MARINE GAS TURBINES

A REVIEW

BY

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Introduction

There is no doubt that the introduction of all-gas-turbine propulsion into the Royal Navy over the past ten years has been highly successful. The overall reliability of twin-shaft plants with two engines for each shaft is, of course, inherently high, but the success of gas turbines is none the less remarkable. This is particularly so when viewed with the benefit of hindsight, when it can be seen that by the standards of today the Olympus and Tyne gas turbines were both at an early stage in their development as marine engines when they entered service. The Olympus had some background of industrial and marine service, but nevertheless still had unresolved significant problems with the combustion equipment. The Tyne, extensively redesigned from the aero engine, had no background of industrial or marine experience at all. Endurance testing ashore at the National Gas Turbine Establishment under simulated marine operating conditions was about to start for the Tyne, but would not start for the Olympus until 1974.

It is worth comparing this situation with the introduction of the LM2500 engine by the United States Navy to service in the DD 963 SPRUANCE Class in the mid 1970s. All resources could be concentrated on a single design of engine instead of being divided between two. Fleet service was preceded by some five years and fifty thousand hours of sea service in the gas-turbine ship *Callaghan* in transatlantic service, in addition to shore testing.

Nevertheless, the bold decision to change to an all-gas-turbine propulsion policy in the late 1960s, in advance of experience from H.M.S. *Exmouth*, was undoubtedly correct, and had the essential virtues of imposing a tight programme on the machinery designer, and getting COGOG plants into service as quickly as possible. Overall success has stemmed from these factors, and from the prudent arrangements made for regular and thorough engine inspection, for GTCU exchange, and for logistic support, allied to a realistic lifing policy.

General Experience

Engine Exchange

Having stated the overall success of R.N. gas-turbine propulsion, it is worth examining in detail the experience gained. TABLES I and II list all Tyne and Olympus engine removals, except for engines reaching their planned lives and those removed at refits in advance of reaching their planned lives. All removals are shown in graphical form in FIGS. 1 and 2, which indicate whether each removal was planned or premature.

As with all statistics, it is necessary to state qualifications to enable the data to be seen in correct perspective. The most important point is that the number of premature removals must be related to the total population of engines in service and to the total running achieved. These factors are indicated by the average running hours reached by the total number of engines now in service. It is inevitable during the first years of service, before many engines could have approached their planned life, that almost all the removals will be premature. Many thousands of running hours on many engines must accumulate before

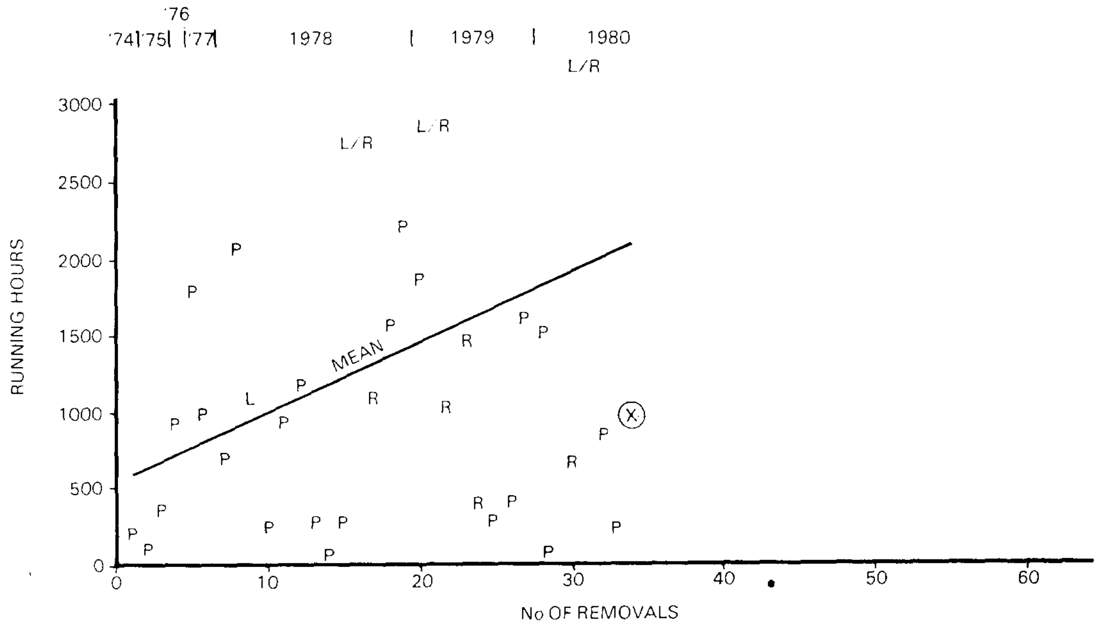

FIG. 1—OLYMPUS TM3B ENGINE REMOVALS

Key: L = Life expired
R = Ship refit
P = Premature
X = Average of 56 engines in service—973 hours

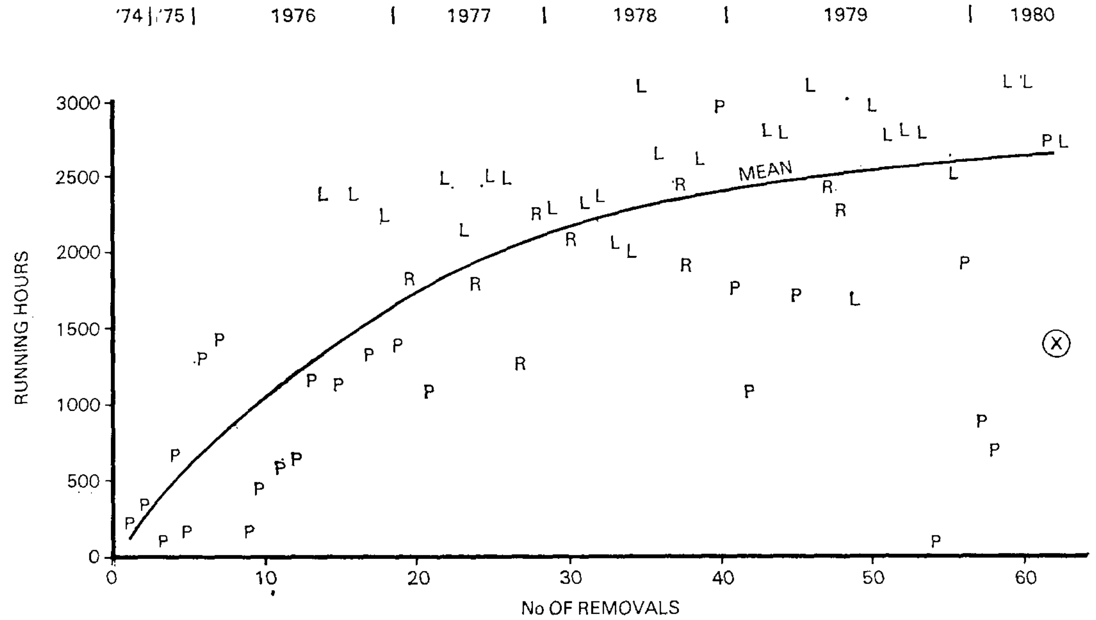

FIG. 2—TYNE RM1A ENGINE REMOVALS

Key: L = Life expired
R = Ship refit
P = Premature
X = Average of 34 engines in service—1390 hours

statistics such as the Premature Removal Rate and Mean Achieved Life start to have very much real significance. The differences between the pictures presented by these figures for the Tyne and Olympus engines illustrates this point. The Olympus in COGOG plants accumulates running hours at less than half the rate for the Tyne (some 600 hours/year and 1500 hours/year respectively), and inevitably appears to have a poorer record of reliability. Opportunities to incorporate modifications improving component life and reliability are related to the removal rate, and the modification status of Olympus engines in service lags far behind that of the Tyne.

TABLE I—*TM3B Olympus premature removals*

Date	*Engine*	*Hours*	*Reason*
11/74	201719	197	Crossed burner fuel pipes
2/75	201731	93	Foreign object damage
6/75	201725	354	Exhaust annulus damage
10/76	201713	930	Nugatory—apparent high oil consumption
4/77	201723	1802	Cracked inter turbine duct bellows
6/77	201708	996	Cracked turbine entry duct
1/78	201743	653	Detached bearing oil feed pipe
2/78	201730	2057	Cracked LP compressor IGVs
5/78	201729	214	HP turbine vibration (build defect)
5/78	201728	931	Cracked turbine entry duct
6/78	201718	1106	HP compressor imbalance
6/78	201745	272	No. 4 bearing failure
7/78	201767	15	HP turbine vibration (build defect)
7/78	201709	277	Turbine failure due to defective supply to one burner
10/78	201717	1538	Turbine failure due to fairing detached
10/78	2017109	2198	Cracked exhaust annulus
4/79	201715	1861	Fuel control system defect
10/79	201762	288	Cracked No. 7 bearing oil feed pipe
10/79	201775	407	Accessory drive bearing wear due to oil contamination
11/79	201731	1607	Crossed burner fuel pipes
2/80	201723	1528	Cracked LP compressor IGVs
3/80	201716	29	Nugatory—apparent high oil consumption
4/80	201753	861	Cracked compressor EGVs
5/80	201742	210	(under investigation)

TABLE II—*RM1A Tyne premature removals*

Date	*Engine*	*Hours*	*Reason*
1/75	901010	93	Damage cause by installation debris
9/75	901014	172	PT Vibration
2/76	901029	129	PT Vibration
3/76	901026	466	PT Vibration
6/76	901013	609	Detached nose cone locking plunger
10/76	901026	1215	Foreign object damage
11/76	901032	1301	HPSOC failure—overheated turbine
1/77	901003	1355	Nugatory—instrumentation fault
5/77	901010	1065	PT vibration, cracked IGVs
12/77	901014	2267	HP compressor front bearing vibration
2/78	901041	2096	Compressor bearing vibration
7/78	901053	1947	Compressor bearing vibration—defective seal
8/78	901009	2605	HP compressor front bearing vibration
9/78	901026	2949	HPSOC failure—overheated turbine
1/79	901032	1766	HP compressor shaft and PT support strut damage
2/79	901063	1000	HP compressor shaft damage
3/79	901004	1711	Cracked 0-stage stator blade
9/79	901031	2	PT vibration
10/79	901040	1899	High oil consumption, gas leakage
12/79	901024	0	Unreliable starting—burners
3/80	901022	840	Failure of No. 5 HP roller bearing
3/80	901007	652	Detached internal wheelcase bolts
5/80	901044	2684	Detached nose cone locking plunger

Planned Life

A fundamental principle in deciding the planned life of an engine build standard is that the great majority of engines (perhaps 75 per cent. at least) should be likely to achieve that life before removal. It is difficult to assess whether that is being achieved, particularly for the Tyne where two build standards with different lives are in service, but overall it is considered that the lives selected have been neither too conservative nor too ambitious. The current selection of engine lives, and their planned extension, are given in TABLE III.

TABLE III—*Tyne and Olympus overhaul intervals: July 1980*

Engine	*Life Standard*	*Part Overhaul*	*Complete Overhaul*	
Tyne RM1A	1	3500 hrs	7000 hrs	Then conversion to RM1C
	2	—	4000 hrs	
Tyne RM1C	1	2500 hrs	5000 hrs	
		3000 hrs	6000 hrs	Expected life by end 1980 with life extension
	2	—	4000 hrs	Will be cleared at NGTE by end 1980: at sea by end 1982
	3	—	7000 hrs	At sea by 1986
Olympus TM3B	1	3000 hrs	6000 hrs	Present life
			Calendar life 6 years	
	2	—	5000 hrs	Cleared at NGTE now: at sea by 1982
			Calendar life 8 years—under investigation	
		—	6000 hrs	Future prospect with life extension
			Calendar life 10 years	

Causes of Premature Removal

Turning now to the causes of premature removals, the first point to be made is that, while not always obvious from the information given, most premature removals were precautionary in nature rather than actual breakdowns; many engines would if necessary have continued in service for some time. The second point is that some defects could have been repaired in place by abnormal methods had the necessary expertise and material been made available, and if the operational situation had allowed. This is generally the U.S. Navy's approach, but it has always been R.N. policy that work beyond the capacity of the ship, with local resources, should be carried out following engine exchange at R.N.A.Y. Fleetlands or by Rolls-Royce. Many defects leading to premature removal were, in fact, well beyond the capacity of local staff to investigate and repair in place.

Engine Health Monitoring

The early detection of serious incipient defects in gas turbines reflects a high rate of success for the engine health monitoring methods and organization, including the use of fitted instrumentation such as vibration monitors and routine visual inspections. A notable exception is the absence of instrumentation to monitor the correct operation of the combustion system, and modifications are being developed to enable temperature to be indicated separately at different positions around the exhaust annulus. Premature removals also illustrate that analysis of lubricant debris, while this is a powerful EHM tool, can give evidence in only a small number of failure modes. The very few engines removed and subsequently found to be serviceable also confirms that EHM methods are generally reliable and successful.

Engine Development

When engines first enter service, it is inevitable that resources are concentrated on developing solutions to the problems revealed by early service, and particularly to those resulting in premature removal. As experience accumulates, and as more engines approach their initial planned life, longer-term problems that limit life come to light, and the direction of development turns from 'trouble shooting' to life extension. Experience shows that the first phase is likely to last for at least five years, though some problems persist for much longer where design solutions cannot be incorporated in engines without removal.

Particular Operating Experience

Premature removals are, of course, only part of the total picture of operating experience. Some other factors are:

(*a*) defects overcome by component replacement or repair *in situ*, including life-limited items;
(*b*) operating problems and incidents;
(*c*) life-limited components scrapped at overhaul.

These involve a multitude of problems, mostly fairly insignificant in themselves and infrequent, but there are some important exceptions.

Olympus Fuel and Combustion Systems

A major source of trouble has existed from the earliest days in the Olympus fuel and combustion systems:

(*a*) Cracking of flare support welds.
(*b*) Unacceptable smoke levels.
(*c*) Low combustion chamber life.
(*d*) Fuel distributor valve stiction and hysteresis.

The first was quickly overcome, and has ceased to be a serious problem. The smoke level of the standard multiflare can with the original burner was very bad, and there has been intensive development to cure this, allied to improvements to extend can life. Smoke levels achieved by different can standards and burners are shown in FIG. 3. A modified burner, known as the 'EX' burner, gave greatly improved smoke performance, but brought with it the need for fuel system modifications to control deceleration rates and prevent flame-out which would otherwise occur with the 'EX' burner.

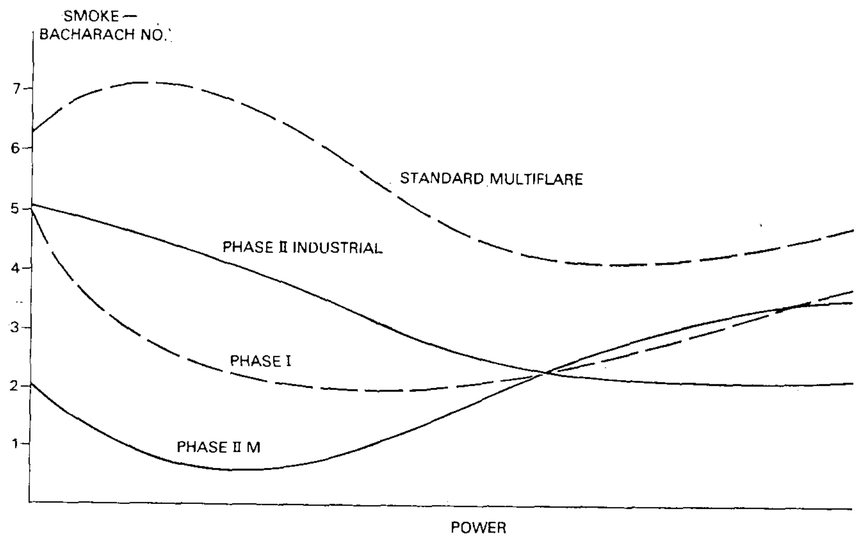

FIG. 3—OLYMPUS SMOKE LEVELS

Fuel distributor valve stiction gave rise to unreliable starting and inconsistent idling, and this GTCU component has now been replaced by a 'pressurizing valve' and HP fuel filter, involving modifications to module and GTCU pipework and components.

These modifications are entirely successful in improving starting reliability, safeguarding against flame-out on deceleration, and reducing smoke, but, of course, they introduce additional complexity. More serious is the introduction of interchangeability problems in matching spare GTCUs with the progress of module modifications, which are likely to persist for some time to come.

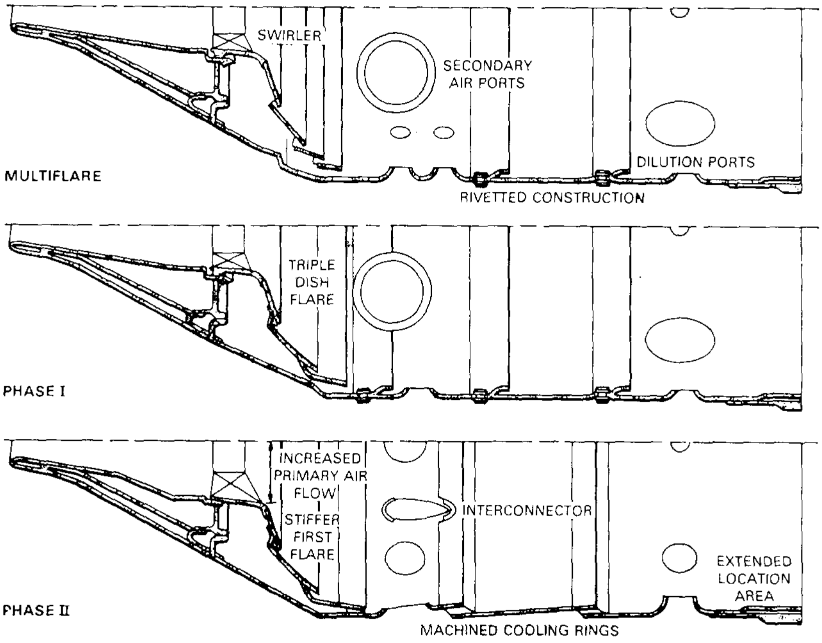

FIG. 4—OLYMPUS COMBUSTION CAN STANDARDS

Combustion can life has been improved from 1000 hours with the original standard to 2500 hours with a developed can referred to as 'Phase I'. The latter, in combination with the 'EX' burner, gives generally smoke free operation, though black smoke is just visible at full power and, at idling, obnoxious white vaporous smoke is emitted. Further development has given a 'Phase IIM' can with no visible smoke at all, and the potential for greatly improved life even with severe high-power operation. Unfortunately the improvements in low-power combustion efficiency have brought with them problems with starting and handling which it has not proved possible to eliminate by simple changes to the fuel system and swirler geometry. This line of development has been abandoned, though it is possible that a similar industrial standard of can could be considered for R.N. use after further experience ashore and proving with the marine fuel control and starting systems. The prize of eliminating the need for *in-situ* can changes is particularly attractive for the CAH, where Olympus usage is expected to be at least twice that in COGOG ships. The standards of can referred to are illustrated in FIG. 4.

Tyne Starting Problems

A persistent annoyance has been unreliable starting of the Tyne, and failures of the starter motor itself. A number of factors are involved, all being addressed under the Continuation Development Programme. These include low reliability of the high-energy igniter units, igniter plug insulant failure and weak operation, and problems associated with burner primary cone angle which in some standards is marginal for good light-up. Inadequate lubrication appears at present to be the source of premature starter failure.

Module Safety Services

Module temperature sensors and fire detectors have been an area of extensive work related to their positions, settings, and testing. A test instrument is in course of introduction to service. Operation of fire-extinguishing systems have been unreliable due to BCF bottle leakage and defects in the mechanical and electrical operating systems. Consideration is being given to the introduction of rechargeable bottles.

Olympus Exhaust Annulus Cracking

The exhaust annulus of the Olympus is severely prone to cracking around a 'top hat' strengthening ring and the welds of strut junctions. A stronger design with five tangential vanes has been developed and will eliminate the problem; it is, however, significant that this superficially simple change also involves modifications to the insulating blanket, instrumentation tappings, turbine casing, mid engine mounting ring, and pipework. Some dockyard work is involved, and care will be needed to ensure that interchangeability problems do not arise. The cost of modifying all engines in the Fleet will be very high. Meanwhile, the need for frequent *in-situ* argon-shielded welding in cramped conditions, and almost inevitable scrapping of the components at overhaul will unfortunately continue.

Tyne LP Coupling Shaft Frettage

Typical damage to the LP coupling shaft helical splines and steady bearing are shown in FIGS. 5 and 6. These defects have come to light during planned strip,

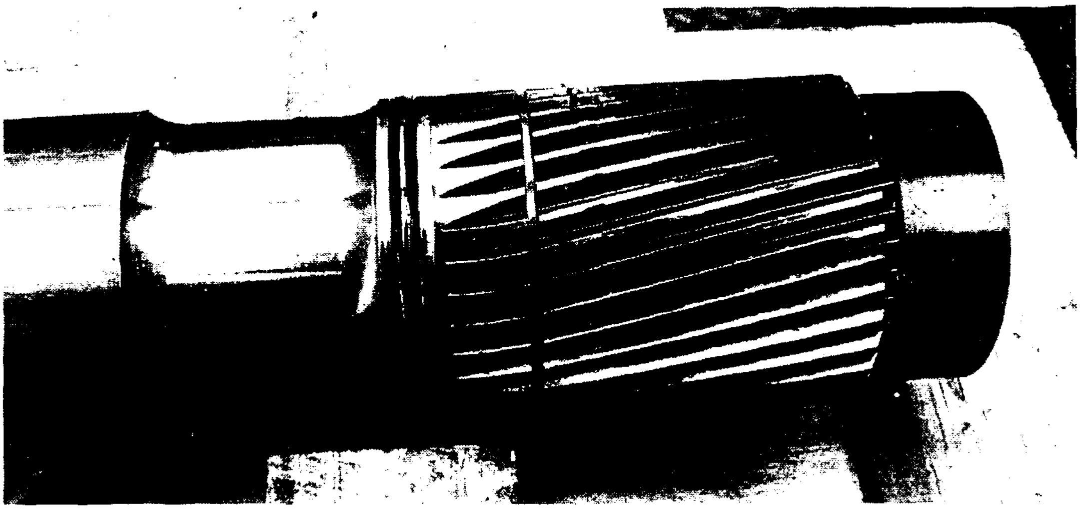

FIG. 5—TYNE LP COUPLING SHAFT: SPLINE FRETTAGE

FIG. 6—TYNE LP COUPLING SHAFT: STEADY BEARING FRETTAGE

Photograph by courtesy of Rolls-Royce Ltd.

and have not resulted in failures in service. Such defects would clearly lead to scrapping of otherwise serviceable components; repair schemes and redesign involving lengthening and nitriding of splines and improved lubrication have been developed to cure the problems.

Tyne LP Compressor Defects

Stator blading at the compressor inlet and outlet of the Tyne has experienced life-limiting defects. The hollow inlet guide vanes (IGVs) develop cracks along their length, shown in FIG. 7. This has been cured by the insertion of a dampening wire inside the leading edge and by exterior glass bead peening. More dramatic is the severe fretting of outlet guide vane (OGV) locating platforms illustrated in FIG. 8, which could eventually lead to detachment and secondary damage. This is caused by flow disturbance created upstream by the intermediate casing support struts very close to the OGVs. An interim modification to dampen the OGV root platforms by injection of Silkoset compound between the roots and the stator is proving successful. A more fundamental modification that removes the excitation by cutting back the struts is now being developed.

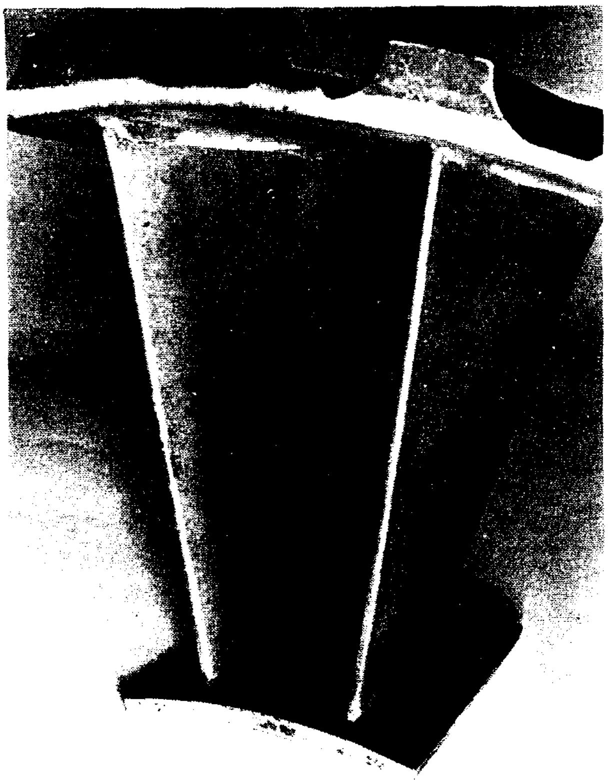

FIG. 7—TYNE INLET GUIDE VANE: CRACKING

FIG. 8—TYNE OUTLET GUIDE VANE: FRETTING OF ROOT PLATFORMS

Tyne RM1C High Temperature Problems

The higher temperatures experienced in the RM1C Tyne have produced new problems in the combustor flame tubes and HP nozzle guide vanes. Flame tube distortion is being experienced in the standard Nimonic 75 material, which the stronger C263 being evaluated as an alternative has failed to cure, as shown in FIG. 9. Nimonic 86 and thermal barrier coatings are proving likely solutions. HP nozzle guide vanes, made in cast X40 cobalt alloy, are suffering leading edge burning and cracking, as shown in FIG. 10. Improvements are under development to redistribute cooling air and to relieve thermal stresses.

Tyne RM1C HP Turbine Blade Corrosion

This well-known problem is shown in FIG. 11 for standard blades in IN738 alloy with pack aluminizing. Coating with platinum aluminide LDC 2 is being introduced; this offers an improvement of at least 50 per cent. in life. Better still are more complex commercial coatings which recent trials at NGTE have shown to be promising; it is hoped that these may be just sufficient for the 7000-hour target life of the RM1C. Further trials at NGTE are planned in 1981 which will include complex coatings under development for the U.S. Navy.

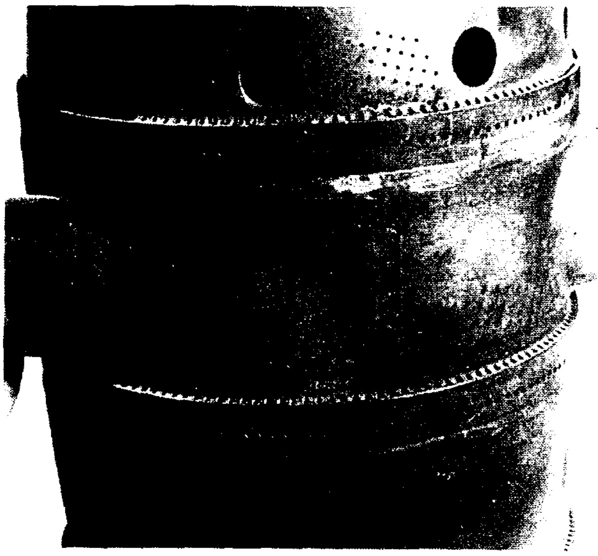

FIG. 9—TYNE C263 COMBUSTION CAN: CRACKING

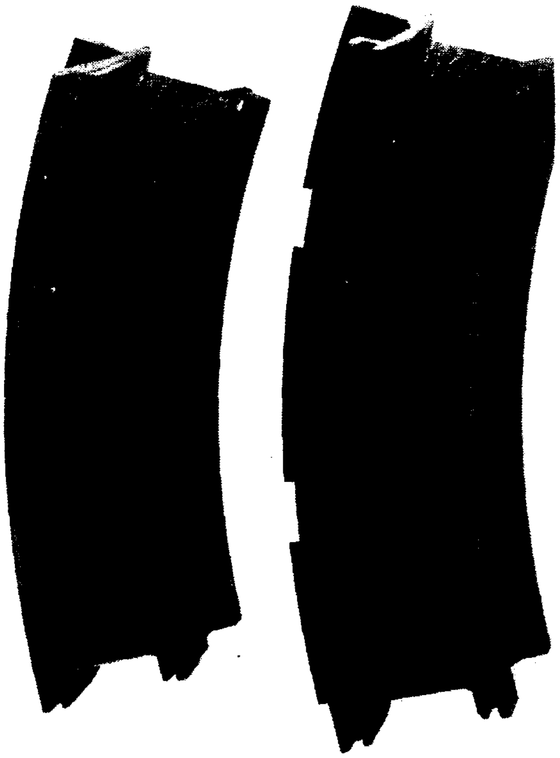

FIG. 10—TYNE HP NOZZLE GUIDE VANES: CRACKING AND BURNING

Olympus Uptakes—Type 21 Frigates

Olympus uptakes in the Type 21 frigates incorporated silencing with internal cladding secured by welded clamping strips; these welds soon cracked, leading to ejection of strip sections from the funnel. It was decided, following noise measurements in a Type 42 without silencing, that this equipment could be removed from Type 21 frigates without penalty. Accordingly a light-weight design of stainless steel uptake has been developed (with the incidental advantage of reduced topweight) and this is being incorporated at refits under Alteration and Addition 140.

Emergency Intake Automatic By-pass Doors

These doors are fitted in all the gas-turbine ships. The design appears satisfactory and operates consistently under factory test conditions; installed in a ship, however, great difficulty is experienced in achieving consistent operation during initial setting up. This is largely due to distortion of the door frame when mounted in the ship's structure. As time goes by, operation becomes increasingly unreliable because of corrosion and dirt, and doors either open well below their set intake depression level or refuse to open at all. No means are provided to prevent ice forming around the seating, and there can be little confidence that they would provide the protection required without assistance. A design of operator-controlled door is being developed for new ship designs, but for ships

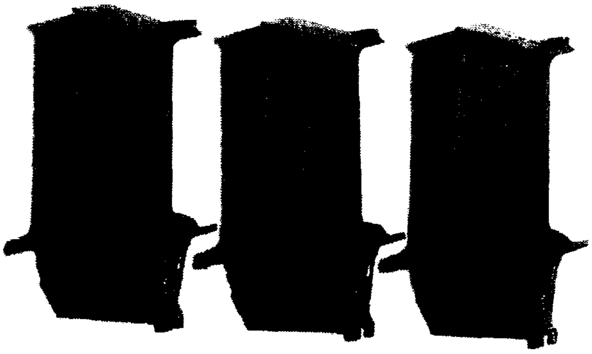

FIG. 11—TYNE HP TURBINE BLADE: CORROSION

in service action to overcome or avoid the problems is being studied urgently. There is evidence that engines are experiencing greater levels of internal corrosion due to leakage through these doors.

Introduction of the RM1C Tyne Engine

The decision to convert the Fleet completely to the uprated RM1C Tyne engine made in the mid 1970s was a very major commitment of development, production, and dockyard resources. It is only recently that it has been possible to assess the extent of this commitment in detail.

Modifications needed to convert the A-rated engine to the RM1C have, of course, been well known for a long time, and involve mainly the combustionware, H.P. turbine, L.P. turbine, and fuel pump. The first two engines have now completed conversion. It is planned to convert ten engines per year; this is expected to give a programme completing in 1986, at a turnround time of six months per engine. However, this is largely dependent upon the supply of components from industry and so, of course, is subject to large fluctuations.

Conversion of module control systems, primary gearboxes, and ship control systems to accept the RM1C needs to be carried out by dockyards at refits. Once converted, the module can accept the A-rated engine with some minor adjustments. The ship control systems must be modified to give the correct Tyne fuel schedule relating PCL setting and engine throttle demand to avoid serious control instability.

Module control system changes are:

(*a*) Speed Signal Generator—introduction of feature allowing governor datum to be set either for RM1A or for RM1C powers and speeds.

(*b*) Overspeed Trip Unit—introduction of unit with the higher speed setting needed for RM1C, with faster response.

(*c*) Pressurizing Valve—gives correct primary-to-main fuel split for RM1C burners.

(*d*) Temperature Control Unit—modification taking account of the different positions of TET thermocouples and different trip datum levels.

Primary gearbox modifications are:

(*a*) Cold oil feed to pinion bearings for improved lubrication.

(*b*) Grooved half-bearing shells for pinion bearings to improve load carrying capacity.

(*c*) Pinion lightened and natural frequency altered by drilling at free end.

(*d*) Taper land thrust bearing to accept higher thrust loads.

The RM1A to RM1C conversion programme is likely to be a dominating feature of gas-turbine support for several years to come with implications affecting every area of documentation, on-board spares, operation, etc.

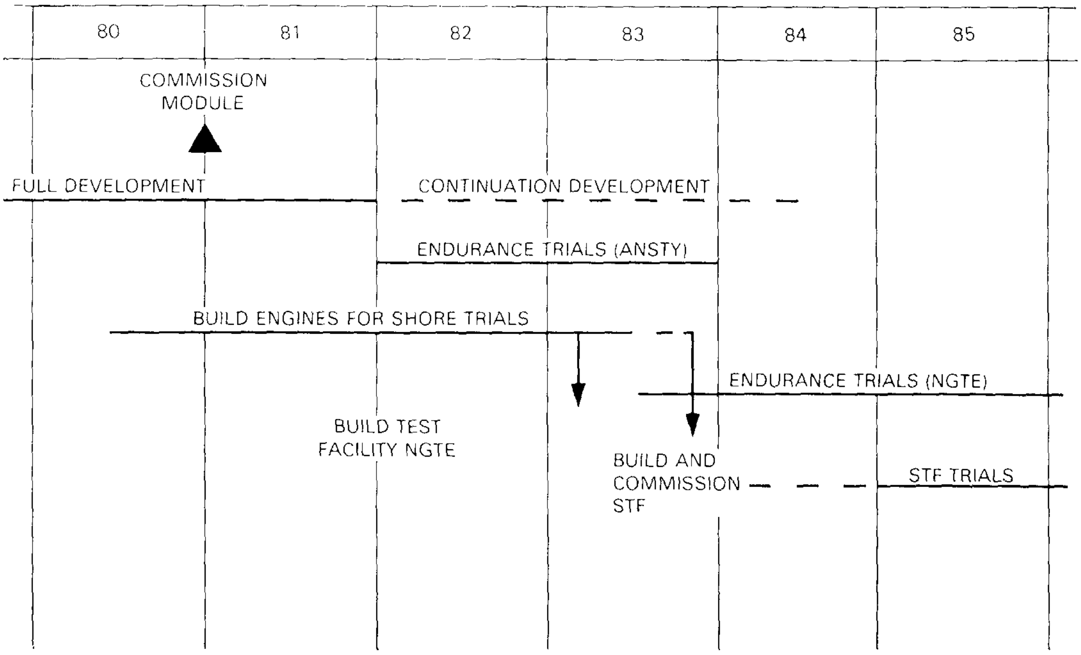

FIG. 12—MARINE SPEY PROGRAMME

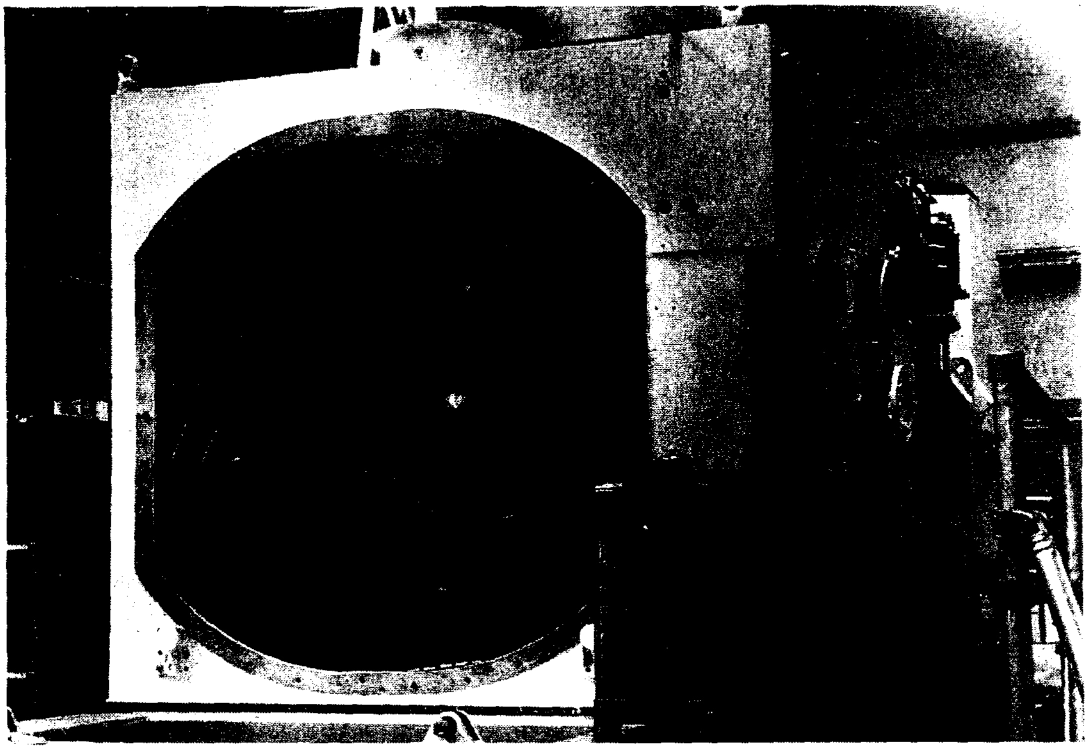

FIG. 13—MARINE SPEY MODULE

Marine Spey Development

The overall development programme, including shore testing at NGTE and inclusion in a shore test facility (STF), is shown in FIG. 12. Manufacture of the prototype module for testing at Rolls-Royce's works at Ansty is now well advanced (FIG. 13), and it is expected to be commissioned for trials by the end of 1980. Gas generator development has now achieved some 500 hours of engine running.

A novel feature peculiar to the marine engine is the reflex airspray burner (RAB) shown in FIG. 14. This device has been developed to eliminate visible

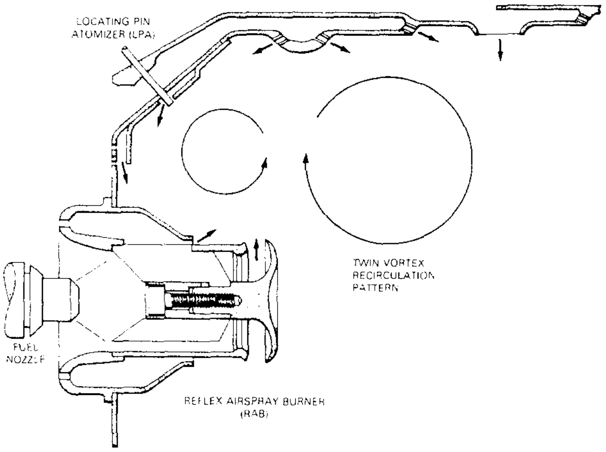

FIG. 14—MARINE SPEY COMBUSTOR

smoke when burning Dieso fuel in the marine engine; recent trials have confirmed that the mechanical integrity, ignition, and handling, and smoke levels are satisfactory, though some adjustments may be needed to reduce carbon deposits on the RAB, flame tube, and auxiliary atomizer. The combustion performance is illustrated by smoke measurements shown in FIG. 15.

Another area of new design is the introduction of cast turbine blades in both stages of the HP turbine, using IN792 alloy and a four-lobed root design compared to MarM alloys and five-lobed roots in the Mk 512 aero Spey (FIG. 16). IN792 has better corrosion resistance (although a protective coating will be required as for the Tyne) and it has a very good creep strength. The root design optimizes the balance between peak stresses governed by lobe dimensions and steady stresses.

Upkeep evaluation by DES(N) has now started though progress is limited by the availability of GTCUs and the module, and the progress of production parts and tooling. Every effort is made to undertake evaluations at the earliest possible time to allow any modifications to be incorporated in designs as soon as possible.

Conclusions

It is now mainly the marine Spey programme alone that can benefit from the lessons of the past brought out in this review. These lessons are believed to be:

Defects

Every effort is being made to ensure that each and every design defect and problem experienced in Tyne and Olympus engines and modules is either not applicable to the Spey or has been eliminated from the design.

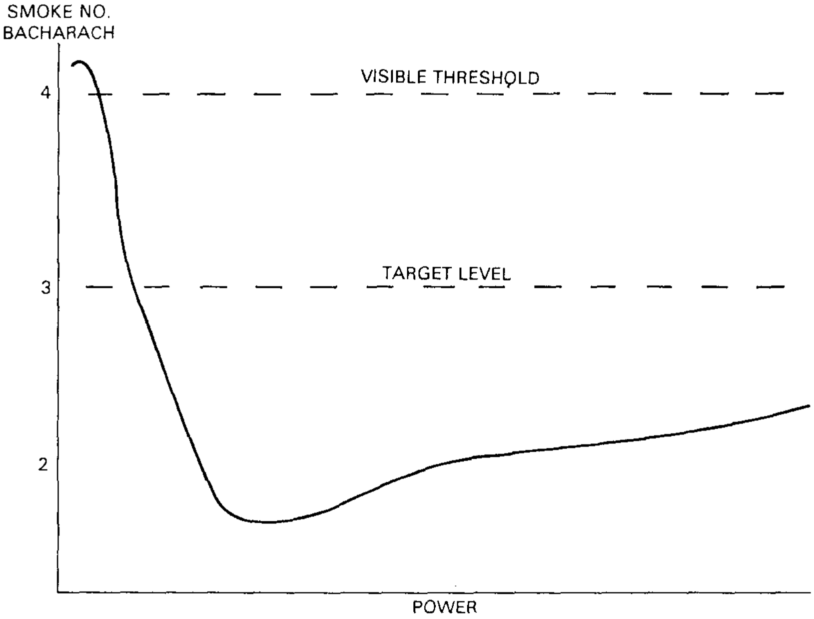

FIG. 15—MARINE SPEY COMBUSTION PERFORMANCE: SMOKE (FUEL DIESO)

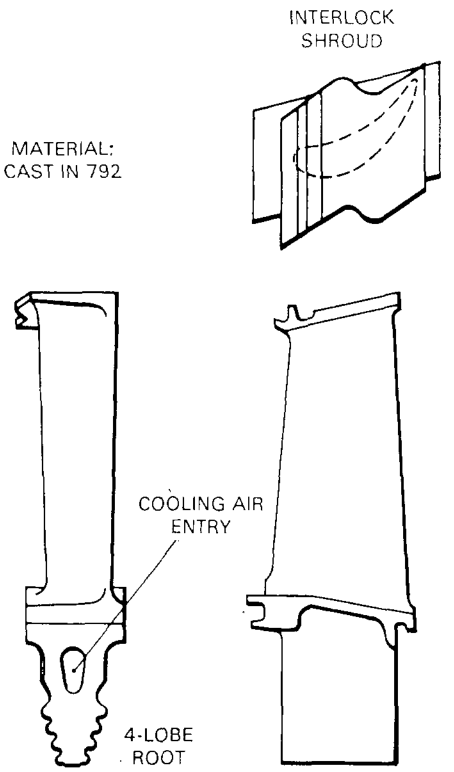

FIG. 16—MARINE SPEY HP TURBINE BLADE DESIGN

Development Status

The development programme and the accumulation of some 6000 hours of endurance testing under simulated marine conditions should ensure that the first engines to go to sea are reliable and free from any significant problems. It should not therefore be necessary to introduce major modifications requiring dockyard work and introducing possible interchangeability problems. A planned life target of 5000 hours at entry to service has been set and there is no reason to believe that this cannot be achieved.

Engine Health Monitoring

Experience suggests that existing conventional methods will be satisfactory, though it is intended to use the facilities made available in new secondary surveillance systems for vibration trend analysis and performance monitoring.

Rating

There has been exhaustive investigation to ensure that the reliability of the engine should be satisfactory when used up to the maximum no-loss temperate rating of $12\frac{3}{4}$ MW. This rating is sufficient for the applications now envisaged, but if a requirement for higher power should arise it would be prudent to recall the technical complexity, organization, and resources required to convert to an uprated engine as demonstrated by the RM1A to RM1C conversion programme.

Acknowledgement

The assistance of Rolls-Royce Ltd. Industrial and Marine Division in supplying certain figures for this article is acknowledged with thanks.