



# **THE GEM ENGINE**

by

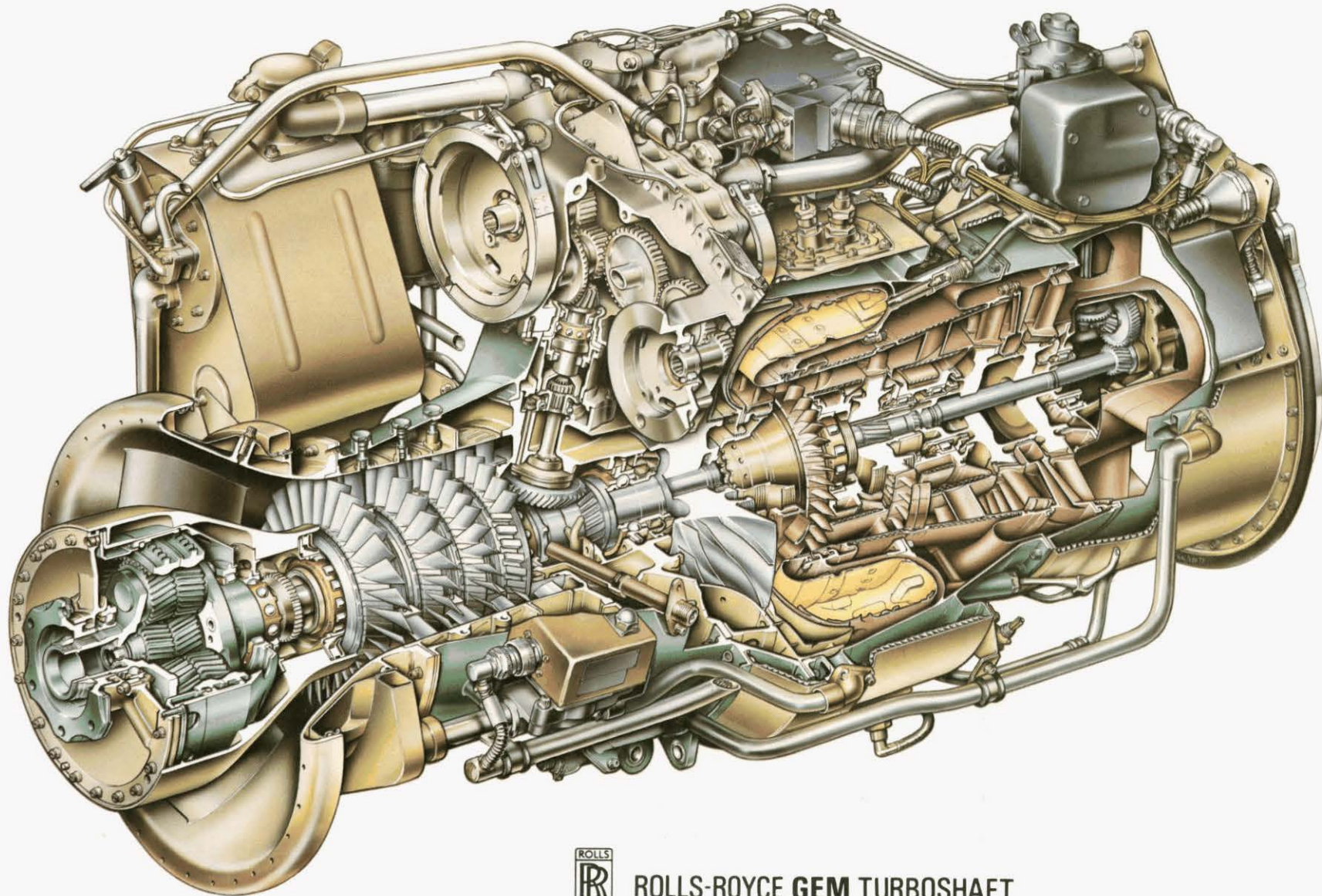
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## ABSTRACT

The Gem engine is already very well known to the helicopter industry as the powerplant for the Westland Lynx and the WG30 helicopters. However, the engine is only at the beginning of a life cycle which is anticipated to continue for many years into the future. It is, therefore, worthwhile making a review of the extensive development programmes which have led to the current position and make an assessment of what has been achieved at this time.

Such a review leads naturally into an examination of future developments and the ongoing programmes to match the engine to the new requirements of the industry. Thus the engineering process is continuing with major programmes to reduce new and operating costs, introduce new technology, achieve power growth and apply the engine to new installations.



ROLLS-ROYCE GEM TURBOSHAFT

## THE GEM ENGINE

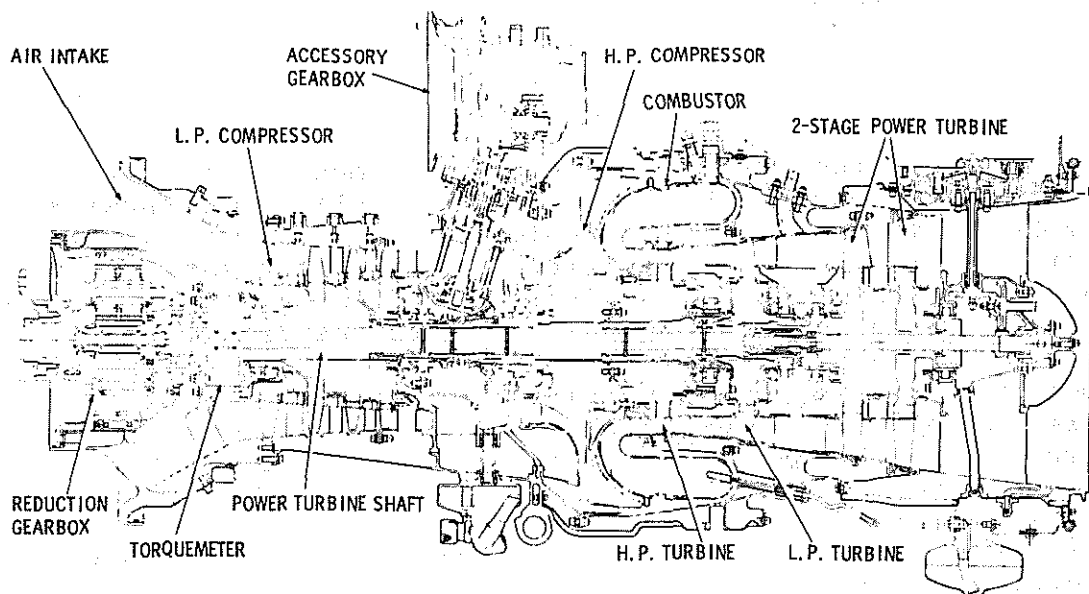
This paper is unashamedly about the Gem engine as this engine has now reached a very important point in its life cycle. The initial development programme has been completed and the engine has been in service for some time. Now we have to develop from this firm base to ensure that the engine achieves the potential inherent in the design concept. This paper, therefore, is not intended to describe the engine, for it is already well known, but to present an overall view of the current and foreseen 'state of the art' for the Gem engine.

The Gem engine was conceived as part of an Anglo-French Helicopter agreement in 1967 and represented the first indigenous United Kingdom small engine to be designed for a decade. The engine (shown in Figure 1) was sized at 900 SHP with relatively light aerodynamic loadings and conservative gas temperatures and stress levels. The logic in this approach was twofold:

- 1) To meet the requirements for a step change improvement in reliability, safety and maintainability and performance over earlier generations of helicopter gas turbines.
- 2) To allow for substantial growth in power without the need for significant redesign which could offset the operational experience already gained in service.



### General Layout Gem2



A/216/3

FIGURE 1

The design and development programme for the engine, which was largely government funded, has occupied Rolls-Royce at Leavesden for almost eight years and has been as comprehensive, if not more comprehensive than that ever employed before in the development of a helicopter engine. This can in part be measured by the development testing time shown in Figure 2 (which also indicates how development testing is continuing). It will be seen that a total of nearly 40,000 hours have now been run using 50 development engines and that a significant amount of this was in flight, using a fleet of prototype development aircraft.

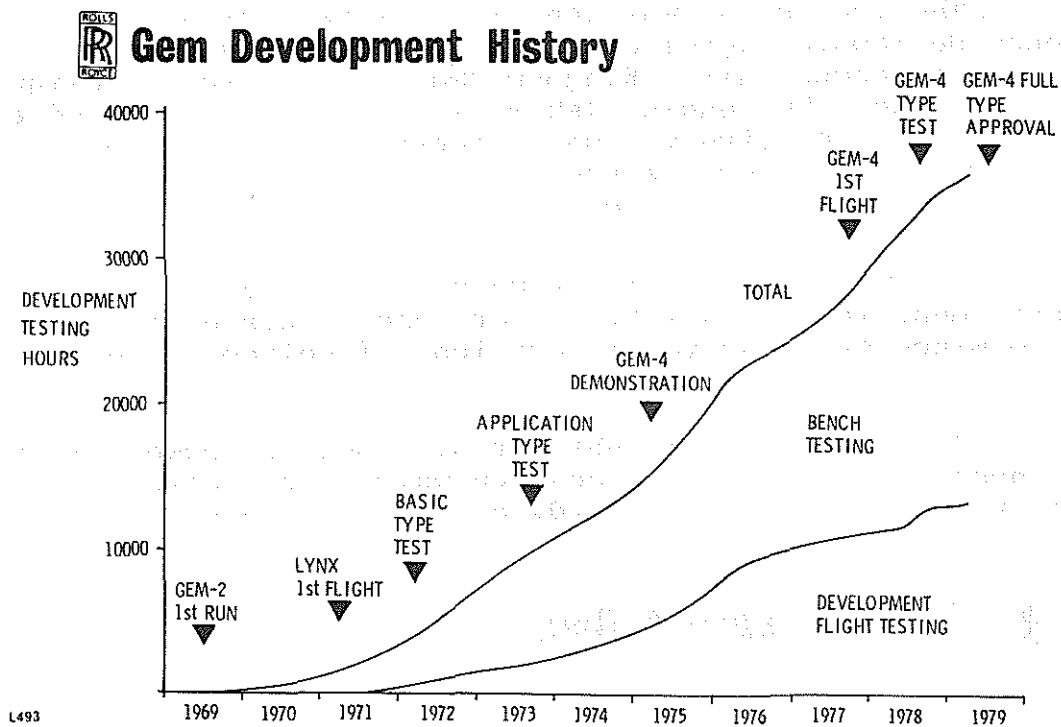


FIGURE 2

During the course of this development test work, integrity testing has been exhaustive and Figure 3 shows the scoreboard for this type of test work, with no fewer than 12 full approval tests completed. At the same time a great deal of testing simulating mission profiles has been carried out and a programme of punishing cyclic testing to demonstrate longevity of parts in service. At the end of the programme came intensive service trials by the first users where the operators, using their own support techniques and operating roles, used the aircraft at a high rate to establish the reliability of the equipment. The fact that they were able to fly at rates in excess of 100 hours per month shows a very creditable performance for a brand new aircraft and engine.



## Testing Scoreboard

APPROVAL TESTS (150 HOURS EACH)	-	12
SIMULATED MISSIONS (1 HOUR CYCLE)	-	2150 HOURS
HIGH FREQUENCY CYCLE TESTING	-	1200 HOURS
INTENSIVE SERVICE TRIALS	-	4
ROLLS-ROYCE	-	400 HOURS
ROYAL NAVY	-	7000 HOURS
ROYAL NETHERLANDS NAVY	-	1170 HOURS
BRITISH ARMY	-	2670 HOURS

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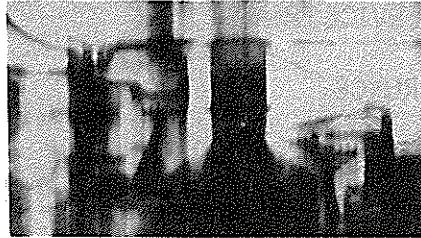
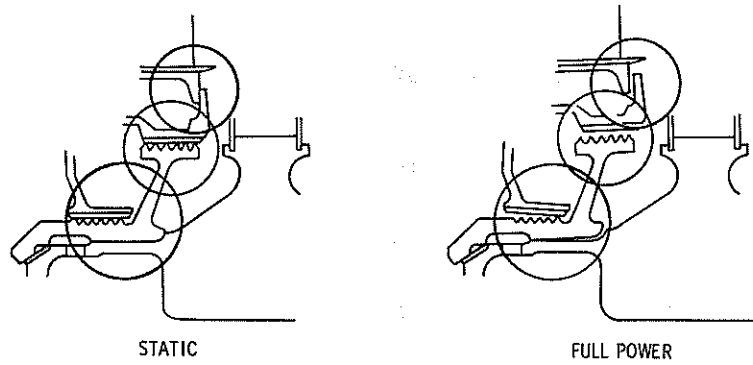
FIGURE 3

As might be expected the development programme for the engine was not without some difficulties and setbacks, normal in such programmes, as the test work explored the design concepts. It is important to appreciate that this work has led to advances in knowledge unattainable in any other way which provide a most important contribution to the future "know how" for ongoing development work for the Gem and other engine projects. Clearly this is not the place to go into great detail on these subjects which are worthy of a paper in their own right. However, in summary it can be said that high technology engines clearly demand a very high standard of development skills some just because of the small sizes and clearances involved. Thus instrumentation techniques are critical and new methods have to be found to analyse development information.

An example of this is the use of X-Rays and cold neutron radiography to examine the internal details of running engines. By such techniques the designer is enabled to observe component movement under thermal and pressure loading and observe the fluid flow in internal passages. It is difficult to interpret, and practically impossible to reproduce, the actual photographic result directly but by a comparative optical system, it is possible to produce very accurate assessments of otherwise non observable events as shown in Figure 4.



## Typical X-Ray Examination (Seal Distortion)



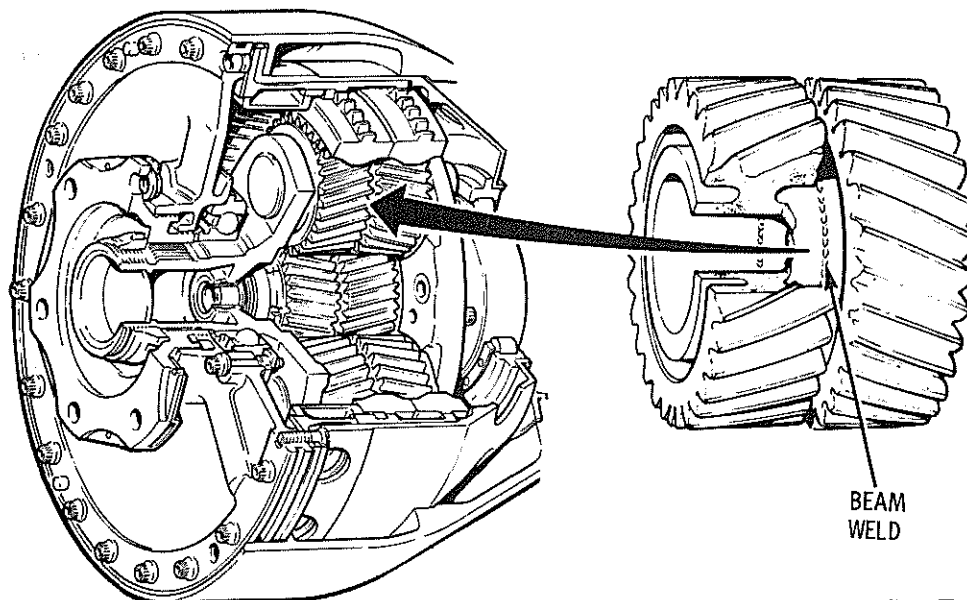
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FIGURE 4

At the same time the designers and production engineers have to develop manufacturing techniques to provide the best technology. One advanced technique, is the extensive use of electron beam welding in the Gem to manufacture parts in a way quite impossible with older fashioned machining techniques. A good example can be found in the layshaft gears shown in Figure 5 where it is possible to finish grind the two gears separately and beam weld them together. The exactitude of tolerances necessary to evenly distribute the loads via double helical teeth on three layshafts can be appreciated; yet today this is considered by the production engineers to be far the most accurate and economical way of achieving the designers requirements.



## Electron Beam Welding Application



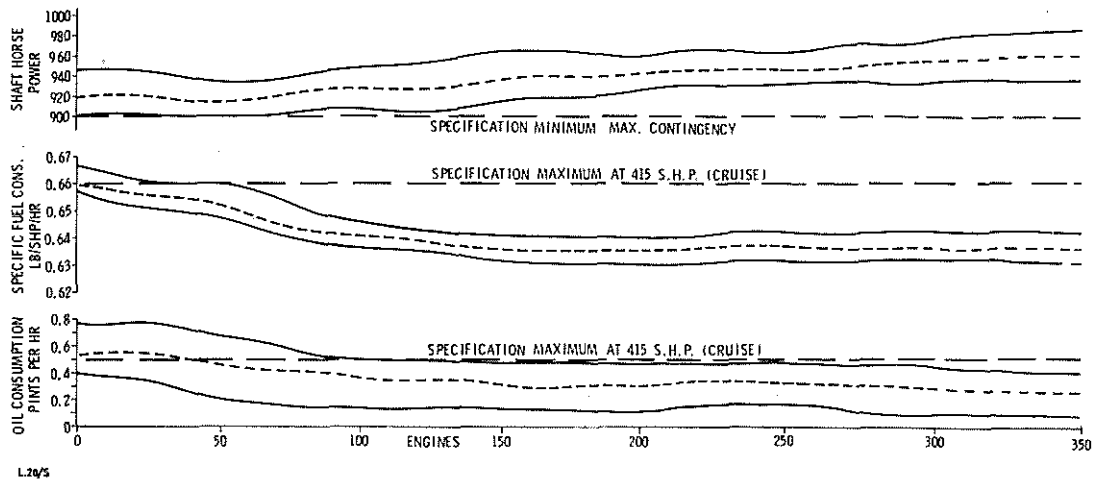
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FIGURE 5

There has also been a learning curve in engine production as the detail changes were made to overcome the difficulties one may expect in an initial production run. This is illustrated in Figure 6 which shows some of the major parameters in performance recorded on test during the first 350 engines. Initially some of the parameters were marginal and engines required re-work and rematching. Today, with a production rate of one per day, the production organisation considers the engine to be one of the best in its ability to perform satisfactorily after straight forward controlled build techniques.



### Gem-2 Rolls-Royce New Engine Performance at Delivery of First 350 Engines



L20/5

FIGURE 6

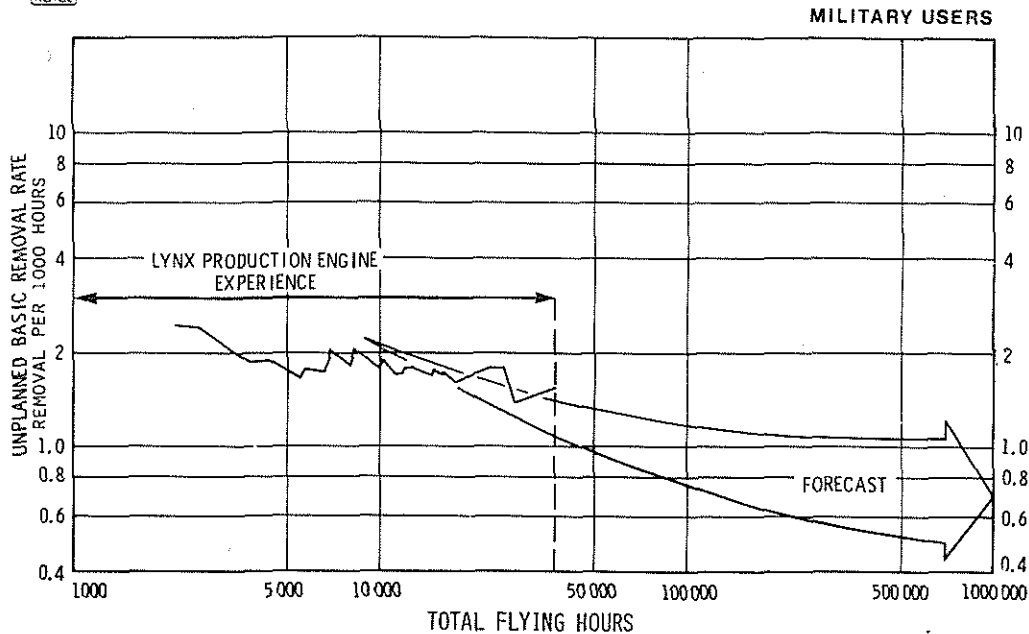
The Gem has now been in service since 1975 and up to date has accumulated 54,500 hours. Some 130 aircraft have been delivered to 7 operators and we have now entered the next phase of life. This could be termed, "Service development" for as the engine experience broadens new problems are shown up which require continuing engineering effort to improve the engine. These can be measured by two parameters, engine reliability and the cleared or approved life.

The reliability is illustrated in Figure 7 which shows the unplanned basic (engine caused) removal rate against a base of total service hours together with the forecast made at the commencement of operations. Statistics always require explanations and this chart is no exception. The current rate is somewhere around 1.5 per 1000 hours having fallen gradually since the first figures were logged. However, many of the causes for removal at the current time can be discounted in that fixes are already available and in current engine production. If this correction is made the rate of occurrence of unfixed problems is under 0.4/1000 hours which is very





## Gem Reliability



L78/1

FIGURE 7

creditable for an engine so young in experience. Unfortunately the statistician has to recognise that new problems are continually appearing and that these will require engineering and design work to provide fixes. However, the rate of occurrence of new problems combined with the rate of providing technical fixes enables us to predict that the forecast reliabilities at the million hour time frame are easily achievable.

The approved life of the engine, or more properly the modules (since the engine itself does not have a life) has been increased rapidly since entry into service when first samples lives were 250 hours. This has been achieved by the satisfactory review of modules either specifically withdrawn from service for examination or available on an opportunity basis. The current detail lives are shown on Figure 8 and it will be noted that a number are now cleared to 'On Condition' without fixed lives.

This is made possible by the demonstration that life related (wear out) features either do not exist or can be detected by in service checks so avoiding the costly business of regular recondition in the overhaul shops to maintain integrity. This is a trend which combined with high lives, where hard times are necessary on say rotative components provide large economic benefits in terms of operating costs. The current experience shows that the initial targets of minimum lives of 2000 hours in the hot sections and 4000 hours in the cold sections of the engine are well within reach.



## Engine Module And Accessory Reconditioning Life

CURRENT MODULE RECONDITIONING RELEASE		
01	REDUCTION GEARBOX	ON CONDITION
02	FREE POWER TURBINE SHAFT	1200 HOURS
03	AIR INTAKE AND LP COMPRESSOR	1000 HOURS
04	ACCESSORY GEARBOX	ON CONDITION
05	HP SPOOL AND COMBUSTION	800 HOURS
06	LP TURBINE	1000 HOURS
07	FREE POWER TURBINE	1000 HOURS

CURRENT ACCESSORY RECONDITIONING RELEASE		
	FUEL FLOW CONTROL UNIT (EXCLUDING PROTECTIVE CONTROL UNIT)	1000 HOURS
	FREE POWER TURBINE GOVERNOR	600 HOURS
	ALL OTHER MAJOR ACCESSORIES	ON CONDITION

FIGURE 8

L384

The Gem is a truly modular engine as shown in Figure 9 which has introduced some considerable changes in the logistics of engine support. The theory of this is shown in Figure 10 which shows how the ability to change engines quickly leads to the use of module exchange to return engines very quickly to service. The very considerable savings in time out of service reduce the spare engine requirements and improve the support economics. After three years in service there can be no doubt that the theory works extremely well in practice and that the benefits inherent are most rewarding to the user. Although the requirement for each module to be independent

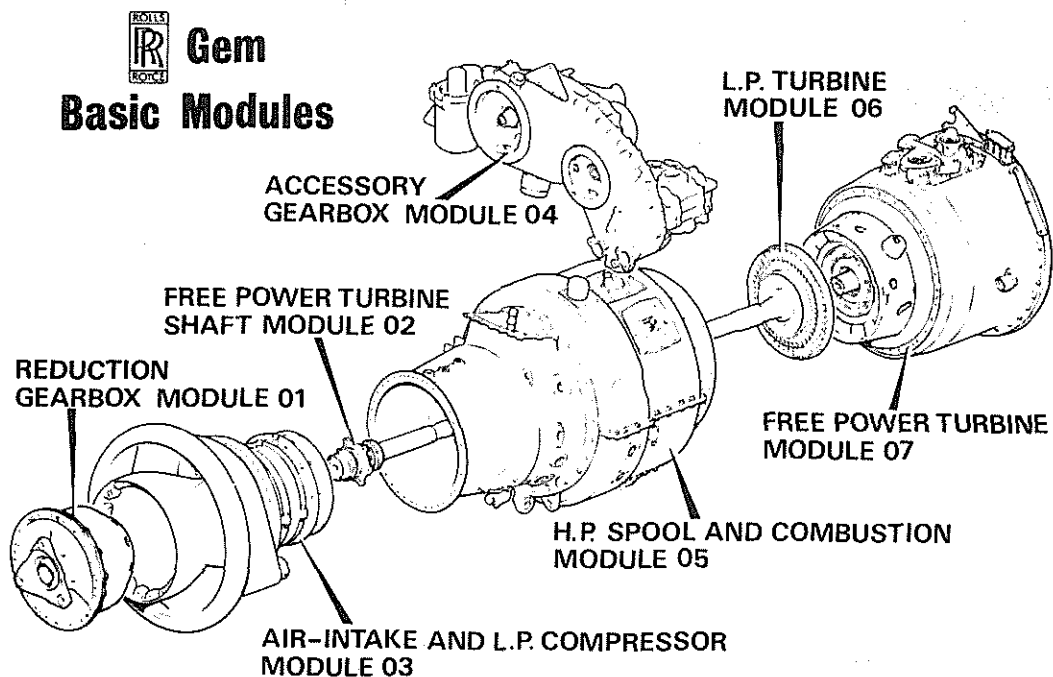


FIGURE 9



# Gem Engine Support Cycle

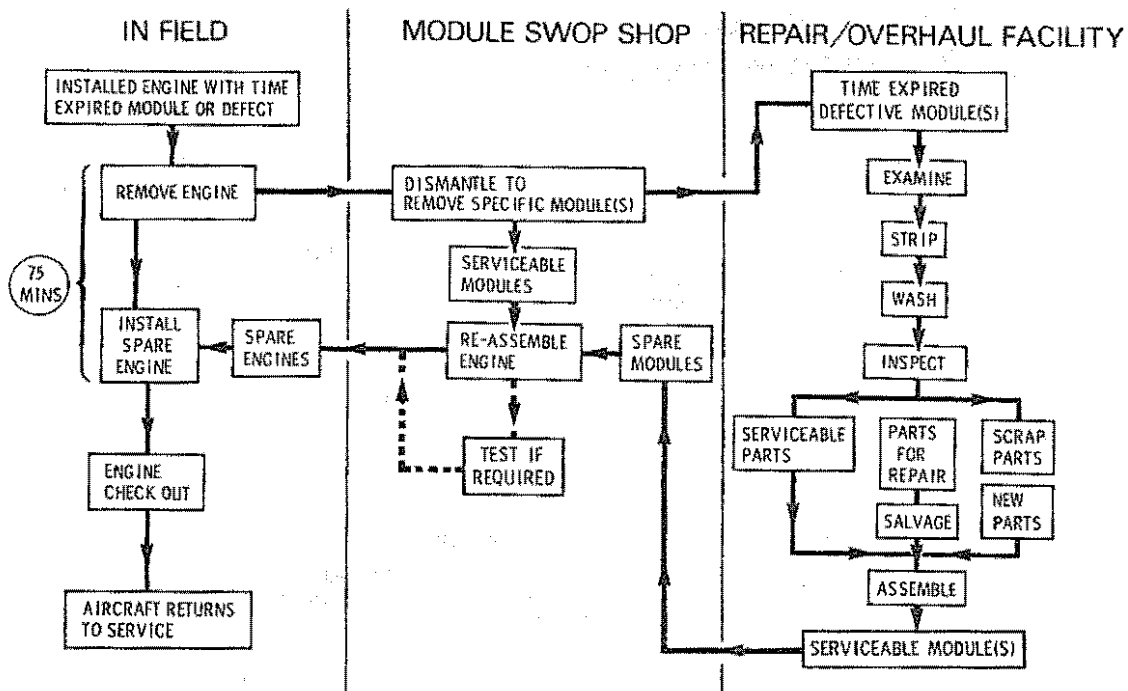


FIGURE 10

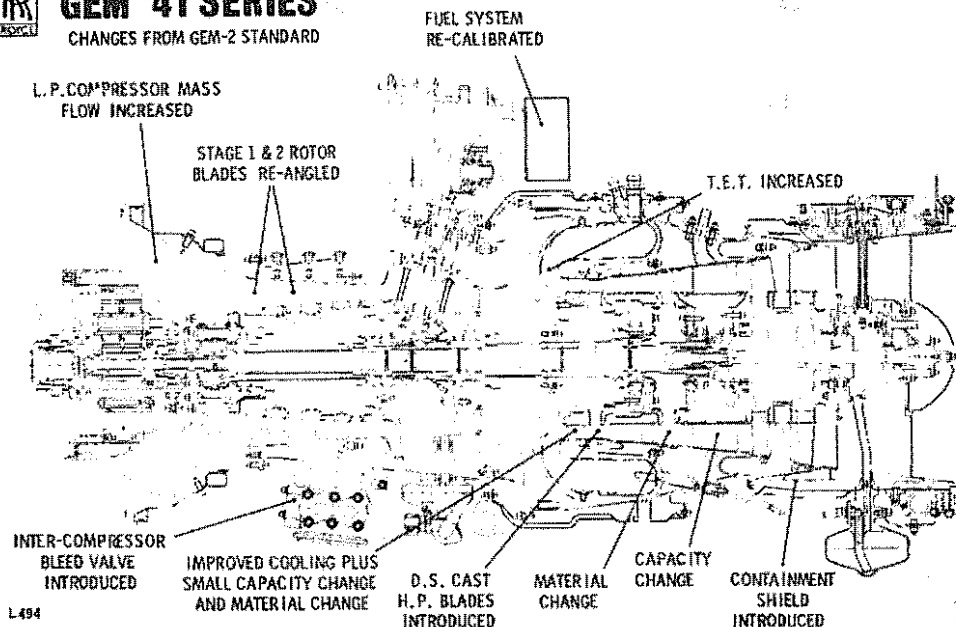
and separately manageable has led to some additional design complication it has simplified and improved the flexibility of support. There can be little doubt that the Gem has, therefore, set standards which will apply to all future engines.

The Gem has already taken its first step in growth, with the introduction of the Gem 41 ratings of 1120 SHP to match the growth requirements for the Lynx and the newly announced Westland WG 30. As shown in Figure 11 this has been achieved by modest stretch of the engine increasing mass flow and temperature. This engine is now in production and is the base line from which one should view the future plans for engine development.



## GEM 41 SERIES

CHANGES FROM GEM-2 STANDARD



L494

FIGURE 11

The total programmes envisaged in terms of power are illustrated in Figure 12 which shows the main directions of change. Firstly, along the bottom scale we have programmes aimed at increasing engine mass flow. These involve the introduction of bleed valves or casing treatments, the introduction of new power turbines to give increased capacity and finally the introduction of a higher mass flow LP compressor and increasing the capacity of the HP compressor.

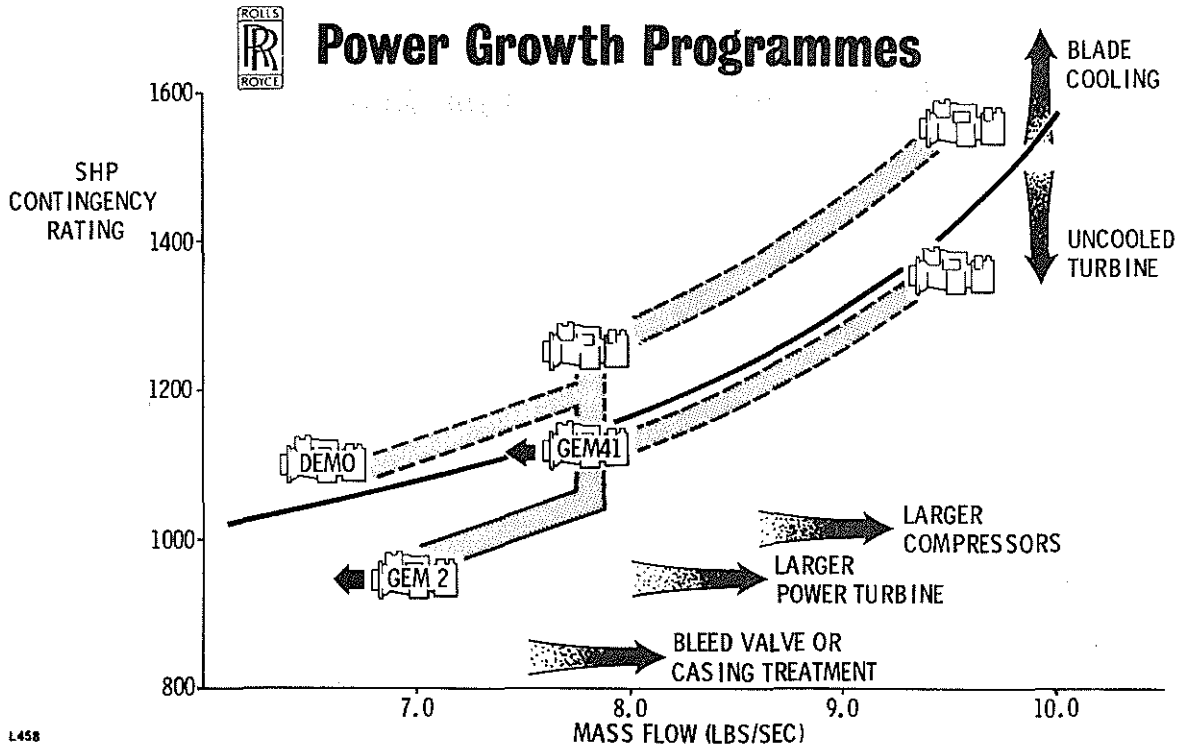


FIGURE 12

In the vertical direction any further significant increase in turbine entry temperature would need the introduction of blade cooling to the first stage of the turbine. This has already been demonstrated by engine test and the design problems are well understood with a continuing test programme in hand. It will, therefore, be seen that there are alternatives available which enable us to plan developments up to at least 1500 SHP depending upon the requirements of the aircraft manufacturers.

It is, therefore, appropriate for one to make a somewhat simplistic view of the market application for the Gem. One parameter which can be used is, on a twin-engine helicopter, the maximum emergency power available related to maximum aircraft all up weight. This is shown in Figure 13 for a complete range of modern helicopters and it will be observed that there is a broad band which can be drawn relating all sizes and types. The width of the band undoubtedly reflects variations in aircraft efficiency and in safety and operating philosophy. However, it can be seen that the Gem matches a group of twin-engine aircraft ranging from 8000 lbs AUV up to, if one considers the top end of our potential development plans near to 20,000 lbs AUV. In addition it is clear that the Gem is suitable for single

engine aircraft, which would be at the lower end of this weight band or more significantly, triple engine machines which would extend the weight band at the upper end. The latter type of helicopter offers some very large advantages over the twin in terms of engine out performance and is clearly, a development aircraft manufacturers will make in the future. The Gem thus has a useful power range for future aircraft and it is appropriate to review briefly the potential market.



## Helicopter Power And Weight

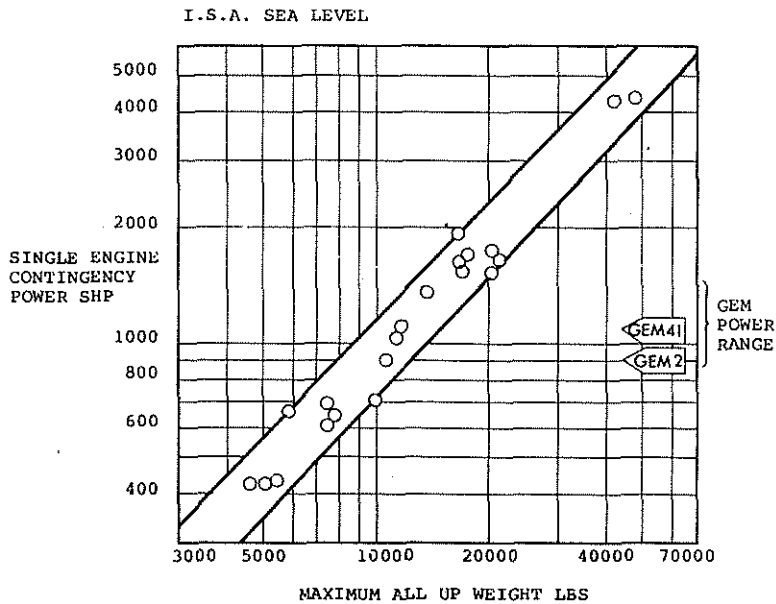


FIGURE 13

Figure 14 shows the history and a forecast for helicopter production in the western world from 1960 to 1990. It is interesting to note the massive military production in the 1960's and early 70's due to US military commitments in Vietnam. However, perhaps more significant for the future is the steady progressive growth of the Civil production requirement reaching around 1800 machines per year.

However, Figure 14 covers all types of helicopters, a large proportion of which are light aircraft. A second analysis of aircraft in the 8,000 to about 20,000 lbs range is shown in Figure 15 which, while still showing the large military production in the late 60's also shows an impressive growth of the Civil market from negligible quantities in the 1960's such that by 1990 it will equal the military market in this class. Since Civil and to a lesser extent military requirements dictate a multi-engine approach it is clear that there is a large potential market for powerplants in the 900-1500 SHP class for which the Gem was conceived.



## Western World Helicopter Production

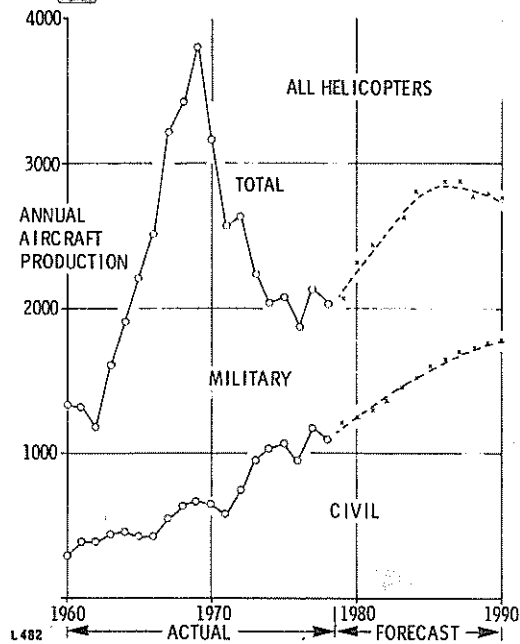


FIGURE 14

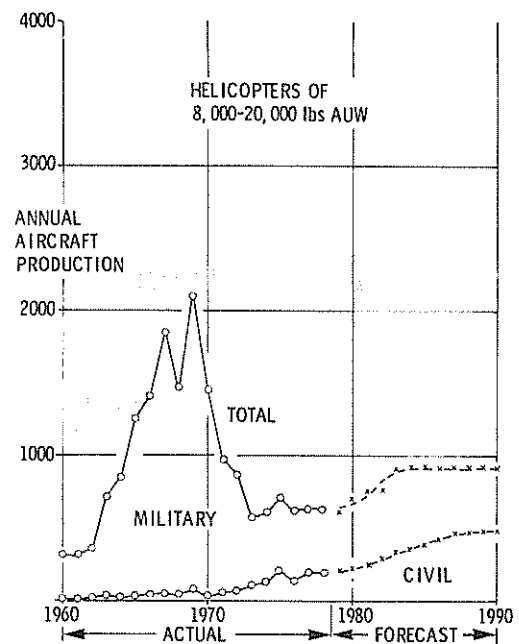


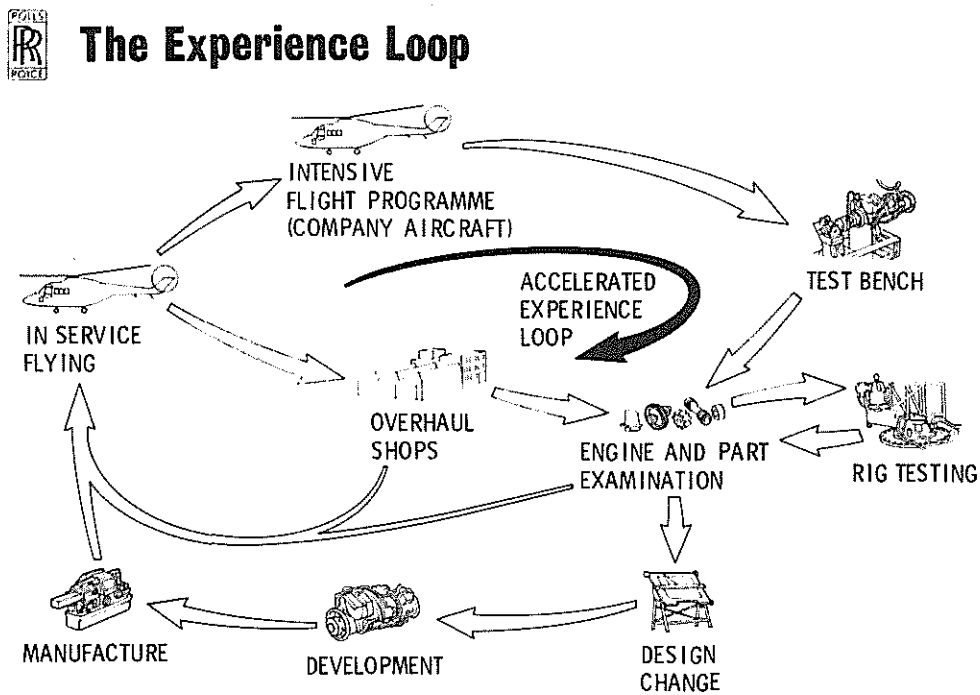
FIGURE 15

We should, therefore, look now at the direction of our future development efforts for the Gem engine to match the ever developing customer needs. It is apparent that there are four basic aims.

These are:

- 1) To continue the development of the existing engines to obtain the highest possible durability and reliability to give low operating costs.
- 2) To modify the engine to reduce first cost to increase the attractiveness to new customers.
- 3) To grow the engine to higher powers to meet future requirements of existing aircraft and make the engine suitable for other applications.
- 4) To adapt the engine to enable it to meet the various requirements of different aircraft manufacturers.

The first of these tasks is the most difficult from a development viewpoint in that the key to high durability, apart from the basic design, is the proof that can only come from experience. Figure 16 shows the cycle which is ongoing. This 'supports' 'in service' engines and at the same time allows the engine to tell the engineers what action is necessary for improved durability as defined by life and reliability.



L490

FIGURE 16

On the Gem our intention is to accelerate this pattern and one loop shows our programme of taking engines which have reached the current limit in service life experience and running them on. This is done by intensive flying in a company aircraft followed by prolonged test bench endurance running. The high life critical parts such as rotatives are then subjected to rig testing to further demonstrate life capability. This programme gives early warning of potential problems so enabling design action to be taken before the problem is apparent to the service users.

At the same time other development programmes are aimed at reducing first cost of the engine and here great care is required as it is important that the changes do not nullify the experience gained already. However, there are a significant number of items where advances in technology lead to the possibilities of cost reduction changes which do not degrade the existing experience background.

An example of this is a programme to develop an electronic fuel system as an alternative to the current pneumatically operated hydro-mechanical system. This takes advantage of the experience accumulated over the last 20 years on the Gnome engine combined with the newest technology from micro-chips to introduce a system such as that shown in Figure 17. Such systems can be less costly and because of the reduction in the number of moving parts more reliable than the earlier generation fuel systems.

An attractive by-product of such electronic fuel systems is that since they are using all the major engine parameters it is possible to 'add on' at very little cost usage recorders. Such devices can have a potent effect on engine operating costs since they make possible an exact knowledge of how the engine is used in terms of temperature and stress, and hence fatigue and creep life. In the past although it has been well understood that there are enormous variations in engine operating conditions it has been necessary in the interests of safety and reliability to mark down life, maximum power and time limits, to the lowest common denominator.

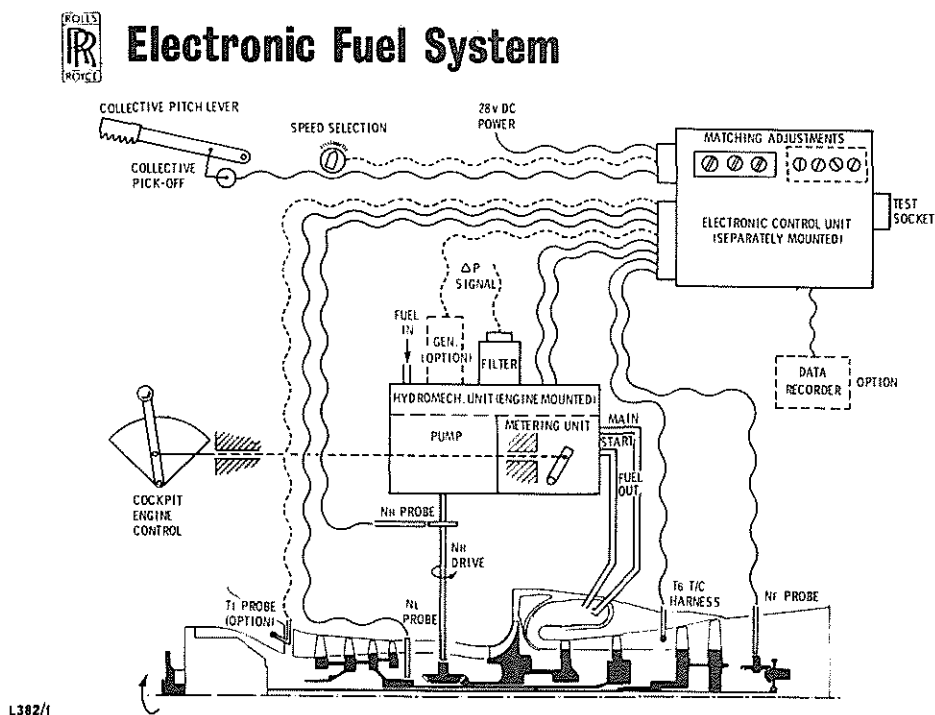


FIGURE 17



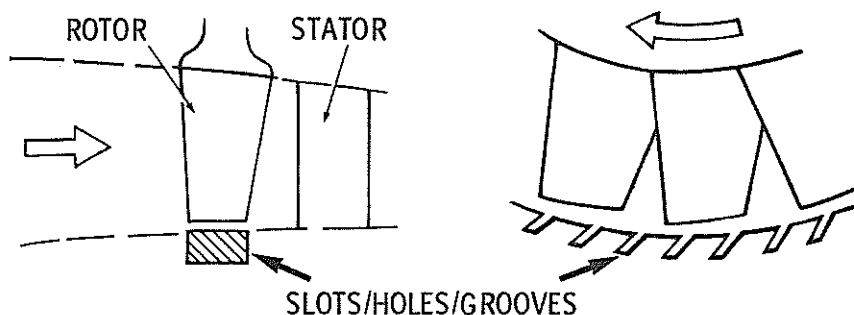
An example of the value of such a record of usage has been during Rolls-Royce intensive flight trials where they showed that only two per cent of the creep life had been used in 400 hours of high duty running. The capability of knowing what usage has taken place, also enables a different view to be taken of engine ratings, since an emergency situation could be met by gross power usage with the certain knowledge that this can be related to the engine capability.

Another area of new technology is the matching of the compressors where the past practice has been to use variables such as a compressor bleed valve, to ensure satisfactory surge margins at low speed, as has been done on the 1120 SHP Gem 41. Research work has shown that another method of achieving good surge margins is possible. This is called casing treatment, as shown in Figure 18, where by careful modification to the airflow passages it is possible to modify the blade stall condition and, therefore, the surge point. The quite dramatic effects of this are illustrated in Figure 19, showing how surge margin is increased, making a variable less necessary. This reduces first cost and eliminates the loss of efficiency inherent where a valve is venting the compressor.



## Compressor Casing Treatment

- INTRODUCES SLOTS/HOLES/GROOVES
- MODIFIES BOUNDARY LAYER
- DELAYS BLADE STALL
- INCREASES SURGE MARGINS
- BEST CONFIGURATION DEVELOPED BY TEST



L462

FIGURE 18



## Typical Effect of Casing Treatment

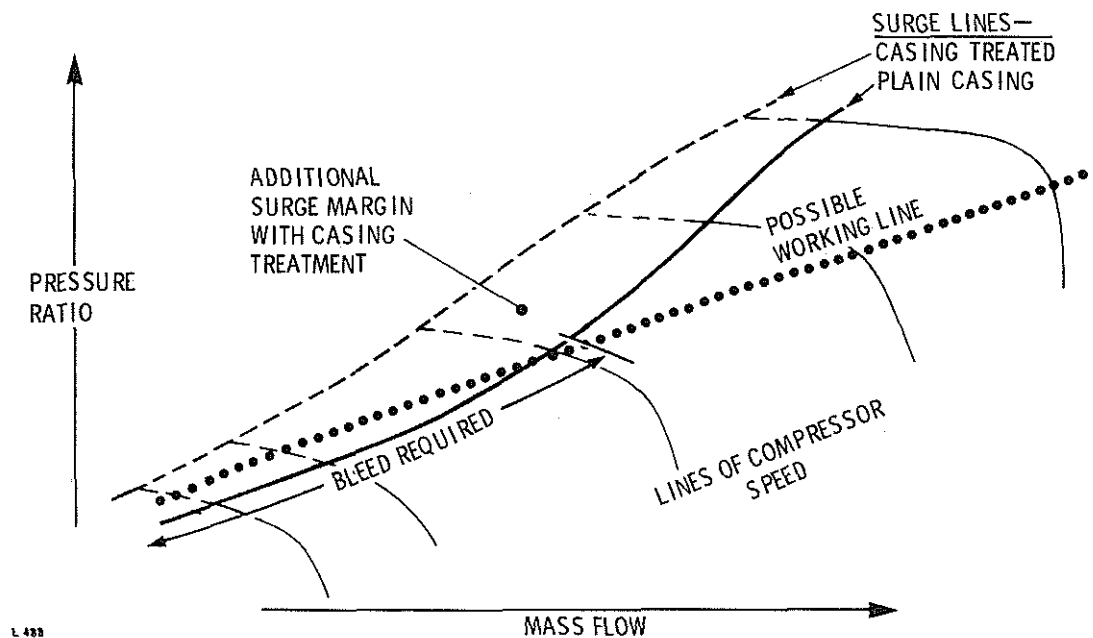


FIGURE 19

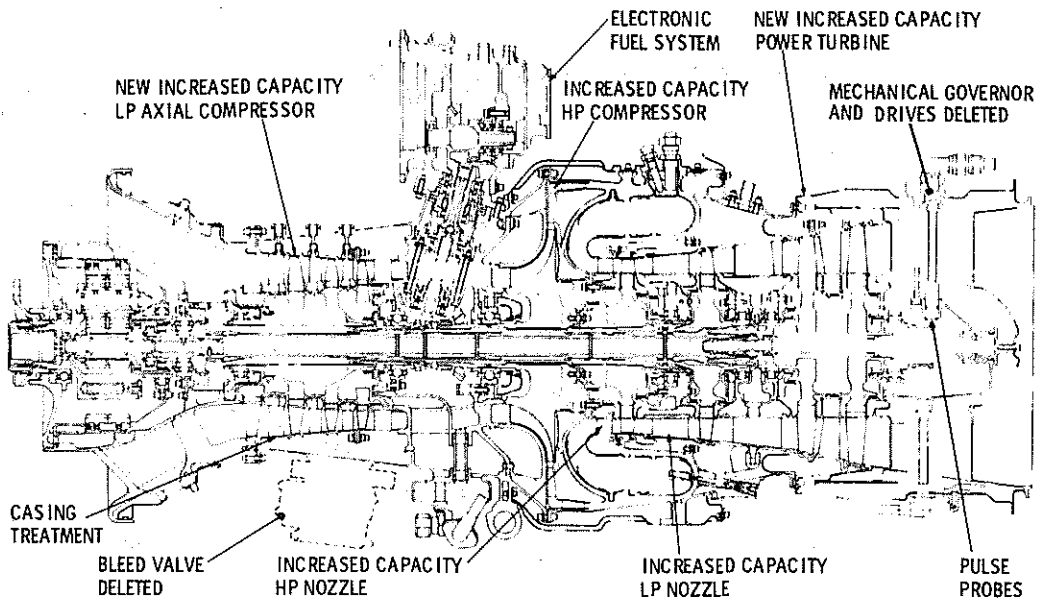
The next steps in development are to grow the engine which is possible by increasing mass flow and/or increasing turbine entry temperature. The latter course involves the use of blade cooling which although fully demonstrated on the Gem engine does involve some additional complications. The first choice is, therefore, to increase mass flow which is achievable without increasing the physical engine size or appreciable increases in engine manufacturing costs.

This is illustrated on Figure 20 which shows some of the cost reduction changes mentioned earlier and how mass flow is increased. The latter is achieved by the introduction of new, interchangeable, low pressure compressor and power turbine modules and by increasing the capacity of the high pressure compressor and the turbine nozzles. This enables mass flow to be increased around 20 per cent to enable powers between 1300 and 1400 SHP to be offered. The engineering programmes to accomplish this are already well in hand and engines of these ratings can be available to meet the needs currently envisaged by aircraft manufacturers.

Matching the engine to the aircraft manufacturers requirements is another major task in that, although one would like to make a standard product, the existing design may not be fully compatible with a new aircraft design.



## An Upgraded Gem



L485

FIGURE 20

Some of the changes necessary are small but in other cases quite large variations are envisaged. Figure 21 illustrates this as an example of a conceptual study for a podded installation. Here a direct right angle drive is used instead of the current reduction gearbox. This design also includes high efficiency intake particle separation and cooling to provide infra-red suppression of the exhaust to meet some specific military aircraft requirements.



## Podded Installation

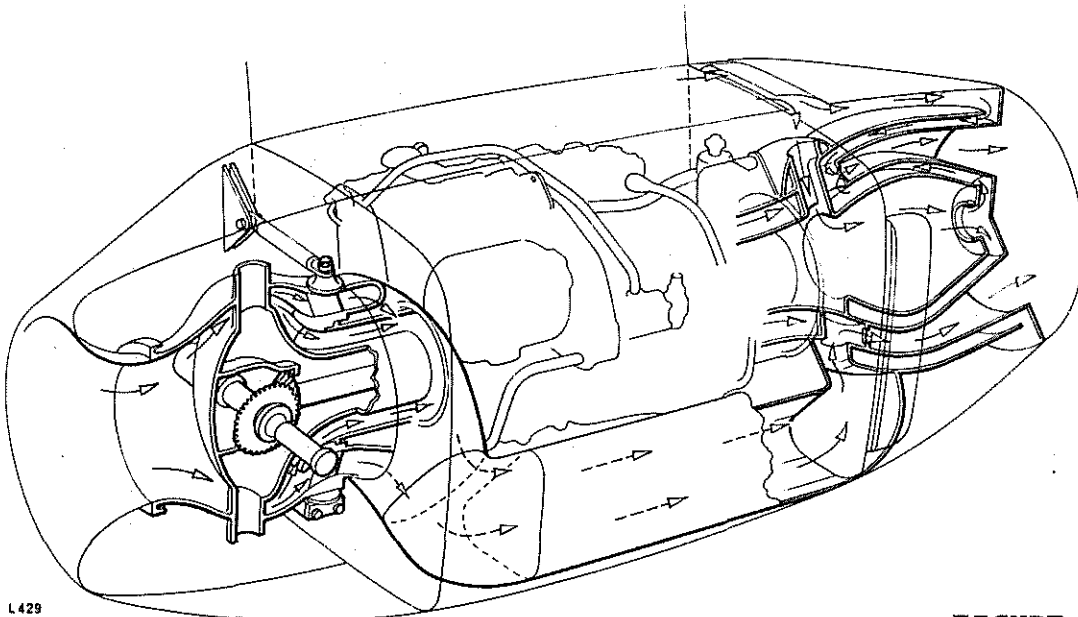


FIGURE 21

It will be appreciated that this paper has only attempted to make a very simple review of the Gem engine as we see it today. However, it is hoped that it has shown that the life cycle of the engine has only just begun. While it is true that the first development phase is complete and the Gem is now an 'in-service' engine there is still a great deal to be achieved. The engineering programmes currently in hand and planned for the future are in fact more intensive than during the first certification or approval programmes.

Clearly we in Rolls-Royce believe that the Gem engine has, with the continuing growth of the helicopter industry, a substantial future in many applications. Indeed, we believe that it has already set standards in techniques and in service behaviour which are an example to the industry and that both Civil and military operators will be using the Gem in its current form and in new derivatives for many years to come.