CRUISE GAS TURBINE EXPERIENCE IN THE ROYAL NAVY AND ROYAL NETHERLANDS NAVY

BY

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ABSTRACT

The Royal Navy and the Royal Netherlands Navy use the Rolls-Royce TYNE RM 1C gas turbine as their cruise propulsion engine, and the fleet achieves some 150,000 running hours per year. Each installed TYNE achieves approximately 1800 running hours per year, a large proportion of the running being at high powers. The article describes the experience of usage, maintenance and technical control of these engines in recent years, gives examples of actions taken and the results achieved. The conclusions give an assessment of the general performance of the RN/RNLN team and the likely way ahead.

Definitions

The parameters used in this article, to assess TYNE engine reliability and performance, are defined below and are based on a 12 month rolling average.

(*a*) *Premature Removal Rate (PRR)*
The quotient of the total number of gas turbine failures and the total number of hours run with all TYNEs in the fleet, expressed per 10,000 hours.

(*b*) *Demonstrated Mean Achieved Life (DMAL)*
The quotient of the total number of hours run by the gas turbines removed and the total number of removals. The gas turbines that are removed and subsequently re-allocated as being serviceable are not included in the DMAL calculation.

(*c*) *Scheduled Removals (Rr-s)*
Removals on completion of the gas turbines' designated or overhaul life.

(*d*) *Policy Removals (Rr-p)*
Removals of serviceable gas turbines for operational reasons e.g. insufficient hours remaining for deployment or ship to ship transfers.

(*e*) *Basic Removals (Rr-b)*
Removals due to a defect, failure or damage that occurred as a result of malfunction of the Gas Turbine Change Unit (GTCU), whilst being used in a manner for which it was designed.

(*f*) *Non-Basic Removals (Rr-nb)*
Removals due to a defect, failure or damage that occurred when the cause was external or was not confirmed during overhaul.

Introduction

The RN and the RNLN have been co-operating in the field of marine gas turbines for over twenty years. The current agreement is in the form of an international Memorandum of Understanding (MOU), which was signed in 1975 and covered both technical and logistic support. This MOU also covers the Rolls-Royce marine OLYMPUS TM3B main or boost engine, where the RN and RNLN are joined by the additional partners of the Belgian and French navies. The main objectives of the MOU are to:

(*a*) To benefit from the economies of scale, thereby minimizing costs.
(*b*) Operate a common pool of GTCUs and spare parts.
(*c*) Achieve an equitable financial arrangement.
(*d*) Adopt and retain common maintenance and engineering policies.
(*e*) To ensure retention of identical technical standards and similar utilization of the GTCUs and ancillary equipment.
(*f*) The provision of mutual operational support.

The MOU covers some 46 ships, that have 92 cruise engine seats, supported by a total of 119 GTCUs. This allows 20 in transit/rework and a planned pool stock of 7.

Brief description of the engine

The marine TYNE RM1C is an aero-derivative simple cycle gas turbine engine, with a two spool high pressure ratio gas generator. Each compressor is driven by it's own single stage turbine and there are ten flame tubes housed in an annular casing. The engine incorporates it's own two stage power turbine, from which a drive shaft extends to the primary gearbox. At a turbine entry temperature of 1274K and at an ambient temperature of 15°C, the engine is rated at 4 MW. The TYNE marine engine is now considered to be mature, however it will see service with the RN and RNLN well into the next century. (FIG. 1) illustrates the difference in configuration of the aero and marine versions of the engine.

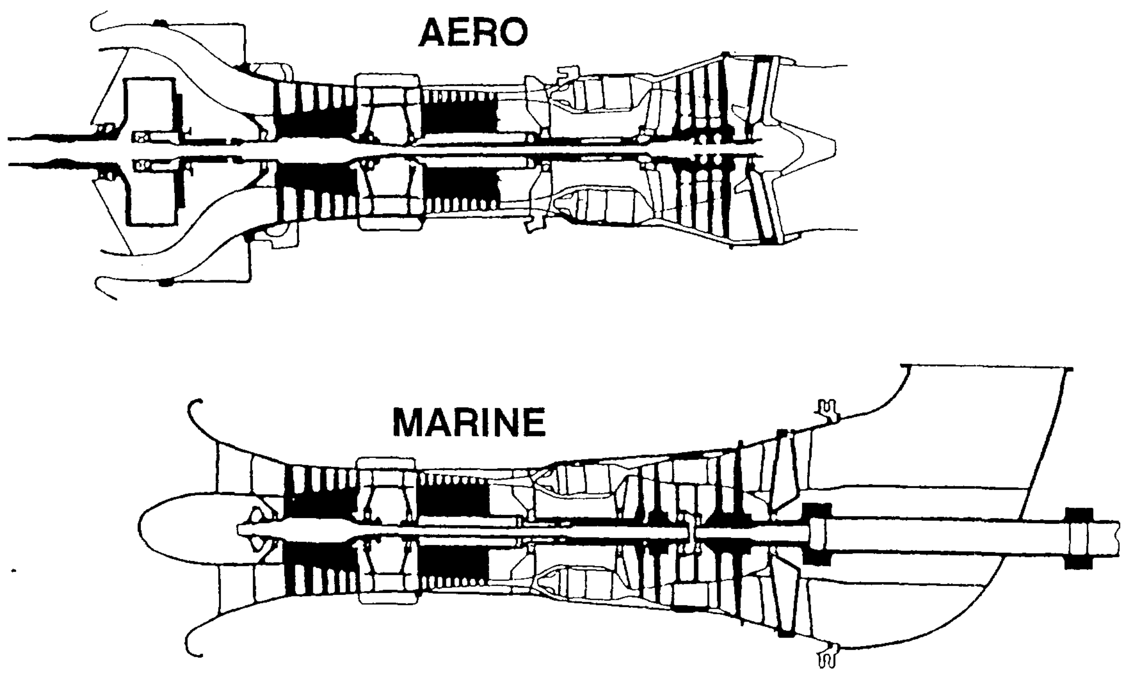

FIG. 1—MARINE AND AERO TYNE CONFIGURATIONS

Engine operation

Generally the TYNE cruise engines are used by the RN and RNLN, in combination with the OLYMPUS in a Combined Gas or Gas (COGOG) configuration, with one engine of each type per shaft. The reason for this configuration was due to the projected operational speed profile, necessary utilization of ship propulsive power and the relatively high fuel consumption of the OLYMPUS at low powers. In the frigates and destroyers of the RN and RNLN, 25% of the total propulsion power available is sufficient for 80% of all operations. A typical frequency distribution of time at power for a destroyer is shown at (FIG. 2). The specific fuel consumption of both engines is shown at (FIG. 3) and the advantage of operating the TYNE at low power is clearly seen.

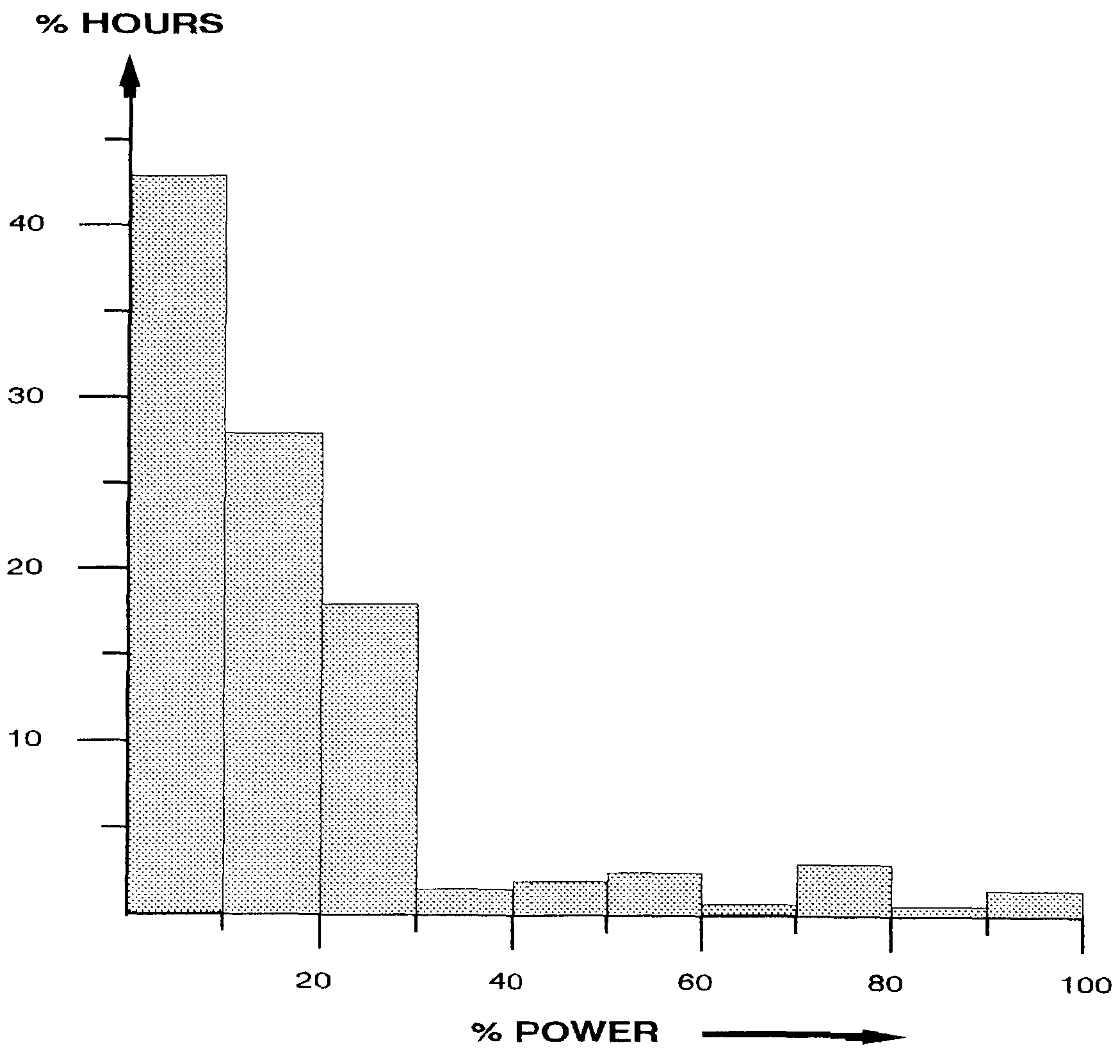

FIG. 2—FREQUENCY DISTRIBUTION OF TIME SPENT AT VARIOUS PROPULSION POWERS
DESTROYERS ALL DUTIES

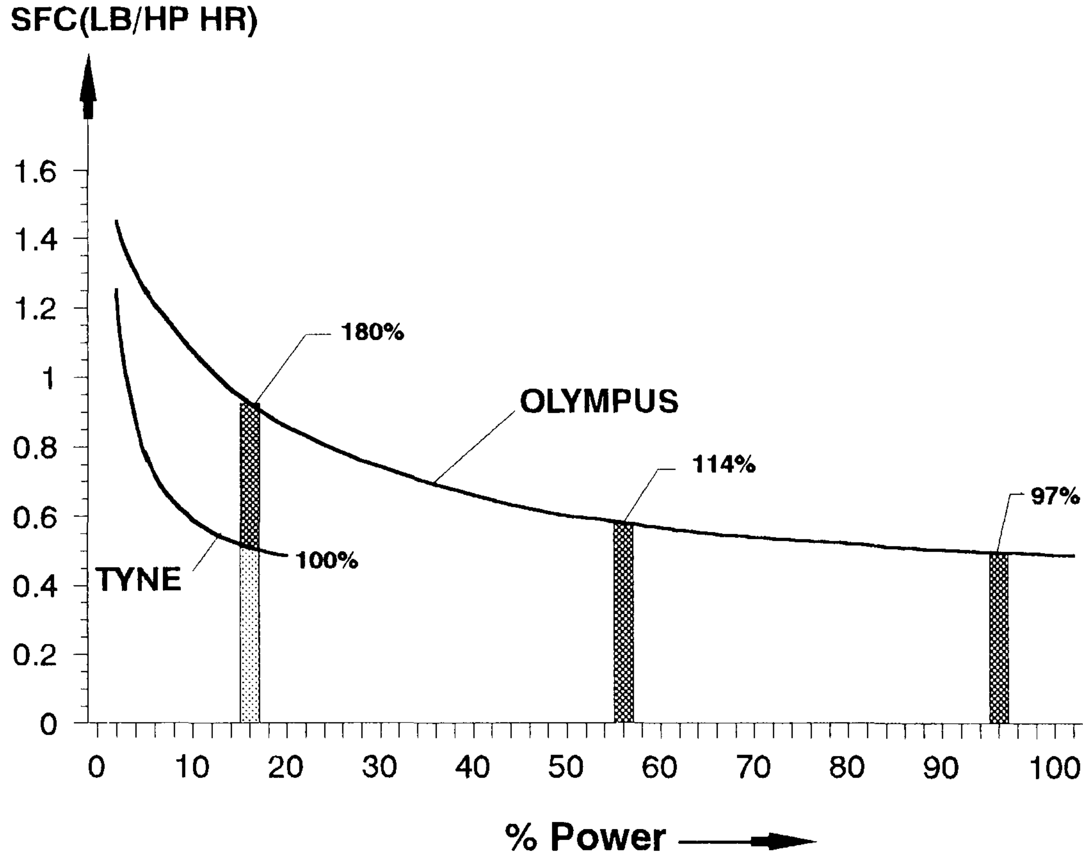

FIG. 3—FUEL CONSUMPTION CHARACTERISTICS

The ships use the flexibility of the COGOG configuration to achieve the best fuel economy in operation. The 'Pie' chart at (FIG. 4) illustrates the typical engine usage in destroyers. The TYNE cruise engine is in use for over 40% of the time in single shaft mode and a further 40% of the time with both TYNE engines providing propulsion power. Over recent years there has been a change in engine usage. Due to the need to achieve new and lower targets of fuel economy, the TYNE has seen higher utilization.

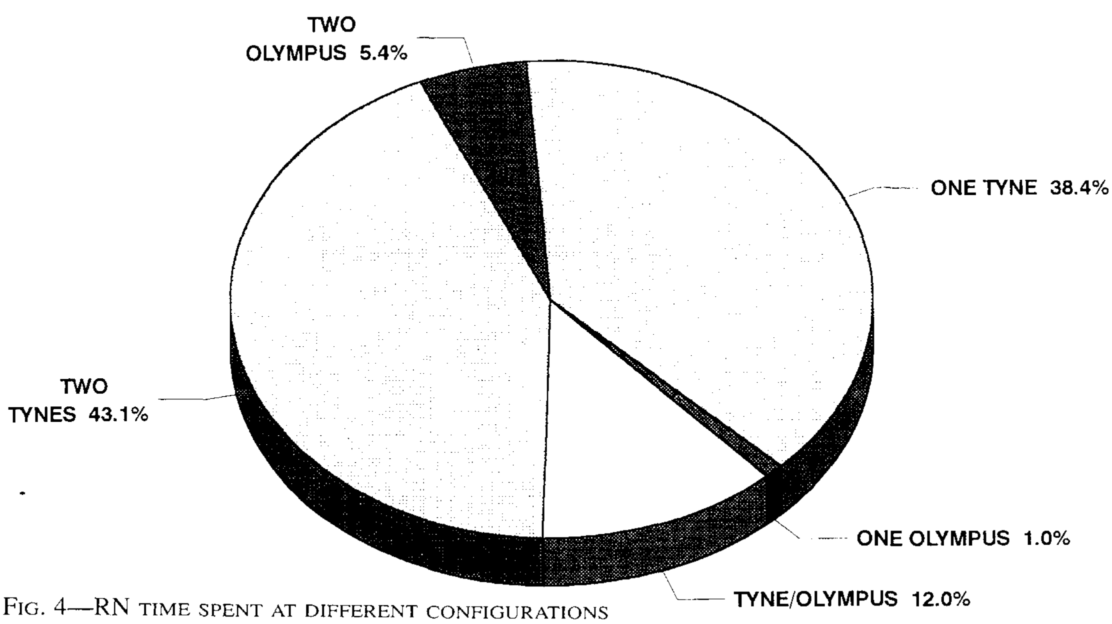

FIG. 4—RN TIME SPENT AT DIFFERENT CONFIGURATIONS
TYPE 42 ON ALL DUTIES

An example of a typical time/power profile of a TYNE engine in a destroyer, prior to 1990, is shown at (FIG. 5), and this is compared with the current situation later in the article. It will be noted that there was a high proportion of time spent above 80% power. The top band of power was known to be used almost exclusively at 100%.

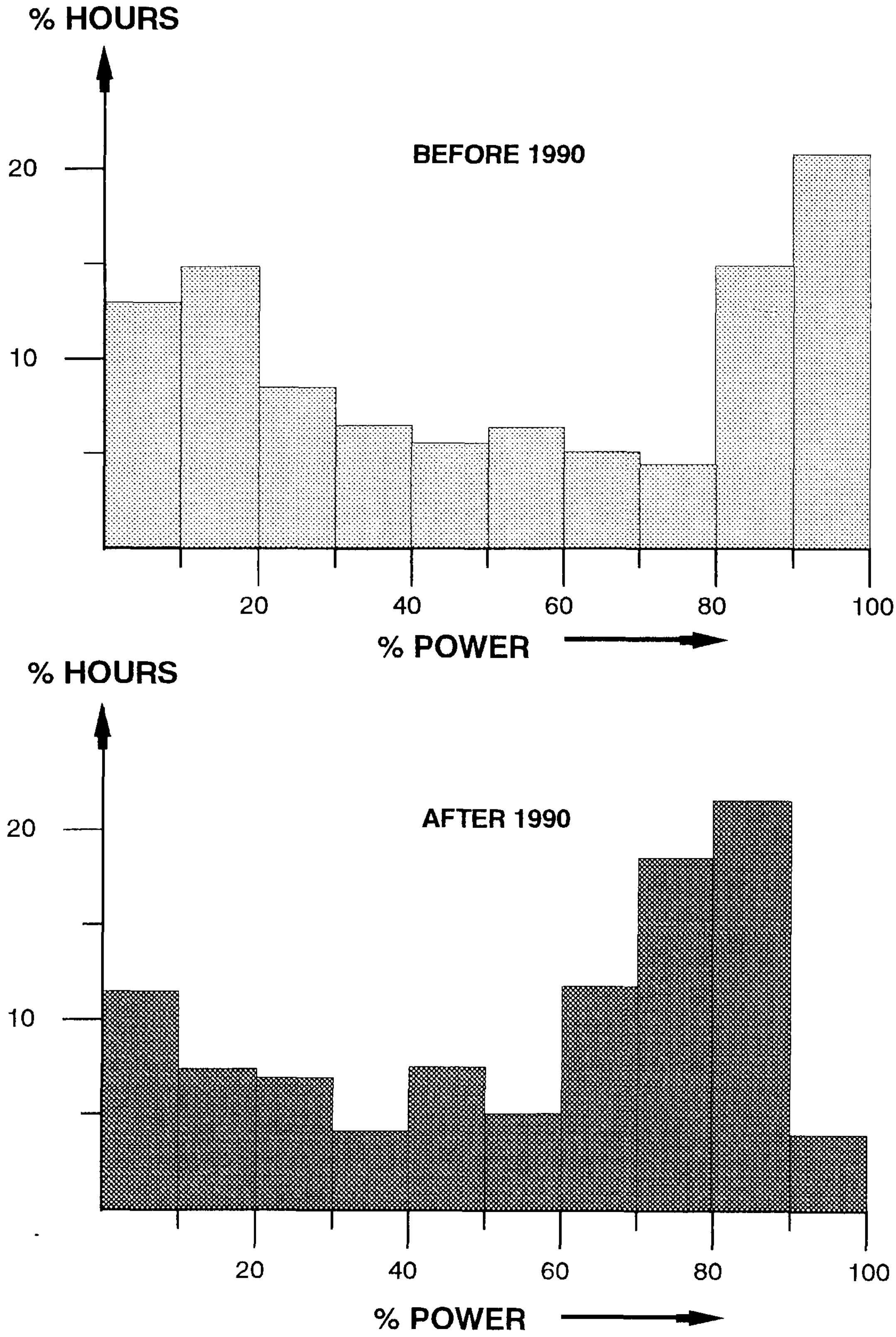

FIG. 5—RN CRUISE ENGINE TYNE/POWER PROFILE

Maintenance policy

The maintenance policy and the manuals used ashore and on board, for RN and RNLN cruise gas turbines are identical; the language used is English.

The standard approach was (and still is) to adopt a system of 'upkeep by exchange' for the GTCU and ancillary equipments. The main reasons for this is that it:

- Reduces operational 'down time'.
- Increases ship availability.
- Minimizes manpower and skill levels necessary for ship's staff.

All important factors for smaller navies.

Some 'in place' repairs are carried out on the basis of exchange of components, such as combustion chambers, external gearboxes and engine/enclosure mounted accessories. The capability for on board repairs has been developed for certain accessories and ancillary equipment, but the use is reserved for cases of operational/logistic need.

Lifing policy

Prior to 1986/7 the policy was to remove GTCUs in accordance with strict rules based on hours run. The engine was said to have a planned life of 5,000 hours, with the possibility of a life extension of 500 hours on inspection at 5,000 hours. This policy was amended in the last two years to allow greater flexibility, once experience was gained and areas of risk identified.

The remainder of the article records the experience from this stage recording actions taken and results obtained.

Experience within the years 1986–1989

The TYNE engine overhaul policy was changed in 1985/6, to introduce what was called a 'hot end overhaul' at alternate 5,000 hour intervals, with little or no other work on other parts of the engine. The intention being that the engine would effectively achieve 10,000 hours between full reconditions, this being a cost savings measure. The strict rules governing life and engine removal were retained.

However the result of the introduction of this policy was:

(*a*) An increase in test bed rejections, mainly due to LP compressor vibration.

(*b*) In service engines were rejected at low running hours for reasons of cracked LP compressor vanes, vibration and bearing problems also in the compressor section.

During this time the overhaul bases were also having problems in maintaining their normally high standard of quality. The net result was that in the years 1987 and 1988, DMAL steadily decreased with both premature and total removal rates increasing rapidly, this is shown on the graphs in (FIGS. 6&7). The major problem being low running hour removals, reflected by the sharp increase in Basic removals in Table 1. Looking at rejections under 1,500 hours over 4 years also illustrates this:

TABLE 1—*Number of TYNE failures below 1,500 hours per year*

Year	1986	1987	1988	1989
Failures	4	14	11	6

The above situation was made somewhat worse by an increase in military tension in the Iraq—Iran war and the numbers of engines in ships, with both

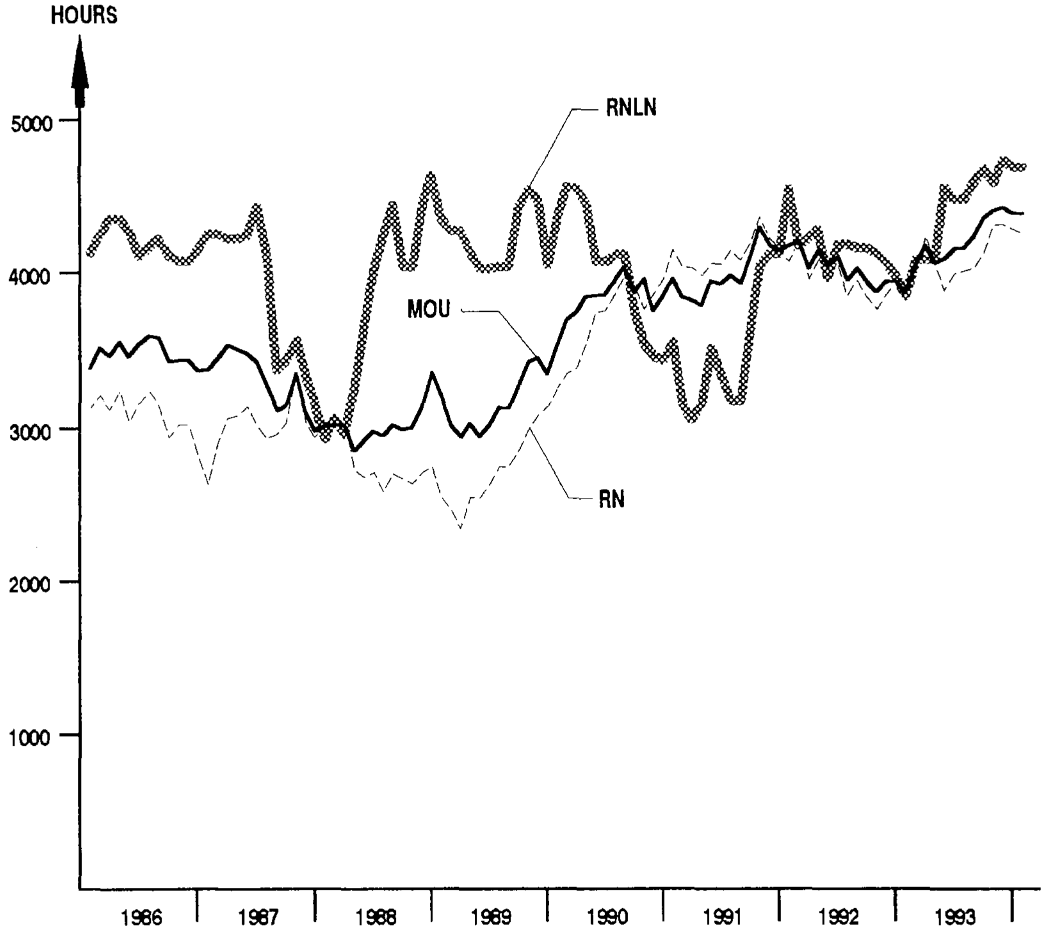

FIG. 6—TYNE DEMONSTRATED MEAN ACHIEVED LIFE

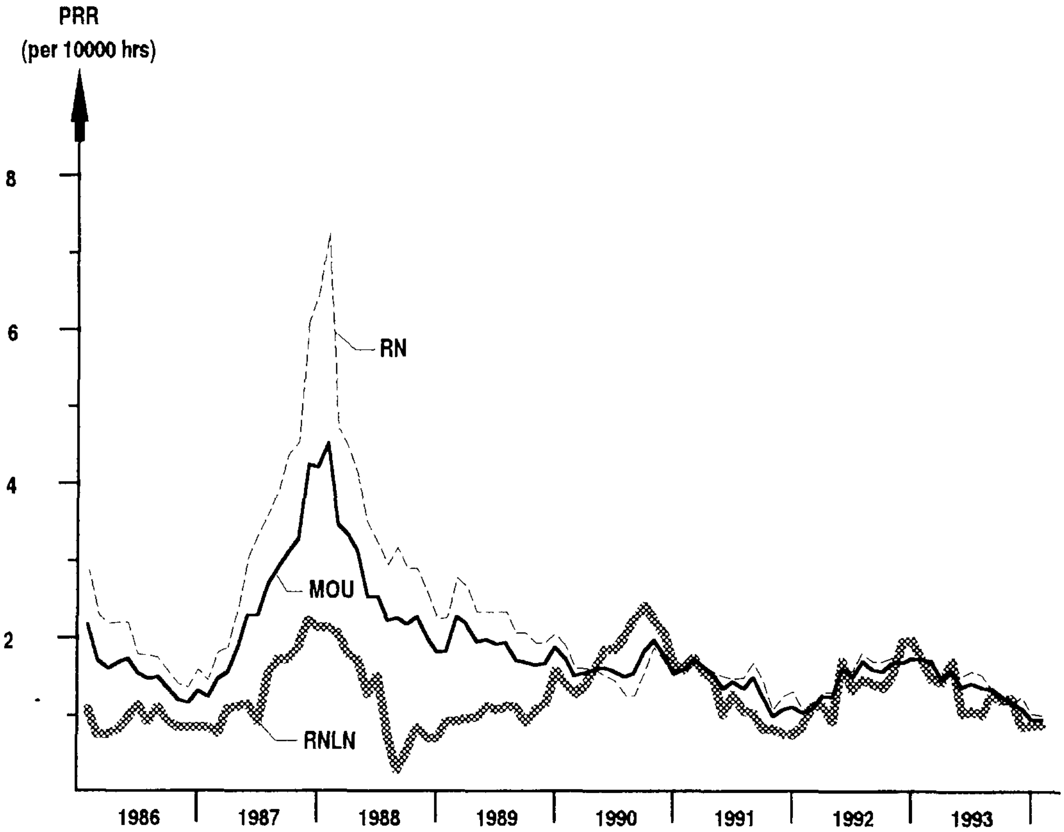

FIG. 7—TYNE PREMATURE REMOVAL RATE

navies, reaching the maximum. The first of these increased demand by the deploying ships creating more Policy removals to the overhaul lines. The second caused a demand for the production engines that had hitherto been used in support of the pool of engines, which severely reduced the level of serviceable engines in the common pool.

The recovery actions commenced in the latter part of 1987 with an in-depth review of test bed rejections and overhaul procedures, which continued through until mid 1988. This review was carried out with the full co-operation of (and between) the two engine overhaul bases at Rolls-Royce and the Royal Naval Aircraft Yard *Fleetlands*. This identified the main areas which needed attention in the cold end of the engine and resulted in an improved work package called 'hot end overhaul and cold end repair', this was subsequently termed 'mini-overhaul'.

In parallel, a review of in-service removals by cause was undertaken to establish areas where actions could be taken to effect an improvement. Three causes were identified as being responsible for over 35% of the removals:

(*a*) *'0' Stage Stator aerofoil cracking.*

Two actions were taken:

1. Extend in-service acceptance standards.
2. Introduce a silicon rubber filling to damp aerofoil vibrations.

These measures were in place by the end of 1988 and there have been no engine removals for this cause since.

(*b*) *LP spool vibration.*

Three actions were identified as being necessary:

1. Improve the balancing methods in one of the repair facilities.
2. Modify No.1 bearing housing to reduce clearances to the outer race.
3. Ensure that the LP compressor steady bearing clearances were maintained at mini overhaul.

Now that these actions are in place, engine removals for vibration are rare.

(*c*) *HP turbine NGV cracking/erosion.*

Although a modification was being developed and on trial in the fleet, it's embodiment was viewed as a long term solution. An investigation into damage being experienced was mounted, resulting in revised acceptance standards for in-service use. Since these have been issued, only one engine removal has occurred for this cause. Trials of the above mentioned modification have therefore been cancelled.

The above actions had stabilized the removal and reliability statistics by the end of 1988, however specific problem areas remained:

(*a*) The common pool of engines had been under the designated level for many months and had approached zero on many occasions.

(*b*) A distinctive difference in achievement of TYNE running hours between shop visits also existed between the RN and RNLN, expressed in terms of DMAL it amounted to over 1,000 hours in favour of the RNLN. Some of this was undoubtedly due to the numbers of low hour basic removals suffered by the RN in 1988 due to changes in policy and quality at overhaul.

Investigation was considered necessary and early in 1989, discussions were arranged, between the RN and RNLN. The teams comprised representatives from the operators, ships project and specialist gas turbine staff. The details of method of usage, operation, maintenance of the gas turbine system and associated equipment, such as the ships fuel and air separation systems, were examined in some detail.

These discussions resulted in several changes in policy, the effects of which were:

(*a*) *Power reduction*

The records of the engines at overhaul bases were examined to establish:

- The condition of component parts.
- Cause and level of rejection.
- If differences existed between the RN/RNLN or ship classes within the fleet.

Two families of engine were established, this was evident by the condition of hot end components, scrap levels were high overall, but the components from the RN engines were significantly worse. The combustion ware, NGV's and rotor blades on all engines showing signs of high/excessive temperature operation. A study of the operational usage indicated that the RN spent a higher proportion of it's time at higher power levels, although at the time this was not thought to be significant. The RNLN had two TYNE engines on trial at 90% power, one of these became available at overhaul and was found to be in excellent condition.

In the middle of 1989 both navies adopted the practice of operating their TYNE engines at a reduced power level of 90%. Examining the current operational profile or time at power as shown in FIG. 5, indicates that the higher band of power was in fact distributed amongst several power bands and not merely added to the next lower band. The small amount of use in the highest band is due to a requirement for setting to work, checking governors etc.

This change has contributed significantly to the increased reliability/availability of the TYNE engine and consequential savings.

(*b*) *Life inspection policy*

The policy of inspection at 5,000 hours and possibly allowing only a further 500 hours, meant that there was insufficient life remaining to plan ahead and to fully use the life remaining. The team agreed that in future these examinations should take place earlier at 4,200/4,500 giving a life to 5,500 hours with the aim eventually, if engine condition allowed and ship's programme required, to extend to 6,000 hours. This change has allowed better planning of the continued usage of engines and been successful in that in the last year, many more engines have exceeded 5,000 hours than previously.

(*c*) *Policy removals and fleet management*

Policy removals concern the removal of serviceable engines, when for example a ship enters a refit period or there may be insufficient hours for the next deployment. Prior to 1989, a large number of these engines would go to the overhaul base for overhaul (sometimes two engines from one ship if running hours were equal). The navies agreed that engine hours needed to be managed such that there was a difference in running between the two shafts, basically designating a preferred engine. The objective being, to ensure that when a ship entered a period of maintenance requiring both engines to be removed, one engine should have useful life remaining, rather than both having insufficient life for deployment.

The minimum engine hours allocated for all regular deployments were also reviewed. A study of the historical records revealed that a strong case could be made for giving a reduced number of total engine hours available, providing that one engine met minimum criteria in terms of remaining hours.

These two actions reduced Policy removals from 1.2 to 0.3 per 10,000 hours or by approximately 5 engines per year. Although this parameter has slightly increased during the last year or so, due to an increased number of 'ship to ship' engine transfers in order to maximize the engine in-service life to 6,000 hours or over.

(*d*) *Modification policy*

The marine TYNE engine being mature and noting that changes can be expensive, a much stricter modification policy was adopted. Modifications would only be approved if they are related to safety, obsolescence or operational reasons. The emphasis was to be put on the completion of the embodiment of existing modifications, particularly where these were known to improve reliability. The relaxation, where possible, of in service acceptance limits was to be adopted in preference to modification action. It was agreed that the latter would be approached in a fairly conservative manner.

Experience within the years 1990 to 1994

The experience in the previous years indicated a need for an improved method of monitoring the trends associated with the engine's reliability, removal and defects. Early in 1990 a database covering these aspects was commissioned and is now in use allowing on line presentation of data in both graphical and tabular form. The database is updated regularly with information concerning engine removal, running hours, defect codes, overhaul work etc. This ready access allows detection of improving/worsening trends in reliability and availability with the formulation of appropriate actions, be they in the overhaul shop, on board or should a change in policy be dictated.

Examples of various ways of presenting and using these data are shown:

(*a*) *Removal Rate*

The chart at (FIG. 8) shows the highest level of monitoring carried out, the removal rates, policy, scheduled, basic and non-basic are calculated on a twelve monthly rolling average. Each of these statistics may be ascribed to part(s) of the organization and their effectiveness:

Policy Removals —Technical and user departments.

Scheduled Removals—Generally the equipment has performed satisfactory.

Basic Removals —Overhaul bases and maintenance.

Non-Basic Removals—Generally maintenance or incorrect diagnosis.

(*b*) *Overhaul procedures*

Late in 1989 and in the early part of 1990 a sudden occurrence of rejections due to internal failures of an external gearbox was noted, some of these occurring at relatively low running hours. As engine removals were assessed, it soon became clear that one of the two overhaul bases was responsible and following investigation was found to be mis-interpreting the requirements of the overhaul specification.

(*c*) *Combustion chambers*

A typical example on the TYNE engine, where the reliability database indicated that an improvement was possible, was in the combustion chamber area. The increasing reliability of the engine allowed a far greater number of engines to get beyond 4,000 hours. This exposed more combustion chambers to life extension inspection. In 1991 thirteen out of fifteen engines were rejected due to degradation of the combustion chambers at the life inspection stage, at an average life of 4,300 hours. Maximizing the life of these engines, besides increasing availability, could offer savings in the order of £1.6M per year.

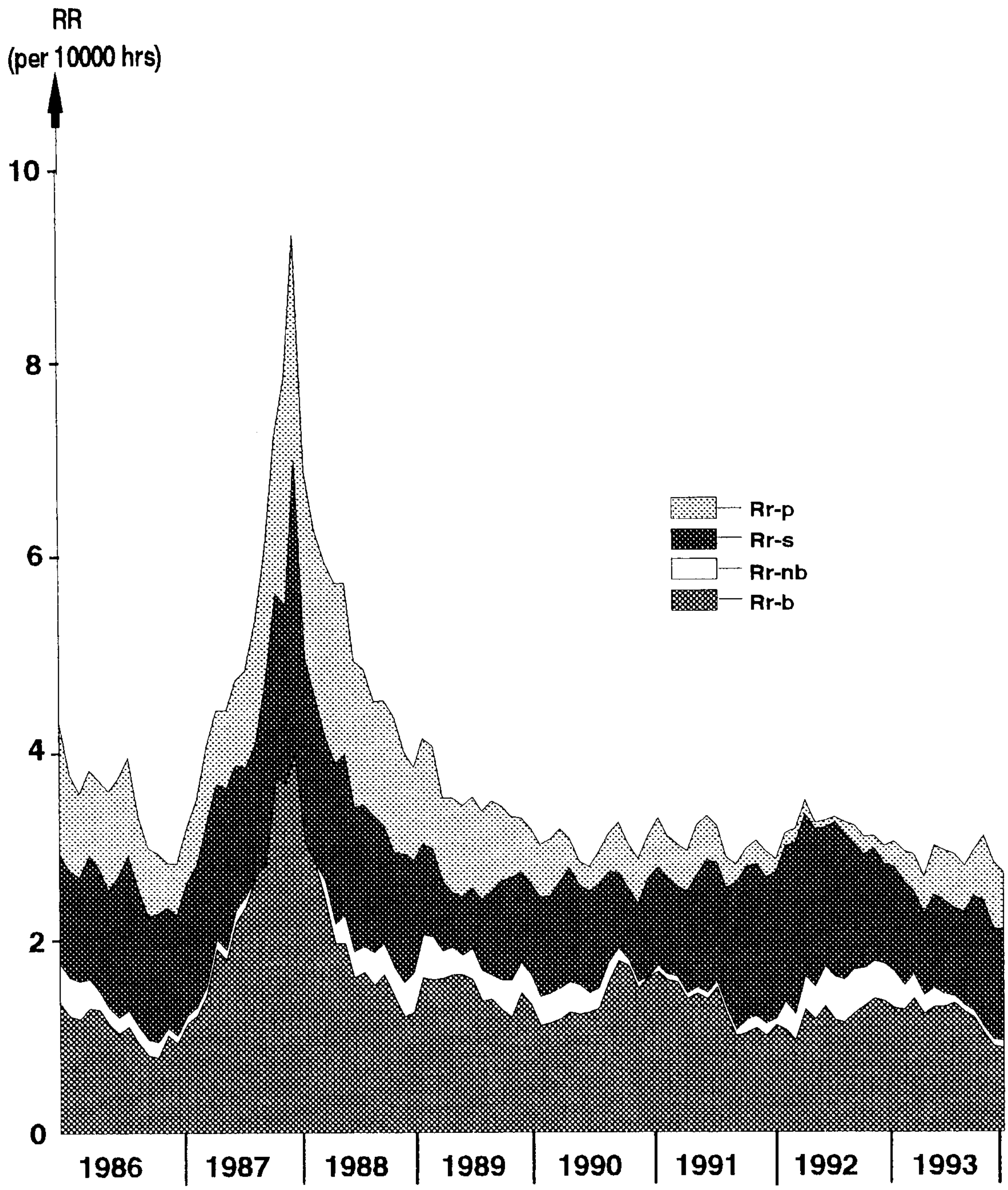

FIG. 8—TYNE REMOVAL RATE

Analysis of the hardware at overhaul confirmed the possibility of considerable relaxation of in service acceptance limits. This included the lengthening of cracks and allowing metal loss acceptable up to a maximum of 3 primary zone cooling holes (213 mm^2) in the primary zone and 4 holes (280 mm^2) in the secondary zone respectively. This criterium was given to aid the specialist inspection team, when carrying out boroscope inspections. The revised limits were issued early in 1992, the result being only five engines were rejected for this cause in 1992 and two in 1993. A contributory factor in this has been the introduction of a few in-service combustion chamber changes, when the remainder of the engine seems to be capable of achieving 6,000 hours or more. This maintenance task had fallen into dis-use, due to manpower constraints, the high numbers of engines involved and difficulty in performing the task.

A parallel investigation was also being conducted into the possibility of modifying the whole chamber (or only the front two sections) by a change of material. This was found to be technically practicable, 7,300 hours being achieved in a service trial. The modification however was rejected as not being cost effective due to the improved life being obtained with the revised acceptance standards.

(*d*) *Logistic simulation*

The data collected and processed within the reliability database are also used as in-puts for the RN Logistic Simulation Model. This model provides an estimate of likely engine arisings/removals to the overhaul bases over a 10 year period. Allowing the provision of the necessary overhaul spares, materials and facilities to support the in-service engines.

The actions above and with others like them, the statistics by which the reliability of the engines are judged have improved and been maintained throughout 1993 and 1994. The availability of the TYNE cruise engine has improved to an acceptable level and has clearly influenced the life distribution of the installed engines. The change in the life distribution of the engines is shown over the period from 1986 to 1994 in (FIG. 9).

The policy controlling the life of the engines and components in the fleet has been modified to allow a much more flexible approach, treating the planned life as a target to be exceeded. Engines now regularly achieve over 5,000 hours, areas of risk have been identified and progress to extend limits of acceptance and running hours will be approached in a fairly conservative manner.

Another area of improvement achieved has been the declared in-service life of critical components such as discs, spacers, and shafts. The life of these components, subject to low cycle fatigue, is controlled by converting the safe cyclic life to running hours. The cyclic life of these components, obtained from stress assessment and cyclic rig testing during development, is divided by a factor originally derived from an assessment of service operation. The RN and the RNLN have installed low cycle fatigue counters in a representative number of ships, to collect data. Analysis of this data has recently enabled life of these components to be increased significantly (33%), many of them will now complete the total predicted engine service life.

During the last year or so, an in-house database has been developed which records the modification status of each engine. This tool is currently in use by the overhaul lines to determine which modifications are to be, or are embodied and also produces the engine log books. The modification and reliability databases can also be linked to investigate the impact of modifications embodied on reliability.

The future

The current predictions are that the TYNE cruise engines will be in service with the RN and RNLN until about the year 2015. There will be an almost linear decline in the numbers of engine seats from todays level of 92.

The way ahead is seen as being one of continued vigilance and assessment of in service experience, searching out the 'hurts' and applying a no nonsense approach to achieve a cost effective solution.

In brief, the following will be the MoD approach:

(*a*) Regard the planned life of the engines as being a target which may be exceeded in a controlled manner. Areas of risk will be further investigated and cost effective solutions found to allow increased running hours and lower removal rates to be achieved. The life of critical components will be respected.

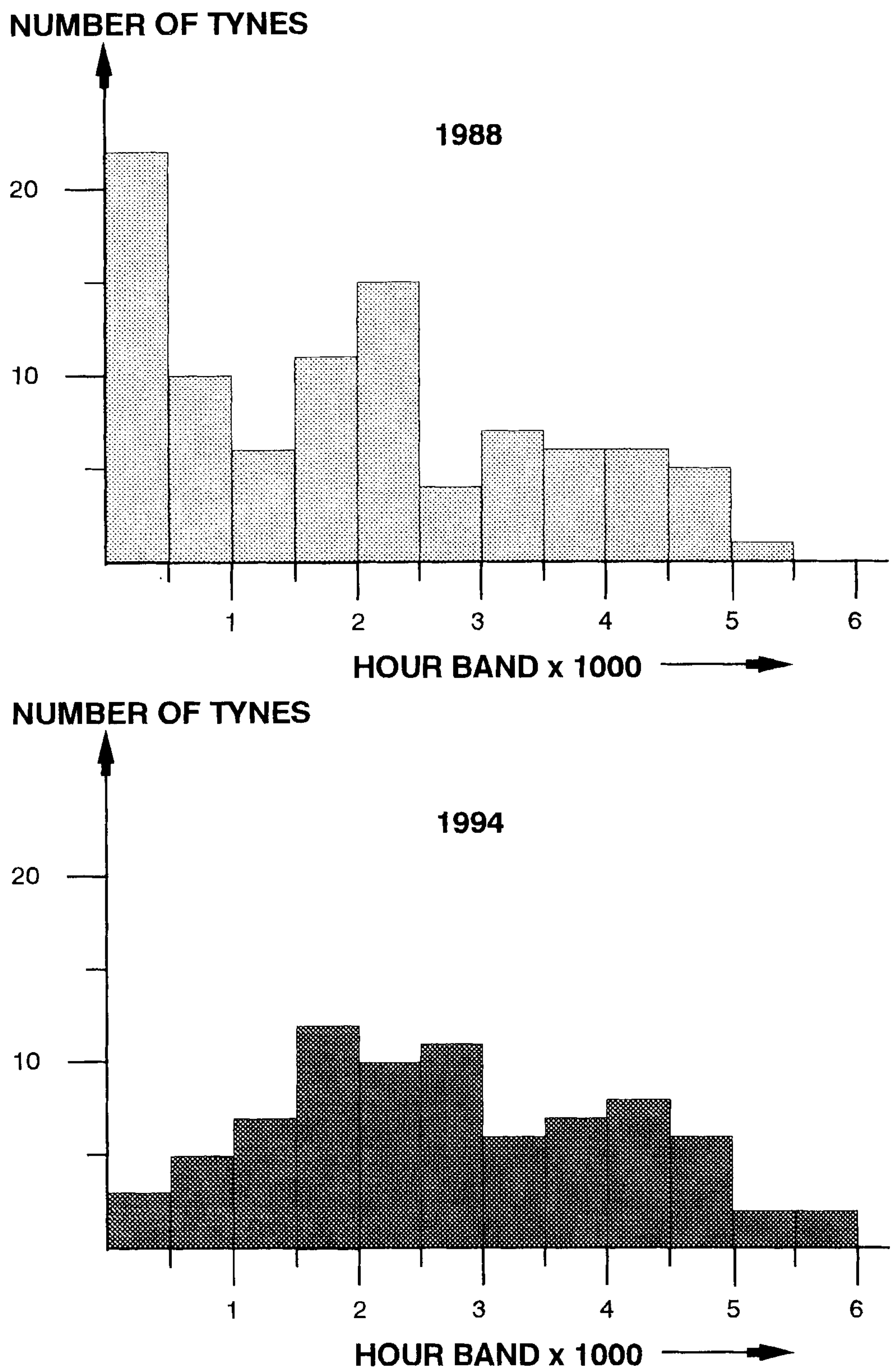

FIG. 9—TYNE LIFE DISTRIBUTION 1988 VS 1994

(*b*) Develop, on a priority basis, improved in service acceptance limits allowing extended running whilst managing risk.
(*c*) Modifications will only be considered for reasons of safety, obsolescence and to resolve operational 'hurts'.

(*d*) Change, whether in configuration, maintenance or policy, nearly always involves expense. Budgets have become tighter and therefore 'financial appraisals' have become a necessary discipline. The solutions adopted will have to pass the 'how much' question, and if the answer is not 'a saving', a very good technical case will be essential.

(*e*) The maintenance policy for these engines will continue to be 'upkeep by exchange', rather than 'repair in place'. This policy has advantages for the smaller navies, as described above.

(*f*) The continued support of the engines in the latter years, as numbers get fewer, will need to be considered with the method of disposal of the ships. If ships are sold complete with gas turbines and some spares, a balance between the requirements of the RN and RNLN and their customer's interests will have to be made. Should the ships be scrapped the support position will be somewhat simpler but be lead by the operational requirements and the ever present financial consideration.

Conclusions

During the last 6 years or so, the RN/RNLN team has been successful in the management of the cruise engine such that the fleet has always had spare engines available. Although in the earlier days the situation became critical, particularly with the fleet coming to full strength at a period of international tension and increased pressures on fuel economy. The latter involving higher annual running hours of the cruise engine than previously planned.

The engines in the last two years have performed well with the improvements, in reliability and removal rates, achieved being maintained. Tables 2 and 3, compare statistics from 1988 with those at the end of 1993.

TABLE 2—*Improving reliability trend from 1988*

Year (January)	DMAL	Total removal rate
1988	3000	8.2
1991	3900	3.2
1994	4400	2.7

TABLE 3—*Number of* TYNE *basic failures below 1,500 hours per year*

Year	1986	1987	1988	1989	1990	1991	1992	1993
Failures	4	14	11	6	4	2	3	0

The estimated savings in terms of the overhaul and repair, afforded by the improved reliability currently achieved, is estimated to be some £4.5M relative to 1988.

The future years will be approached with some confidence that this can be maintained and in some areas possibly improved. It has been recognized that there will still be a need to manage risk and produce solutions to 'in service hurts' that are both cost effective and technically acceptable.

Acknowledgments

The authors express their appreciation to the engineering and overhaul personnel from both Rolls-Royce plc and RNAY *Fleetlands*, the FCOGOG team and RNLN gas turbine department, who all contribute to the successful upkeep of the TYNE RM1C marine cruise engine.