Design Aspects of Recent Developments in Rolls-Royce RB211-524 Powerplants

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This paper describes recent design changes in the RB211-524 powerplant. In response to the market requirement for a wide bodied aircraft to make journeys of increased range, the specific fuel consumption of the latest -524 engine has been improved by 14% compared with initial versions.

The paper shows how the potential of the three shaft concept has been coupled with the latest aerodynamic technology to produce over 25% more thrust at essentially the same engine size. This increased thrust has been achieved while meeting the latest noise and gaseous emissions regulations and while achieving continuing improvements in engine reliability.

The paper describes the introduction of electronic engine control to provide improved aircraft operation and maintenance. It also shows how the needs of the latest wide body, long range, twin engined aircraft under development can be met by combining the core of the -524 engine with a larger fan to produce a powerplant with a further 25% increased thrust capability.

INTRODUCTION

The family of RB211 engines was originated in the early 1970's with the -22B designed for short/medium haul wide bodied aircraft. The -524 engine was the first derivative with take-off thrust increased from 42,000 lb to 50,000 lb aimed at long haul operations. Development of this engine has continued up to the present day. The design philosophy has been to introduce modifications to increase thrust and reduce fuel consumption whilst improving the mechanical reliability of components also.

The RB211-535C and -535E4 are further derivatives aimed at a lower thrust range - below 40,000 lb. As these engines were primarily aimed at twin engined aircraft great emphasis was placed on reliability. The in-service experience has justified the faith placed in the derivative approach an mature reliability targets have been achieved from the outset of airline service.

The advanced technology proven in the -535E4 has now been applied to the later -524 engines.

The family of RB211 engines is shown in Figure 1.

70,000
60,000
50,000
40,000
30,000
Thrust lb

FIGURE 1 THE RB211 FAMILY - CONTINUING PRODUCT IMPROVEMENT

The RB211-524G is the latest development of this three shaft family of high bypass ratio engines. It has an initial take-off rating of 58,000 lb thrust and a specific fuel consumption which is 14% better than the earliest -524 variant. It is ideally suited to non-stop operations over very long ranges.

Certification of the engine is scheduled for the spring of 1988 and it is due to enter airline service in the spring of 1989. Bench development commenced at the beginning of 1987 and has shown sufficient promise to enable Rolls-Royce to offer further uprating to 60,600 lb thrust for entry into service at the end of 1989, and potential for further uprating at the same fan diameter is foreseen. Design studies for engines in the 70,000 lb thrust class are also taking place using the -524G core as the basis but with an increased diameter fan.

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The design concepts laid down for the original -22B have been retained in all the later derivatives. The rotor assemblies are short resulting in stiff structures and the structural load paths in the high pressure module are separated from the gas path resulting in good control of tip clearances. The principle features are shown in Figure 2. The result is an excellent record in performance retention – typically sfc is within 1% of the new engine values after 5000 hours in service.

Progressive development of the engine has continued by incorporating modifications which have been carefully designed for incorporation into existing engines as well as into new engines.

RB211-524 engines fitted into L1011 aircraft have also benefitted from these improvements although the take-off thrust in this application has remained unchanged.

The most recent development of the -524D to enter airline service is the -524D4-B.

The principle changes are an improved combustion liner to meet emissions legislation, derived from the -335E4 engines, a new HP turbine and new IP turbine blading. Further improvements have been achieved by optimising the blading in the HP compressor and correcting the residual whirl at exit from the turbine exhaust struts. Detailed refinements have been also been made to the gas path with regard to sealing, smoothness and refinement of tip clearances. Reliability has also been addressed with new location bearings.

An outline of these component changes is shown in Figure 4.

It is appropriate at this stage to describe these changes in more detail as they form an essential part of the -524G specification.

3D AERODYNAMICS

The efficiency improvements in the compressors and turbines which are at the heart of the component developments have been derived from 3D calculation methods supported by a complementary programme of model rig tests. The major emphasis in this work has been to obtain efficiency improvements by better control of the flow in the end wall regions and thus incurring less loss. Flow in these regions, because of the drag of the end wall shows a fundamental trend of deviating from the mainstream design flow direction. These are termed secondary flows with consequent secondary losses.
The analysis methods have lead to the adoption of curved and leant blading rather than the earlier blading with straight leading and trailing edges.

Also profile design has been improved by determining shapes from a prescribed velocity distribution, thereby avoiding velocity fluctuations associated with step changes in curvature. A typical aerofoil designed by 3D is shown in Figure 5.

The rig test results of the HP NGV designed with 3D aerodynamics compared to the conventional NGV is illustrated in Figure 6.

- Technology lead in application of advanced aerodynamics
- 3-dimensional designs
- Secondary flow control
- Supercritical components

* e.g. HP turbine
  * Fan
  * Fan OGV
  * Tail bearing housing fairing

- Over 4% sfc improvement

**FIGURE 5 RB211-524G/H ADVANCED AERODYNAMICS**

**FIGURE 6 RB211-524 "3D" HP NGV TEST RESULTS**

**HP TURBINE**

One of the principal factors in determining the rating of an engine is the temperature capability of the HP turbine and it can have a major impact on operating costs. This was well illustrated in the -22B engine when a new design of HP turbine blade in cast directionally solidified material eliminated the major cause of unreliability. This design of blade which is shown in the family of RB211 cast blades in Figure 7 has been the basis for all further developments in both the -535E4 and -524D4 engines. It has now achieved over 19,000 hours in service on the wing.

The HP blade designed for the -524 engine is vacuum cast in a conventional equiaxed alloy. It has ten small cooling passages similar to the forged blade used in previous Rolls-Royce cooled turbines.

Whilst this design is very efficient in terms of cooling air consumption and it achieves 15,000 hours in airline service, it has not been possible to manufacture by directional solidification techniques to enhance its creep and thermal fatigue life and thus its potential for further uprating is limited.

**FIGURE 7 RB211 HP TURBINE ROTOR BLADES**

A new turbine design with potential for increased temperature capability was certified for all -524 engines in 1987. Figure 8 shows this blade which was designed with a strong family likeness to the -535E4 HP turbine which had already been endurance tested at the temperature which met the -524 requirement, although with lower cooling air temperature on account of the lower compression ratio of the engine. Like the -535E4 the HP blades are cast by directional solidification in-house by Rolls-Royce.

**FIGURE 8 RB211-524 HP TURBINE BLADE REDESIGN**

The complex design matrix involving aerodynamics, heat transfer and stress thus follows well proven principles. In detail it is a new design as the flow capacity of the -524 engine is 15% greater than the -535E4 and the blade is 0.1 in. longer in a spanwise direction. The design was preceded by aerodynamic rig tests which confirmed that the efficiency targets could be optimized by reducing the number of blades from 102 to 92.

The aerofoil has seven cooling passages. The leading and trailing edges are separate and the centre five passages are joined to permit the cooling air to pass up and down in a multipass system. Cooling in the passages is supplemented by film cooling. A new
Refinement in the field of film cooling is used on this blade, the cooling hole is shaped to diffuse the air as it emerges onto the aerofoil surface in order to improve the effectiveness of the cooling air in reducing metal temperature. The benefits of this type of film cooling as shown in Figure 9.

**Figure 9 Observed Film Flow Direction**

The distribution of the metal temperature is modified by introducing turbulators in the internal passages to improve heat transfer. Also the larger internal passages have low pressure loss which permits flexibility in the selection of film cooling holes.

The mechanical design is such that the ceramic core is robust to avoid breakage during the casting process and to achieve good dimensional control on the wall thickness. Progressive development of the casting technology and close co-operation between the designers and manufacturing technologist have greatly improved the process capability of this blade compared with earlier designs.

The cooling air feed system follows well tried principles. There are pre-swirl nozzles to direct the air onto the disc at minimum loss and the air is transferred to the firtree root in the blade by drilled holes in the disc rim.

**Figure 10 RB211-524 HP Turbine Shroud Segment**

The turbine blades are shrouded with interlocking faces. Detailed refinements are made to control the flow of cooling air over the upper surface including a fence which reduces turbine overtip leakage losses for a given tip clearance. In addition the tip clearance is optimised around the flight cycle by matching the rotor growth to the casing by directing the flow of cooling air over thermal control ring attached to the segmented static shroud ring as shown in Figure 10.

**Combustion Chamber**

All civil engines have been subject to US legislation since 1 January 1984 with regard to unburnt fuel and smoke emission. Additionally compliance with limits established by ICAO with regard to carbon monoxide (CO) and oxides of nitrogen (NOx) was required from January 1987.

The design approach to these requirements has been one of progressive development. Mechanical durability has been improved whilst maintaining acceptable functional parameters such as ignition and relighting, outlet traverse and altitude stability.

The latest standard of combustion liner is illustrated in Figure 11.

**Figure 11 RB211-524 Improved Reliability Low Emissions Combustor**

**IV Turbine**

The IP turbine consists of twenty-six low aspect ratio vanes which carry the support structure and services for the rear bearings of the HP and IP systems. The aerofoil is subjected to pressure loss due to secondary flows as shown in Figure 12. Detailed pressure measurements have identified vortices in the exit plane of the vanes. 3D flow calculation methods were used to analyse the flow streamlines in the passage as shown in Figure 13. As a result, a new aerodynamic design with the trailing edge leaned in the axial and tangential directions was derived in order to reduce the size of the vortices and the pressure losses associated with them.

Efficiency improvements established on scaled aerodynamic rigs have made a significant contribution towards achieving fuel consumption benefits in -524D4 "upgrade" engines.

Using data generated for the IP NGV, a new IP blade was designed by matching the entry flow conditions of the IP NGV which provided further improvement in the LP turbine also.
The RB211-524 engine has remained competitive in the marketplace by improvements in component efficiency using advanced design techniques. Increase in compression ratio has been modest and turbine entry temperature has been reduced slightly. The reliability of the engine has demonstrated that potential for uprating existed which would enable Rolls-Royce to compete in the market for engines to power the Boeing 747-400 and long range wide body twin engined aircraft.

In the design studies carried out to define the optimum cycle, two paths were considered.

The first approach was to improve the efficiency of the core engine and increase the rating by throttle-push. This approach had a number of disadvantages such as:

- Redesign of the rotors would have been required as speeds were substantially increased.
- Rematching of the turbines was required to optimise the cycle and to maintain acceptable loads on location bearings.
- Changes would be incompatible with retrofit into existing engines.

The approach finally adopted was to retain the core of the RB211-524G engine and to incorporate a wide chord fan and integrated common nozzle assembly developed in the -535E4 and the Tay engine programmes. Increases in the overall compression ratio and turbine entry temperature have been made to achieve the required take-off thrust but hot end reliability has not been sacrificed to achieve ratings.

An advanced digital full authority fuel control unit has replaced the hydromechanical system, designed for compatibility with the electronic cockpit of the B747-400. The objective is to provide a simple and precise means of engine control.

Existing well proven systems are retained for control of bleed valves, variable inlet guide vanes and reverse thrust as there is little benefit to be gained from linking the control of these functions to the FAFC as they are optimised for the cruise regime which is the dominating influence on fuel consumption on long stage length operations.

THE WIDE CHORD FAN

A snubberless wide chord fan has been in service in the -535E4 engine since 1984 and has accumulated over 500,000 hours and 250,000 flight cycles. The lead fan set has achieved over 10,000 hours. A scaled version of this design has been adopted for the -524G as shown in Figure 14.

<table>
<thead>
<tr>
<th>Fan performance</th>
<th>Comparison of surge characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional fan and OGV</td>
<td>Wide chord fan and OGV</td>
</tr>
<tr>
<td>Pressure ratio</td>
<td>Cruise thrust range</td>
</tr>
<tr>
<td>Stage efficiency</td>
<td>Current working line (cruise)</td>
</tr>
<tr>
<td>Flow</td>
<td>Current sea level working line</td>
</tr>
</tbody>
</table>

The advantage in terms of improved efficiency is shown in Figure 15, which compares the wide chord fan with the conventional snubbed fan of the -524E4.
The aspect ratio is lower than that of the conventional fan, to achieve acceptable vibration characteristics. The number of blades is correspondingly reduced - in the -524G from thirty-three to twenty-four. Also the pressure rise through the hub section can be increased and a higher level of efficiency achieved than in the conventional fan.

In addition to the performance benefits, the wide chord fan and disc assembly is also 60lb lighter than the snubbed fan of the -524D engine.

The mechanical design of the wide chord fan blades follow the well proven -535E4 design. Titanium alloy skins are separated by a honeycomb cell core. The panels are shaped and formed to optimise weight and structural integrity before being joined together by means of diffusion bonding.

The fan is matched to a new design of fan outlet guide vane using supercritical aerofoil shapes. These vanes have a structural duty to perform in addition to an aerodynamic one. In the RB211 the engine thrust trunion is located on top of the OGV assembly and the axial thrust of the core engine is transmitted to the thrust trunion through the vane engine.

Thus the design is a compromise between aerodynamic and structural requirements. Following 535E4 practice the whole of this front end assembly of bearing panels, engine stators and fan OGVs was changed from steel to titanium to reduce weight. One of the considerations in such a design is the reduction in stiffness as a result of the change in Modulus of Elasticity between steel and titanium. This will affect axial stiffness and the sensitivity of the structure to the effect of rotor unbalance. However in both respects, the new structure has been entirely satisfactory in the engine test programme.

The objective of the supercritical profile is to achieve increased lift within a given chord by increasing the suction surface Mach number. This must be done without incurring high profile loss and by controlling the change from peak surface velocity to exit velocity efficiently. Analytical tools have been developed to shape the aerofoil to avoid back surface separation of the boundary layer as shown in Figure 16.

FIGURE 16 RB211-524G - BYPASS OGV MID-HEIGHT SECTIONS

In the -524G design, this has permitted an increase in space/chord ratio, by retaining the axial chord and changing the number of aerofoils from seventy in the -524D to fifty-six in the -524G. Thus reduced trailing edge blockage and profile loss have also contributed to the overall gain in efficiency which is illustrated in Figure 17.

FIGURE 17 RB211-524 BYPASS OGV LOSS

COMMON NOZZLE ASSEMBLY

The -535E4 engine exploited the concept of mixing the hot and cold gas stream and expanding through a common propelling nozzle. This concept of transferring energy from the hot stream to the bypass stream to improve propulsive efficiency had been used on earlier low bypass ratio engines such as the Conway and Spey engines, but had not been used on high bypass engines because the dynamic head is a much greater proportion of the exhaust total head than in the earlier engine types. Thus there is a risk that the pressure losses associated with the mixing process could outweigh the theoretical thermodynamic gains.

However it has been shown that in the three shaft high bypass ratio engine, marrying the single stage fan to the common propelling nozzle enables the fan working line to change so that fan efficiency may be optimised throughout the engine operating range.

The reasons for this are because the proportions of the nozzle area occupied by the fan and core streams vary with engine thrust and thus the effective area of the nozzles may change. By reducing the effective core area, the pressure ratio across the LP turbine is reduced and thus the fan slows down at a given thrust.

If the fan is running at a high non-dimensional speed, it will be operating at less than optimum efficiency and thus in slowing it down, it moves to a more favourable point in its efficiency characteristic.

The short three shaft engine concept also favours the common nozzle in that the external drag associated with the increased external surface area of the nozzle is kept to a minimum.

There are two choices of mixer design available, annular or chuted. In the -535E4 engine operating over short stage lengths the compromise between mechanical simplicity and lower weight on the one hand and optimised performance on the other favoured the annular nozzle. In the -524G operating for long periods at cruise the need for optimum efficiency has favoured the chuted mixer. This is shown in Figure 18.

The common nozzle also enhances reverse thrust performance as the thrust from the core engine is reduced when it is expanded into the space upstream of the common nozzle normally occupied by the bypass flow.
The design of this new HP vane employs the 3D aerodynamic principles described earlier. Improved efficiency derives from reduced suction surface Mach numbers and a curved trailing edge optimised to reduce radial pressure gradients. The aerodynamic efficiency improvements appear from reduced secondary losses and from an improvement in rotor inlet conditions.

The aerofoil has two large compartments with large feed areas. This allows for rows of film cooling holes to be placed anywhere on the pressure surface to optimise the temperature distribution during development.

Fan shaped cooling holes give excellent cooling, so the pressure surface is thickened to improve the convective cooling from the sides of the film cooling holes. Also the thick wall enables the film cooling rows to be placed closely together whilst ensuring adequate strength.

Earlier designs of HP vane used a tube in the front compartment to provide impingement cooling. However the fan shaped long holes now give adequate cooling without the need for a tube. Foreign object damage will also be reduced with the thick walls.

The material of both HP and IP nozzle guide vanes have been changed to MAR-M-002 to improve creep strength. This will permit an increase in metal temperature on the suction service, where the pressure difference across the wall is at a maximum, but where film cooling penalises efficiency. Also cracking in the platforms is greatly reduced. Earlier vane materials had good oxidation resistance without coating, but the new materials require an aluminate coating for protection.

Much detailed attention has been given to reducing gas leakage from flanges and seals. This provides a direct benefit to fuel consumption but it also assists in maintaining acceptable internal cooling air temperatures, which have a tendency to rise as thrust rating of the engine increases.

PERFORMANCE

The progressive improvement in take-off thrust and fuel consumption of -524 engines is illustrated in Figure 20. Overall specific fuel consumption has been improved by 14%. The figure illustrates the benefit of the step-by-step approach to engine development as each stage is consolidated before the next one is made and the technology advances are progressive.
The benefit of the wide chord fan technology and the component changes within the core engine have been established on other projects. However the case for the integrated nozzle is a more difficult one to make as the advantages in mixing hot and cold exhaust streams have to be weighed against increased weight and increased surface area in the mixer, resulting in additional powerplant drag. Figure 23 shows the results of the optimisation study which illustrates the advantage for a mixed exhaust remains in spite of the other factors. Reverse thrust is also improved by 4000 lb as a result of closing off the bypass duct and overexpanding the hot stream flow.

**FIGURE 21 RB211-524G SFC STATUS**

These improvements have maintained the competitive position of the engine in the marketplace and have led directly to the next step in the chain of development activity, that of incorporating the proven technology of the wide chord fan and integrated nozzle which are the cornerstone of the -524G.

The internal parameters the -524G relative to the -524D4 engines have increased as follows:

- Thrust at take-off rating: +9.4%
- Mass flow: +3.6%
- Overall pressure ratio: 12%

Figure 22 illustrates that hot end life has not been compromised by uprating as the turbine entry temperature remains within the limit established by the earlier -524 engines. This remains true even for the -524H, rated at 60,600 lb take-off thrust.

**FIGURE 22 RB211 - THRUST GROWTH WITHOUT INCREASING TEMPERATURE**

Surge free handling on the -524D4 at altitudes up to 45,000 feet will be enhanced as a result of the changes to optimise the blading in the HP compressor and more precise control of fuel flow through the digital fuel control.

The full authority digital fuel controller (DFC) is a system which is fully compatible with the aircraft electronic cockpit, yet retains existing proven control systems for the thrust reverser, inlet guide vanes and bleed valves. The system replaces the hydromechanical fuel flow regulator with a dual channel, electronic controller driving a new fuel metering system.

The DFC gives the -524G improved starting, low power stability, transient response and power control.

Pilot workload is reduced because the system eliminates throttle stagger, control system drift, and asymmetric thrust, and also performs more operational and system checks automatically.

The electronics are fully duplicated, with automatic switching from one lane to the other in the event of component failure, with the additional protection of a mechanical overspeed governor in the extremely unlikely event of both lanes failing.

Schematic diagrams of the DFC system are shown in Figures 24 and 25.
System design advantages

1 Safety
   Any element can fail in any mode with no risk to engine integrity.

2 Operation reliability
   Use existing reliable systems and technologies wherever possible
   asking improvements where required.

3 Performance
   All the advantages of a FADEC system including:
   • Improved idle control
   • Consistent acceleration times
   • Fixed throttle take-off and climb
   • Aircraft communication
   • Fault detection and accommodation
   • Improved altitude re-light
   • Engine health monitoring

4 Operation reliability
   • Improved reliability and life
   • Reduced maintenance
   • Improved control
   • Thrust level — surge protection
   • Limits protection
   • Analogue or electronic aircraft compatible

5 Safety
   - Fault detection and accommodation
   - Engine health monitoring
   - Improved altitude re-light
   - Aircraft communication
   - Consistent acceleration times
   - Fixed throttle take-off and climb
   - Use existing reliable systems and technologies

6 Engine condition monitoring
   COMPASS is the system being developed by Rolls-Royce to provide a comprehensive condition monitoring package for airlines dealing with on-wing, ground, test cell and maintenance data. The monitoring will cover mechanical items as well as analysis of engine performance down to modular level provided the necessary instrumentation is fitted to the engine. The COMPASS system is illustrated in Figure 26.

7 Thrust reverser
   • When the shut-off valve is normally activated by a pilot-initiated signal, but will also be activated by a signal from the FAFC if the LP mainshaft breaks.

8 An engine driven dedicated electrical power generator with duplicated stator windings.

The systems within the digital fuel control are duplicated to provide redundancy at levels which range from those failures which have no effect on flight operation and would permit aircraft despatch, to failures of a remote nature which may result in an uncommanded engine shut-down.

FIGURE 24 RB211-524 DIGITAL CONTROL SYSTEM

FIGURE 25 RB211-524G/H — FULL AUTHORITY DIGITAL FUEL CONTROL BENEFITS

Each lane is fully capable of controlling the engine without any engine run trimming and communication between the lanes ensures a high degree of fault tolerance. Each lane includes the pressure transducers necessary to control the engine.

The dual computer module in each lane is thoroughly and continuously checked by setting another identical computer alongside the control computer to monitor every output. Simple circuitry disables outputs from the control computer if it disagrees with the monitor and will eventually carry out a lane change should the fault persist. This whole operation would result in a minimal engine thrust disturbance — about 3% for less than one second.

This provides a very high level of fault detection and allows the despatchability analysis to assume that the computer element has no dormant faults.

The FAPC box also contains electrically separate circuits which control the engine in the very remote event of a breakage in the main shaft connecting the fan and turbine in the LP spool. The other principal elements of the system are listed below.

1 Combined LP and HP fuel pumps which supply fuel to the fuel metering unit at the required pressure.

2 The Fuel Metering Unit modulates the fuel flow to the engine in response to commands from the FAPC to the engine.

3 The shut-off valve which is normally activated by a pilot-initiated signal, but will also be activated by a signal from the FAFC if the LP main shaft breaks.

4 There is a mechanical governor operating on the HP spool which predicts the engine in the event of a failure in the control system producing high fuel flow.

5 An engine driven dedicated electrical power generator with duplicated stator windings.

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ENGINE CONDITION MONITORING

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FIGURE 26 COMPASS FOR RB211-524G — SYSTEM SCHEMATIC

It will consist of a number of computer programmes, a filing system and interfaces suitable for installation in airline ground-based computer systems. It has been designed for use with a variety of engine types, principally RB211-524G, V2500 and Tay, but will be sufficiently flexible to be extended for use with other engines.

COMPASS can be configured to run on lines or in batch mode and in a system which reports by exception, only alerting the user when it is necessary.

With modern methods of data transmission between aircraft and ground, measurements taken in-flight can be processed within minutes/hours of their generation by sophisticated on-ground analysis systems such as COMPASS. Thus the airline operator has visibility of the current health of his engines at any point in time not only in terms of performance parameters, also mechanically, through trends in oil pressure/temperature, vibration levels, etc.
Apart from changes to the front of the IP compressor to accommodate this, the core of the engine is otherwise common with the -524G/H. A new nacelle with integrated propelling nozzle is proposed. The component and thermodynamic cycle changes improve the fuel consumption by 2 - 4% depending upon thrust level.

Data recorded during take-off, can be normalised so that the TGT and shaft speed margins which each engine has relative to its red line value when operated at full power on critical take-off conditions, can be estimated.

The estimated margins can be trended throughout the engine life, thus enabling the airline operator to anticipate and thus avoid operational disruption caused by red line exceedances.

Monitoring the mechanical behaviour of the engine, by recording vibration characteristics, oil pressure, temperature and consumption provides information to detect incipient failures, thus enabling the engine to be removed and repaired before failure occurs.

RB211 GROWTH

With the emerging large twin and trijet markets there is a recognised requirement for a development in engine thrust beyond the -524H at 60,600 lb currently available.

Although a modest increase in static thrust to 62-63,000 lb within the present carcase can be foreseen, increasing jet velocity and noise considerations will preclude much further substantial thrust growth.

Correspondingly a further development of the RB211 is being studied - the -524L. The engine is planned to embody a larger diameter fan around the existing -524G/H core thus obtaining an initial thrust of 65,000 lb within current noise levels.

Through core engine development a further thrust growth of 10% is intended for the engine together with fuel consumption improvements, equally applicable to the -524G/H and -524L.

Thus there is scope for further development of the RB211-524 family of engines, to meet the future needs of airlines in all applications which require large fan engines.

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