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THE PW200 ENGINE
DESIGN FOCUS ON RELIABILITY & MAINTAINABILITY

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ABSTRACT

The PW200 is a small free turbine, turboshaft engine in the 600 SHP class. This paper begins by describing the engine, then traces the design philosophies employed to ensure it meets high reliability targets coupled with competitive performance and cost effective maintainability. Lessons learned from experience and operator feedback are discussed, followed by a more detailed review of the maintenance aspects, accessibility features and operational procedures. A brief review of the first engine installation, the PW205B, in the MBB 105 LS helicopter is also provided. Finally, P&WC's confidence in the approach taken is translated into guarantees and a comprehensive warranty policy.

1. INTRODUCTION

The PW200 has presented the challenge of designing, producing, and supporting in the field, a turboshaft engine in the 600 SHP range with the reliability of the PT6 Twin-Pac; an initial Time between Overhaul (TBO) of 3000 hours and a Basic Unscheduled Removal (BUR) Rate of 0.15/1000 hours or better at maturity.

Pratt & Whitney Canada (P&WC) has extensive experience in this regard, with a complete line of small gas turbine engines operating in diverse applications. In addition to the two turboshaft engines presently in helicopter service, the PT6T Twin Pac and the PT6B-36 single turboshaft engine, the PT6A Family of turboprop engines for business, utility, trainer and commuter aircraft, the JT15D turbofan engines powering business jets, and more recently the PW100 turboprop engines powering the new class of 30-70 seat Regional Airline aircraft, are providing an unsurpassed level of in-service reliability.

The PW200 engine is specifically designed as a powerplant which is easy to maintain, and will result in low direct operating costs for light and medium helicopters in the 4000 to 8000 lb. maximum gross weight size. Powers between 450 and 900 shaft horse power will be developed as part of this engine family.

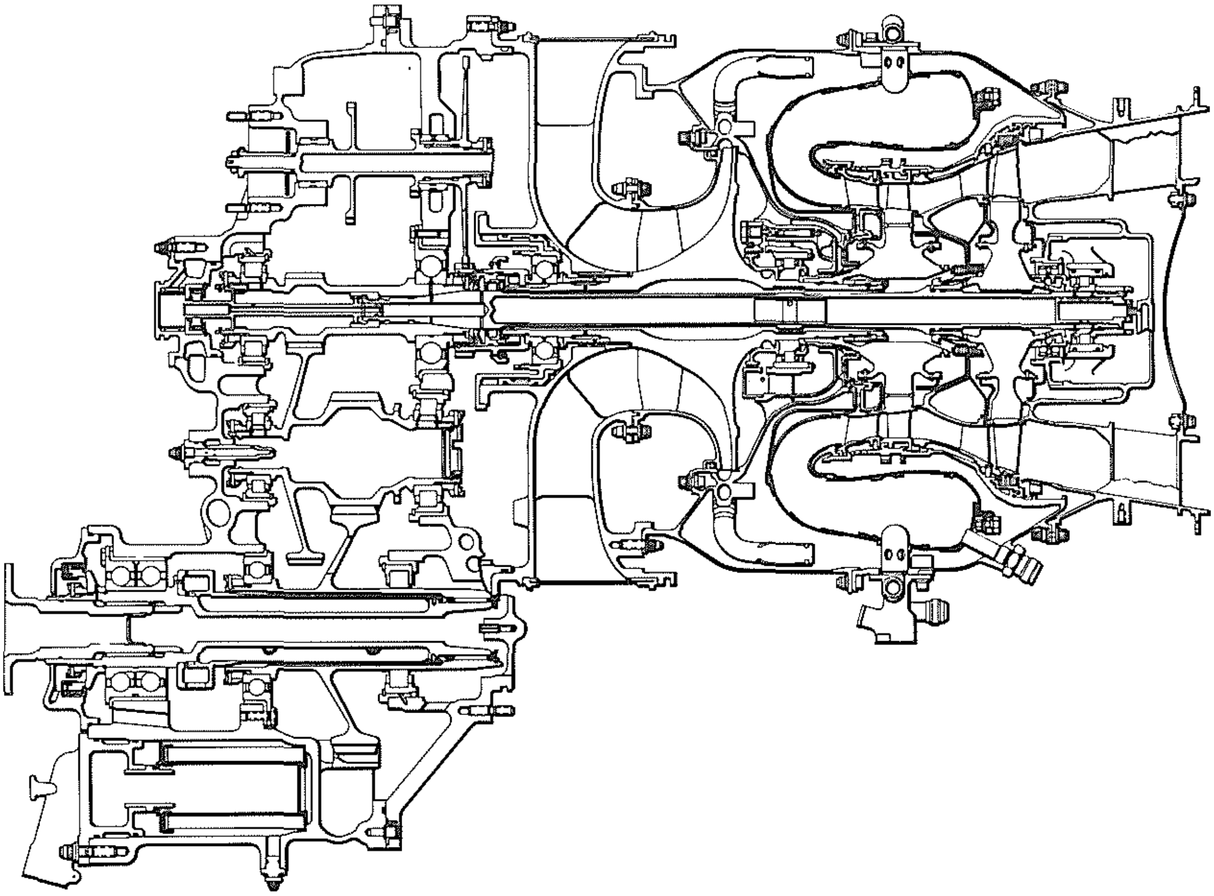


FIGURE 1

2. ENGINE CONFIGURATION

The engine configuration has been set with helicopter installations in mind. It has three major modules; the gearbox, the turbomachine and the control system. A cross section is provided in Figure 1.

The gearbox module is located at the front of the engine providing a front drive to the helicopter. The power drive train, the accessory drive train, the oil system components and the torque measuring system are contained within this single gearbox assembly. A high accuracy phase shift torquemeter is incorporated in the output drive shaft where gearbox torque is the highest. This torquemeter uses a phase shift sensor to measure the twist of the output shaft relative to an unloaded reference tube. The sensor signal is conditioned by the electronic control unit to provide accurate torque measurement for cockpit display and engine control.
The accessory gear train provides the fuel control drive, the starter generator drive, oil pump drives, a permanent magnet alternator drive, and an optional accessory drive. The lubrication system is unregulated and all oil returns to the gearbox sump where it is scavenged through the chip detector to the external tank.

The turbomachine module has the minimum number of rotating components for a helicopter turbine engine; a single centrifugal compressor, a single stage compressor turbine and a single stage power turbine rotor driving the gearbox through a concentric shaft. Air enters the engine through a PT6 type radial inlet with a protective screen. The large inlet area ensures low losses and, combined with straightening vanes, provides excellent tolerance to inlet distortion.

The compressor is a single stage centrifugal unit with a P&WC patented pipe diffuser giving an overall pressure ratio of 8:1. The impeller is a one piece unit flank milled from a titanium forging, and has blades that feature a transonic inducer with a back swept exducer to give high efficiency and surge margin. The pipe diffuser forms an integral part of the gas generator casing and provides efficient diffusion and turning of the air prior to the combustor section.

The reverse flow, annular, combustor system is similar to that of other P&WC small engines but has been improved by utilizing a single piece construction which eliminates sliding joints and uncontrolled leakages. Fuel is introduced into the combustor by multiple airblast nozzles ensuring a good temperature distribution into the turbine and preventing engine flameout during operation in inclement weather.

The compressor turbine stage comprises an air cooled integrally cast vane ring and a forged disk with separately cast blades. The vane cooling scheme features impingement cooling of the leading edge and ejects the cooling air through slots in the suction surface of the trailing edge to minimize the losses in main gas stream. The Directionally Solidified MAR M 200 blades provide a creep life in excess of 2 TBO periods.

The counter rotating free power turbine stage comprises an uncooled integrally cast vane ring and a forged disk with separately cast shrouded blades. The tip shrouds improve both the blade tip leakage and the blade dynamic characteristics.

The control system features an electronic unit which provides more accurate torque and temperature measurement, improves helicopter handling, reduces pilot workload and provides data for system fault diagnosis during maintenance action. The electronic unit is designed to be either engine mounted with fuel cooling or airframe mounted with air cooling. The mechanical fuel metering unit features a three dimensional cam which will provide the engine with excellent acceleration characteristics throughout the helicopter operating envelope.

The first of the PW200 family to be certified will be the PW206A, rated at 603 SHP for Take-off and 619 SHP for 2½ Minute One Engine Inoperative (OEI) as illustrated in Figure 2. It will be installed in the McDonnel Douglas MD-900 helicopter (Figure 3) with first deliveries expected in 1993, and is also under consideration by other helicopter manufacturers.

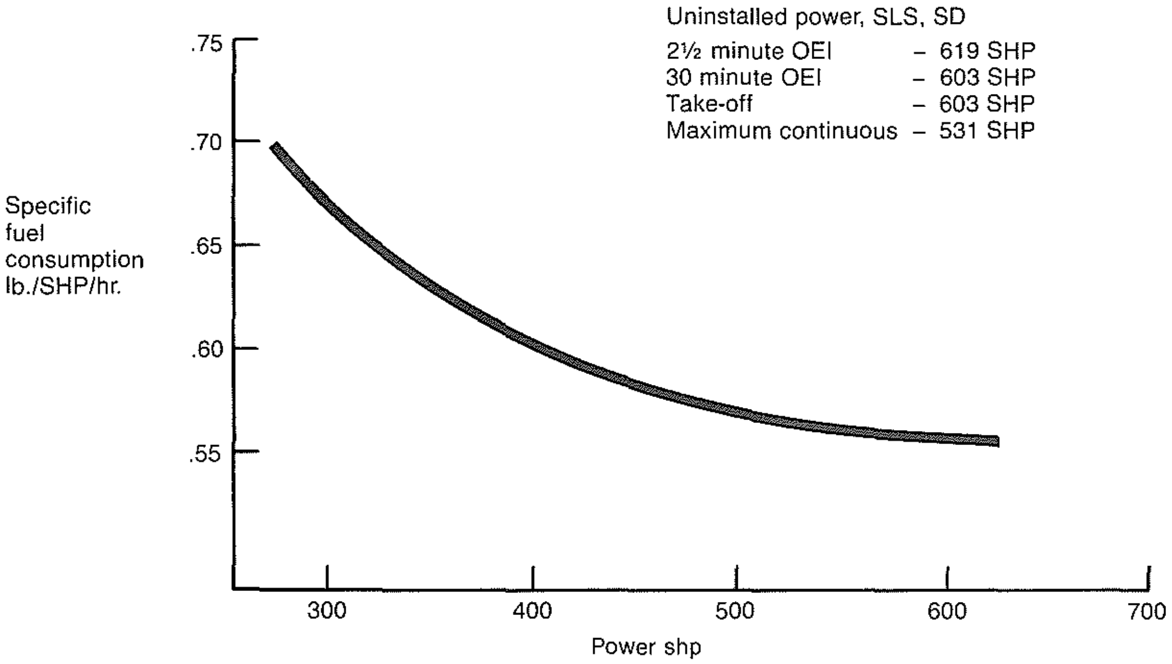


FIGURE 2: PW206A TURBOSHAFT PERFORMANCE

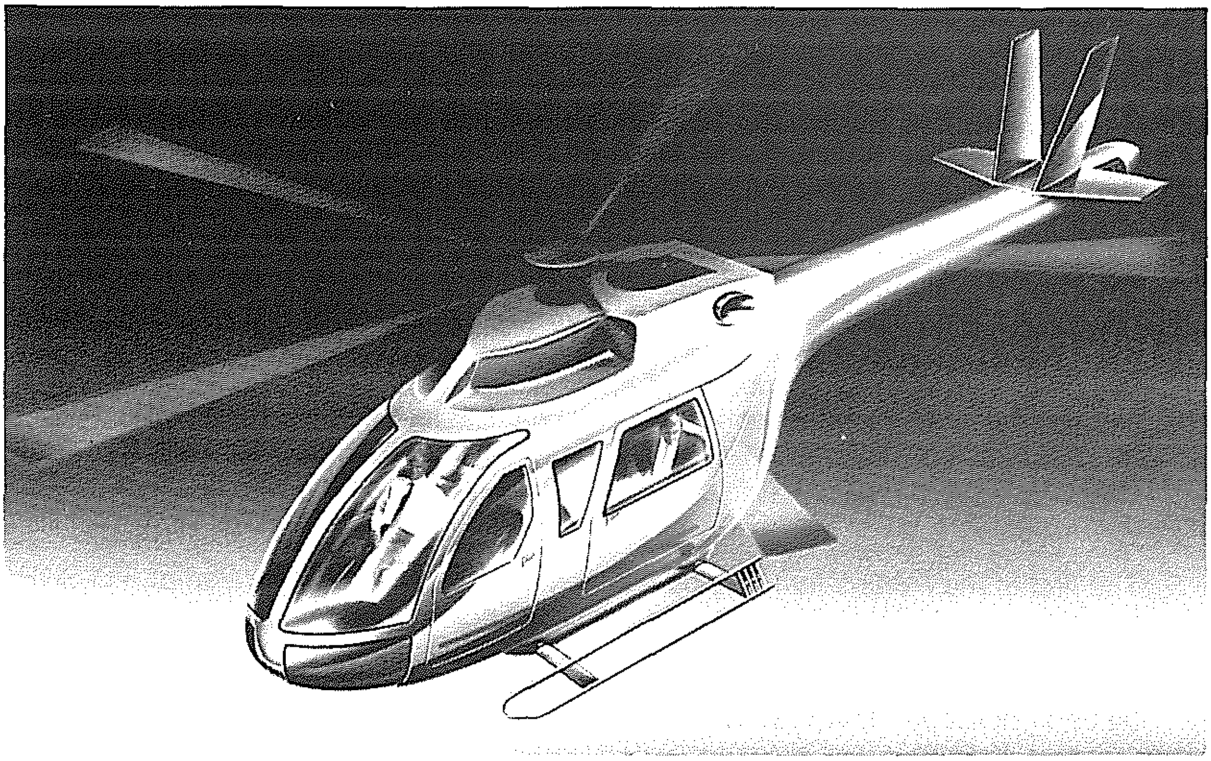


FIGURE 3

3. DESIGN PHILOSOPHY

P&WC'S track record on reliability is given in Figure 4. To a large degree, these levels are set during the early stages of design when overall engine configuration is finalized. If the shafting layout does not allow sufficient space for low stressed disks or if bearing and accessory locations are chosen without due consideration for adverse thermal environments or ease of maintenance, then even the most capable detail design techniques will not provide the necessary long life components and trouble-free engine systems. Similarly, if the basic thermodynamic cycle of the engine is set assuming over-optimistic component efficiencies and inadequate temperature allowances for development problems and production scatter, then the engine will enter service with excessive turbine temperatures resulting in low hot section life with no economically sound way of correcting the problem.

	Millions of Hours	Basic Unscheduled Removals Per 1000 hrs.	In-flight Shut Downs Per 1000 hrs.	Basic TBO hrs.	High-time TBO hrs.
PT6 turboprops	129	.02	.003	3500	21,000
PT6 turboshafts	18	.022	.0015	4000	6500
JT15D turbofans	10	.06	.005	3500	4000
PW100 turboprops	2	.05	.009	2500	5500

FIGURE 4: P&WC SMALL GAS TURBINE ENGINE RELIABILITY

It is at this early stage that basic design philosophy is most important and has the biggest impact on the final product. The underlying design philosophies for the PW200 can be summarized as follows:–

3.1 The "ilities"

The same careful attention has been paid to reliability, durability, producability, repairability and maintainability as is paid to the more traditional considerations of performance, weight and cost. Safety, of course, is paramount.

In the PW200 engine layout where trade-off analyses identified features that would lower life cycle costs with the judicious addition of weight or cost, these features were incorporated. The rear turbine bearing was deliberately placed behind the power turbine rotor, incurring additional weight, to provide the coolest possible operating environment for the bearings and to minimize the problems associated with oil lines crossing the hot gas path. This also provides a more rugged and durable engine structure.

3.2 Size

Engine frame size was set with allowance for substantial future growth in engine power. This has been achieved by selecting an engine performance cycle which uses modest turbine temperatures, at least 25°C lower than the PT6B-36 presently operates in the field, and by assuring space for future gas path volume increases so that power growth can be achieved by engine mass flow increase with less impact on reliability than a throttle push approach.

3.3 Simplification

Demonstrated "state-of-the-art" technology was used to reduce the number of major components in a simple engine layout.

A prime example of this is the single stage 8:1 pressure ratio, high efficiency, centrifugal compressor. P&WC is a recognized world leader in the aerodynamic and structural technology of centrifugal compressors. High efficiency single stage compressors up to 15:1 pressure ratio have been successfully demonstrated (Ref. 1) negating the need for more complex and costly axial compressors in small gas turbine engines.

3.4 Materials

A conservative approach was taken in the choice of established materials, proven by previous engine experience, processed in forms providing excellent damage tolerance. All of the materials used in the PW200 have been substantiated by service experience in PT6 turboshaft engines.

The use of integrally cast turbine discs was rejected, in spite of their lower initial cost, in favour of separately bladed rotors to allow the use of forged Waspalloy, with it's superior Low Cycle Fatigue (LCF) strength, for the compressor turbine (CT) disc and Directionally Solidified (DS) cast MAR-M-200 for the higher temperature creep limited CT blade. This approach leads to much higher component service lives and in many cases of blade distress, allows reuse of the disc with consequent reduction in helicopter direct operating costs.

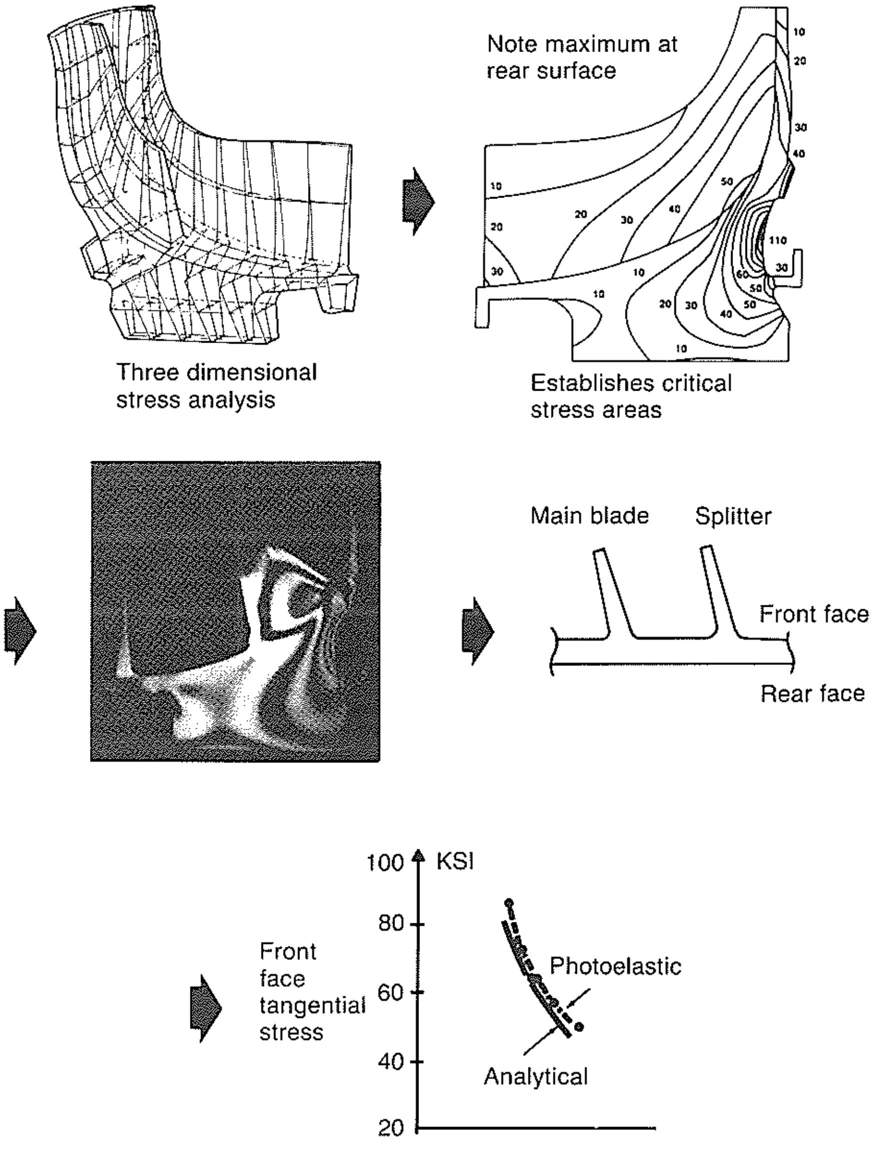
This approach also has an additional advantage for the power turbine rotor; the overspeed failure mode can be controlled to ensure that the lower tensile strength blade fails before the forged disc, thus minimizing the energy of the fragments released during inadvertant rotor failure, and making successful containment by the engine casing much easier.

3.5 Detail Design

P&WC has relied upon substantiated design criteria, building on the good attributes of the P&WC family of small gas turbines while improving the marginal areas. P&WC is constantly improving its design criteria, which are documented in the Design Manual, to incorporate the "Lessons Learned" during development and in service. These design criteria have been recently re-affirmed by the successful entry of the PW100 Turboprop into service with an unexcelled level of reliability, a BUR rate of better than .05/1000 hours after less than 2.0 million operating hours.

Particular care was taken in detail design, using modern methods of analysis, and substantiated by test data, to optimize components to meet high life targets.

Three dimensional finite element analysis evaluated the complex stress distribution in the major rotating components which are Low Cycle Fatigue (LCF) life limited. The analytical model used for the PW200 impeller, together with a comparison of predicted and measured stress in the critical back face area is shown in Figure 5.



Photoelastic techniques provide excellent confirmation of analysis method

FIGURE 5: PW200 IMPELLER STRESS ANALYSIS

The analytically predicted LCF lives are confirmed by extensive spin pit testing, under representative loading conditions, of all LCF limited components. In 1988 the P&WC spin pit facility accumulated in excess of two million test cycles in support of component Service Bulletin LCF lives.

This approach, modern analytical design backed by extensive component spin pit testing, has resulted in unexcelled compressor and turbine disk LCF lives in P&WC engines, see Figure 6. The PT6 family has now accumulated over 150 million hours of service without suffering a single high energy hub failure of any rotor in any engine. To ensure that the PW200 rotors enter service with an initial LCF life of 10,000 cycles they have been designed by these same methods with a target life of 30,000 cycles and they will be spin pit tested. Prior to engine certification each disk will accumulate at least 120,000 cycles to support the 10,000 cycle Initial Service Bulletin Life. After certification a program of residual life testing of disks returned from the field will be used to increase the Service Bulletin LCF Lives to at least 20,000 cycles at engine maturity.

Service Bulletin LCF life-cycles	Impeller	Compressor Turbine	Power Turbine
PT6 turboprop	19,000	18,000	20,000
PT6 turboshaft	29,000	10,000	30,000
JT15D turbofan	7150	14,000	14,000
PW100 turboprop	15,000	15,000	15,000
PW200 initial	10,000	10,000	10,000
mature	20,000	20,000	20,000

FIGURE 6: P&WC LCF PROCESS ENSURES HIGH DISC LIFE

4. LESSONS LEARNED

In addition to a continual, formal updating of design criteria in the P&WC Design Manual, periodic reviews are held to ensure that operational experience is reflected in new engine models. For the PW200, two conferences were held (and more are planned) with groups of turboshaft operators where the layout and design of the engine were discussed at length; prototype hardware was also made available, with practical demonstrations of maintainability.

These discussions provided invaluable input and have lead to the incorporation of important improvements to the engine.

4.1 Casing Material

P&WC's traditional use of magnesium alloy casings (except in Military applications where aluminum is the rule) came under some fire from those operators in maritime environments. Although the Twin-Pac experience with a magnesium reduction gearbox epoxy coated was felt to be favorable in terms of relatively little corrosion seen at overhaul levels, other powerplants had not fared as well. Concern was expressed that a smaller, more mobile helicopter would be subjected to a harsher environment than the larger models. Furthermore, the level of maintenance action required in order to ensure protective finishes are not chipped or damaged is intolerable.

Against these arguments is the ever-present weight penalty. It has been agreed that the gas path components will be aluminum alloy but discussions continue on the best approach for the gearbox housing.

4.2 Impeller

Concerns were expressed that the vane leading edge geometry was too sharp to be practical in an erosive environment with inevitable loss of engine performance. A benchmark sand ingestion test to the requirements of MIL-E-8593D, were successfully carried out. Although the results were encouraging, with a power loss of less than 4%, areas of the vane which suffered significant erosion were identified and are being improved. The subject is also being addressed through careful attention to intake system design for dirt particle separation.

4.3 Bearings

The output shaft bearing, initially conceived as an integral shaft bearing, will change in light of PT6T Twin-Pac experience, to accommodate a separate inner race.

All the journal bearings in the accessories zone of the gearbox are under review. Our own JT15D fan experience has been good but concern about the effects of widely varying oil pressures associated with the PW200 non-regulated oil system on these types of bearings has been raised.

It should be noted that the main shaft bearings are all under race lubricated to provide enhanced cooling and lubrication. Controlled stiffness bearing housings and oil film dampers are used to reduce the dynamic sensitivity of the rotors to unbalance loads.

Positive anti-rotation devices have been incorporated on all bearing races.

4.4 Bleed-off Valve

PT6 engines have traditionally used a bleed-off valve (BOV) to modulate compressor delivery pressure where necessary for surge avoidance in transient response. These valves by their very nature are not robust, and are difficult to maintain. In the design of the PW200 compressor, and in the setting of the engine running line, additional surge margin has been incorporated. Early flight testing has been successfully completed without a BOV. Because engine surge characteristics can be severely influenced by installation factors such as inlet distortion and exhaust re-ingestion, provision for a BOV has been retained should the need arise.

4.5 Engine Wash

The demonstrated benefits of regular compressor washes and periodic hot section washing will be followed through in this engine; a built-in wash ring will accommodate the former, and the turbine area can be accessed by removal of a fuel nozzle — without disturbing the other nozzles — as required.

4.6 Temperature Measurement

The power section features an array of chromel-alumel thermocouples which measure exhaust gas temperature. This signal, along with other input parameters, is used to compute a temperature indicative of compressor turbine inlet temperature and defined as measured gas temperature (MGT). Initial designs featured an integral harness; customer input has prompted a redesign to a multi-piece arrangement which is externally accessible to install, maintain or replace.

The foregoing provides a flavor of how design features are being modified by experience and opinion. The process is dynamic; while the core engine is now close to being set for production definition, the externals continue to evolve. Other areas under review are the provision for the incorporation of an engine scavenge oil filter to protect airframe oil coolers, and the incorporation of an engine fuel heater to eliminate the requirement for anti-ice additives in the fuel. An integral engine oil tank is also being considered.

5. MAINTAINABILITY

Considered with inherent reliability as paramount to both commercial and technical success, the subject has had a major impact on design.

5.1 Routine Line Maintenance

Scheduled maintenance has been limited to easily accessible Line Replaceable Units (LRU's) and simple visual checks. Figure 7 depicts the various tasks involved, along with estimates of the manhours required to accomplish them and the time interval in each case. The time intervals have been chosen to match anticipated aircraft inspection intervals.

Task	Nature of task	Estimated man-hours	Interval	
			Routine	150 hr.
External check	visual-tubing, wiring, control linkage, leaks, etc.	.1	✓	
Oil system level check	visual	.1	✓	
Oil system filter check	remove, inspect	.3		✓
Oil and oil system filter change	replace	.3	every 300 hours	
Fuel system filter check	remove, inspect	.2		✓
Fuel system filter change	replace	.1	every 300 hours	
Fuel nozzle inspection	—	—	at overhaul only	
Magnetic chip detector	remove, inspect	.2		✓
Ignition igniter	condition and functional check	.1		✓
Compressor wash	desalination	.2	✓	
Compressor wash	performance recovery	.4	50 hours or weekly	
Compressor inlet area	corrosion, dirt, deposits, erosion, FOD	.3		✓
Compressor inlet screen	cleanliness and condition of mesh	.1	✓	

FIGURE 7: SCHEDULED LINE MAINTENANCE

5.2 Hot Section Inspection (HSI)

The PW200 engine family will not normally require periodic hot section inspection. However, under certain unforeseen operating conditions, trend monitoring of engine performance parameters may indicate the need for an HSI.

Should an HSI be required, the engine has been designed for easy access down to the compressor turbine (Figure 8). Working from the rear of the engine, the pressure and scavenge lines are first disconnected at the exhaust case struts, to allow removal of the exhaust case assembly. The power turbine and shaft are then removed as an assembly module. The power turbine vane assembly can next be removed to expose the downstream side of the compressor turbine.

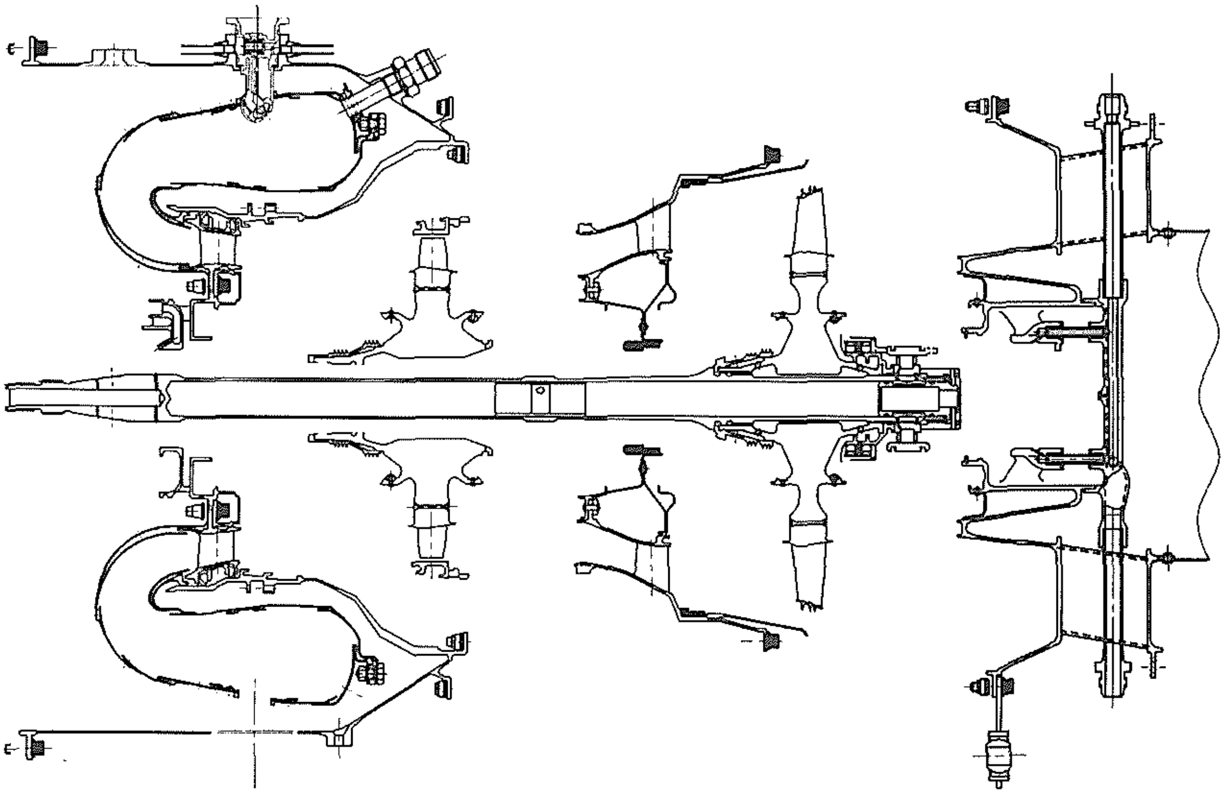


FIGURE 8: HOT SECTION INSPECTION

By next removing the compressor turbine disk assembly, good visibility of the rest of the hot end components is afforded. Should it be found necessary to proceed further into the hot end, the turbine support case assembly, containing the compressor turbine vane assembly, fuel nozzles and combustion chamber can be removed as a module and disassembly completed.

It should be noted that minimal special tools are required for the above. Further, all the above components are field replaceable. The use of nominal turbine spacers precludes the need for any stack-up measurements and there are a limited number of vane classes involved. The compressor turbine can be replaced without the need for rebalancing of the compressor rotor assembly.

5.3 **Unscheduled Maintenance**

Should scheduled maintenance checks or engine condition trend monitoring of performance parameters indicate the need to investigate further, provision has been made for borescope inspection. The compressor can be viewed through the inlet, the power turbine through the exhaust, and the combustor/compressor turbine areas by removal of any fuel nozzle.

Accessibility features of the engine are depicted in Figure 9. The removal/installation of speed probes, permanent magnet alternator, torque sensor, pressure adjustment valve, the various gearbox seals, electrical harness, hydraulic pump, fuel control and more have each been studied and validated. A preliminary maintenance guide has been published.

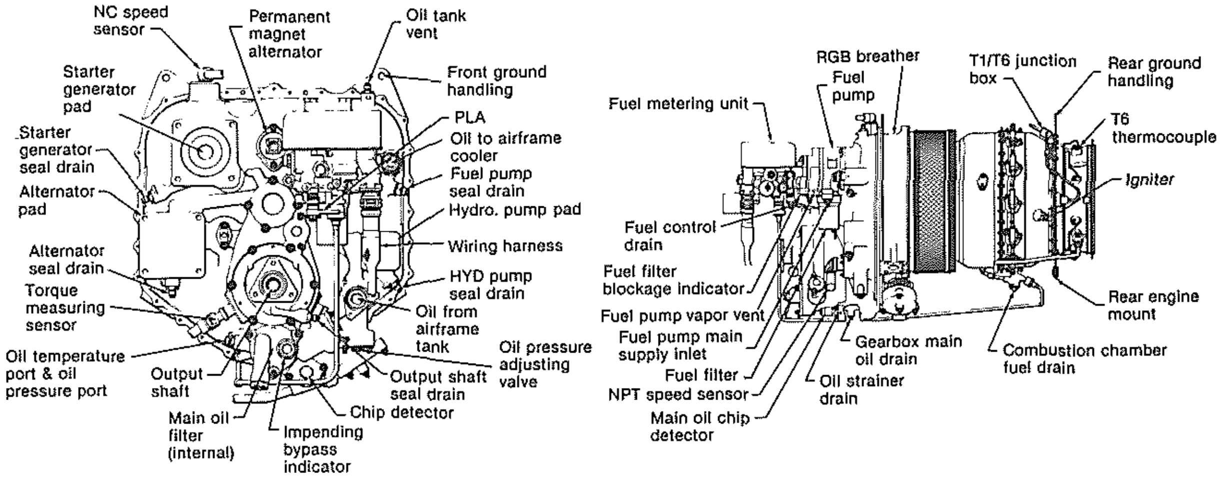


FIGURE 9: COMPONENT LOCATION

5.4 **Troubleshooting**

The symptoms and potential causes of problems have already been identified and documented (Ref. 2) for each major area, viz compressor area, hot section, compressor and power turbine areas, gearbox, oil and fuel systems plus the engine control system.

For each, a brief description of the zone is available along with inspection criteria and line or light maintenance requirements. Detailed maintenance and repair criteria will be available later in the Maintenance Manual. Where possible, symptoms are confined to engine parameters; MGT, torque, fuel flow, power turbine speed and compressor turbine speed. These are all required for power assurance checks on the aircraft and are inevitably the first sign of impending problems. Taken together with the scheduled line maintenance addressed earlier, a solid base of good housekeeping is generated.

6. BO 105 LS XO1 PROGRAM

The BO 105 LS XO1 program (see Figure 10) is a joint undertaking of MBB Helicopter Canada Ltd. (MCL) and P&WC. The program is intended to be a limited demonstration of the PW200 series engine — in this case, the PW205B — and also provides MCL with its first look at a candidate engine for several proposed helicopter developments.

Details of the program are available elsewhere (Ref. 3); in the context of this paper, testing at Fort Erie, Ontario, provided the following.

6.1 Ground Test

- Confirmation of installation features and engine accessibility, particularly with respect to line replaceable units.
- Operating experience with the PW200 series engine.
- A verification of, and the ability to influence, the interaction between engine controls and the dynamics of the BO 105 rotory system.
- Demonstration of emergency procedures and failure modes associated with the engine installation. A total of 163 single, double and triple failures were simulated in the wiring connecting the engines, the fuel controls and the airframe. None resulted in unexpected or undesirable occurrences. Engine and airframe limits were never exceeded.

The program began with the first start of a PW200 series engine in an airframe on 29 June '88. To date, 63 ground tests have been conducted, involving 120 engine starts and a total of 51 hours of engine running time.

6.2 Flight Test

- Clearance of an initial flight envelope.
- Demonstrated handling and operation of the PW205B within this envelope.
- Determination of the engine installation losses.

The first flight occurred on 6 October '88 and some 25 flight hours (27 flights) have been conducted so far.

FIGURE 10: BO 105 LS X01 HELICOPTER

7. GUARANTEES

7.1 Reliability

The confidence level of the foregoing philosophies and actions can best be expressed in the form of fleet-wide reliability rates guaranteed by P&WC for newly manufactured or overhauled PW200 engines.

- Basic Unscheduled Removal Rate (BUR) Guarantee
  - Less than 0.25/1000 hours at 100,000 engine hours.
  - Less than 0.15/1000 hours at 1.0 million engine hours.
- Basic Inflight Shutdown (IFSD) Rate Guarantee
  - Less than 0.08/1000 hours at 100,000 engine hours.
  - Less than 0.05/1000 hours at 500,000 engine hours.
  - Less than 0.025/1000 hours at 1.0 million engine hours.

The above rates are for all engine chargeable causes, including vendor supplied engine accessories.

7.2 Time Between Overhaul (TBO) Philosophy

The PW206A engine will have an initial TBO of 3000 hours. P&WC is developing a modular overhaul plan designed to independently escalate the TBO of the gearbox and power section as soon as may be practical within sampling constraints imposed by fleet size and fleet utilization factors. This is done by providing the certifying authorities with satisfactory field samples at increasing TBO intervals until the full engine reaches a mature basic TBO of 3500 hours.

In practice, for high utilization fleet operators, there is no theoretical TBO limit. As demonstrated on other P&WC engines, achievement of TBO's in excess of mature basic TBO depends largely on the operating and maintenance practices of the individual operator. Within the guidelines of the relevant PW200 Service Bulletin which will outline the overhaul sampling program, P&WC will inspect overhaul engines submitted as samples and make appropriate TBO recommendations for the individual operator. However, in all cases, TBO extensions must have concurrence of the relevant certifying authorities.

7.3 P&WC Warranty Support

The warranty support P&WC provides for its products is second to none. P&WC's warranty for the PW200 engine family includes four elements of protection:

a) Warranty

P&WC warrants that at the time of delivery all goods will be free from defects in material or manufacture and will conform to P&WC's applicable specifications.

Remedies include repair or replacement at no charge during the first 500 operating hours, within 12 months of delivery, and transportation charges are accepted under certain provisions.

b) Engine Service Policy

P&WC will repair engines or modules damaged as a result of defects in workmanship or materials during the first one thousand (1000) operating hours after first flight by the original operator and will provide free on-aircraft repair, shop repair and/or overhaul as required.

c) **Parts Service Policy**

A pro-rata credit is granted for primary parts (all major parts in the engine) requiring replacement or repair during their class life. For the PW206A engine, the class lives range from 2000 hours to 5000 hours. It should be noted that these provisions apply to any new primary parts embodied during initial engine assembly or procurred subsequently as spare parts. Thus protection is offered as long as an engine is in operation.

d) **Campaign Changes**

Additional allowances are granted for the modification or replacement of primary parts within their class life under P&WC designated campaign changes. For Airworthiness Directives (AD's), a complete 100% credit for parts and labour to comply with the directives are granted.

8. CONCLUSIONS

The process described in this paper sets a firm foundation for the PW200 engine family towards meeting its reliability and maintainability goals. Evolution of this engine will continue as the engine moves through development and is certified in late 1991.

When the PW206A enters service in 1993, a trained team of technical field representatives backed by P&WC's total support package, will be in place to ensure a smooth transition into active service.

P&WC is fully committed to the concept of Total Quality Management and will foster a team approach with the OEM's and operators as the engine accumulates service experience, promoting an active support program of product enhancement to maintain cost effective operation of the PW200 engine family.

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