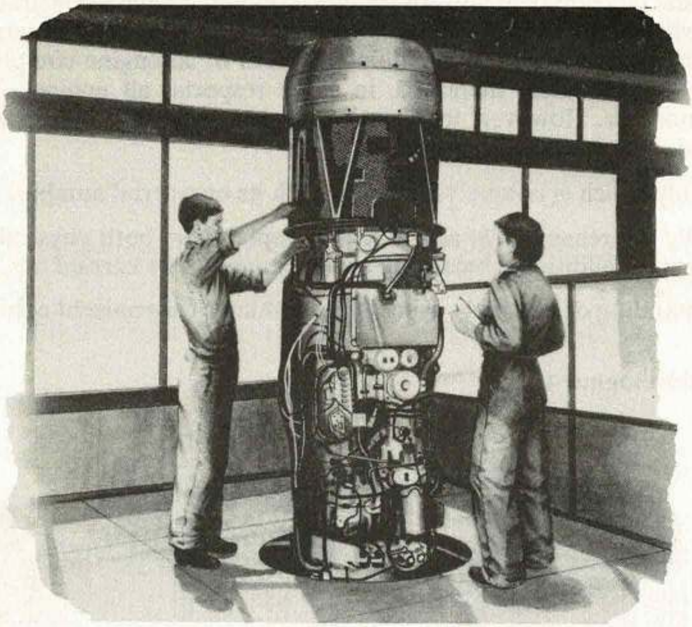
CHAPTER 1
MODULAR ENGINE CONSTRUCTION



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Introduction

1. Until recent years the Service maintenance policy for all aircraft engines was one of fixed life. An engine, when initially introduced into service, was given a conservative life in flying hours to overhaul, and that life was increased as the engine proved its reliability. When it had reached life expiry, or developed a defect in any part of the engine other than externally mounted components, it was removed from the airframe and returned to the manufacturers for overhaul or repair. The RAF carried out few repairs on aircraft engines, and facilities were limited.

2. To support such a maintenance policy a considerable number of spare engines were required, to compensate for those being overhauled or repaired. But at that time, the cost of engines was low compared to the present day and provisioning reserves were very generous.

3. However, there was a growing awareness by both engine manufacturers and aircraft operators in general, that with certain fundamental design changes, engine maintenance could be made far easier, and less costly. Therefore, in the 1960's a change in gas turbine engine construction began to evolve. An aero engine manufacturer designed an engine that could be dismantled into two distinct sections (later to be known as modules); one was the compressor section, and the other the combustion and turbine system. The design proved to be successful, and pointed the direction in which further developments would be made. In the United Kingdom the developments culminated with the introduction of the Rolls Royce RB211 engine, which is comprised of seven modules, and has proved to be most successful in service.

4. The first fully modular engine that entered service with the RAF was the Rolls Royce Turbomeca Adour, which has twelve modules. The Adour was followed by the RB199 which has 16 modules, and the RB211. These engines are currently in use, and have a long Service life ahead of them.

Engine Module – Definition

5. In order to appreciate the development and advantages of modular engine construction it should first of all be established what the term 'Engine Module' means. In general terms, an engine module can be described as a major self-contained section of an engine comprising a number of components or sub-modules; therefore, in some respects, all engines can be considered to be partially modular. However, for Service and maintenance purposes a more specific definition is required, hence an engine module is:

- A complete major assembly which is uniquely identified with its own serial number.
- An assembly which is fully interchangeable and is readily replaceable both physically and functionally, without requiring additional balancing or adjustment to be carried out.
- Designed for ease of dismantling or assembly using the minimum of specialized equipment and tools.
- Capable of separate life development.

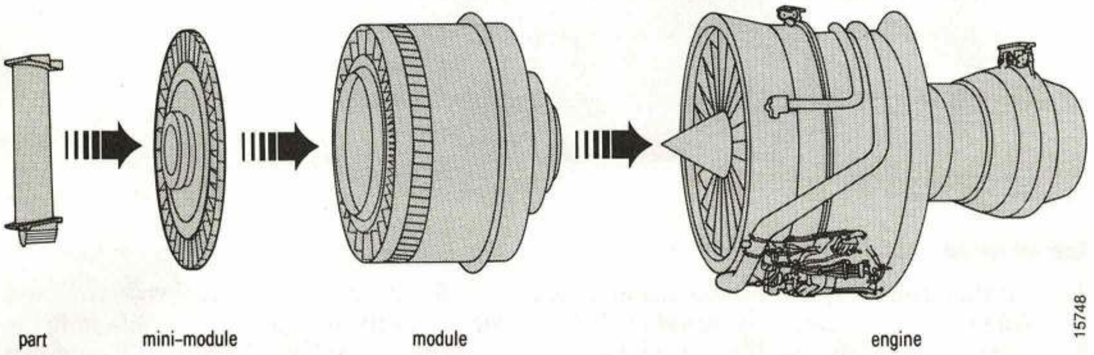


Fig 7.1.1 Engine module

Modular Engine Development

6. **Conventional non-modular engines.** Maintenance considerations are not given a high priority in the design of conventional non-modular engines. They require extensive dismantling to be carried out to gain access to internal engine components, consequently maintenance costs in terms of both man hours and spares are very high.

7. On some non-modular engines, certain major components which operate at very high temperatures are now replaced at unit level. However, when their full service life has expired, all non-modular engines are returned to the manufacturers for overhaul.

8. **Semi or partially modular engines.** Partially modular engines were designed on the conventional non-modular principle, and were in service prior to the advent of modular maintenance. They were managed and maintained under a fixed life policy, and overhauled at the manufacturers when they became life expired.

9. However, when the advantages of modular maintenance became apparent, the Service decided to revise the maintenance policy for certain non-modular engines, to a servicing pattern based upon modular maintenance. They were then designated semi, or partially modular engines. The change in maintenance policy was achieved in consultation with the manufacturers, during which, it was decided:

- How many modules the engine should be divided into.
- The points at which the modules should be either separated or disconnected from each other.
- To establish the life of those modules that had not previously been lifed.

10. Following the changes, and at the appropriate time, the units concerned were equipped and the personnel trained for the new maintenance policy. Module repairs are carried out if they are within the units capability and if they are cost effective.

11. There is very little opportunity for 'on condition' maintenance on semi-modular engines, since there are no designated access points for internal boroscope inspections.

12. **Fully modular engines.** Fully modular engines are designed to a modular specification, with engine maintenance a major design consideration. They include the following features:

- They are built up wholly of distinct engine modules.
- Similar modules are fully interchangeable between similar engines.
- The engine can meet performance specifications following module or multi-module replacement, without the need for performance measurement, other than routine running to prove correct engine assembly.

13. The fully modular engine design also includes the provision of access ports within the casings of critical engine modules, to enable internal inspections to be carried out whilst the engine is in the aircraft. Such inspections are necessary for an effective 'on condition' maintenance policy to be operated. Magnetic chip detectors are located at selected points in the oil system as aids to engine health monitoring. External components are mounted for ease of access, and the engine designed for ease of removal from, and installation into the aircraft.

Advantages and Disadvantages of Modular Construction and Maintenance

14. There are many advantages and some disadvantages, arising from modular construction and maintenance. Those can be summarised as follows:

Modular Construction – Advantages

- The engine design and construction enables 'In depth' maintenance to be carried out at operational units.
- Modules can be replaced quickly with a minimum of disturbance to the remainder of the engine.
- Similar modules are freely interchangeable between similar engines.
- Module lives can be developed independently from recorded information based upon operational experience.
- Modules are easy and cheap to transport, and to store.

Modular Maintenance – Advantages

- Increased Service participation in engine maintenance which leads to:
  - Greater Service expertise.
  - Decreased turn round times for repairs which contributes to greater operational readiness.
- The engine design enables individual modules to be maintained 'on condition'.
- The Service has greater overall control of engine fleets.
- Fewer spare engines are required, leading to lower inventory costs.
- Dispersed resources and repair facilities.
- Less dependence on industry.

Modular Construction and Maintenance – Disadvantages

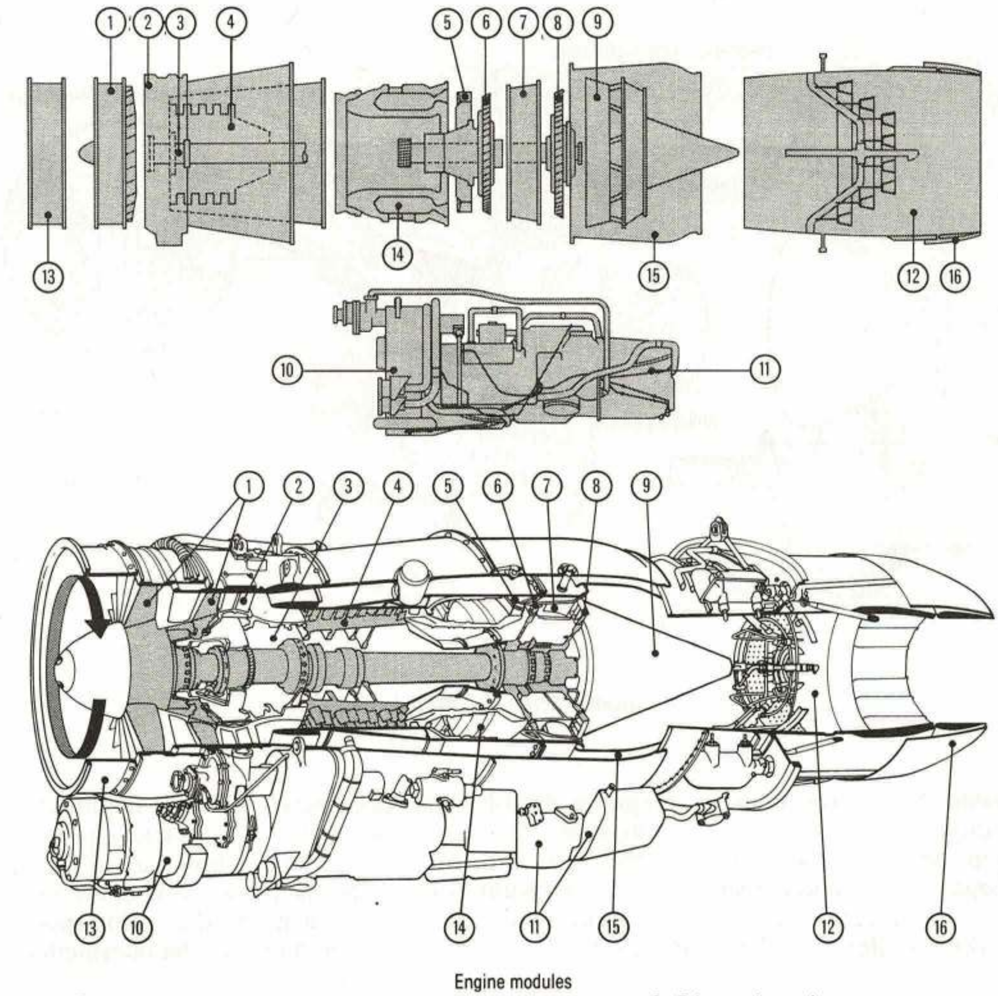
- High capital outlay on equipment, facilities, and training.
- Increased RAF establishment of technical and supporting personnel.
- Industry is deprived of some Service feedback of information.

Typical Fully Modular Engine

15. The fully modular engine illustrated by Fig 7.1.2 is an axial flow turbofan engine. It has a two stage low pressure (LP) compressor and a five stage high pressure (HP) compressor, each compressor being driven by a separate turbine through co-axial shafts. In the design shown, the LP shaft passes through the HP shaft. The engine has a fully annular combustion system, a by-pass duct, an exhaust system and an afterburner. The engine consists of 12 modules, and a number of major non-modular assemblies, each capable of being removed and maintained as a separate unit. All rotating modules are pre-balanced. The 12 modules and non-modular assemblies are:

- Air intake fairing.
- Module M–01. LP compressor, stages 1 and 2 rotors, stage 1 stators.
- Module M–02. LP compressor stage 2 stators and static seals.
- Module M–03. Intermediate casing, internal gearbox, HP compressor shafts and bearings.
- Module M–04. HP compressor assembly, drum, blades and stators.
- Combustion casings and liners.
- Module M–05. HP Nozzle guide vanes.
- Module M–06. HP turbine rotor.
- Module M–07. LP nozzle guide vanes, casing and bearings.
- Module M–08. LP turbine rotor.
- Module M–09. Exhaust mixer and cone.

- Module M–10. High speed gearbox.
- Module M–11. Oil tank, cooler, and filter.
- Module M–12. Afterburner vapour gutter and manifold.
- Exhaust collector.
- By-pass duct.



Engine modules

1. LP compressor.
2. LP compressor stage 2 stators.
3. Intermediate casing and internal gearbox.
4. HP compressor assembly
5. HP nozzle guide vanes.
6. HP Turbine rotor
7. LP nozzle guide vanes.
8. LP turbine.
9. Exhaust mixer and cone.
10. High speed gearbox.
11. Oil tank, cooler and filter.
12. After burner – vapour gutter and manifold.

Major non-modular assemblies

13. Air intake fairing. 14. Combustion casing and liners. 15. By-pass duct. 16. Exhaust collector.

15749

Fig 7.1.2 Engine modules and non-modular assemblies

16. **The air intake fairing.** The air intake fairing is interposed between the aircraft air intake and the LP compressor (Fig 7.1.3). The grooved front flange carries an annular ring, which forms a seal with the air intake. The rear flange is bolted to the LP compressor.

17. **Module M–01.** The LP compressor stages 1 and 2 rotor blades, the stage 1 stator vanes and the rotor shaft are housed in the LP compressor front casing (Fig 7.1.3). A curvic coupling (ref para 37) fitted to the stage 1 rotor disc transmits the drive to the LP compressor from the LP turbine. Located and supported inside the LP shaft is an anti-icing tube, to the front of which is attached an air inlet spinner. The rear flange of the LP casing is bolted to the front flange of the intermediate casing.

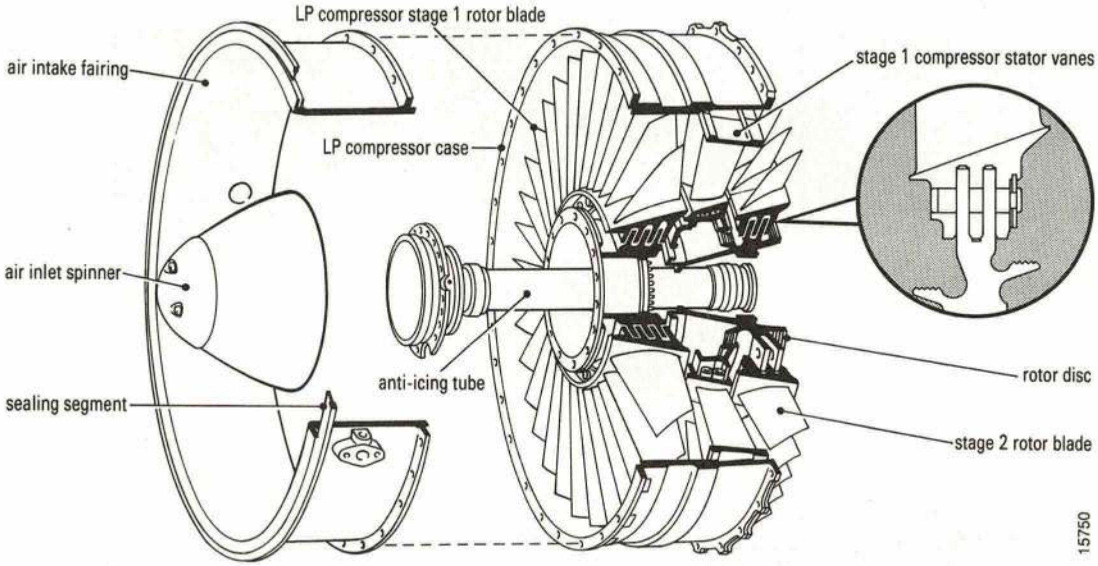


Fig 7.1.3 Air intake fairing and Module M–01

18. **Module M–02.** The module comprises the LP compressor stage 2 stators mounted in tandem and a static seal (Fig 7.1.4). The static seal is bolted to the base of the leading row of vanes, and forms an air seal with the rotating seal on the rear of the LP compressor. The two rings of stator vanes, and the seal, are retained within a case that fits into a recess in the front diameter of the intermediate case. The case is retained by a front flange that is interposed between the rear flange of the LP compressor casing and the front flange of the intermediate casing.

19. **Module M–03.** The intermediate casing houses the internal gear box and HP compressor stub/intershaft and bearings (Fig 7.1.4). Also contained within the casing is a circumferential airfoil fairing that divides the airflow between the HP Compressor and the by-pass duct. Six cast struts support the internal gear box, the case of which carries the bearings that support both the LP and HP shafts. The internal gear box also houses the bevel gears that transmit the drive from the HP compressor shaft to the quill shaft that in turn drives the high speed gear box. The intermediate case also carries the front engine mounts that transmit the engine thrust to the airframe.

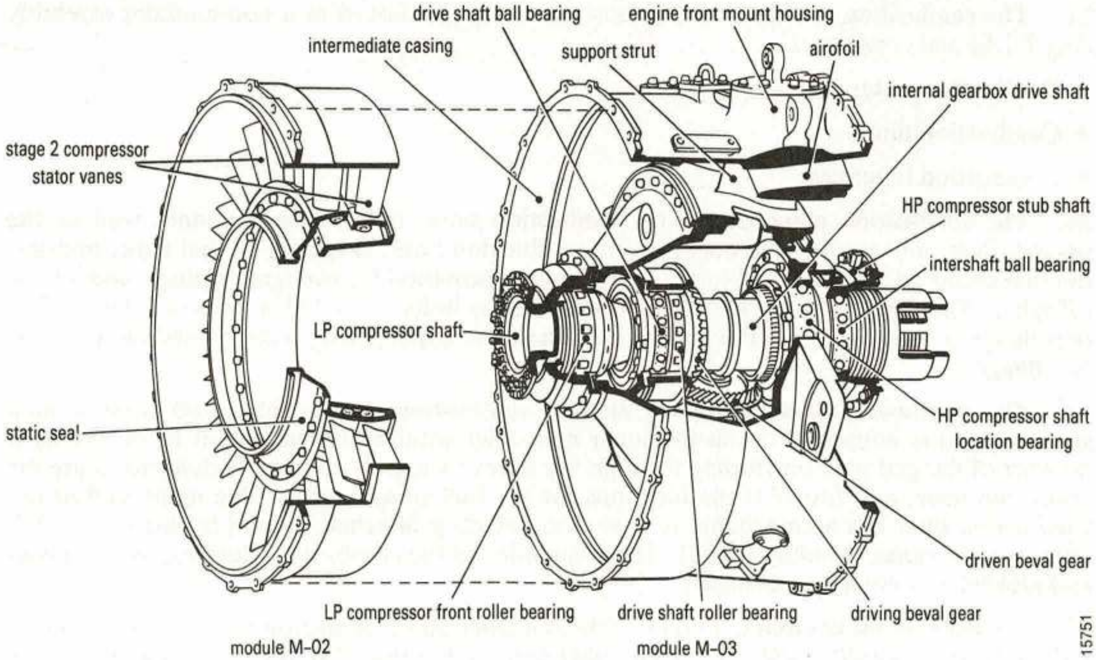


Fig 7.1.4 Module M–02 and Module M–03

20. **Module M–04.** The HP compressor module M–04 comprises two assemblies, the HP compressor rotor, and the HP compressor case and vanes (Fig 7.1.5). The HP compressor rotor consists of five machined discs welded together to form the rotor drum. The five stages of rotor blades are keyed and locked onto the drum. The drum is connected to the HP stub shaft at the front, and driven by the HP turbine shaft at the rear. Both front and rear connections are made with curvic couplings. The case carries four stages of stator vanes, it also has an outer flange to which the combustion outlet case is bolted.

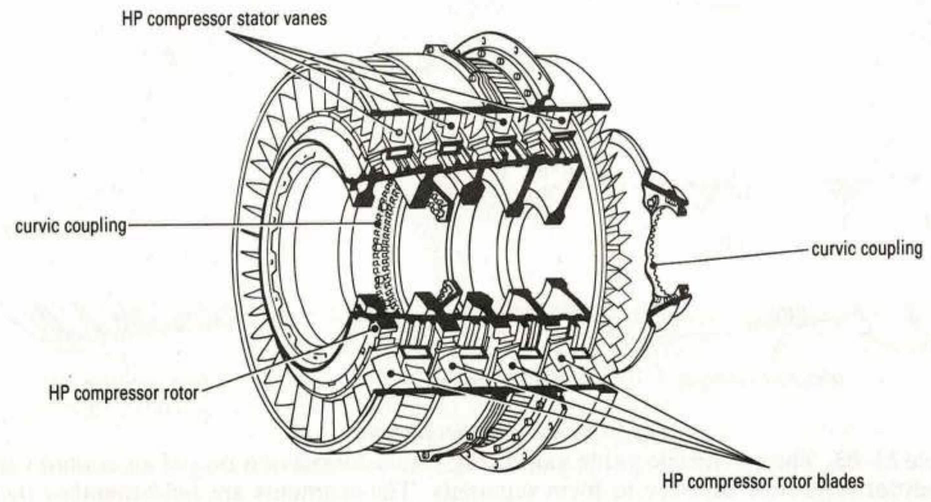


Fig 7.1.5 Module M–04

21. **The combustion section.** The combustion section is classed as a non-modular assembly (Fig 7.1.6) and consists of:

- Combustion outer case
- Combustion liner
- Combustion inner case

22. **The combustion outer case.** The combustion outer case forms the inner wall of the by-pass duct, and locates and encloses the combustion liner. It carries 18 fuel spray nozzles, the fuel manifold and fuel feed tubes. It also makes provision for two ignitor plugs, and hot air off-takes. The front flange of the casing is attached by bolts to the HP compressor flange. The rear flange is bolted to the HP nozzle guide vane case, a spacer ring is interposed between the two flanges.

23. **The combustion liner.** The fully annular combustion liner is fabricated from welded sections, and is housed between the inner and outer combustion casings; it is located by a number of flanged pins protruding through the outer casing. A removable deflector plate fits inside the liner, and provides the locations for the fuel spray nozzles. The inner wall of the combustion liner has a detachable rear section, which is attached to, and is part of, the HP nozzle guide vanes (Module M–05). The remainder of the combustion liner can be removed and refitted as a complete assembly.

24. **Combustion inner casing.** This consists of a front and rear section which form the inner wall of the combustion system. The front inner casing has a ring of vanes around the front of its outer surface (the HP compressor outlet guide vanes), which forms the inlet to the combustion liner. The casing is retained by a front flange, which bolts to an internal flange on the outer casing. The rear section of the inner liner is bolted to, and becomes part of the HP nozzle guide vane module. The front and rear inner casings are bolted together with an adjusting spacer ring between them.

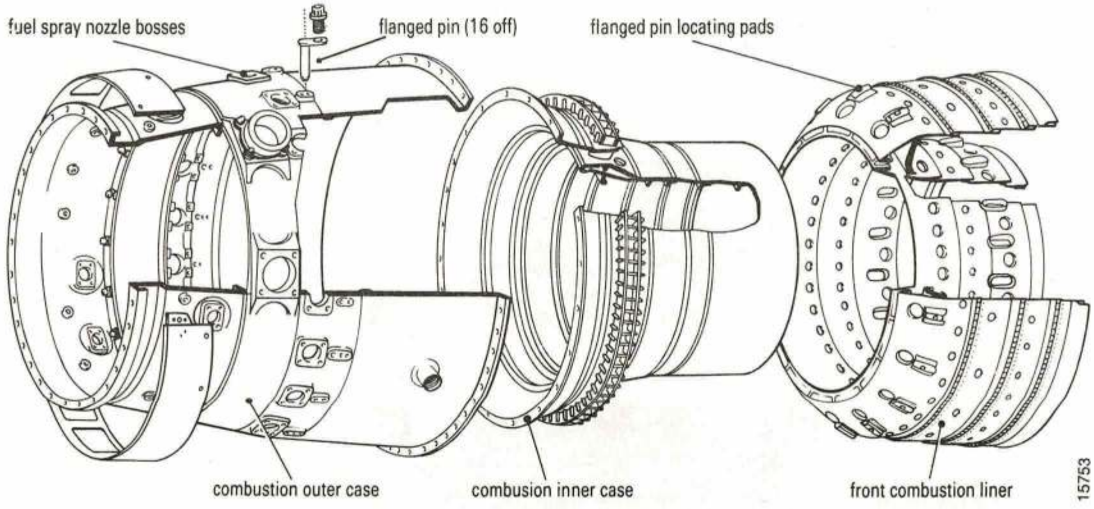


Fig 7.1.6 Combustion section

25. **Module M–05.** The HP nozzle guide vanes (Fig 7.1.7) consist of a ring of air cooled vanes welded together in groups of three to form segments. The segments are held together by an HP turbine front air seal and an outer retaining ring to form a circular nozzle. The adjusting spacers between the abutting flanges of the HP nozzle guide vanes, and the outer and inner

combustion casings, are supplied in various sizes. These enable the HP nozzle guide vanes to be adjusted either forwards or rearwards, to obtain the necessary running clearance between the HP nozzle guide vanes and the HP turbine rotor.

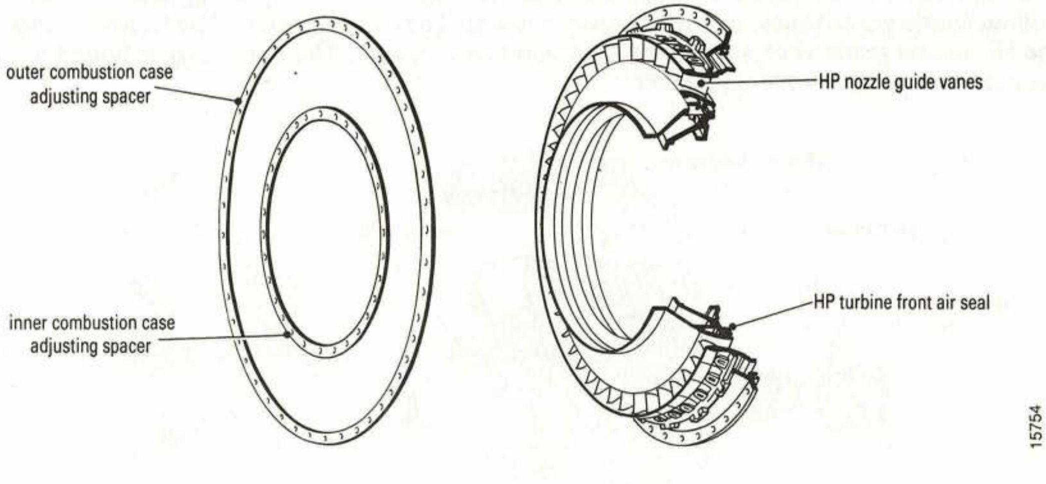


Fig 7.1.7 Module M–05

26. **Module M–06.** The HP turbine rotor assembly (Fig 7.1.8) consists of a rotor shaft, a stub shaft, a disc and blades. The blades are air cooled, and attached to the disc by fir tree roots and locking plates. The turbine disc has a cooling air labyrinth seal machined on its front face, and two further seals on the rear face. A curvic coupling on the front face of the disc mates with a corresponding coupling on the aft end of the rotor shaft. The stub shaft provides an inner location for the main turbine roller bearing, and is connected to the rear end of the turbine shaft by a curvic coupling.

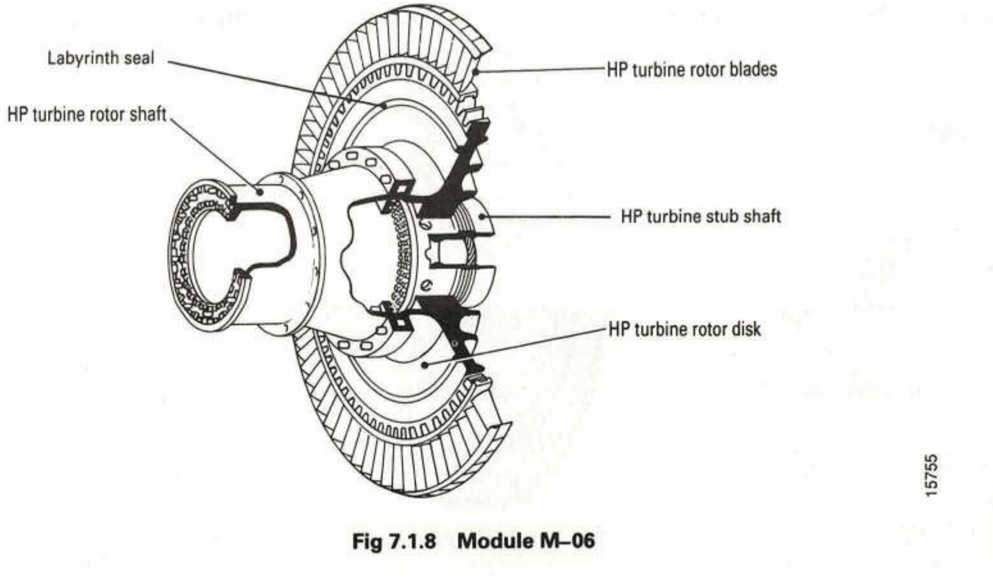


Fig 7.1.8 Module M–06

27. **Module M–07.** The LP nozzle guide vane casing (Fig 7.1.9) incorporates the turbine bearing housing. The nozzle guide vanes are located and contained within the outer casing. Flanges and panels secured to the front and rear of the vane platforms form the housing for the HP turbine and LP turbine roller bearings. Pressure and return oil for lubrication, and cooling and vent air, are conveyed in tubes that pass through the outside casing, and through the hollow nozzle guide vanes, into the bearing housing. The casing is secured by its front flange to the HP nozzle guide vane and combustion outer case flanges. The rear flange is bolted to and supports the exhaust cone and mixer.

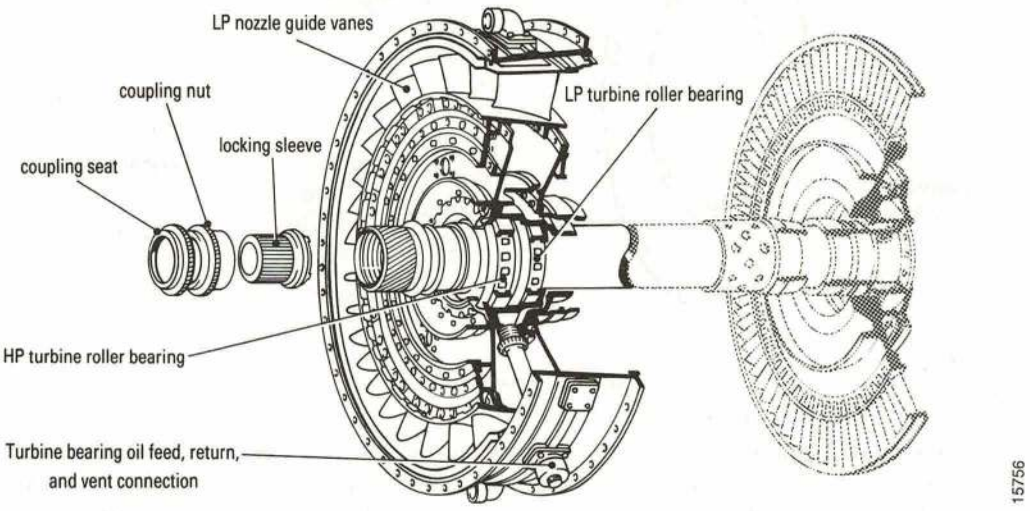


Fig 7.1.9 Module M–07

28. **Module M–08.** The LP turbine and rotor assembly (Fig 7.1.10) consists of a shaft, disc and blades. The blades are attached to the disc by fir tree roots and locking plates, and the disc is secured to the shaft through a curvic coupling on its rear face. The LP turbine shaft, which has a male helical spline on its front end, passes through the HP turbine shaft, and the external

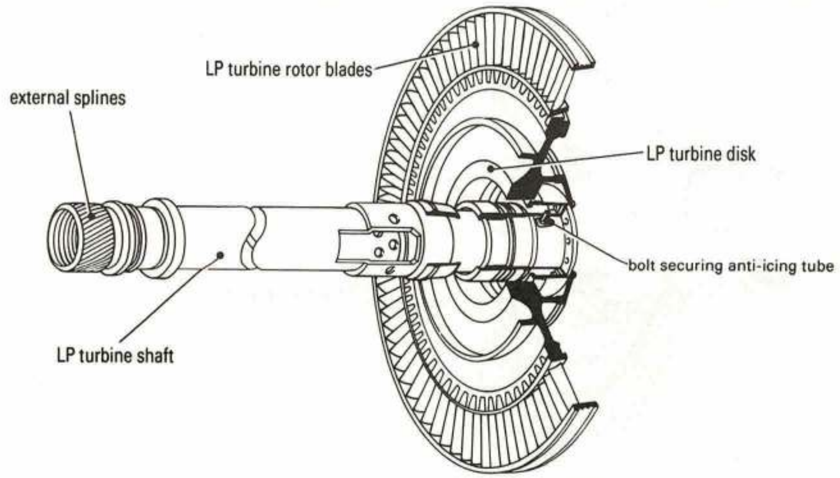


Fig 7.1.10 Module M–08

splines engage with mating splines on the LP compressor shaft. Adjustment is made through a coupling nut, and the assembly is secured by a locking sleeve. An anti-icing tube secured by bolts to the rear end of the turbine shaft, passes forward through the shaft and retains the locking sleeve in position.

29. **Module M–09.** The exhaust mixer and cone (Fig 7.1.11) is a fabricated assembly consisting of two concentric cases, connected by seven 'A' frame struts. The inner case front flange is bolted to the rear flange of the HP nozzle guide vanes, and the rear flange is bolted to the exhaust diffuser case. The exhaust cone is secured to the exhaust mixer by tubes or hollow spokes which pass through airofoil struts on the inner case. The spokes are attached at their upper end to the front sole plates of the 'A' frame struts. Air scoops protruding into the by-pass air flow, duct cooling air through the hollow spokes into the exhaust cone.

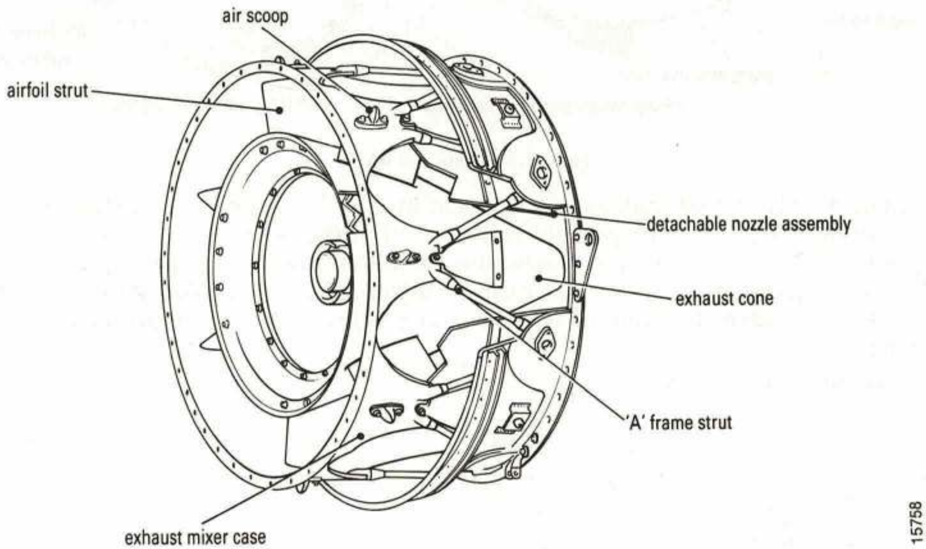


Fig 7.1.11 Module M–09

30. **Module M–10.** The high speed gear box (Fig 7.1.12) is mounted on the lower half of the intermediate case. It is located by dowels, and retained in position by three mounting link assemblies which attach to lugs on the gear box. The gear box provides drives for:

- Hydraulic pump
- Fuel pump
- Oil pumps
- Alternator
- Starter motor
- Tachometer generator
- After burner fuel control

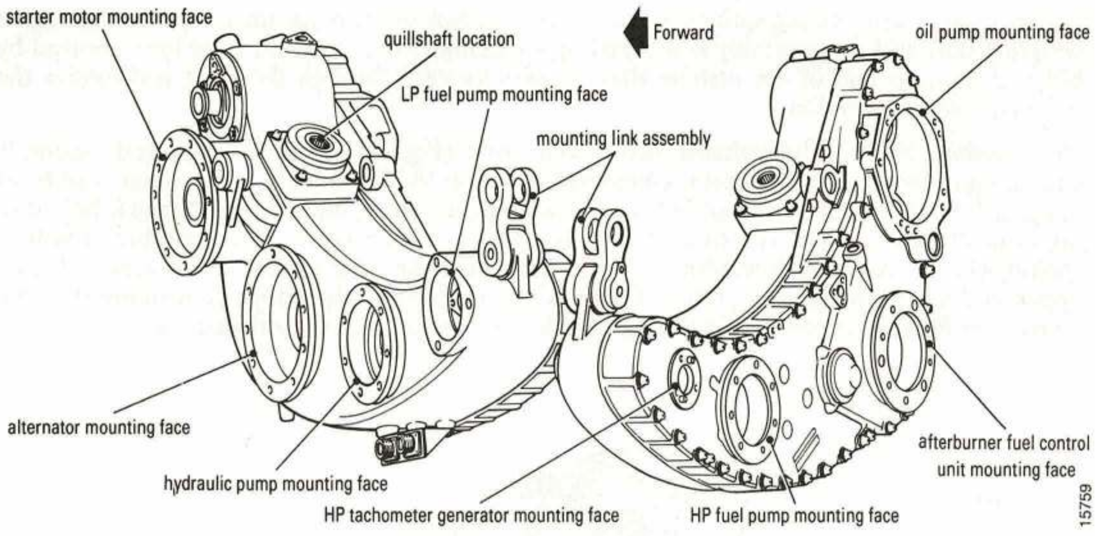


Fig 7.1.12 Module M–10

31. **Module M–11.** The oil tank and filter assembly (Fig 7.1.13) is a casting that is suspended on the underside of the rear by-pass duct. The front of the assembly is supported by a pillar passing through the by-pass duct to a mounting on the turbine casing. Two links at the rear of the oil tank attach to brackets on the exhaust mixer. The fuel cooled oil cooler, the after burner fuel filter, and the pressure oil filter, are housed in a block which forms the front wall of the oil tank.

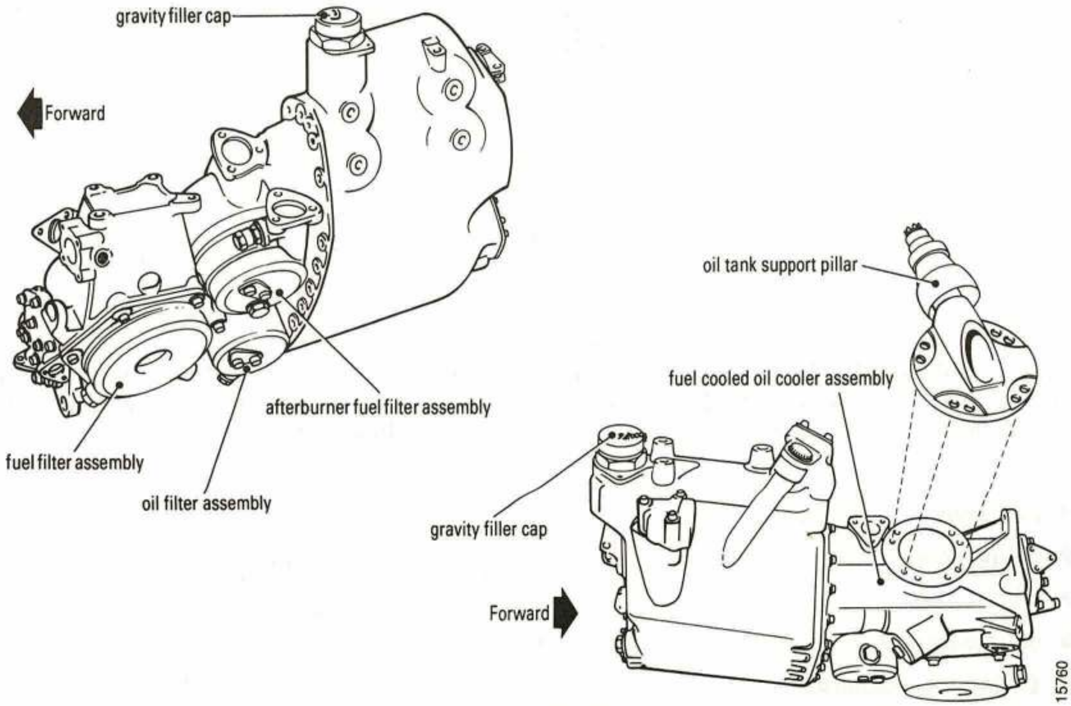


Fig 7.1.13 Module M–11

32. **The accessories pack.** The accessories pack facilitates the removal and fitment of modules M–10 and M–11, the engine Fuel Control Unit and associated interconnecting tubing, as one major assembly, to gain access to the remainder of the engine.

33. **Module M–12.** The after burner vapour gutter and manifold (Fig 7.1.14) are mounted on four radial support tubes which are attached to the diffuser case. The four blunt nosed vee shaped vapour gutters are attached by links to the rear of the radial support tubes, the largest gutter being foremost. The fuel spray manifold assembly is in the form of circular rings of tubing that are situated upstream of the vapour gutters, and mounted on the rear side of the support tubes. They are fed with fuel through internal drillings in the two horizontal support tubes. Two catalytic ignitors are contained in housings between the two inner vapour gutters.

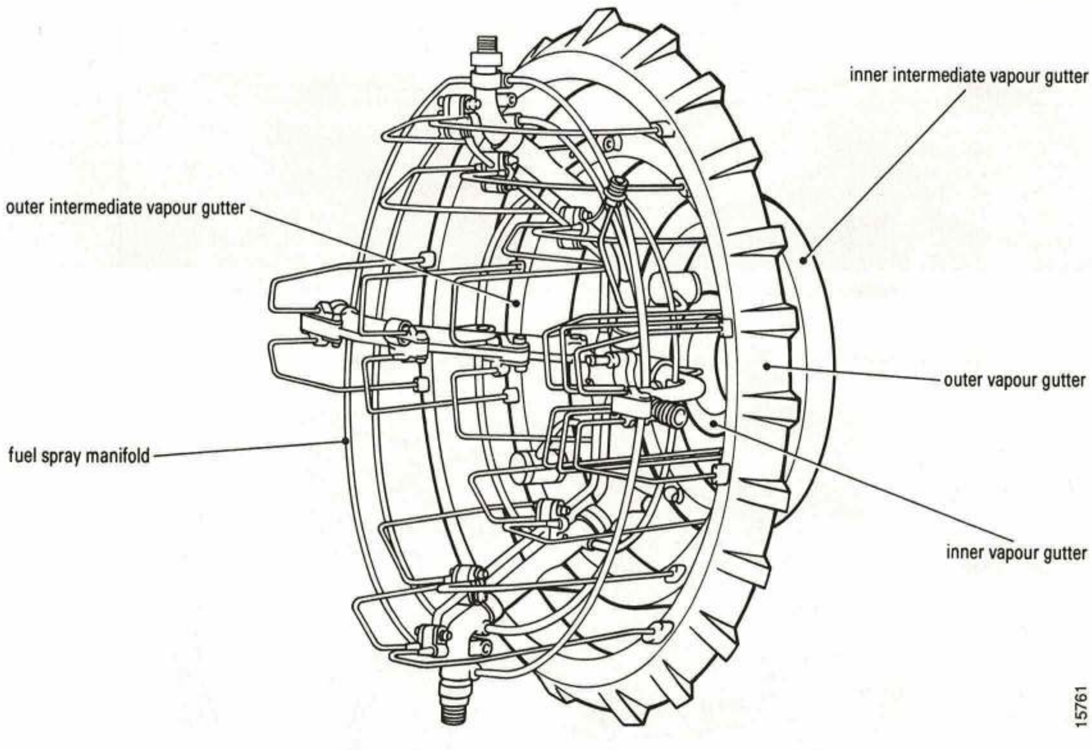


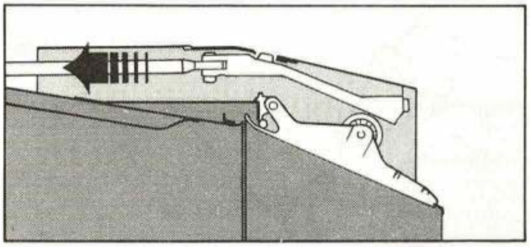
Fig 7.1.14 Module M–12

34. **The exhaust collector.** The exhaust collector (Fig 7.1.15) consists of the following components:

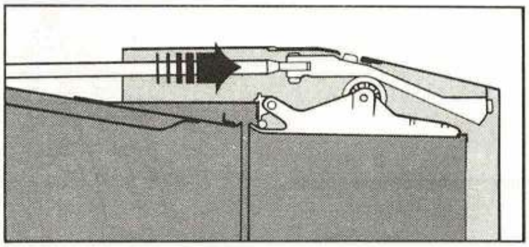
- Diffuser case
- Exhaust collector case
- After burner vapour gutter and manifold
- Variable area final nozzle
- Nozzle actuating components

The diffuser case is a forged circular casing that secures the after burner vapour gutter and fuel spray manifold, and the four rams (operated by HP fuel) that actuate the variable nozzle, it also makes provision for the engine rear mounting. Its front flange is secured to the exhaust mixer case, and the rear flange supports the exhaust collector case.

35. The exhaust collector case is a fabricated casing divergent at the front, and convergent at the rear. The variable nozzle segments are attached to the rear of the duct and consists of 16 overlapping segments, eight of which are active segments, and the remainder sealing segments. The exhaust collector case has a fuel shield mounted on its inside to prevent fuel from reaching the collector case wall, it also has a fuel drain valve to drain fuel from the casing, if, during the starting cycle the engine fails to start. The exhaust collector is surrounded by a dimpled stainless steel heat insulating blanket.



nozzle fully closed



nozzle fully open

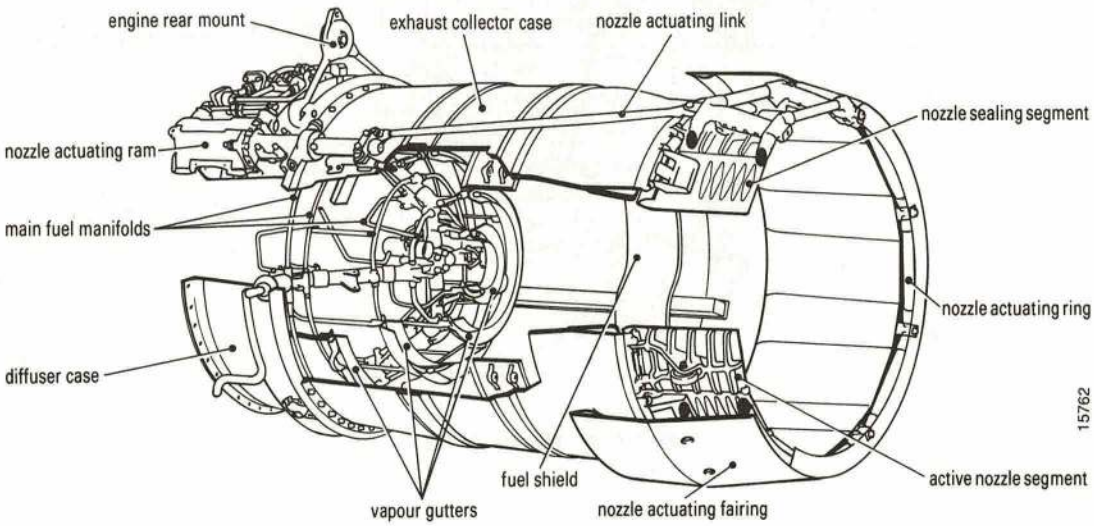


Fig 7.1.15 After-burner exhaust collector and variable nozzle

36. The by-pass duct (Fig 7.1.16) consists of two circular casings that enclose the engine from the compressor, or intermediate case, to the exhaust mixer. The casings are bolted together through mating flanges. The front section is bolted to the intermediate case rear flange. The aft section of the duct has a hardened sealing face riveted to the casing rear end, which mates with an expanding seal located on the exhaust mixer front face. This allows for freedom of expansion, and prevents leakage of air from the by-pass duct. Both front and rear sections have access ports for various engine and aircraft services.

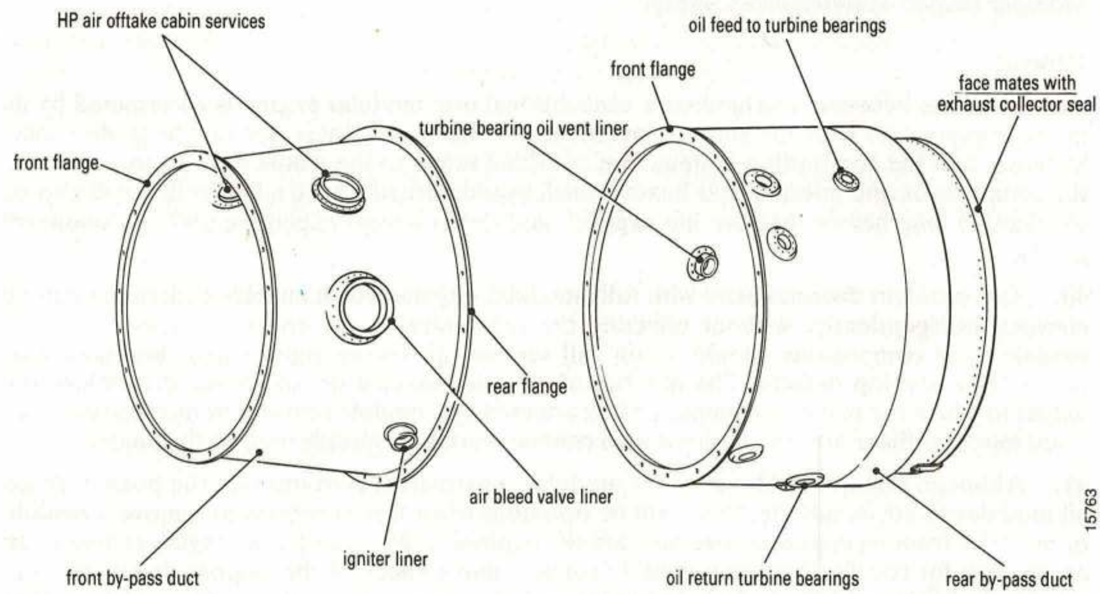


Fig 7.1.16 By-pass duct

The Curvic Coupling

37. The curvic coupling Fig 7.1.17 is used on some modular engines for coupling together heavily loaded rotating assemblies and shafts. Each half of the coupling has two rows of specially shaped teeth which, when meshed, ensure consistent accuracy of alignment. This eliminates the need for rebalancing the engine after module changes, enabling modules with rotating components to be changed in the field. An offset arrangement of coupling bolt holes, or dowels, ensure that couplings only mate in one position.

38. When modules with curvic couplings are removed from an engine, the special blanks that are provided should be fitted to the coupling faces to keep them free from damage. Cleanliness is essential, and the slightest damage, if undetected, can lead to engine vibration.

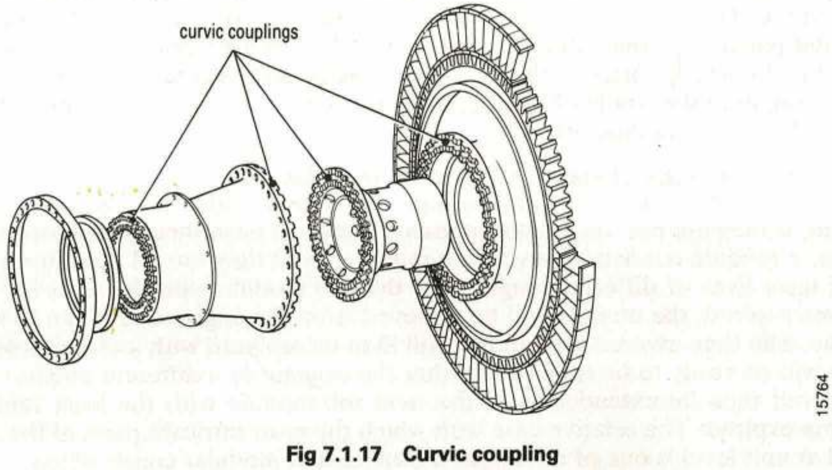


Fig 7.1.17 Curvic coupling

Modular Engine Maintenance Concept

General

39. The time between overhaul on a conventional non-modular engine is determined by its major components with the shortest overhaul life. Invariably these are nozzle guide vanes, turbines, and the combustion system. But overhaul refers to the whole engine, consequently the compressors and internal gear boxes, which would normally have a longer life, will also be overhauled long before they are life expired, and this is a most expensive and uneconomical practice.

40. This problem does not arise with fully modular engines which enables each module to be changed independently, without effecting the remainder of the engine. Consequently, all modules and components should attain full service life before replacement becomes due, unless they develop defects. The number of modules making up an engine determines the extent to which the rest of the engine will be affected by a module removal or rectification. The more modules there are, the easier it is to confine work to a specific area of the engine.

41. Although one of the objectives of modular construction is to increase the possibility for all modules to attain full life, there will be occasions when it is expedient to remove a module or modules from an engine before they are life expired. If for example an engine arrives in an engine bay for rectification, or a module change, and a check of the engines documentation reveals that there is only a small percentage of life remaining on one or more of the other modules, it then becomes cost effective to forfeit the remaining life and change the module(s).

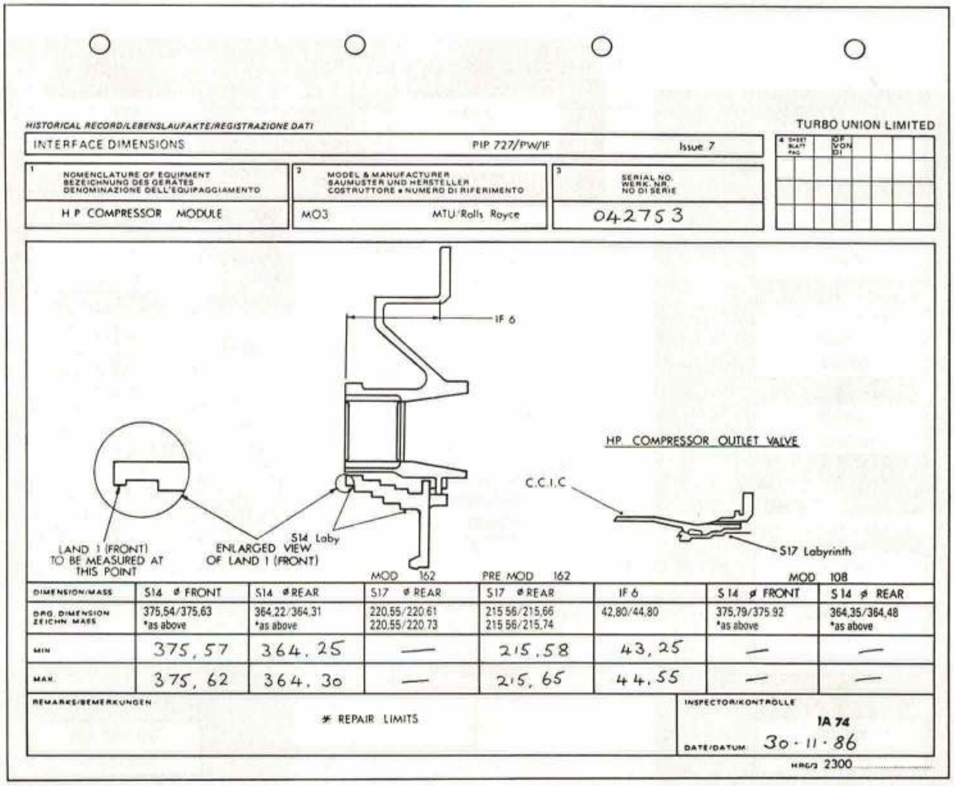
Modular Engine Maintenance

42. **Module removal.** The amount of work required to remove a particular module from an engine will depend upon its position within the engines configuration. For example, on some engines, Modules M–01 or M–02 (LP compressor modules) can be removed or replaced without disturbing the remainder of the engine, and with the engine mounted in the stand in the horizontal position. However, if any of the other modules have to be removed, or if the engine requires complete disassembly, it is turned to the vertical position (LP compressor at the bottom) and is mounted on a build stool. Disassembly commences at the top or rear of the engine, with the removal of the exhaust system and turbine modules. It then progresses downwards, each module being disconnected and removed in its turn as it becomes accessible until the compressor case (Module M–03) is reached, it is this module that carries the main engine mountings which support the engine in the build stand in both the horizontal, and vertical positions. Therefore at this point the engine must be remounted in the build stand in the horizontal position so that Modules M–01 and M–02 can be disconnected and removed, leaving Module M–03 supported in the stand. The engine is then completely disassembled into modules. Throughout the whole of the foregoing procedure, the special equipment and lifting tools provided for each module are used.

43. **Engine module maintenance.** All engine modules can be dismantled into smaller assemblies. These sub modules, or mini modules are uniquely identified with their own serial numbers and, if they are not 'on condition' items, they will have their own allocated lives. If, for example, a module consists of seven sub-modules, and they are all lifed items, they may possibly all have lives of differing lengths. As the sub module with the least life remaining becomes time expired, the module will be removed from the engine and taken to the module servicing bay. The time expired sub module will then be replaced with a serviceable item, and the module will be ready to be refitted to either the original or a different engine. The life of the module will then be extended until the next sub-module with the least remaining life becomes time expired. The relative ease with which the most intricate parts of the engine can be replaced at unit level is one of the major advantages of modular construction.

44. **Interface inspections.** All components and modules removed from an engine to gain access to other modules are visually inspected for damage, wear and corrosion. The inspections are necessary to ensure that the module is suitable for further service. Each module will have specific detailed inspections laid down, which will itemize the components, and the areas requiring inspections, including the mating faces.

45. **Engine dimensional and clearance checks.** When fitting and removing certain modules to and from the engine, dimensional checks have to be carried out, and the results recorded. The requirements for the checks, and the permissible maximum and minimum dimensions are given in the appropriate engine Air Publication. The results of the checks are entered on the modules log card (Fig 7.1.18). The reason for the checks is to ensure that the running clearance between rotating parts of mating modules are within prescribed limits. If the clearances are too small, there may be lack of mechanical freedom during rotation. If they are exceeded, smooth gas flow, or air sealing of labyrinth seals may be effected. The reason for dimensional variations between modules may be due to manufacturing differences (for all engine components are manufactured to a tolerance) or through wear. Provision is made for adjustment of some modules by using shims or seals of various sizes to obtain the correct clearance. However, there are modules where no adjustment is possible and, if the required clearance is not obtained when they are assembled to the engine, the module(s) have to be replaced.


HISTORICAL RECORD/LEBENSLAUFAKTE/REGISTRAZIONE DATI

TURBO UNION LIMITED

INTERFACE DIMENSIONS   PIP 727/PW/IF   Issue 7

1 NOMENCLATURE OF EQUIPMENT / BEZEICHNUNG DES GERATES / DENOMINAZIONE DELL'EQUIPAGGIAMENTO	2 MODEL & MANUFACTURER / BAUMUSTER UND HERSTELLER / COSTRUTTORE • NUMERO DI RIFERIMENTO	3 SERIAL NO. / WERK. NR. / NO DI SERIE
H P COMPRESSOR MODULE	MO3 MTU/Rolls Royce	042753

	MOD 162			PRE MOD 162		MOD 108	
DIMENSION/MASS	S14 ø FRONT	S14 ø REAR	S17 ø REAR	S17 ø REAR	IF 6	S14 ø FRONT	S14 ø REAR
DRG DIMENSION ZEICHN MASS	375,54/375,63 *as above	364,22/364,31 *as above	220,55/220,61 220,55/220,73	215,56/215,66 215,56/215,74	42,80/44,80	375,79/375,92 *as above	364,35/364,48 *as above
MIN	375,57	364.25	—	215.58	43,25	—	—
MAX	375,62	364.30	—	215,65	44,55	—	—

REMARKS/BEMERKUNGEN: * REPAIR LIMITS

INSPECTOR/KONTROLLE: IA 74

DATE/DATUM: 30·11·86

HRG/2 2300

15765

Fig 7.1.18 Module record card

46. **Engine bays.** Engine bays have a far more important role on units involved in modular maintenance than they had hitherto. More space, facilities and equipment are required than was necessary when engines were returned to the manufacturers for overhaul or repair. The unit engine bay is either purpose built or is an existing building or hangar that has been specifically adapted for the purpose.

47. **Work planning.** The smooth flow of work through the engine bay (Fig 7.1.19) depends upon careful planning and the maximum use of personnel, facilities and equipment. The planners take into account the known expected workload, including those engines that are installed in operational aircraft and have modules or components that are not 'on condition', and are approaching periodic inspection or life expiry. This can be complicated by unexpected operational demands on the aircraft, resulting in a sudden increase in flying hours which will advance the anticipated date of the periodic maintenance. Or conversely a prolonged period of inclement weather that restricts flying and so retards the expected date. Allowances must also be made for engines that develop faults and require unscheduled maintenance, and unforseen circumstances such as the Engine Test Facility becoming unserviceable.

48. From the foregoing it can be seen that planning has to be very flexible, and adapt to unexpected situations as they arise. Many problems are avoided by flying and maintenance planners working as a team. However, the fact that modular engine maintenance is under the direct control of the unit operating the aircraft, gives the planners a degree of independence not previously enjoyed.

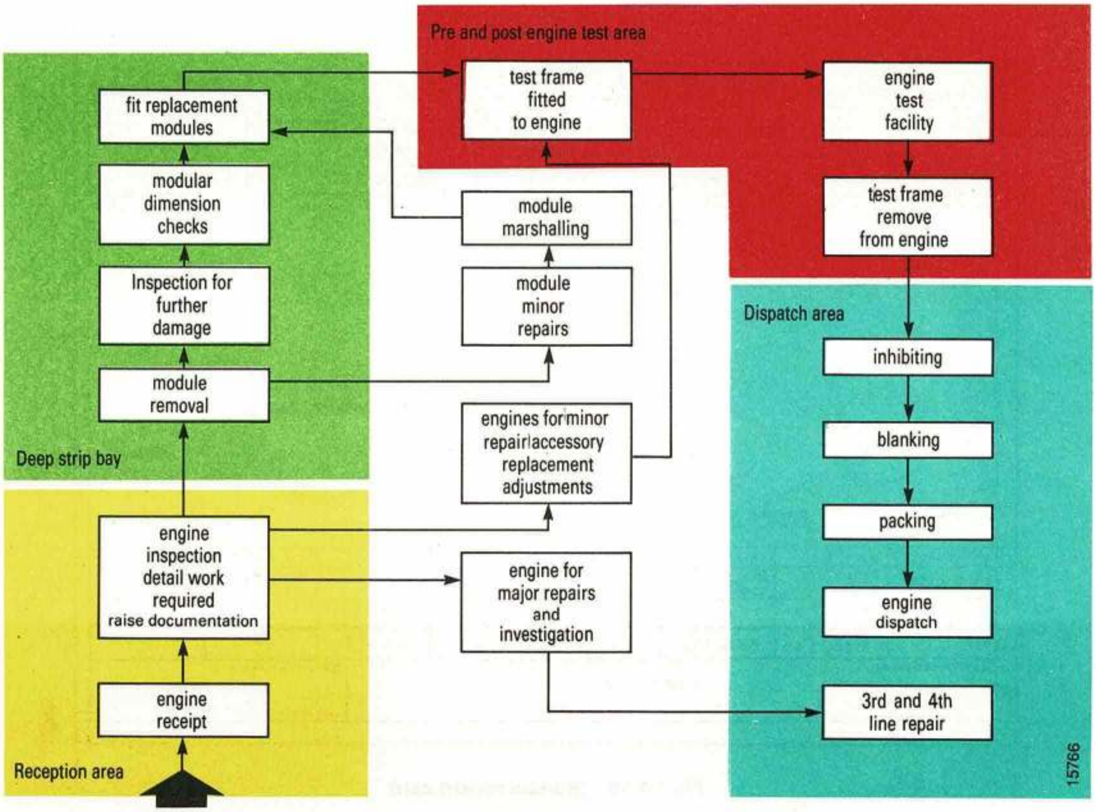


Fig 7.1.19 Engine bay typical work flow diagram

The Cost of Modular Maintenance

49. Modular construction and 'on condition' maintenance has given maintenance planners increased flexibility. The greater percentage of aero engine repairs and rectification are now carried out at user units, resulting in decreased repair turn round times, and increased serviceability – but there is a price to pay.

50. **Manning and equipment.** The increased manning levels of technicians and other tradesmen, and the provision of specialist training, plus the special tools, engine bay equipment and engine test facilities are extremely expensive.

51. **Engine and module management.** In order to manage its resources efficiently, and to achieve their maximum potential, the RAF has selected some types of modular engines and, using a central computer, monitors the location of every engine and module, and their serviceability states, this provides instant access to a current overall state of its engine fleet, highlighting any problems of supply, maintenance, or other circumstances, that may be affecting serviceability. This immense amount of data requires the attention of skilled support staff, all of which involves considerable expense.

52. **Increase in documentation.** An engine with sixteen modules rerquires record cards and supporting documentation for each module. When a module is to be changed, the modification states of all the engine modules has to be checked to ensure that, prior to fitting, the new module is compatible with the other engine modules. This requires a substantial increase in documentation management compared with that required for a non-modular engine, and although on some units this task is now being computerized, which will speed up and simplify the job, and possibly require less personnel, there is the initial cost of the computers, and training of operators, and it may take many months to computerize the necessary data.

53. These expenditures offset to some degree the financial advantage gained by requiring approximately 30 per cent less spare engines for aircraft fleets fitted with modular engines, and maintained under a modular maintenance policy, than those with conventional non-modular engines.

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