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# CF-105 POWER PLANT INSTALLATION

## (PRATT & WHITNEY J 75)

*AVRO AIRCRAFT LIMITED*

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C O N F I D E N T I A L

# C-105 ENGINE INSTALLATION

## PRATT & WHITNEY J-75





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## GENERAL DESCRIPTION OF THE J-75 ENGINE

The J-75 engine is a two-spool seventeen-stage axial flow compressor with an annular combustion chamber and a split three-stage turbine. The compressor consists of a ten-stage low pressure unit with seven stages in the high pressure unit. The low pressure compressor is driven from the second and third stage coupled turbine wheels and the high pressure compressor is connected independently to the first-stage turbine. The compression ratio is about twelve to one at sea level military rating. To improve the characteristics of the combined compressor unit a low pressure overboard bleed valve is provided on each side of the engine. These are automatically controlled to improve acceleration and prevent compressor surge at high altitude by allowing low pressure air to escape overboard during low power operations. High pressure bleed air is used to close these valves as well as to provide other functions such as anti-icing. High pressure air is also used for the Aircraft air conditioning system. The annular combustion chamber contains eight burner cans. Fuel is delivered to these cans through dual orifice nozzles in clusters of six in the inlet of each can. High energy ignition units and two spark igniters are used to initially ignite fuel.

An afterburner is fitted to this engine incorporating a double wall construction through which the normal temperature turbine exhaust gases flow to reduce the temperature of the outer wall of the afterburner. A two position convergent exhaust nozzle is used and is actuated through twenty-four air cylinders using high pressure compressor air bleed. The convergent nozzle is used in conjunction with an air frame fitted ejector to simulate convergent divergent nozzle characteristics.

The low pressure compressor provides power to an accessory pad at the nose of the engine on which is mounted a constant speed drive and alternator. The high pressure compressor provides power to three separate accessory pads from the waist of the engine of which only the central pad, originally intended as a starter flange, is used for accessory power take-off and starting.

## ENGINE MOUNTING

The basic philosophy used in the design of all engine mounts on this installation has been the reduction to a minimum of trial and error methods of making a connection. Such devices as a simple pin may be fitted in five seconds but could just as well require five minutes, even with the aid of a hammer! Devices of this type are not used.

Adjustment of the engine has been kept to a minimum. At the front of the engine no adjustment whatever is required whilst the afterburner nozzle can be adjusted vertically at the rear outboard mount, and horizontally at the rear centre mount. Simple templates will be provided for each of these adjustments so that time taken to adjust the engine position should not take more than thirty seconds during the installation.

JUST BELOW

Of a total of five pick up points on the engine, two are positioned on the compressor inlet case horizontal centre line, the outboard one taking vertical loads only, with the inboard taking vertical side, and fore and aft loads. The three rear pick ups are in the plane of the turbine housing and will take only tangential loads, i.e. the side mounts inboard and outboard take vertical loads, and the centre mount will take only side loads.

The four mounts which take vertical loads are all designed so that the act of assembling will also pick up the engine from its assembly rails over varying distances, and conversely when these mounts are detached, the engine is automatically lowered to the rails, ready for removal. The weight of the engine alone accomplishes this; it is not possible to apply any load greater than the weight of the engine to the rails, and airframe structure.

1. Front Inboard Mount.

A steel forging, carrying the inboard front mount of each engine is attached through a tubular structure to the underside of the wing straight on to the centre spar forward. This forging is also braced back to a single central pick up under the wing to take all fore and aft loads. Projecting inside the engine shroud, the pick up consists of a spherical split housing, the rear half wings upward and rearward around a hinge point to admit the mounting ball attached to the engine. The hinge pin is extended to pass through the engine shroud from where it is rotated by a small lever accessible from the space between the two engines.

The lower attachment of the half socket joint is secured by means of a bolt, which again is accessible through a fixed pocket in the shroud from the space between the two engines. As the bolt is inserted and tightened, the engine is picked up from the assembly rail some .025" to .040". Access to this mount has been made from space between the engine, via an access door, due to a lack of space between engine and shroud.

2. Front Outboard Mount.

A simple strut takes vertical loads only up into the wing, via rib #4 at the front outboard mount. The ball and socket joint at the engine end is attached through mating conical surfaces to the engine flange. These conical surfaces provide up to 1/8" of lift during the tightening process. Access is provided via a door in the fuselage skin through the fuselage structural frames.

3. Rear Centre Mount.

Taking care of side loads only, this mount consists of a rectangular spigot, protruding from the bottom surface and fitted through the top surface of the wing into a bush which is trunnion mounted to the engine flanges. Lateral adjustment by means of eccentric bushing is provided here to rotate the engine around the front inboard mount, so that the clearance between afterburner nozzle and the aircraft mounted ejection shroud can be checked. Loads are taken out through the wing skins and Beam #1. Within the mounting unit a titanium barrel is used to minimize heat transfer to the aluminum wing lower skin. The adjustment point is accessible from the top surface of the wing.

4. & 5. Rear Side Mounts.

A linkage has been used for the rear side mounts so that wing deflections will not be opposed by the torsional rigidity of the engine. Vertical struts, attached at the horizontal centre line on each side of the engine hang from bell-crank levers which are interconnected by a horizontal cross tube so that vertical loads can be taken by each strut, whilst the support points are free to twist in a vertical direction relative to the engine. Disconnect points are located in each vertical strut.

The inboard strut disconnect has been designed to enable quick operation to be achieved in a location which is not so readily accessible as the outboard one. A Marman clamp, attached by a hinge to the strut is used. Access is obtained through the space between engines via a small removable cover on the engine shroud.

The outboard rear mount disconnect is more complex in that the engine is lifted into its flight position when the attachment is made. This is achieved by a small gear box retained on the upper half of the strut containing a nut, which is rotated by means of a worm drive, to engage the threaded end of the lower half-strut. When lowering the engine the nut will disengage after the engine is resting on the assembly rail. Vertical adjustment is provided by this joint so that the correct vertical clearance between the afterburner nozzle and the aircraft mounted ejector shroud can be maintained.

It is imperative that the rear and side mounts be attached or disconnected in the correct sequence, as follows:-

> On engine installation, the inboard mount <u>must</u> be assembled <u>before</u> the outboard mount.
>
> On engine removal the inboard mount <u>must</u> be disconnected <u>after</u> the outboard mount.

## AIR FLOW AND FIREWALL ARRANGEMENTS

The basic requirements dictating the design of airflow passages through the engine bays are governed by the supersonic performance of the engine air intake. In order to achieve optimum performance of the intake over subsonic, transonic and supersonic speeds, a by-pass passage has been designed at the engine inlet casing capable of taking 16% of the engine mass flow. Lightly spring loaded gills prevent reverse flow, under those low forward speed conditions which would cause a depression at the engine inlet.

The firewalls are designed to allow the very high supersonic airflows to pass from the intake, through Zone 2 and into the afterburner ejector nozzle with a minimum of resistance, and maintaining all fire prevention requirements. In order to achieve this a special arrangement of firewalls was necessary. A 'can' of stainless steel is wrapped around the upper part of the engine, extending from the inlet casing to the engine-supplied firewall. The upper two-thirds of the engine accessory section is thus separated from the air being fed into the combustion zone, or Zone 2. A spring seal completes the separation by joining the lower edge of the can across to the engine shroud. The whole of the area around the combustion and afterburner zones of the engine is used to pass the airflow from the upper two-thirds of the intake by-pass through to the final nozzle ejector.

A series of holes at the forward end of the engine can allows a restricted amount of air to pass into the accessories zone of the engine, circulating along the upper two-thirds of the engine skin before passing into the lower part of Zone 1, which houses all the engine accessories. Below the engine can, the engine supplied firewall forms the sealing barrier between the two zones. The seal is completed at this point by means of a spring loaded member mounted on the airframe, and this member can be readily displaceable, to allow engine installation or withdrawal. The air circulating around Zone 1 escapes overboard through a 2.5 inches dia. ejector tube set into the forward main access door.

The lower third of the intake by-pass annulus is ducted separately overboard, through three air/oil coolers set in parallel. The gills described above continue over this section of the by-pass, so that under intake depressions cases, no air will be passing through the coolers.

Cooling and ventilation at all forward speeds of less than approximately M.=5 are provided by means of two ejector nozzles, one at the jet pipe nozzle being basic design, and the second at the overboard outlet from Zone 1.

The jet pipe nozzle ejector, without afterburner, and with engines only idling will only produce a few inches of water depression, but the area available here is very generous, for the small air flows required under engine idling conditions. A special ejector pump is provided at the Zone 1 outlet operated by engine compressor discharge air. A butterfly valve is installed in the pressure line, being opened on a signal from a pressure switch sensing differential pressure between the intake duct, and ambient. Thus, when an engine is started, the intake depression resulting will switch on the Zone 1 ejector pump. A small depression also results from the basic jet-pipe nozzle ejector, and the gills around the intake by-pass are drawn to the closed position, resulting in a depression throughout the engine bay. A series of very lightly spring loaded doors, opening inwardly, at the forward end of Zone 2 will now open to admit air to the nacelle. The areas concerned have been adjusted so that sufficient air can be drawn through to ventilate both Zone 1 and Zone 2, that for Zone 1 travelling forward, on the outside of the engine can, through the holes at the forward end of the can, back through Zone 1 and overboard at the ejector pump, whilst that for Zone 2 travels rearward, straight to the jet-pipe ejector.

This method of ventilation will continue during flight, until the aircraft has reached a forward speed high enough to create a static pressure in the intake duct higher than ambient, when the ejector pump in Zone 1 will be switched off, the by-pass gills will open and ventilation will then be as described with the cooling air being provided by engine spillage.

Completing the firewall arrangement, that part of the engine tunnel aft of the engine firewall is lined with insulation blankets, of fire resistant material, to protect the fuselage from engine fires. That part of Zone 1 which is not protected by the steel engine can is made from titanium sheet of the appropriate thickness to give the designed fire resistance.

Drainage of the rear engine tunnel is achieved through a series of overboard drains, protected from pressure losses at high forward speeds by check-valves. Engine drains, along with Zone 1 drainage, are dumped into the Zone 1 ejector.

## ENGINE FUEL SYSTEM

Fuel is taken in to the engine on the right hand side, through an engine driven centrifugal booster pump, which supplies a bank of three parallel gear pumps. One of these feeds the main engine, and the other two the afterburner. Failure of the main engine stage is covered by a transfer valve which will by-pass one of the afterburner stages for main engine use. The remaining stage will then supply afterburner flow to the extent of its capacity.

From the pumps fuel is delivered to a Holley hydro-mechanical control unit which meters fuel flow as a function of high pressure compressor speed, high pressure compressor discharge pressure and air inlet total pressure and temperature, along with power lever position. Low pressure spool speed is limited by means of an overriding fly ball governor which bleeds off the compressor discharge total pressure.

The fuel is then directed through a fuel oil heat exchanger, (which is adequate for sea level engine oil cooling but must be supplemented by other coolers for most flight cases), to the 48 fuel nozzles, of which six are in each combustion can. A normal pressurizing and dump valve schedules flow to primary and secondary passages.

Afterburner fuel is also controlled hydro-mechanically as a function of compressor discharge static pressure. Operation is initiated through an electric actuator and a fuel pressure signal from the afterburner fuel control unit automatically selects the afterburner nozzle position.

The basic engine emergency fuel system is actuated through solenoids operating a shuttle valve, and consists essentially of a metering valve with a pressure ~~prop~~ drop proportionate to inlet total pressure.

## ENGINE DRIVEN ACCESSORIES

1. Alternator Constant Speed Drive Unit.

Provision is made on the engine for driving aircraft accessories from the low pressure compression shaft via a pad located at the centre of the air intake. This pad is used to drive an alternator, sufficient power being available for 40 K.V.A. output.

A comprehensive description of the functioning of the electrical system, including the alternator may be found elsewhere, so this section will describe only the drive unit used to maintain a constant speed input to the alternator, the housing, cooling, and anti-icing provisions made in the nose bullet.

A General Electric constant speed drive unit, utilising a ball-piston hydraulic pump and hydraulic motor is mounted directly to the engine pad provided. This unit converts an input speed, variable between 2250 r.p.m. and 7500 r.p.m. to a constant 8000 r.p.m. output, with 1% steady state variation, and up to 5% transient condition variation. Weight of the drive is 62 lb. A flange at the output end accommodates the Lucas-Rotax alternator. Permission to use the engine oil system for this drive has been refused by the engine manufacturer, and we have therefore used a separate oil system for this unit combined with the lubrication system for the accessories gearboxes. A full description will be found later in this section.

To house the alternator and constant speed drive unit, a fairing is mounted separately on the engine pad. A circular inlet at the front admits ram cooling air to the alternator, whilst radially disposed exits allow the cooling air to pass out to the engine intake. A series of ports at the engine pad carry compression air to the forward portion of the fairing, which is made from porous steel. The hot air passes through the skin, and through a number of holes drilled into the alternator cooling duct, to provide anti-icing for the fairing, and the alternator, respectively.

Services to and from the alternator and constant speed drive are carried through two struts to the engine intake fairing.

Access to this area, for any purpose other than visual inspection, is achieved by engine removal only.

2. Accessories Gearboxes

Three pads are provided on the engine high pressure compressor gearbox, intended for use with one hydraulic pump, one generator, and one starter motor. Since the first two drives are inadequate to meet our hydraulic system requirements, the starter pad, which is the centrally disposed drive, has been adapted to suit our needs. An engine input gearbox is bolted to two of the three engine pads, although the input drive is taken from only the central or starter pad. By the use of three spur gears, the output side of this gearbox provides two identical drives, each capable of taking starting torques and each capable of the 200 H.P. output required by the hydraulics pumps. Physical limitations dictate the use of the inboard pad on each engine for accessory drive use, leaving the outboard one free for the starter motor.

A right-angled bevel gearbox, is mounted to the accessory drive pad on the engine input gearbox. A drive shaft connects this gearbox to a similar bevel gearbox which is part of the main accessories gearbox. This drive shaft incorporates universal joints at both ends combined with end-float to accommodate relative movement between engine and gearbox. To facilitate engine removal, these drive shafts are provided with quick disconnect couplings. Shear sections are provided to protect the engine gearbox in the event of main accessory gearbox seizure.

The main accessories gearboxes, driven as described above, are centrally located, side by side in the fuselage between the engine shrouds. Each carries five output drives, two facing aft for the flying control system hydraulic pumps, one facing forward for a spare drive for possible future needs, and one vertical drive to the collector tank fuel booster pump. The lower part of each box is used as the accessories gearbox lubrication oil tank, holding one gallon of oil with provision for pressure filling, and a sight glass for level checking. Both boxes are mounted in a removable panel which attaches to the fuselage frames, with a tie-strut taking fore and aft loads to the main fuselage frame at Station 591.

The vertical drive is connected to a drive shaft driving upwards to a small self-lubricated bevel box, mounted to the drag strut of the inboard engine mount. This box carries an output shaft driving forward to a second bevel box attached to the underside of the collector tank connected to the centrifugal fuel booster pump mounted therein. Since the drive shaft between the two bevel boxes is some 5 feet long, a steady bearing has been incorporated midway along the shaft. All shaft joints in this sub-system are sufficiently flexible to accommodate all airframe deflections, shear sections are provided to protect the gearboxes, and protection against damage due to possible broken shear sections is incorporated at the main gearbox ends of the drive shafts. A disconnect joint is provided in the vertical drive shaft from the main accessory gearbox, to provide a means of isolating the fuel booster pump during gearbox maintenance rotation.

Access for hydraulic pump removal, gearbox servicing and inspection is obtained through two centrally disposed access doors, forward and rearward, respectively, of the main gearboxes.

## 3. Oil System

There are two identical oil systems one for each set of engine driven accessories. Each oil system which, as stated before, supplies oil for the constant speed drive unit operation and for the gearbox drive system lubrication, is a self contained system provided with air and fuel heat exchangers, filter and deaerating tank. The system is pressure filled via a coupling point on the main accessories gearbox.

For engine removal, self sealing - quick disconnect couplings are provided in the pipe lines passing through the shroud which are accessible through the engine access doors.

The sump in the main accessories gearbox acts as a scavenge oil collector tank for the gearboxes, scavenge pumps are provided in these boxes to facilitate this function. These pumps are rated higher than the input oil flow to the gearboxes to ensure that oil will not collect in the gearboxes.

The oil is passed from this sump to the deaerator tank by the main pump via the centrifugal separator. Return oil from the constant speed drive unit is also returned to this separator. From this tank the oil is passed back through the heat exchangers and filter to the drive unit and gearboxes.

The separated air in the tank is passed through a relief valve and vented to the gear section of the main accessory gearbox. This relief valve controls the oil pressure in the system and is set at 30 p.s.i.

On engine starting at low temperature the oil pressure will obviously be high, so the maximum pressure is limited to 200 p.s.i. by a by-pass valve combined with the main pump. Under cold conditions the flow by-passes the heat exchangers to assist in reducing warm-up time. To prevent a high rate of oil flow from the deaerator vent to gearbox the diameter of the piping is reduced over a specified length resulting in approximately no flow for cold oil but capable of passing the maximum air and oil mist flow under normal operating conditions.

The gearboxes and drive unit are interconnected into an air pressurization system supplied with air from an aircraft source at a regulated pressure of 7 p.s.i.g. A relief vent is provided on the main accessories gearbox which assists the regulation of the pressurization system by venting excessive air pressure to atmosphere. A centrifugal thrower is incorporated in this vent to prevent oil vapour being released.

## ENGINE CHANGE PROCEDURE

In order to achieve a rear fuselage structure with as few breaks as possible, it was decided to remove and install engines from the rear of the aircraft, and provide access through the main fuselage only where necessary. Initial investigations indicated that a complete break at station 742 would be required, with the whole of the structure aft of this point being removed for the installation of either engine. However, on re-examination it was decided that the considerable handling problems with such a large single item of structure would inevitably lead to an engine change time in excess of the 30 minutes allowed by AIR 7-4.

For aerodynamic reasons the rear end of the fuselage has been kept as small as possible, consistent with reasonable removal clearances, but it was found that only the lower section of the fuselage prevented the break point from moving rearwards to Station 803. We therefore made 803 the complete break station and made the lower portion of fuselage between 742 and 803 into a hinge-mounted, detachable panel under each engine. The structure aft of 803 consists of three separate items, one fairing shroud around each afterburner, and one central "sting".

Prior to engine removal operations, in order to ensure that ground equipment loads are not carried to those parts of the aircraft structure not capable of taking them, the whole aircraft must be jacked through the main jacking points, to a set position.

To prepare the rear end of the aircraft for engine removal it is necessary to:-

(a) Remove the central "sting" by releasing 4 toggle latches.

(b) Remove the rear fuselage fairing concerned by releasing 4 toggle latches.

(c) Remove the lower hinged panel (742-803) by extracting two hinge pins.

When this has been done, two removal rails must be inserted into the engine tunnel, one on either side, engaging on the support brackets provided inside the tunnel. Clearances between engine and airframe are small, therefore guides have been provided over the first 5 feet of travel. The rails are 20 feet long, weighing 120 lbs. each, and when in position are locked by pins to the rear fuselage.

A special engine removal trolley, carrying its own support rails which will mate exactly with those now in the aircraft must now be positioned behind the aircraft, and the two sets of rails pinned together. A "push-pull" rod in the centre of the stand may now be connected to a fitting provided at the bottom of the engine afterburner diffuser flange.

Whilst this procedure is being carried out, other members of the crew will open all access panels to the engine and mounts. These are:-

1. Main engine access door forward.
2. Main engine access door rear.
3. Central hydraulics door, ahead of Sta. 581.
4. Outboard front mount access door.
5. Centre rear mount access door (in top of wing).
6. Rear outboard mount access door and shroud door.
7. Rear inboard mount access door (on aircraft centre of fuselage).
8. Air conditioning connection access door (outboard fuselage).
9. Bleed Valve overboard connection (outboard fuselage).

Access to all electrical cables and plubing connections to the engine is obtained through doors 1 & 2. These should now be disconnected. Because of the limited space available, it will be necessary to remove completely a section of the main fuel inlet line. The lower firewall member must be lowered, and retained. When all pipes and cables have been disconnected, the mounts may be detached, ensuring that the rear outboard mount is removed <u>before</u> the rear inboard one. This operation will lower the engine to the assembly rails, and the engine may now be winched onto the removal trolley, whence it will be replaced with the change engine via overhead, or mobile crane, and the foregoing procedure reversed to install this engine.

## ENGINE STARTING

The engine is started by means of a torque application at a standard A.N.D. pad, under the waist of the engine. A special gearbox has been added to provide an alternate pad for use by the accessories gearbox, since no other pad with the required torque carrying capacity exists on the engine.

The drive is connected mechanically to the high pressure compressor, the low pressure spool being driven pneumatically there from.

The starter unit used is an AiResearch A.T.S. 100-8 Air Turbine unit, which weighs 21½ lb. and is capable of supplying the maximum torque permitted by the engine drive, when supplied with the appropriate air source.

Access to the unit is through the main engine service door, which carries a smaller door to permit assembly of the 3½" air hose directly to the starter air inlet. This smaller door is designed to automatically close as soon as the hose is disconnected. A Wiggins lanyard-operated automatic coupling is used to meet the break-away disconnect requirement. When the aircraft taxies away from the starting-point the lanyard, attached to a fixed point on the ground, triggers a spring in the coupling, which is thereby ejected from the starter. As soon as the coupling is cleared the door will close and lock.

Incorporated in the starter motor are two centrifugal switches, the first one operating at 700 r.p.m. to switch on the ignition system, and the second one at 3000 r.p.m. to switch off the ignition and also to shut-off the supply of compressed air to the unit. A light in the cockpit indicates "IGNITION ON", and informs the pilot of the time to advance his throttle from "OFF" to "IDLE".

Starting times will be almost entirely dependent on the ground power unit used. Present proposals for a "Readiness Shelter" will include a power source capable of a 20 second start, whilst the mobile starting unit envisaged will be capable of providing a start within 25 to 35 seconds, depending on climatic conditions and altitude at the base.

A report was issued 18 months ago outlining Avro's reasons for the adoption of the present starter system. These basic reasons still justify the fitment on the aircraft of an air turbine unit. Installed weight, adequate starting torque, simplicity of the airborne mechanism, and consequent reliability are features which have not been bettered by any other system, on known data, with the sole exception that an improvement of between 2 and 3 seconds in starting time could be achieved by a fuel-air turbine, with what we consider to be exorbitant penalties in all other desirable qualities.

In the initial design stages, efforts were made to achieve a completely automatic start, involving a sequence of operations only, with no significance whatever being attached to timing. Objections were raised by Pratt & Whitney to the proposed scheme, on the grounds that hot starts would result from the initiation of ignition prior to the introduction of fuel into the combustion chamber. As the engine fuel system incorporates a pressurising valve, which will delay the introduction of starting fuel until the desired pressure is attained, it is difficult to understand any technical arguments against such a system, however, presumably to standardise starting techniques, and to avoid the necessity of a small development programme with an automatic start as the end result, Pratt & Whitney have insisted that manual advance of the throttle lever be made at a fixed speed of the high pressure compressor.

The starting procedure is, therefore as follows:

1. Master switch - "ON"

2. Starter switch - "ON"

3. When the ignition light comes on, advance throttle from "OFF" to "IDLE".

4. When the ignition light is extinguished, the starter air supply is automatically cut-off and the engine accelerates to "IDLE".

5. Observation of jet-pipe temperature gauge and/or the thrust indicator will now indicate the state of the engine.