THE RTM 322 – DESIGNED FOR POWER GROWTH

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Abstract

There has always been a requirement for the power of helicopter engines to increase during the operational life of the aircraft. This is usually as a result of changing operational requirements in respect of increased payload, equipment and extended range or expanded flight envelopes. Today there is also a complementary demand to enhance reliability, maintainability and reduce the overall life cycle cost of both the airframe and engine.

The design philosophy at the conceptual stage of an engine's development dictates the ability to provide cost effective power growth as the engine matures. Power growth potential, allied with life cycle cost reduction, was a fundamental design requirement at the launch of the RTM 322.

This paper examines the power growth strategy of the RTM 322 and explains how this influenced the initial design of the engine, allowing a growth path to be derived which could be followed whilst minimising the requirement for design change. It explains how advanced technology has been utilised to provide a simple and cost effective approach to power growth, whilst at the same time continually addressing the need to reduce the life cycle cost of the engine. The significant potential that exists for increasing power of the RTM 322, and concurrently addressing the requirement for reduced life cycle cost is explained as a low risk, low cost strategy made available due to the engine being designed for power growth at its inception.

RTM 322 Today

The RTM 322 is a sophisticated, state of the art, two-spool turboshaft gas turbine engine. It is compact, lightweight and durable.

The engine architecture comprises a 3 stage axial flow compressor combined with a single centrifugal compressor, both manufactured in titanium. 'Blisc' technology is utilised where the blading of the three axial stages is machined as an integral part of the supporting disc. The inlet guide vanes and first stage of the compressor are of variable geometry design. The combustion chamber is a precision machined component of reverse flow design in order to maintain the compactness of the overall engine geometry. It incorporates a highly sophisticated wall cooling system to maintain integrity at the combustion temperatures. The turbine consists of a two stage axial flow 'gas generator' turbine and a two stage axial flow 'power turbine'. The gas generator turbine incorporates three dimensional aerodynamic geometry and internal and surface film cooling. The blades are manufactured as 'single-crystal' castings to allow greater durability and extended life. The power turbine blades are designed in materials such that internal cooling is not necessary, thus providing an efficiency gain in the engine thermodynamic cycle. Only two bearing compartments are required to support both the gas generator and power turbine/output power shafts. An integrally cast oil tank, plus the use of cast or machined passages for transfer of fluids greatly reduces the use of external pipe work thus allowing easier maintenance access and reduced risk of handling damage. The engine is controlled by a dual channel Full Authority Digital Engine Control (FADEC) and was the first helicopter engine to use such technology. Each channel independently provides complete engine control and management functions, by the electronic control unit working in tandem with its hydromechanical devices (fuel pump etc) through provision of dedicated sensors located throughout the engine. The engine is provided with an optional inlet particle separator. The highly advanced design uses a combination of ballistic trajectory focusing and pressure differential extraction, thus avoiding the need for a separate powered fan system with its inherent problems of reliability and erosion of moving parts.

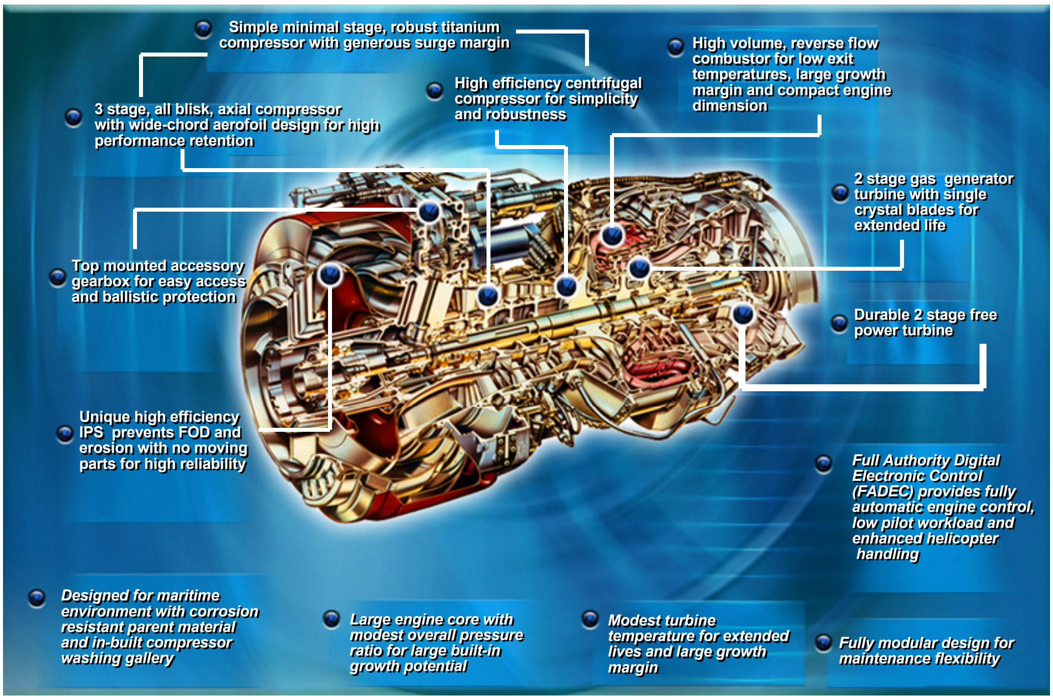
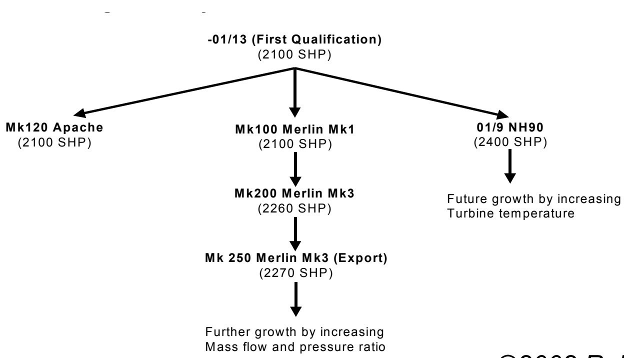


Fig 1 RTM322 Design Features

The RTM 322 is a family of engines, not just one single engine mark. It is in current service operation in three helicopter applications. The Mk 100 engine variant in the European Helicopter Industries EH101 Merlin Mk 1, the Mk 200 engine in the EH101 Merlin Mk 3 and the Mk 120 engine in the Agusta Westland WAH-64 Apache. In all three applications the engine is demonstrating extremely high rates of reliability to date. The UK Ministry of Defence are operating all three aircraft to form the nucleus of the joint operations covering battlefield, maritime and tactical troop transportation roles. Furthermore the 01/9 variant is currently completing civil certification for use in the NATO Helicopter Industries NH-90 helicopter, and the Mk 250 engine variant is presently undertaking qualification for export sales of the EH101.

The development and qualification history of the RTM 322 to date is represented in the following diagram:



The power ratings of the current RTM 322 engines can be seen in the following table:

	MAX Cont	60 Min	Take Off 5 Min	O.E.I 2 Min	O.E.I 30s
Mk 100	1840	2000	2100	2240	-
Mk 120	1840	2000	2100	2240	-
Mk 200	1890	-	2260	-	2500
Mk 250	2000	2150	2270	2400	-

All powers are SHP, ISA, SLS

As well as being designed to be compact, robust and powerful, low acquisition cost and low life cycle costs were essential requirements of the engine's design. A low part count, the use of latest manufacturing techniques, design for reliability and design for ease of maintenance have been essential factors in achieving the low life cycle cost of the RTM 322. This has been further supported by the key design features incumbent in the engine which has led to excellent levels of operational availability through minimal. maintenance downtime and ease of operational maintenance.

To date current marks of the RTM 322 have accrued over 65,000 flying hours in both service operation and development flight programmes.

This has been undertaken on six aircraft types, EH101 Merlin Mk 1 and Mk 3, WAH-64 Apache, NH-90, Sikorsky S-70C and SH-60B.

Current orders and selections for production engines exceed 1100 in 9 different countries. The RTM 322 customer base now includes UK, France, Germany, Holland, Sweden, Finland, Norway, Portugal and Denmark.

The RTM 322 has captured 70% of all sales of EH101 aircraft, and 82% of all sales of NH90 aircraft.

Future Requirements

Throughout the operational life of rotorcraft the operational requirements will frequently change and evolve. These changes may result from the need for additional equipment from increased payload, from extended range requirements and/or expanded flight envelope requirements. Meeting this demand for improved overall operational capability, rotorcraft will almost always require additional engine power and/or improved fuel burn. However at the same time rotorcraft will require enhanced reliability and maintainability resulting in low life cycle costs.

The history of rotorcraft confirms that helicopter weight grows through the life of the aircraft programme and that airframe changes to encompass physically larger engines can be extremely costly. This increase in weight creates a requirement for additional engine power to simply restore aircraft performance to its original levels, with still more power required to provide additional capabilities to match the extended operational requirements. The following chart clearly demonstrates the case that helicopter weight increases through the operational life of the aircraft.

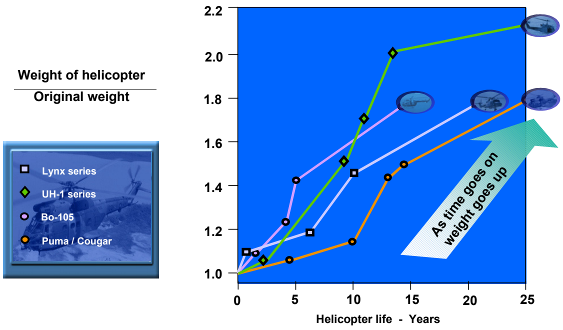


Fig.2 Historic weight increase of Helicopters

To meet this forecasted demand for increased engine power a growth strategy has been derived for the RTM 322 to take it from its initial baseline standard with a take off rating at 2100 SHP to that in excess of 3000 SHP.

The demand for low life cycle cost is an ever increasing requirement both on the airframe and engine manufacturers. From an engine view point life cycle cost can be split into five major components:

- Fuel Burn
- Maintenance man-hours
- Maintenance material cost
- Unit cost of engine
- Development cost of engine.

Clearly, while the demand for engine power growth and reduced life cycle cost exist concurrently there is a trade off or exchange between the two, and it is the optimisation of this exchange which is key to successful product growth.

RTM 322 Growth Strategy

The design strategy of the RTM 322 was to provide for substantial power growth throughout the engine family, whilst reducing the life cycle cost relative to existing engines and maintaining the same overall geometry envelope and the maximum level of commonality of components. A fundamental design requirement, at product launch, was for a greater than 50% growth capability to accommodate existing aircraft power increase demands and to satisfy the needs of new emerging airframes. The strategy that exists today, therefore, was embedded in the engine design when it was first launched.

There are three primary means of increasing the power from a turboshaft engine whilst maintaining its core size.

- Increasing engine mass flow and increasing the pressure ratio
- Increasing the turbine operating temperature
- Improving the individual turbomachinery component efficiencies and reducing losses.

Whilst thermodynamics dictate that the overall efficiency of a turboshaft engine improves with increased pressure ratio and increased combustor exit temperatures we are governed by the law of diminishing returns. For the same increase in pressure ratio or exit temperature there is progressively less return in performance and the non-recurring cost of achieving this improved performance is increasing. It is therefore essential that any power growth strategy, for a turboshaft engine, fully recognises not only the technology advancements required and the return on performance but also the cost of the technologies, plus their affect on life cycle cost, and maintains consideration of what is ultimately affordable.

The power growth plan of the RTM 322, through increased mass flow and/or increased turbine operating temperatures is depicted in the following chart.

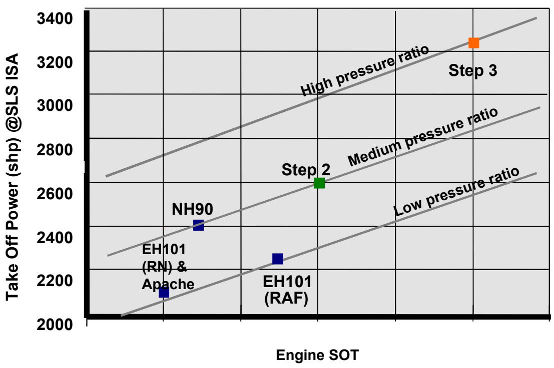


Fig. 3 RTM322 Power Growth

The baseline engine qualification take off power of 2100 SHP, as used for the Mk100 and Mk 120 engines, is achieved with a modest overall pressure ratio and a modest turbine operating temperature. Therefore right from the start the potential for power growth was designed in.

Growth Step1
Increases in pressure ratio have been achieved with minor and very low risk changes in compressor geometry without changing the combustor and turbine, and similarly turbine temperatures have been increased at very low risk by maintaining existing turbine components.

Step 1 of the growth plan has already been exploited. For the Mk 200 engine in service with EH101 Mk3 the take off power rating was raised to 2260 SHP by a rise in turbine temperature whilst maintaining the pressure ratio and mass flow the same as the baseline engine. This only required a minor change in the configuration of the secondary air cooling system. For the 01/9 engine in NHI NH90 an increased flow compressor has been used with a moderate increase in overall pressure ratio to increase the take off power rating to 2400 SHP. With the increase in mass flow the power rating has been achieved whilst decreasing the turbine operating temperature when compared with the Mk 200. Consequently a further power increase remains available within step 1 by combining the 01/9 increased flow compressor with the Mk 200 turbine operating temperatures.

Growth Step 2
Step 2 of the growth plan builds upon the increased mass flow compressor of the 01/9 engine, by addressing turbine operating temperatures solely. As previously described, modest temperatures were required in the baseline engine thus providing a high potential for increase with consequent changes only required to cooling configuration and material selection in some of the gas path components.

Growth Step 3
Step 3 of the growth plan is achieved by a further increase in mass flow by the introduction of a further increased pressure ratio compressor which has been demonstrated through a research and rig test programme. This can be accompanied by the turbine operating temperatures demonstrated in step 2, or further power growth can be achieved by increasing these temperatures even further whilst still utilising currently demonstrated technology/design. Step 3 permits take off power ratings in excess of 3200 SHP and still at moderately low risk and low development cost. The further increased turbine temperatures described here could be combined with the compressor mass flow from Step 2 to achieve an intermediate growth if desired.

Underpinning the RTM 322 growth strategy has been the Advanced Small Turbine Engine Core (ASTEC) research programme. It was through this programme that the step 1 increased flow compressor was developed and the step 3 compressor demonstrated. The objectives of the programme have been to identify affordable technologies to support existing and new turboshaft engines up to 3300 SHP and define an optimum technical programme for their demonstration. The ASTEC programme has a broad scope and the specific requirements that have been addressed include not only power growth and rating structures but specific fuel consumption, power/weight ratio, cost and technology timescales. A parametric performance study was undertaken to indicate the appropriate cycle options (airflow, pressure ratio, turbine temperatures) to achieve the required engine performance. In parallel a survey was performed addressing component technologies which were applicable to new and/or derivative engines in the defined timescale. This included materials, turbine blade cooling techniques, compressor technology etc. This information was then collated to define a set of whole engine concepts for comparison and evaluation, and down selection to enable specific detailed investigation. The down selection criteria included:

Performance	- hot and high power - power/weight - specific fuel consumption
Recurring Costs	- Unit cost - Maintenance cost - Fuel burn
Non-recurring Costs	- Development Cost - retrofit of existing engines - Installation change
Observables	- exhaust gas flow and temperature

Each of the identified component technologies were analysed, one at a time, for their worth both in terms of power growth and effect on life cycle cost. It was through this aspect of the programme that the exchange or trade off between power growth and reduced life cycle cost was fully explored. The identified technologies can be “cashed” either as a direct power increase (with possible increase in life cycle cost), as a life cycle cost saving at a constant power, or as a compromise where a mix of increased power is achieved at a constant or less reduced life cycle cost saving. Life cycle cost considerations dictated the growth strategy to be based upon derivative cycles/engine designs as opposed to all new engine cycles/designs. This is a reflection of the modern design of the RTM 322.

The ASTEC programme has thus enabled the identification of the required, affordable technologies in order to optimise the exchange between power growth and life cycle cost reduction. This has then in turn allowed a growth plan to be derived in iterative steps where the detailed component requirements for each step are defined. The programme has also enabled the detailed design and demonstration of a number of the technologies, most notably the increased flow/increased pressure ratio compressors.

Review of Major Components/Technologies

This section looks at the major components of the RTM322 that are instrumental in the power growth strategy and describes how the in-built capacity for power growth, as a fundamental requirement of the original engine specification, allows the growth steps previously described to be achieved at moderately low risk and moderately low cost.

Before addressing individual components it is important to recognise the overall engine design and architecture. All engines in the RTM 322 family, including the planned growth engines, maintain the same overall dimensions and internal architecture. This enables engine growth within existing airframes without the need for expensive airframe re-design. The RTM 322 has been deliberately designed to have as large a core size as possible within the engine space installation envelope as this determines the growth possible within the existing engine geometry by increased mass flow.

Compressor growth was detailed in the previous section. Starting from a modest pressure ratio in the baseline engine configuration, it has been relatively simple to achieve the increased flow/pressure ratio compressor referenced in step 1 and the further increased pressure ratio compressor demonstrated in the ASTEC programme by addressing the aerodynamic geometry of the gas washed components. The material remains unchanged as titanium.

The current combustor has a very large volume with walls fabricated in high temperature resistant nickel based super alloy sheet and a sophisticated wall cooling system. A thermal barrier coating is plasma sprayed onto the inner surface. As such it is not anticipated that any changes would be required to satisfy the growth steps of the engine other than new fuel spray nozzles. Under the ASTEC programme a reverse flow air spray combustor has been successfully demonstrated should this be chosen in preference to the current reverse flow vaporiser design.

The High Pressure gas generator turbine blades are conventionally cast for the Mk100 engine, but have already developed to a single crystal blade alloy, specifically developed by Rolls-Royce, for all other currently qualified marks. For the step 1 growth exploited in the Mk200 engine, where the turbine temperature was raised, the geometry and materials of both blade stages remained unchanged, the only difference being an increase in first stage cooling flow (the second stage is currently uncooled in all applications). To support the growth steps 2 and 3 a change is required to blade materials to introduce “second generation” single crystal technology in association with improved cooling effectiveness. Such materials are already widely used in other Rolls-Royce military and civil engines, and hence provides a low risk development, as they are “off the shelf” technologies. The change is limited to materials; there is no requirement for geometry change. The blades are already shroudless in design which means that blade stresses and disc loads are minimal and creep lives are maximised for a given rotationary speed. To operate at the temperatures specified for step 3 it will also be necessary to apply new materials and cooling to the second stage blades.

The power turbine blades remain as conventionally cast nickel based alloys for all currently qualified marks and also for step 1 of the growth plan. To support growth steps 2 and 3 a blade material change is required to the first stage blade only. The change is to an already established Rolls-Royce propriety conventionally cast material that is widely used on a number of other engines, and hence again is “off the shelf” technology.

All marks of RTM322 are fitted with a highly sophisticated dual channel Full Authority Digital Engine Control system. This provides significant advantages, such as low pilot workload through carefree handling, very rapid engine responses - providing increased safety margin and crisp aircraft manoeuvrability, together with built in test and health and usage monitoring system capability. Increasing the power through the growth steps of the RTM322 requires no more than changes to software schedules in the engine’s electronic control unit which are very easily achieved.

It can be clearly seen therefore that the technology insertion required to support the growth strategy is minimal. Where technology insertion is required it is already available and/or demonstrated and it confirms that the growth strategy for the RTM322 is both a low risk and a low cost strategy.

Conclusions

The RTM 322 is now an established family of modern turboshaft engines with a rapidly expanding customer base. Recognising the historic requirement for power growth due to changing operational requirements of helicopters during their life cycle, and today’s drive for ever decreasing life cycle cost, the RTM 322 has been designed with a built-in growth strategy that optimises the two requirements.

This growth strategy puts the RTM 322 in a unique position to meet both the power requirements and the life cycle cost reduction demands of future variants of transport, maritime and attack helicopters. Such platforms that are likely to benefit include growth versions of the NHI NH90, EHI EH101, Sikorsky S-92 plus Blackhawk upgrades, Agusta Westland/Lockheed Martin US101 and Boeing AH-64D.

The growth strategy is clearly shown as a low cost/low risk strategy due to the required technology insertion being already available and/or demonstrated, and the original design specification of the RTM 322 requiring that the product, at is conception, was designed for power growth.