to the rear ends of the sealing plates.
- The final nozzle area is varied by the axial movement of the unison ring which causes the unison ring rollers to move along the segment cam faces and pivot the segments about the hinge ring. During actuation, the unison ring is held normal to the final nozzle axis by four flexible cables which interconnect the hydraulic actuators. A worm gear arrangement in each actuator drives the flexible cables and ensures synchronous movement of the actuators and hence correct axial positioning of the unison ring.

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Spray and Stabilizer Group

The spray and stabilizer group consists of ten stabilizer support pylons, an inner and an outer stabilizer and segmented spray ring, and an upstream fuel spray ring. The upstream fuel spray ring is an elliptical sectioned circular stainless steel tube designed to deliver a large proportion of the fuel supply to the stabilizers. Drilled orifices in the leading edge of the spray ring are angled alternately inward and outward so that the fuel spray is broken into a wide band of small droplets which avoids overloading of the stabilizers with raw fuel and hence improves the rich limit characteristics of the afterburner and reduces the possibility of flame out. Brackets on the forward face of the spray ring are bolted to a spigot on the trailing edge of each rear frame vane. The spray ring has a single feed which is slightly offset from the vertical at the bottom of the rear frame outer casing.

- The stabilizer support pylons, are equally spaced round the inner diameter of the engine rear frame. The outer ends of the pylons are bolted to the engine rear frame outer casing immediately forward of the rear flange. The 'Y' shaped pylons are of stainless steel sheet with an aerofoil section and extend inward and rearward into the inlet of the afterburner assembly. A fuel inlet elbow on the outer end of each pylon transfers fuel to a 'Y' shaped pipe located inside the pylon. The aft ends of the pipes are welded to inner and outer spray ring segments. The segments are made from short lengths of stainless steel tubing which, when assembled in position, form two segmented fuel spray rings. Equi-spaced fuel orifices are drilled in the downstream face of the spray ring segments.
- Two flame stabilizers are fitted immediately downstream of the segmented sprayrings, the outer stabilizer being supported by all ten pylons, the inner stabilizer by five of the pylons. Both stabilizers are of stainless steel to withstand oxidation and distortion, and have a 'V' cross-section, the apex of which points upstream. A circular disced groove in the apex of each stabilizer collects the fuel from the spray ring segments and evenly distributes it over the stabilizer regardless of any slight distortion or displacements of the spray rings relative to the stabilizer. Five radially disposed, stainless steel cross fire gutters with a cross section similar to that of the flame stabilizers, are equally spaced between the inner and outer stabilizers to assist in an even distribution of flame during afterburner operation.

Afterburner Ignition System

The hot streak method is used to light up the afterburner. A hot streak igniter valve operates automatically on commencement of the light up sequence, and introduces intermittent pulses of metered fuel into the primary combustion zone of the engine combustion chamber. The injected fuel ignites and produces a core of extremely hot gases which extends through the HP and LP turbine sections and

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ignites the afterburner fuel at the flame stabilizers. The core of hot gases is augmented by additional fuel injected through a relay jet located on the engine rear frame outer casing. Full details of the operation of the hot streak igniter valve will be issued later in Section 2 of this part.

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INSTALLATION

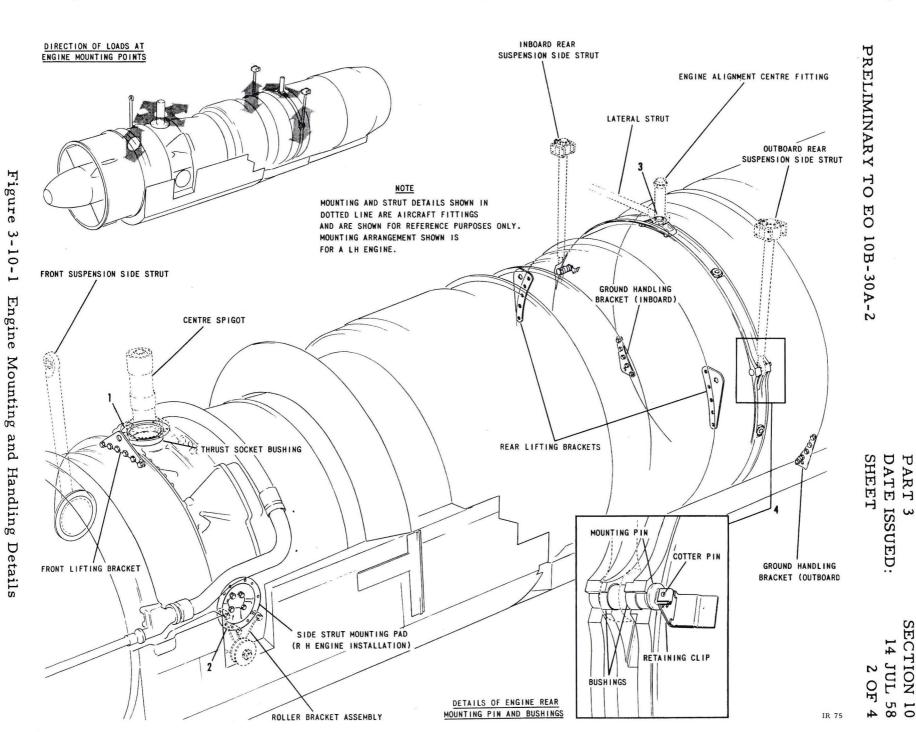
General

The Iroquois powerplant is designed for simplicity of handling, installation, and maintenance. Special tools are not required during engine installation and standard fittings and couplings are used on connections between the engine and airframe. Systems components are readily accessible for periodic maintainance without removing the engine from the airframe. Engine mounting and handling details, and installation details, are shown in Figure 3-10-1 and 3-10-2 respectively.

Engine Mounting

- The engine mounting is a five point arrangement which permits free radial and axial expansion of the engine, and prevents torsional loading of the engine due to relative engine/airframe deflections. By using the two main structural components of the engine for attachment, the mounting arrangement also provides adequate load support under all operating conditions. The mounting points are in transverse planes, with two points located on the front frame assembly and three on the rear frame main support ring. Referring to Figure 3-10-1, the engine mounting points accommodate the following aircraft parts:
- (a) Front frame top mount (1) Thrust socket bushing and centre spigot.
- (b) Front frame side mounts (2) Inboard front suspension side strut and outboard roller bracket assembly (these are interchangeable to suit RH or LH engine installation requirements).

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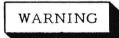
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- (c) Rear frame top mount (3) Engine alignment centre fitting and lateral strut.
- (d) Rear frame side mounts (4) Inboard and outboard rear suspension side struts.
- The net axial thrust of the engine is transmitted to the airframe by the centre spigot at the front frame top mount. This spigot also absorbs side loads tangential to the front frame casing, and a radial load caused by engine/airframe deflections at maximum thrust. The front and rear frame side mounts take vertical loads only, whilst the rear frame top mount takes side loads only. As all the loads at the rear frame are tangential to the main support ring, the rear frame casing is of relatively light construction.

Engine Handling

A mounting pad on each side of the front frame and drilled holes in the rear frame main support ring are provided for ground handling purposes.



The inlet frame lifting eyes and the afterburner lifting brackets are for component handling only and must not be used to support the weight of the engine.

Installation

- Three lifting brackets are provided; one at the top of the front frame, and one on each side of the rear frame. In addition, a jacking pad on the underside of the engine and brackets on the lower side of the rear frame facilitate engine handling during installation. Adjustments required to correctly align the engine within the engine nacelle are effected at the rear mountings.
- 6 Detailed instructions regarding engine installation procedures will be found in the applicable Arrow 2 Engineering Order.

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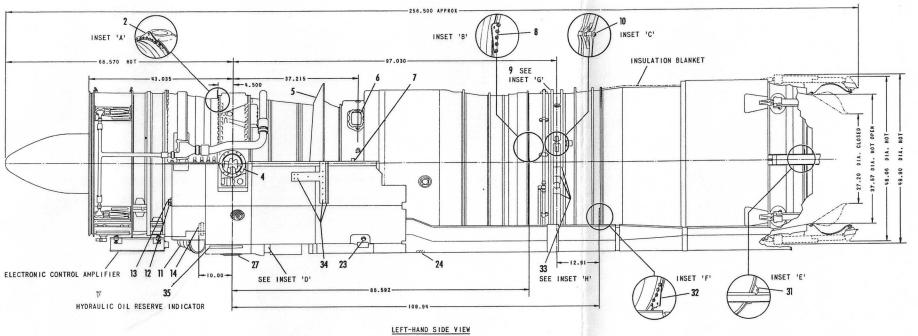
STARTER AND OIL FILTER

ACCESS DOORS SUPPLIED BY
AIRCRAFT MANUFACTURER

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RIGHT-HAND SIDE VIEW

INSET 'G'

7 CABIN AIR BLEED VALVE ELECTRICAL CONNECTOR I AIR DUCT SEAL ADAPTOR

NOTE

AND DECIMALS OF AN INCH.

UNLESS STATED OTHERWISE

DIMENSIONS REFER TO THE COLD CONDITION AND ARE

FOR NOMINAL VALUES ONLY.

ALL DIMENSIONS ARE IN INCHES

3 FRONT MOUNTING TRUNNION PAD (TOP) 4 FRONT MOUNTING TRUNNION PAD (LH SIDE)

5 NACELLE AIR RESTRICTOR

2 FNGINE FRONT LIFTING BRACKET

ANTI-ICING MAGNETIC

CONTROL AMPLIFIER

3 2 SEE INSET 'A'

IGNITION

EXCITER BOX

OXYGEN BOTTLE

ELECTRONIC CONTROL

AMPLIFIER

-13.215 -9.12-

6 NACELLE AIR TAKE-OFF CONNECTION

INSET 'J'

8 ENGINE REAR LIFTING BRACKETS

9 ENGINE ALIGNMENT CENTRE FITTING ATTACHMENT POINTS

IO REAR MOUNTING PINS

THERMOCOUPLE

LATCH CONNECTOR

HOT STREAK TIMER CONTROL

RAM TEMPERATURE SENSER

ELECTRONIC 1 CONTROL AMPLIFIER OXYGEN BOTTLE

II AIRCRAFT POWER TAKE-OFF (MAY BE ROTATED TO SUIT INSTALLATION)

12 CONSTANT SPEED UNIT OIL SUPPLY CONNECTION (NOW DELET. ED.)

IGNITION EXCITER BOX 29 28

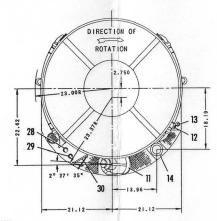
ANTI-ICING

CONNECTORS

LEADS

IGNITION EXCITER

SEE INSET 'J'



ELECTRONIC CONTROL AMPLIFIER, ANTI-ICING MAGNETIC CONTROL AMPLIFIER, OXYGEN BOTTLE AND IGNITION EXCITER BOX OMITTED FROM THIS VIEW FOR CLARITY

13 CONSTANT SPEED UNIT OIL RETURN CONNECTION (NOW DELETED)

14 FUEL HILET CONNECTION

OIL FILTER

BOTTOM VIEW

WITHDRAWAL CLEARANCE

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RESERVE

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15 OIL TANK OVERFLOW DRAIN CONNECTION

16 OIL TANK REFILL COUPLING CONNECTION

17 HYDRAULIC OIL COUPLING CONNECTION

IE HYDRAULIC RESERVOIR BLEED VALVE

CONTROL DOOR

19 HYDRAULIC ACCUMULATOR NITROGEN CHARGING VALVE

20 FUEL PUMP AIR BLEED VALVES

21 OIL TANK DRAIN COCK

22 STARTER MOUNTING FLANGE

23 AIRCRAFT POWER CONTROL LINKAGE CONNECTION (MAY BE FITTED TO EITHER SIDE OF THE ENGINE FIREWALL ASSEMBLY)

24 COMBUSTION DRAIN CONNECTION

25 COMBINED DRAINS CONNECTION

26 FIRE EXTINGUISHER CONNECTION

27 GROUND HANDLING JACKING PAD

28 P. AIRCRAFT QUICK DISCONNECT

29 Pr AIRCRAFT QUICK DISCONNECT

30 ELECTRICAL CONNECTIONS

31 AFTERBURNER LIFTING BRACKETS

32 GROUND HANDLING JACKING BRACKETS

33 ENGINE HANDLING FACILITIES

34 AIR RESTRICTOR FLAP INSTALLATION POINT (LH SIDE)

35 HYDRAULIC OIL RESERVE INDICATOR

36 ANTI-ICING AIR TAKE-OFF CONNECTION

37 FRONT MOUNTING TRUNNION PAD (RH SIDE)

38 AIR RESTRICTOR FLAP INSTALLATION POINT (RH SIDE)

Figure 3-10-2 Installation Details

INSULATION

SEE INSET 'C'

SEE INSET 'F'

31 SEE INSET 'E'

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INSTALLATION

POWER CONTROL LEVER INPUT SHAFT - ASSEMBLING AND SETTING-UP

NOTE

The following instructions should be read in conjunction with Figure 3-10-3.

General

The power control lever input shaft can be assembled to either side of the engine, to conform with the airframe installation used. The cockpit power control lever and the engine input shaft are synchronized by coupling the linkage at a fixed datum point, namely, the 13 degree engine ground idle position. The position indicator (1) pointer (2) and micrometer adjustment (5) are used to adjust the shaft setting during assembly.

Input Shaft Sub-assembly Procedure

- Assemble the input shaft sub-assembly details before the shaft is installed on the engine in the following manner:
- (a) Assemble the quick disconnect coupling (3) to the universal joint extension shaft (4).
- (b) Assemble and tighten the micrometer adjustment clamp nut and bolt (5) to a torque loading of 100-140 in. 1b, then loosen the nut until it clears the clamp face one full thread.

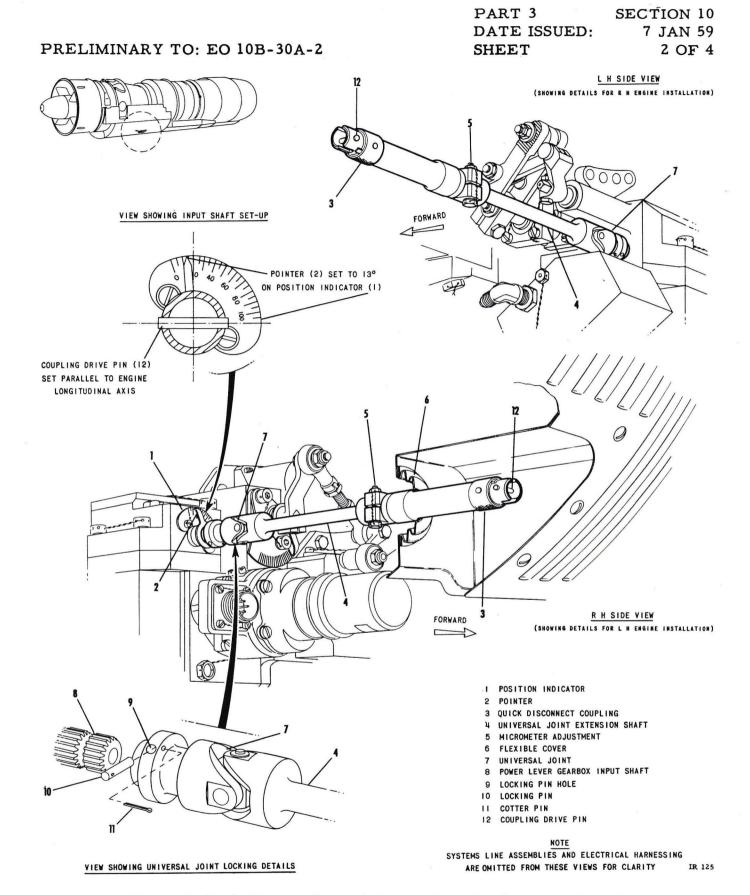


Figure 3-10-3 Power Control Lever Input Shaft Set-up Details

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Assembling Input Shaft to Engine

3 Carry out the following operations to assemble the input shaft to the engine:

- (a) Remove the engine control access door from the firewall assembly.
- (b) Remove the input shaft flexible cover (6) from the power control linkage firewall support bracket.

NOTE

When necessary, interchange (RH or LH) the power control linkage firewall support cover plate with the input shaft flexible cover (6).

- (c) Fit the input shaft universal joint (7) to the power lever gearbox input shaft spline (8), positioning the universal joint locking pin hole (9) to the most convenient position for locking.
- (d) Insert the universal joint locking pin (10) and secure in position with the cotter pin (11).

Setting-up Input Shaft

- 4 Use the following procedure to set-up the input shaft:
- (a) Hold the input shaft (8) and pointer (2) at the 13 degree ground idle position.
- (b) Compare the angular relationship of the coupling drive pin (12) to the engine longitudinal axis.
- (c) Using the micrometer adjustment (5) rotate the quick disconnect coupling (3) until the coupling drive pin (12) is visually sighted at zero degrees parallel to the engine longitudinal axis.



Ensure that the micrometer adjustment (5) clamp nut has been loosened one full thread from the clamp face before the adjusting bolt is turned.

(d) Retighten the micrometer adjustment clamp nut and bolt to a torque loading of 100 to 140 in. lb.

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NOTE

After operation (d) recheck the pointer setting (2) and ensure that the coupling drive pin (12) is correctly positioned.

- (e) Wirelock the micrometer adjustment clamp nut and bolt.
- (f) Reassemble the input shaft flexible cover (6) to the firewall support bracket.
- (g) Reassemble the engine control access door when the engine is installed in the airframe.

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ENGINE OXYGEN SYSTEM

General

The engine oxygen system is designed specifically to promote rapid engine relights in flight and to extend the range of altitudes at which relights can be successfully accomplished. The system delivers oxygen, to Specification AN-O-1C, Grade A, Type 1, at the rate of 0.05 lb/min to each of the two injectors located adjacent to the igniter plugs in the combustion chamber, and consists of an oxygen cylinder and valve, a regulator, two check valves and the piping necessary to deliver the oxygen to the injectors. Apressure gauge incorporated in the regulator indicates when renewal of the oxygen cylinder is necessary. Access to the gauge is through a detachable panel on the engine nacelle. As described in Section 6 of this part, the oxygen system can only be operated when the aircraft undercarriage is retracted.

Cylinder

The oxygen cylinder is located on the underside of the inlet frame outer casing, adjacent to the electronic control amplifier, and is supported by two band clamps. It is bound with wire along the body as a precaution against shattering. The cylinder has a capacity of 96 cub. in. and operates at a nominal pressure of 2000 psi at 21.1°C (70°F) which is, under normal conditions, sufficient for approximately fourteen relights. A self-opening valve, fitted in the neck of the cylinder, opens automatically when a specially designed coupling nut is screwed onto the valve body during installation of the cylinder. The valve body incorporates a gold-plated bronze safety disc designed to blow out if the pressure in the cylinder reaches 4250 to 4275 psi at 21.1°C (70°F), the oxygen escaping through holes in the disc retaining plug. During operation, the oxygen flows from the cylinder to the oxygen regulator through the

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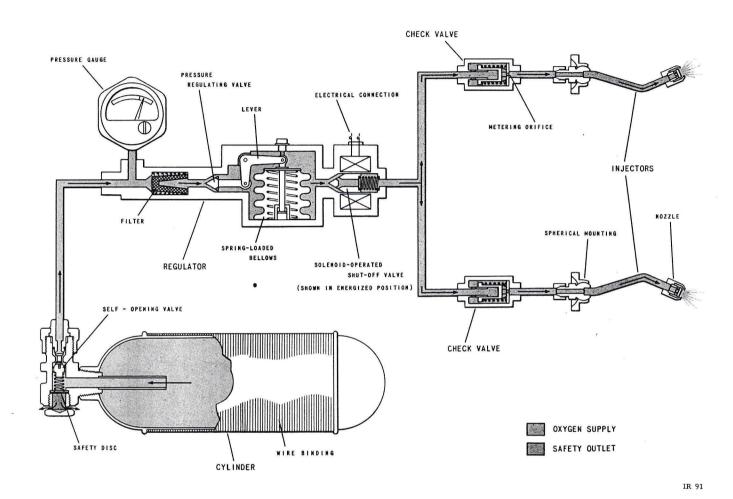


Figure 3-11-1 Schematic Diagram of Engine Oxygen System

valve and an external pipe.

Regulator

- The oxygen regulator comprises essentially a bellows-operated pressure regulating valve, a pressure gauge, and a normally closed solenoid-operated shut-off valve. The regulator is mounted on the inlet frame adjacent to the oxygen cylinder. When operative, the regulator provides a steady flow of oxygen at a pressure of 60 to 70 psi. The oxygen supply from the cylinder to the regulator passes through a filter located in the inlet passage of the regulator.
- The pressure regulating valve is actuated by a lever attached to the free end of an evacuated spring-loaded bellows. When the engine relight circuit of the electrical system is energized, the solenoid-operated shut-off valve located in the outlet passage of the regulator is open. The pressure in the bellows chamber decreases

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and the bellows expand to open the pressure regulating valve. Oxygen then flows through the valve, and as the pressure in the bellows increases to the predetermined value, the position of the valve stabilizes. Should the pressure in the chamber tend to increase above the set value, the bellows contract and reduce the valve opening to maintain a constant pressure. Conversely, if the pressure tends to fall, the bellows expand and increase the valve opening. When the solenoid is de-energized and the shut-off valve closes, the pressure in the bellows chamber increases and holds the pressure regulating valve closed.

Check Valves

Two check valves of the spring-loaded sleeve type, are located immediately upstream of the mid frame oxygen injectors. When oxygen is released by the regulator, the pressure overcomes the spring force and passes through the valve. The oxygen then passes through a metering orifice in the outlet port of the check valve. During normal engine running the spring-loaded valves close to prevent combustion gases from backing up the oxygen lines to the regulator.

Injectors

Two bosses, near the bottom of the mid frame casing and in line with the fuel injectors, provide a spherical type mounting for the oxygen injectors. Each injector consists of a stainless steel tube with a standard union fitting on the outer end and a nozzle which engages in a hemispherical combustion pot in the combustion base plate. The stainless steel nozzle in the inner end of the tube is surrounded by a sleeve which directs the oxygen towards the igniter plug.

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FINAL NOZZLE CONTROL SYSTEM

INTRODUCTION

General

- 1 The forward thrust produced by a turbojet engine is dependent on the extremely high velocity to which the exhaust gases are accelerated as they leave the engine. To control this high velocity, a convergent final nozzle is used to reduce the effective area opening to atmosphere and so produce the required exit velocity.
- The area of the final nozzle aperture has considerable influence on the performance of the engine by its effect on turbine inlet and outlet temperatures and pressures, the mass airflow through the engine, and the exit velocity of the exhaust gases. If the aperture is too large for a given operating condition, it will cause a drop in the velocity and hence momentum of the exhaust gas stream, resulting in reduced thrust. If too small, the aperture will produce a thrust increase, but high exhaust temperatures and turbine back pressures will occur with consequent damage to engine parts and danger of engine surge.

Types of Final Nozzles

On non-afterburning engines, a fixed area final nozzle is generally adequate to meet the performance requirements of the engine. With afterburning engines, the minimum final nozzle requirement is a two position type which opens during afterburning to allow the increased volume of exhaust gases to escape without adverse effects on the engine. However, high performance engines with a fully modulated afterburning range, such as the Iroquois, require a progressively variable final nozzle, which alters the exhaust outlet area according to changing conditions over the entire engine operating range, including afterburning.

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Final Nozzle Control Requirements

- 4 To obtain maximum performance from the engine, a final nozzle area operating line, see Figure 3-12-1, is selected which will fulfil the following general requirements:
- (a) Low RPM Range A large nozzle area to reduce turbine back pressure, hence facilitating engine starting and permitting rapid accelerations to the upper speed range without over-temperature conditions and surge.
- (b) High RPM Range A reduced nozzle area to produce the highest possible exit velocity and thrust consistent with exhaust gas temperature limitations.
- (c) Afterburning Range An increased nozzle area to allow the escape of an additional volume of exhaust gases while producing the highest possible exit velocity and thrust consistent with exhaust gas temperature limitations.
- 5 In each of the preceding requirements, exhaust gas temperature is an important consideration and in all cases it is a limiting factor. Thus a control device is necessary which will prevent excessive temperatures and possible structural damage to the engine. This is provided by the exhaust temperature trim (T7), which can override the basic nozzle area control when in the upper rpm range and during the afterburning advance and retard range. During engine starting and acceleration in the low rpm range, the T7 trim is applied to the basic fuel schedule, taking temperature readings downstream of the LP turbine. Complete details of the electrical and electronic aspects of the T₇ temperature trim as applied to the fuel and final nozzle control systems, are contained in paragraph 22 and in Section 6 of this part.

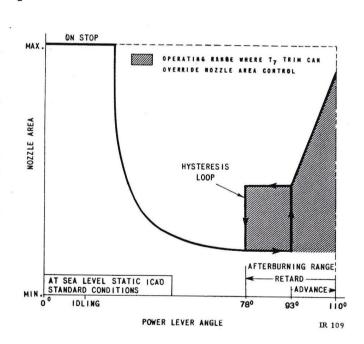


Figure 3-12-1 Typical Final Nozzle
Operating Line

As seen in Figure 3-12-1, afterburner operation begins at a power lever angle of 93 degrees and thereafter continues anywhere in the 78 to 110 degree range. Above 93 degrees the engine fuel flow and hence the thrust output remains constant while the afterburner fuel flow and thrust output is modulated by movement of the power control lever. Between 93 and 78 degrees the afterburner fuel flow and thrust is

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constant while the engine fuel flow and thrust is modulated. Thus, it is seen that once the afterburner is lit at 93 degrees, smooth thrust modulation is provided throughout the entire afterburning range from 78 to 110 degrees. This characteristic enables the pilot to retard the power control lever to settings below 93 degrees, in order to maintain formation flying for example, without having the afterburner cut out. The hysteresis loop in the nozzle area operating line is a function of the T7 trim and allows the additional volume of exhaust gases to escape without detriment to the engine while the afterburner is operating in the 78 to 93 degree range.

7 Control of the final nozzle area is automatic, thus alleviating the pilot of this responsibility. The following paragraphs describe the control principles and operation of the final nozzle control system components. A detailed description of the mechanical arrangement and construction of the final nozzle itself is contained in Section 9 of this part.

Control Principles

- The pressures and temperatures at various points in the engine bear a definite relationship to each other as the engine operating conditions change. If for example the final nozzle area of the engine were to remain constant throughout the entire operating range, the pressure ratio across the turbine would have the characteristic of increasing steadily in value as the engine speed increases.
- It follows that if the final nozzle area is varied to maintain the pressure ratio across the turbine at constant value, a large nozzle area is required during the low rpm range, and a small nozzle area during high rpm operation of the engine. Referring to Para 4, it will be seen that this characteristic will satisfy the general control requirements in the engine operating range. Hence a control system is selected which will vary the nozzle area to maintain a constant pressure ratio across the turbine.
- Since the turbine pressure ratio tends to decrease during afterburning, due to the increased temperature and expansion of the exhaust gases, the selected control system opens the nozzle to maintain a constant turbine pressure ratio; this also gives the highest possible proportion of the available thrust. However, during afterburning, exhaust temperatures and turbine back pressures are critical and may under certain operating conditions exceed the acceptable limits. Therefore, by utilizing the T₇ trim control to artificially reduce the turbine pressure ratio, and hence increase the nozzle area, when adverse conditions are encountered, safe and efficient operation of the afterburner is attained under all operating conditions.
- 11 A measure of the turbine pressure ratio is obtained by applying two suitable control variables, namely the HP compressor delivery pressure (P₄), and the LP turbine discharge pressure (P₇), to a pneumatic-mechanical device termed the

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ted to detect deviations in the pressure

pressure ratio senser. The senser is calibrated to detect deviations in the pressure ratio from an established value and transmit error signals to the actuator control valve. These signals are proportional to the deviation.

The position of the actuator control valve, as described in Section 4 of this part, modulates the hydraulic pressure applied to the final nozzle actuators and hence determines the velocity of the actuators and the rate of change of the final nozzle opening or closing. Feedback in the system is the direct effect of changes in nozzle area on the value of the turbine pressure ratio (P_4/P_7) . Thus, when an error in pressure ratio is detected, the correction applied to the final nozzle continues until the change in nozzle area is sufficient to restore the pressure ratio to the desired value. At this time the error is reduced to zero and the control system and actuating mechanism stabilizes. This type of system is known as a 'closed loop' control system, and is fundamentally an integrating or 'zero steady-state error' system.

COMPONENTS COMPRISING THE SYSTEM

- 13 The final nozzle control system comprises the following units, together with the necessary connecting lines:
- (a) Pressure Ratio Senser
- (b) Actuator Control Valve
- (c) Proportional Air Valve

These operate in conjunction with the Exhaust Temperature Trim and the Electronic Control Amplifier. The units (a), (b) and (c) are briefly described in the following paragraphs, the other units are described in Section 6 of this part.

Pressure Ratio Senser

- 14 The pressure ratio senser is designed to sense the pressure ratio across the the turbine and to control the final nozzle at a degree of opening which maintains the pressure ratio at a constant value in order to satisfy the requirements discussed in Para 4 of this section. As described in later paragraphs, the senser is designed to be insensitive to changing conditions, such as an increase in altitude, which would affect the absolute values of P₄ and P₇ and otherwise upset the desired relationship between the pressure ratio and the nozzle area operating line.
- 15 The senser consists primarily of one fixed area metallic diaphragm and one variable area type (see Figure 3-12-2) mounted on a common spindle. One end of the spindle is connected to the free end of a spring-loaded evacuated bellows, and

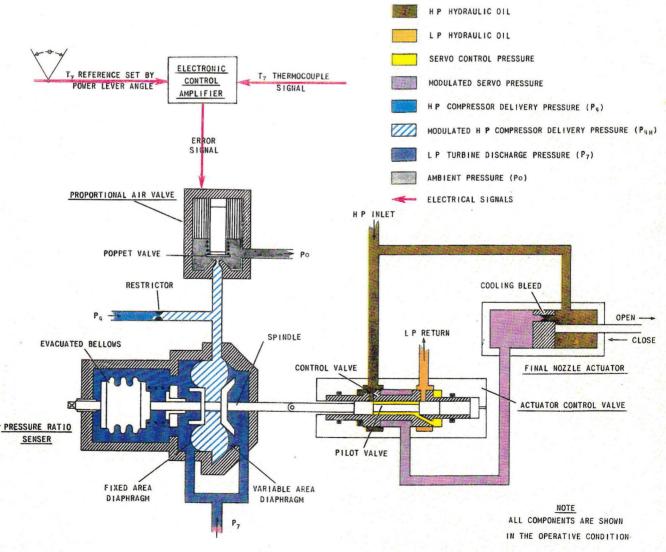
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the other end is linked to the actuator control valve. The components are arranged so that the chamber formed between the diaphragms is subjected to HP compressor delivery pressure (P_4) , while the outer side of each diaphragm and the bellows are exposed to LP turbine discharge pressure (P_7) . The resultant pressure force on the variable area diaphragm is directly opposed by the total forces exerted by the fixed area diaphragm, the bellows and the bellows spring. The outer edge of the variable area diaphragm is seated against the chamfered face in the housing so that when the diaphragm spindle moves to the right, the effective area of the diaphragm exposed

to the pressure force is reduced. Conversely, when movement to the left occurs, the



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diaphragm area is increased.

- When the turbine pressure ratio tends to increase, for example, when the engine rpm increases, the force balance existing between the diaphragm and bellows arrangement is upset and the spindle moves to the right. However, this movement results in a reduction in the effective area of the variable area diaphragm acted on by the increased pressure ratio. An equilibrium position is reached due to the increasing force exerted by the compressed bellows spring balancing the decreasing resultant force exerted by the pressure acting on the variable area diaphragm.
- 17 The reverse action occurs when the turbine pressure ratio tends to decrease, when for example afterburner light-up is obtained. The spindle and diaphragm assembly moves to the left until equilibrium is restored between the forces exerted by the diaphragm and bellows arrangement.
- The variable area nature of the diaphragm in effect causes it to act as a spring which is complementary to the coil spring. The diaphragm has another feature in that its 'spring rate' decreases as the absolute pressure values of P4 and P7 reduce, thus tending to produce a constant deflection, and hence movement of the spindle, for a constant change in pressure ratio regardless of the relative pressure levels. If a fixed area diaphragm was used, total movement of the spindle for a given change in pressure ratio would decrease as altitude increased.

Actuator Control Valve

- Movement of the pistons in the final nozzle actuators is regulated by the actuator control valve which is positioned as a function of the movement of the pressure ratio senser spindle. Variations in P4/P7 pressure ratio regulate the position of the valves in the actuator control, to direct hydraulic oil at varying degrees of pressure to the space on the left-hand side of the final nozzle actuator pistons. HP hydraulic oil at a constant pressure is applied to the space on the right-hand side of the final nozzle actuator pistons at all times.
- The actuator control consists of a floating type control valve, and a spool type pilot valve housed in a casing. The pilot valve is connected to the pressure ratio senser spindle to regulate and direct the flow of servo control pressure acting on the right-hand end of the control valve, depending on the relative position of the pilot valve. The left-hand end of the control valve communicates with HP hydraulic oil at a constant pressure. The control valve, acting as a function of the pilot valve, varies the area of the final nozzle by regulating the value of modulated servo pressure applied to the left-hand side of the final nozzle actuator pistons. Movement of the control valve to the right, closes the HP hydraulic oil supply port and simultaneously uncovers the LP return port, thus relieving the modulated servo pressure acting on the left-hand side of the piston in each of the final nozzle actuators and

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causing the final nozzle to close. A detailed description of the mechanical arrangement of the final nozzle actuators is contained in Section 4 of this part.

Proportional Air Valve

- 21 The proportional air valve consists of a solenoid-actuated, spring-loaded, variable area type poppet valve. A fixed area restriction in the P₄ supply line upstream of the control unit creates a drop in P₄ pressure when the poppet valve is open. For an overtemperature condition, the solenoid is energized proportional to an error voltage originating in the exhaust temperature trim system.
- The exhaust temperature trim system measures the jet pipe temperature by a series of thermocouples, the output of the thermocouples being compared with a reference voltage in the electronic control amplifier. The reference voltage is varied by the power lever angle to provide safe limits during cruise and maximum engine speed conditions. An excess of measured jet pipe temperature over the required value as set by the power lever angle, creates an error voltage which is amplified and applied to a proportional air valve.
- The error voltage energizes the solenoid coil, which opens the poppet valve against the spring tension, thus relieving P₄ pressure. The reduction in sensed pressure creates an artificial decrease in the turbine pressure ratio which in turn causes the final nozzle to open, thereby reducing the exhaust temperature as a result of the increased expansion ratio across the turbine. The trimming action continues until the overtemperature is eliminated.

SUMMARY OF FINAL NOZZLE CONTROL OPERATION

Operation at Low Engine RPM

In the low rpm range, immediately above idling speed, the final nozzle area is at the maximum value, the final nozzle actuators being fully against their respective stops. The turbine pressure ratio in this rpm range is below the established value, and hence the diaphragm spindle in the pressure ratio senser and the actuator control valve has moved to the left. This uncovers the HP port in the control valve and permits pressure build-up of modulated servo pressure acting on the left-hand side of the final nozzle actuator piston. Pressure equalization across the piston head of each actuator results in movement of the actuators to the fully open position, thus the final nozzle area is at the maximum value.

Operation at High Engine RPM

During engine operation in the high rpm range, the turbine pressure ratio tends to increase and the diaphragm spindle and pilot valve move to the right. This

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movement causes the actuator control valve to move to the right and reduce the opening of the actuator control valve HP port. Simultaneously the LP return port is partially uncovered and the modulated servo pressure acting on the piston head of each final nozzle actuator is relieved, causing the pistons of the actuators to move to the left and reduce the area of the final nozzle.

Operation During Afterburning

A decrease in the turbine pressure ratio tends to occur during afterburning. This decrease positions the diaphragm spindle and pilot valve towards the left of the neutral position. This causes the actuator control valve to move to the left and partially close the LP return port. Simultaneously the actuator control valve HP port is uncovered permitting modulated servo pressure to build up on the left-hand side of the pistons in the final nozzle actuators. The pressure differential across the pistons results in them moving to the right to increase the final nozzle area until the desired pressure ratio is restored. At this time the actuator control valve and the pistons of the final nozzle actuator stabilize in their new position.

Operation During Overtemperature Conditions

When an overtemperature condition is sensed by the electronic control amplifier, the resultant error voltage is amplified and applied to the proportional air valve solenoid. The air valve opens and bleeds off P₄ pressure acting on the pressure ratio senser to create an artificially low turbine pressure ratio. This results in movement of the actuator control valve to the left, which in turn results in a build-up of modulated servo pressure acting on the final nozzle actuators. The resultant pressure differential across the pistons of the actuators causes the pistons to move to the right to increase the nozzle area, until the exhaust temperature is within limits and the error signal is reduced to zero.