THE MTR390 TURBOSHAFT ENGINE

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Abstract

This paper presents the MTR390 turboshaft engine used to power the Tiger attack helicopter. The MTR organisation who produce the engine, and the workshare of the three partner companies, MTU, TM and RR is described. Modularity, maintenance and the growth potential of the engine are covered, as are the engine design, development and test experience. A summary of the programme status is presented, with an overview of other potential applications for the engine.

1. Introduction

The MTR390 turboshaft engine has been developed jointly by MTU, Turbomeca and Rolls-Royce, for the Eurocopter Tiger attack helicopter, and for use in other military and civil aircraft.

The development and qualification programmes have been completed, which together with the AMT programme completion in 1997, will lead to the qualification of the initial production engine at the end of 1997. The production investment contract has been signed, preparing the way for production engine delivery in 2000. The MTR390 has obtained its Military and Civil Type Certificates.

The first production application will be the Eurocopter Tiger for the French and German armies, due to enter service in the next millennium. Potential export opportunities for the Tiger helicopter with the MTR390 are being pursued, as are other helicopter applications.

2. Engine Partnership

MTR is a partnership of three of the largest European aero-engine companies, MTU, Turbomeca and Rolls-Royce, and as such utilise their total experience in collaborative projects, whole engine production and in service support. In addition each partner company adds its own unique technology experience. The workshare is 40, 40 and 20% respectively.

Responsibility for the engine parts is shared between the partners; Turbomeca for the compressor, gearbox, control system and various accessories; MTU for the combustion chamber, combustor casing, gas generator turbine, intermediate casing and several accessories; Rolls-Royce for the power turbine and the drive shaft.

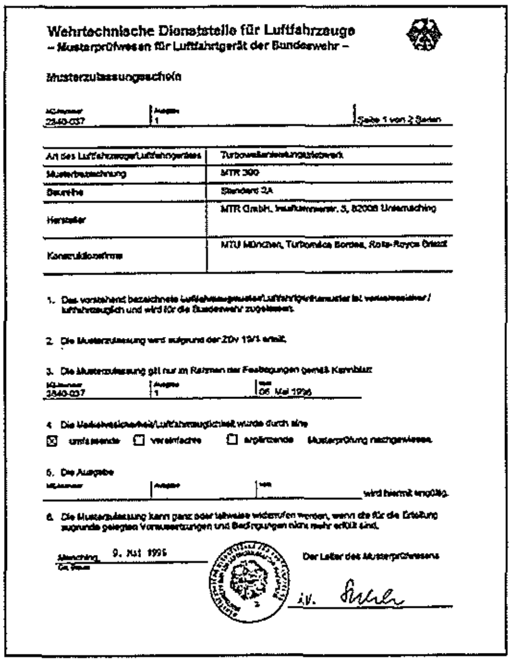
Design and development of the components was carried out by the appropriate responsible partner companies. MTR directs and co-ordinates the design, development, production, marketing, sale and support of the engine and acts as the contractor to the French and German governments and other customers.

Programme History

The beginnings of MTR started with the formation of MTM in 1978, consisting of TM and MTU. Following this the MTM385R engine was defined in 1984 and shortly, RR began participating in the programme, resulting in the definition of the uprated MTR385-R3 engine in 1986.

MTR was founded in 1989, and the development contract for the MTR390 was signed. The first engine ran shortly after this in December. Successful flights were achieved in 1991 in both the Eurocopter Panther Flying Test Bed and the first Eurocopter Tiger attack prototype aircraft, after achieving Qualification A, flight clearance for the development standard engine. The qualification testing was completed in 1994, the same year in which the first Accelerated Mission Test started, part of a life demonstration programme of the engine.

The Military Type Certificate was issued in 1996, see Fig.1, and the Civil Type Certificate was obtained in 1997, see Fig.2. In this year also, the Production Investment Contract was awarded by the French and German authorities.



Wehrtechnische Dienststelle für Luftfahrzeuge
– Musterprüfwesen für Luftfahrtgerät der Bundeswehr –

Musterzulassungsschein

2840-037 | 1 | Seite 1 von 2 Seiten

Art des Luftfahrzeuges/Luftfahrtgerätes	[illegible]
Musterbezeichnung	MTR 390
Baureihe	Standard 2A
Hersteller	MTR GmbH, [illegible] 3, 82008 Unterhaching
Konstruktionsfirma	MTU München, Turbomeca Bordes, Rolls-Royce Bristol

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2. Die Musterzulassung wird aufgrund der ZDv 19/1 erteilt.
3. Die Musterzulassung gilt nur im Rahmen der Festlegungen gemäß Kennblatt
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Der Leiter des Musterprüfwesens

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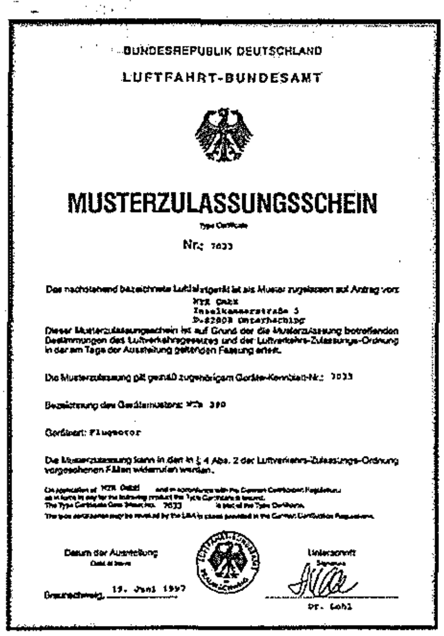
Figure 1



BUNDESREPUBLIK DEUTSCHLAND

LUFTFAHRT-BUNDESAMT

MUSTERZULASSUNGSSCHEIN

Type Certificate

Nr.: 7033

Das nachstehend bezeichnete Luftfahrtgerät ist als Muster zugelassen auf Antrag von:
MTR GmbH
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Die Musterzulassung gilt gemäß zugehörigem Geräte-Kennblatt-Nr.: 7033

Bezeichnung des Gerätemusters: MTR 390

Geräteart: Flugmotor

[illegible]

Datum der Ausstellung

Braunschweig, 19. Juni 1997

Unterschrift

Dr. Lohl

Figure 2

3. Main engine features

The MTR390 engine is in the 1000 kW power class, with a competitive cruise SFC against other engines in the class. It has been designed with both military and civil applications in mind for helicopters in the 2.5 to 7.5 tonne weight class.

It has an excellent One Engine Inoperative (OEI) power rating, with limited maintenance action after the OEI rating has been used. The 30 second OEI rating is a 32% power increase over the maximum continuous rating, and the engine is cleared for two applications per mission. This is most useful for multi-engined helicopters, should one engine fail, the power of the other engine can be increased to enable it to land safely, or in the case of a military helicopter, to escape from a threatening situation.

The engine has an integral reduction gearbox, which reduces the power turbine shaft speed of approximately 27,000 rpm down to an output shaft speed of 8,000 rpm. By changing just four gears in the reduction gearbox, the output shaft speed can be reduced to 6,000 rpm. This is most useful to helicopter manufacturers, as they prefer low output shaft speed, as the helicopter rotor gearboxes can be lighter and smaller.

The engine is a compact design, with a power to weight ratio of >5.5 (kW/kg). A high power to weight ratio enables the helicopter to maximise its useful payload.

The engine has been designed with a 50% power growth capability, within the current engine envelope. This is most desirable to military helicopter operators, as it enables the overall weapons system to develop, without major changes to the engine installation.

4. Workshare and design features

The workshare split is shown in Fig.3. Engine testing has been shared between the three companies, taking place in France, Germany and the UK.

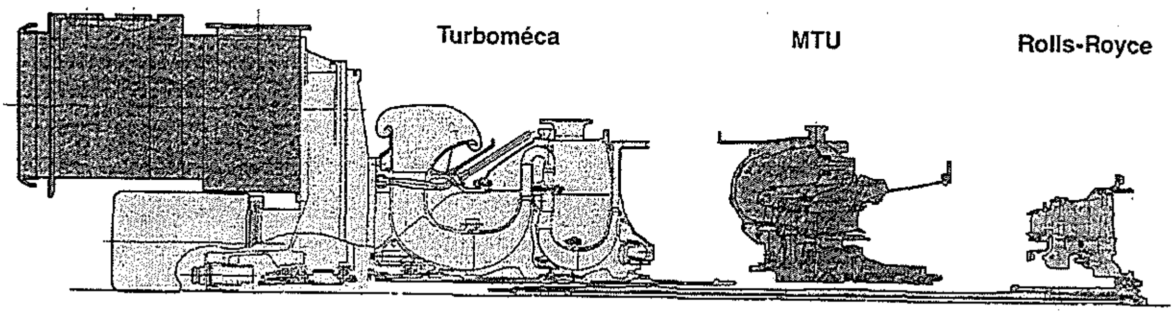


Figure 3

The engine is of a modular design with two shafts, twin centrifugal compressors, single stage gas generator turbine and a two stage power turbine. It has a combined accessory and reduction gearbox. The engine has an electronic control unit (FADEC).

5. Modularity and maintenance

The engine consists of four separate, interchangeable modules, including the FADEC, see Fig.4. Modules can be changed without the need to retest the engines, nor are any special checks or adjustments required on module change. This is very useful to operators as it enables them to quickly replace damaged parts of an engine without the need to remove the whole engine.

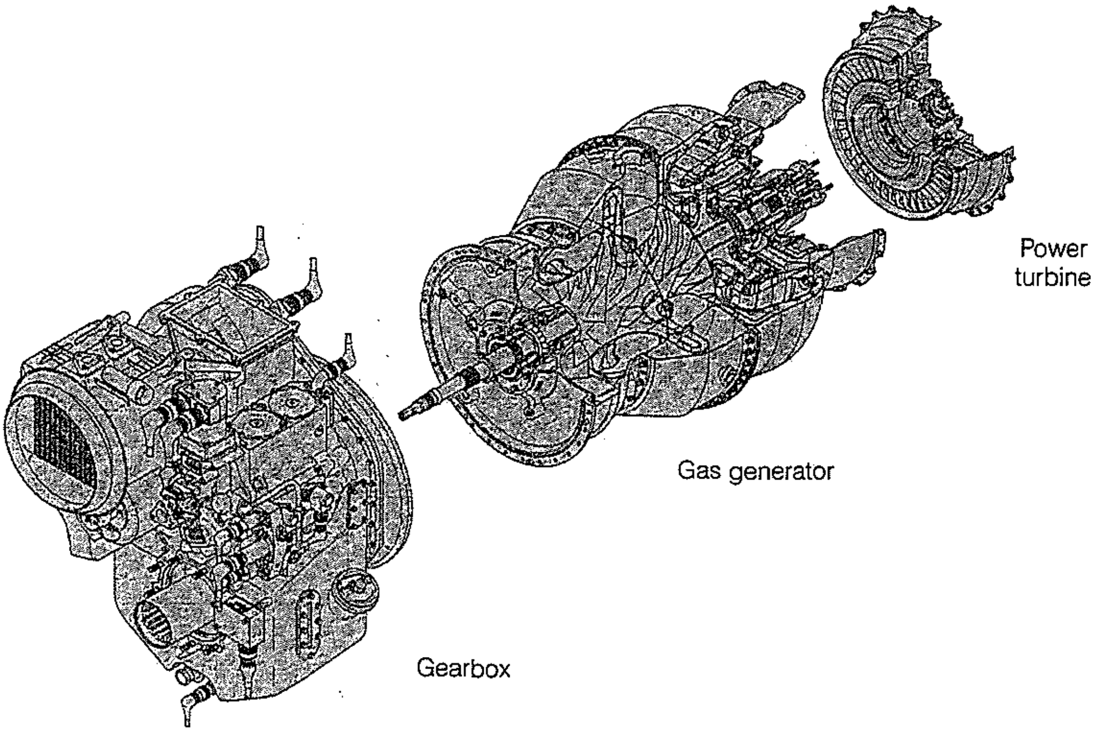


Figure 4

Maintenance time and costs are reduced by on 'condition monitoring' carried out by the FADEC, with its built in diagnostic aids, pre-clogging and by-pass indicators for the fuel and oil filters and chip detectors in the oil system to monitor bearing condition. The built in test failure detection system also informs the maintenance personal of the location of faults, to minimise maintenance time. Also, a maintainability programme has been carried out throughout the project life, including successful demonstrations on installed and uninstalled engines to prove the maintainability concepts.

A minimal toolkit is required for first line maintenance, consisting of just ten handtools. All line replaceable units (LRU) can be removed by one operator, in an average time of 15 minutes, and there is no wire locking. The power turbine module can be removed and refitted whilst the engine is installed in the aircraft, and a complete engine change can be performed in the Tiger helicopter in 40 minutes.

All of these aspects reduce the downtime of the aircraft, and maximise the helicopter utilisation.

6. Engine details

The main engine components are as shown in Fig.5.

The gearbox module contains both the accessory and reduction gearboxes. It has an integral oil system, which offers good ballistic tolerance to smallarms fire. The location of the fuel and oil filters adjacent to each other gives the engine tolerance to fuel icing conditions, as the heat from the oil system is transferred to the fuel.

The two stage centrifugal compressor is erosion and FOD tolerant, and has a low parts count. There are no inlet guide vanes as would be necessary with an axial compressor. The compressor does not require a bleed valve as it offers a very wide surge margin. Tests carried out in icing conditions have shown that the intake does not suffer from ice formation, and hence no anti-icing system is required. These points lead to a reliable and rugged low cost unit.

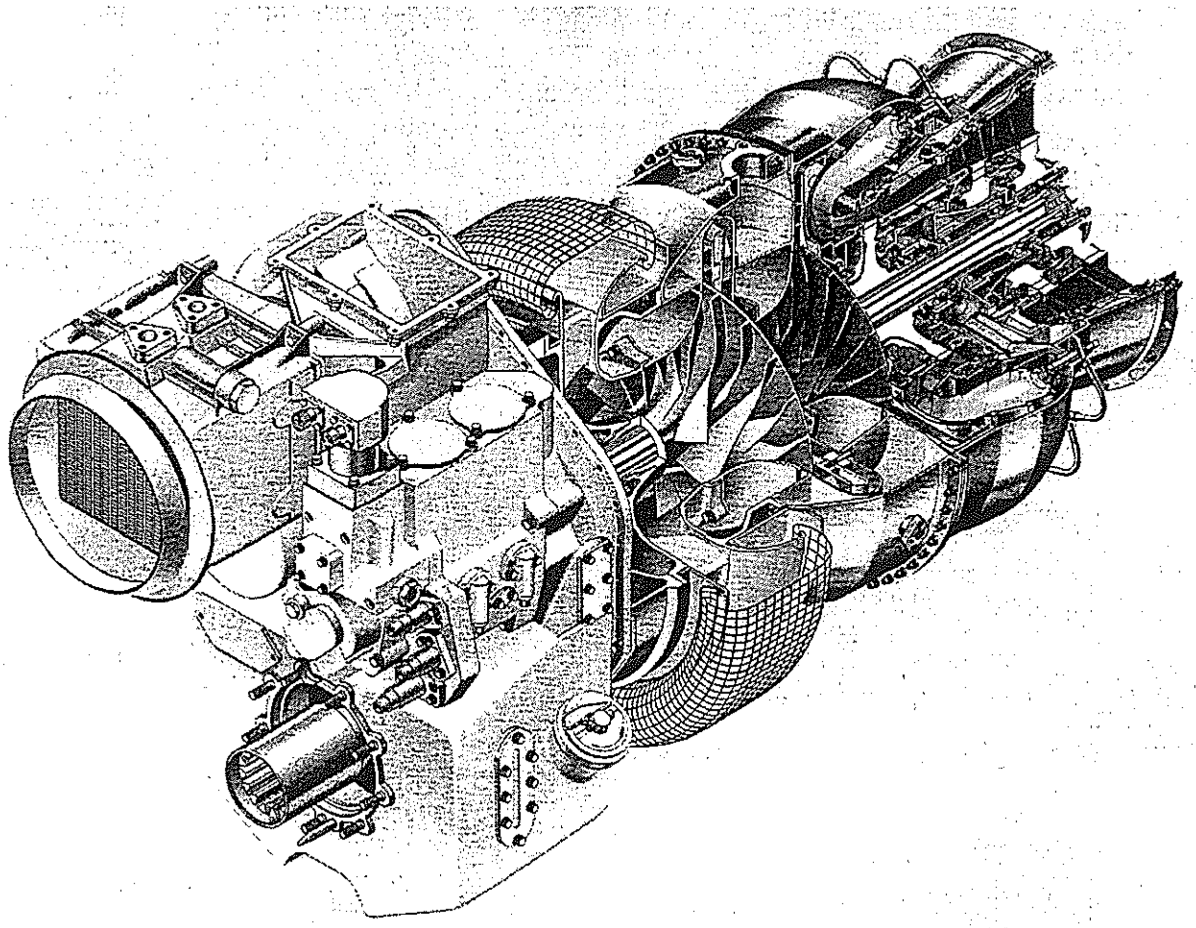


Figure 5

The combustion chamber is annular and reverse flow, resulting in a shorter more compact engine with a high combustor efficiency. A shorter engine also means shorter shafts, with less shaft flexing and minimal blade tip rubs, so performance retention is improved. An airblast atomising fuel injection system is used, which is tolerant to dirty fuel, and gives low emissions.

The gas generator turbine is single stage, with 2nd generation cooled single crystal blade material and powder metal disc. The advances in materials and blade design enabled the change from the traditional two stage gas generator in this power class to a single stage design providing weight and cost advantages. The two stage power turbine is uncooled and incorporates single crystal blades, with all turbine blades using 3D aerodynamics for greater efficiency. Additionally the power turbine is contra-rotating relative to the gas generator, which further reduces losses, and improves the engines efficiency.

Engine control is provided by use of FADEC (Full Authority Engine Digital Control). The FADEC provides complete control of the engine, functions are performed automatically, and thus the pilot workload is reduced. The main tasks of the FADEC are isochronous power turbine speed control (maintains a constant rotor speed), acceleration control, limitation of the turbine temperature, engine speeds and torque, power synchronisation between the engines, automatic acceleration of the engine up to OEI rating should one engine fail and supervisory and health monitoring tasks in conjunction with the engine health monitoring system (limit exceedance monitoring, life usage computation and engine performance monitoring). In addition, deceleration performance of the engine was optimised by use of the FADEC, providing the helicopter with high manoeuvrability, most advantageous to a combat helicopter. The built in test failure detection has optimised recovery laws to enable the engine to continue operating. The FADEC frees the pilot from having to worry about the engines, and allows the pilot to concentrate on the mission, see Figs.6 and 7.

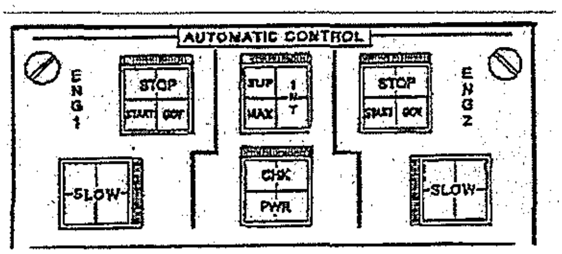


Figure 6

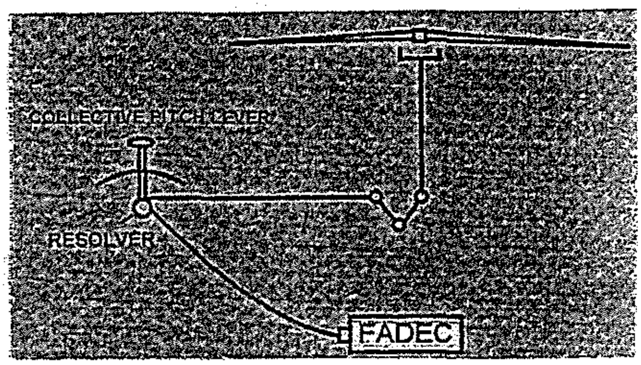


Figure 7

7. Design and development

Traditionally components were designed on a drawing board, by application of past experience and the use of established design procedures. Relatively little was understood about the way in which they would function in the engine environment. To validate the designs, they were tested. If they failed, they were redesigned, using the information gained from the analysis of the failure. This was most often a lengthy process, and the costs involved were high, due to the high number of components that had to be manufactured, and the large amount of testing involved.

The MTR390 was designed and developed with the aid of computers. These were used to create the initial designs, known as CAD (Computer Aided Design) models. Stress models were created from these, by dividing the CAD models into elements, described mathematically by nodes. The engine environment, for instance loads and temperatures, could then be simulated to observe how the design would cope under these conditions.

Similarly, mathematical performance models were created from data gathered in rig tests and from existing designs and were used to simulate the characteristics of the compressors and turbines. They contain information on component efficiencies, engine bleeds, thermodynamic and mechanical losses, and are used to predict steady state and transient performance, analyse engine test results, and optimise control laws.

A real time simulation test rig was made to develop the FADEC and its control laws. This can simulate the rotor, engines and the other FADEC, to fully explore the control aspects of the FADEC.

Other models exist such as the whole engine model (WEM), used for vibration, shaft and engine carcass deflection analysis, and air systems model to investigate the secondary air system and seal performance.

The models are enhanced and validated by rig testing of individual components, such as frequency analysis of blades, and cyclic spin testing of discs. This confirms the accuracy of the models, and provides empirical data to finally validate the designs.

Whole engine testing is used to fine tune the design, and confirm the durability of the engine through endurance type testing, and provide lead fleet reliability information through accelerated mission testing (AMT). Endurance testing is designed to confirm the turbine component lives by running the engine at very high temperatures, AMT is based on the actual predicted mission profile the engine will experience in service, and therefore provide data on reliability. These tests were carried out according to the Military specification MIL-E-8593A. Whole engine testing is also used to explore the flight envelope of the engine, using altitude test facilities, and for the clearance of different fuels and oils, and to explore engine performance in such areas as icing conditions, sand and corrosive environments.

Test experience

During the programme, a total 14,985 hours of engine running have been completed. Development bench running of 9193 hours has been accumulated, including 1500 hours of endurance testing and 1,800 hours of AMT. Flight engines have logged up a total 5790 hours, 5010 hours in the Tiger, and 780 hours in the Panther FTB.

Within the engine testing, few fundamental problems have been revealed, which have been satisfactorily rectified by modification, the AMT has revealed no major design problems, and confirmed the low performance deterioration of the engine.

During the sand testing performed with the aircraft filter fitted, excellent performance retention was demonstrated, <4% power deterioration, <1% SFC deterioration over 10 hours of running. The test conditions were equivalent to operating in an environment that is two times worse than a whiteout sandstorm. A whiteout sandstorm is considered to be equivalent to 53 mg per cubic metre. The engine parts were in excellent condition, and suitable for further use.

The engine has demonstrated its ability to run on a wide variety of fuels and oils, including diesel and leaded fuel, without deterioration or the need for overhaul, giving greater operational flexibility.

The engine has proven its ability to operate down to very low temperatures. During cold weather trials in Sweden, the helicopter was soaked down to -21°C, with the battery in the aircraft, and the engines started first time. Successful starts have been performed down to -50°C in the altitude test facility.

The engine has no visible smoke, with a very low SAE smoke number, see Fig.8. The exhaust emissions are very low, and comparable to civil turbojet engines, although there are no specific requirements that helicopter engines of this class must meet.

Proven low SFC and power deterioration over 800 hours of AMT, 3% and 4% respectively, equivalent to 2000 hours of service use.

Proven corrosion resistance as demonstrated whilst running for 95 hours ingesting salt water, and subsequently being stored in a salt laden atmosphere. The engine components were suitable for further us

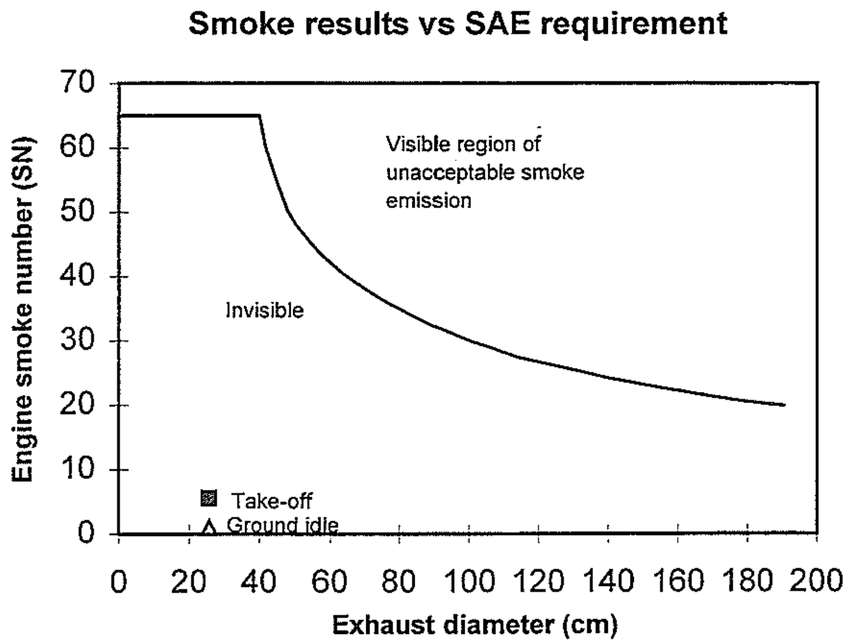


Figure 8

Reliability

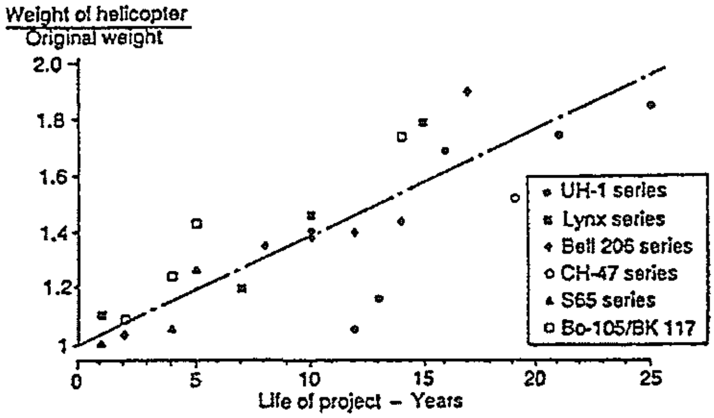
The engines in the flight programme have proved to be very reliable. In the 5,800 flight hours there has been 1 unplanned 'in flight' shutdown, caused by a software problem which has now been corrected, and 1 basic unplanned engine removal. Considering this is during the development flight programme, it is an impressive result. The engine was designed from the outset to be a simple and reliable design, with a low parts count to lead to a reliable engine.

Eurocopter are impressed with the MTR390 in the Tiger helicopter.

8. Growth potential

The engine was designed with a 50% power growth capability, achievable within the engine envelope. This is most desirable, as the overall weapons system develops, and the helicopter weight increases, so the engines can meet the extra power demand, without changes to the installation, see Fig. 9.

Helicopter gross weight increase



- Historically helicopter power requirements have increased as weight increases

Figure 9

Modifications to achieve an intermediate 20% power growth would include a new 1st stage impeller, stator outlet temperature increase of 120°K, combustion chamber modification, improved gas generator blade cooling and power turbine nozzle cooling. There would also be a slight capacity increase of the turbines, and gearbox modification.

Further modifications for 50% power growth include a new impeller design, SOT increase of 150°K, further improved gas generator blade cooling and 2nd stage power turbine nozzle cooling. There would also be a rematch of the turbine capacities, and gearbox modification.

The power growth can be realised with no effect on engine weight, life or reliability, with the same SFC at maximum power and slightly improved SFC at part power.

9. Programme status

The development phase will be concluded with the completion of the AMT programme, and qualification of the initial basic production engine, by the end of 1997. The production investment phase has now begun, and production tooling will be operational by the end of 1999, the first production engine test will take place in 2000. The production contract is anticipated shortly by the launch customers, the French and

German Ministries for an initial batch of 320 engines to be start delivery by the middle of 2000, with a total expected order of 1000 engines by the launch customer.

Potential exports of the Tiger with the MTR390 (the only installed engine) include Turkey, Sweden, Norway and Australia.

Other potential applications for the MTR390 engine exist; re-engining of the Lynx, to provide an improved payload capability and enhanced performance; powering the Advanced Light Helicopter being developed by HAL of India, a naval helicopter; the OHX program in Japan; the SST class of helicopter in China and the Augusta A129 attack helicopter.

Derivatives of the engine were planned at the initial design stage, including the 6000 rpm output speed version, to enable the MTR390 to be used in other helicopter applications, aided by the FADEC, which is easily adjustable to adapt to other applications. The design is also viable for use in direct drive versions.

Summary

The MTR390 has now almost finished a successful development test and flight programme, due to be completed in 1997. This will lead to production of the engine for the Tiger attack helicopter, due to begin in 2000.

The engine has also been designed and developed with other military and civil applications in mind, and to this end, has obtained both Military and Civil Type Certificates.

Acknowledgements

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