THE SUCCESSFUL DEVELOPMENT HISTORY OF THE MTR390 TURBOSHAFT ENGINE FROM THE DEFINITION OF THE DESIGN TO THE SERIES PRODUCTION

P. Schinzl[1)], F. Malzacher[1)], P. Moncoutie[2)], B. Brereton[3)],
G. Schuberth[4)], M. Lauvaux[4)]
1) DaimlerChrysler Aerospace, MTU München
2) Turbomeca
3) Rolls Royce
4) MTR GmbH

1. ABSTRACT

This paper presents the MTR390 turboshaft engine used to power the Tiger attack helicopter by an emphasis of the development history. 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 well as engine design and test experience. A summary of the programme status is presented with an overview of other potential applications for the engine.

2. INTRODUCTION

The MTR390 (Fig. 1) is a new turboshaft engine in the 1000kW range being jointly developed by three of the largest European engine companies: MTU in Germany, TURBOMECA in France, and ROLLS-ROYCE in Great Britain.

The three companies have been working together for more than 30 years on several programmes like Adour, Larzac, RB199, EJ200, RTM322, ... The declared goal of the MTR partner companies is to create an engine that will not only suit the TIGER/GERFAUT programme but will also compete in the military and civil market for the next 20 to 30 years.

The development and qualification programmes have been completed together with the AMT programme completion in 1997 and led to the qualification of the production engine in 1999. As a result of the successful completion of all certification requirements the MTR390 has obtained its Military and Civil Type Certificates. The production contract in has been signed preparing the way for production engine delivery in 2001.

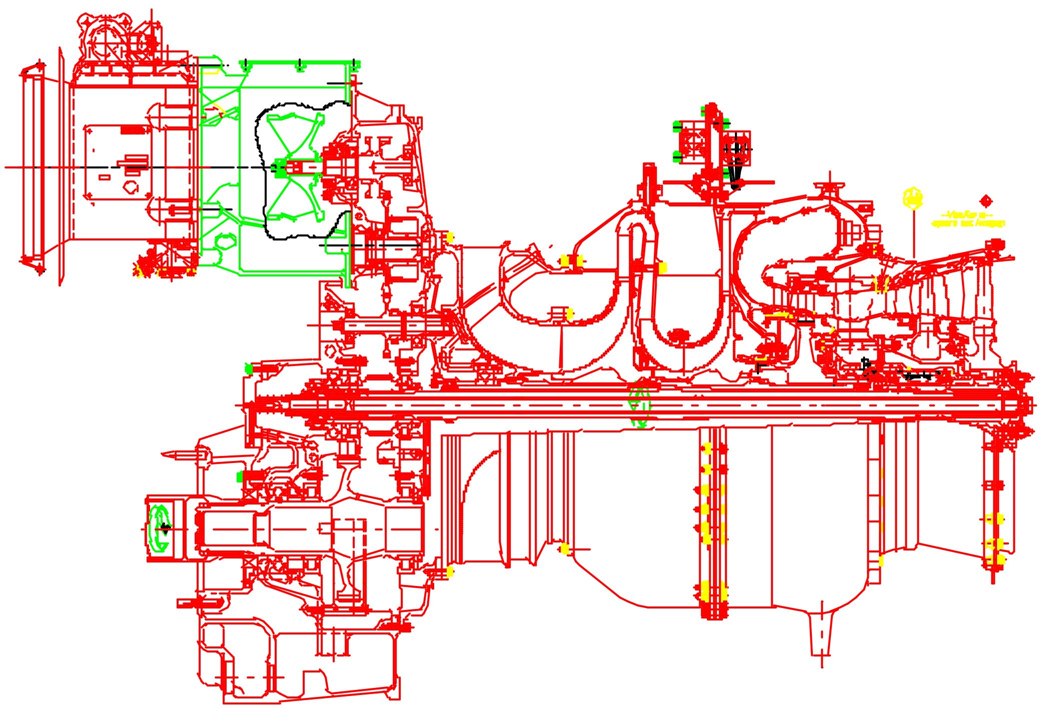

Fig 1: General Arrangement

3. ENGINE PARTNERSHIP

MTU TURBOMECA ROLLS-ROYCE GMBH (MTR) GmbH is a joint company established under German law in Munich in 1989 by MTU Motoren- und Turbinen-Union München GmbH, Turbomeca S.A. and Rolls-Royce plc.

The purpose of the company is

- to act as contractual party vis-à-vis the authorised governmental authorities and other potential customers for the MTR390 engine
- to responsibly manage and coordinate among the partner companies the development, airworthiness, production preparation, production, marketing, sales, licensing and support of the MTR390 engine.

MTU:
MTU Munich is part of DaimlerChrysler AG and responsible for all aero engine business as the leading German engine company.
MTU is in charge of the design and manufacture of the Combustion Chamber, the High Pressure Turbine, the interduct and rear bearing chamber and the oil cooler

Turbomeca (TM):
Turbomeca, as part of the French SNECMA Aero Engines Group, is the world leader in turboshaft engines for helicopters. Its engines cover the largest power range from 450 to 3.000 shp and equip helicopters made by the world's leading manufacturers.
TM is in charge of the design and manufacture of the compressor (LP - HP), the gearbox (reduction and accessory drive), most of the accessories and the FADEC

Rolls-Royce (RR):
Rolls-Royce is a world-leading power systems business meeting the needs of customers in propulsion, electrical power and materials handling around the world.
RR is in charge of the design and manufacture of the power turbine, the stub shaft and the power turbine shaft

4. MAIN ENGINE FEATURES

The MTR architecture is the result of an optimisation study, commonly carried out by the three partner companies.

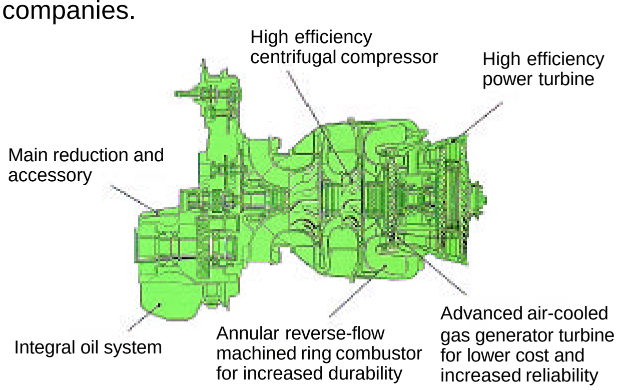

Fig. 2: Engine architecture

5. DEVELOPMENT HISTORY

The development of the MTR390 engine started officially on 1st January 1988. Within two years, the technical requirements were specified and the main development contract was approved by the end 1989 followed by the first engine run in December 1989.

The engine development phase was divided into three major steps:

- Qualification A: Preliminary flight release
- Qualification B: Military Type Certificate (Musterzulassung)
- Qualification C: Release of the production standard

The first development phase – Qualification A – was required for the clearance of the MTR390 engine for the FTB (flying test bed) and prototype testing. In accordance with an agreed qualification procedure, engine and accessories tests i.e. 60 hrs endurance run, vibration investigation, engine overspeed tests, software integration, power turbine overspeed test (cut shaft), oil and fuel system performance tests, oil flow interruption test in order to clear negative g flights, equipment vibration and fire tests etc., were successfully performed. The completion of these tests with the so-called engine standard 1A ended in the clearance for FTB tests in the 'Panther' helicopter and flight tests in the 'Tiger' prototype helicopter.
The first FTB flight was successfully performed with two MTR390 engines on 14th February 1991 while the first flight on the 'Tiger' prototype helicopter PT1 took place with prototype engines on the 25th April 1991.

The main subject of Qualification B (Military Type Certificate) and C was to satisfy the Airworthiness

requirements and to release the production engine standard.
With a 'new' defined engine standard 2A, additional engine and rig qualification tests were carried out and successfully completed, i.e.

- rain ingestion test
- snow ingestion test (simulated with crushed ice)
- 150 hrs type endurance run
- overspeed tests
- vibration surveys
- oil/fuel clearance runs within several 150 hrs endurance tests
- 30 seconds OEI demonstration (8 shots of 30'' each)
- inclination tests
- accelerated mission testing (2 engines, each 1.200 hours running) representing an ageing equivalent to 4.300 Tiger mission hours;
- sand ingestion tests (with and without sand filter)
- corrosion test
- exhaustive aircraft - engine interface qualification (control system, …)

One important step in achieving this qualification milestone was the test campaign performed on the altitude test facility (ATF) at Centre d'Essais des Propulseurs (CEPr) in France. Within several test phases the following major qualification justification were performed:

- Demonstration of the starting and restarting envelope
- Demonstration of the auto-relight function within the operating envelope
- Demonstration of the specified engine performance within the operating envelope
- Clearance of engine fuels and oil brands for operation within the specified envelope
- Icing test with a representative helicopter air intake.

Based on the engine qualification evidence (engine tests, analyses, FMECAs, etc.) the engine standard 2A was granted the military Type Certificate by the German Airworthiness Authorities on the 09.05.1996.

Subsequent to the issue of the Type Certificate, the development of the engine and software concentrated on performance improvement, optimisation of acceleration and deceleration software laws and consideration of maintenance aspects. In order to separate the Qualification B and C standards, an interim standard (2B) was introduced with improved performance features and improved ease of maintenance. This led to the introduction of some modifications. Although most of the qualification tests were performed with the engine standard 2A, all results achieved were transferred to the final qualification standard which will be declared as engine build standard 2C at the end of the engine development phase. The successful completion of qualification of the MTR390 engine closed with the handing over of the Qualification C Certificate by the military customer.
In parallel to the military certification activities, MTR started to gain the civil type certificate. From the very beginning of the development programme, a civil application of the MTR390 was intended and therefore the MTR390 engine specification is based on two main airworthiness regulations, the British Civil Airworthiness Requirements (BCAR) Section C, issue 13, which is equivalent to JAR-E change 6 and the Military Specification MIL-E-8593A.

In November 1992, MTR contacted the LBA in order to discuss possible ways of obtaining the Civil Type Certificate for the MTR390 turboshaft engine. As result of these discussions MTR decided in November 1994 to apply for a German Type Certification in the frame of a Simplified Type Investigation according to §4 LuftGerPO.
The reason for selecting this way was that the company preferred to use the advantage of the German Procedures to avoid additional costs potentially resulting in a repetition of the majority of certification activities which would have resulted when using the Joint European Procedures.
This route was possible because the Military Certification Basis was JAR-E, change 6. Therefore MTR complies with the German regulations that require the same level of safety in the case that the LBA validates a German Military Type Certificate.

At the beginning of June 1997 the final civil documentation was submitted and accepted by the German Civil Airworthiness Authorities supported by the German Military Authorities. Based on the evidence given to both Airworthiness Authorities, the Civil Type Certificate was granted by LBA on 19 June 1997.

6. ENGINE DETAILS

6.1 Compressor

The compressor is a two stage centrifugal system providing a pressure ratio of 14 with high efficiency. The important surge margin enabled to delete the bleed valve after extensive rig and engine testing.
The centrifugal compressor is particularly well adapted for small turbo-shaft engines because it reduces the engine compartment length for installation into the aircraft and also vulnerability to battle damage for military applications.
Its simple design with a minimum of parts (2 stages, no bleed valve, no IGVs) is an advantage for a good reliability.

It demonstrated particularly good tolerance to FOD during the development and qualification tests (sand, ice, water, …).
Both stages can be easily inspected with boro-scopes in order to monitor the mechanical condition.

6.2 Combustor

A reverse-flow annular combustor was chosen for its advantages regarding the whole engine architecture. Best adapted to the centrifugal compressor design, it minimises engine length, provides good accessibility to fuel nozzles and allows a short and rigid generator rotor.

The combustor [1] can be shortened only provided rapid fuel conversion is achieved in its primary combustion zone. Primary zone conversion is controlled by the fuel mixing and vaporisation subprocesses. These processes can be precipitated by achieving a preferably small size of fuel droplet, a high relative velocity between the drops and the gas, a preferably homogeneous fuel distribution in the primary zone, and a high turbulence level conducive to efficient mixing. Therefore, the fuel conditioning system proved to be a key criterion.

In order to improve the fuel conditioning system MTU developed a new type air blast atomiser which is illustrated in Fig. 3.

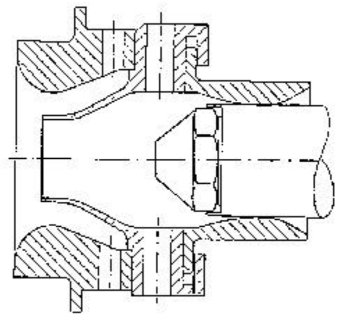

Fig. 3 Air blast atomiser

According to this design the fuel is sprayed onto a venturi insert by means of a pressure atomiser. The two counter-rotating primary zone vortices concentrates the burning process in the centre of the primary zone. The secondary airstream forms a layer on the flame tube wall. This system prevents contact of the burning gases with the flame tube walls. Fig. 4 shows the flame generated by this type of atomiser.

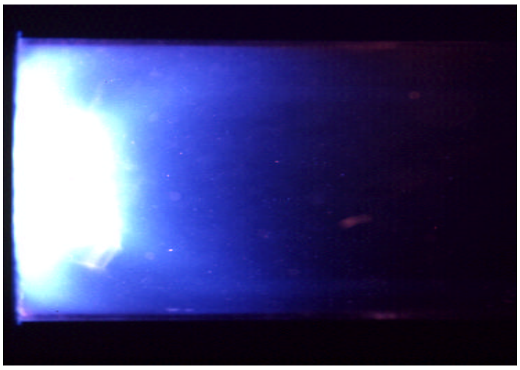

Fig. 4 Flame structure at atmospheric pressure

The high homogeneity inside the primary zone leads to homogeneous temperature profiles at the combustor exit and on the flame tube (s. Fig 62.3). So, the achieved OTDF and RTDF values leads also to a minimisation of the cooling air for the compressor and power turbine:

OTDF < 30%
RTDF < 14%

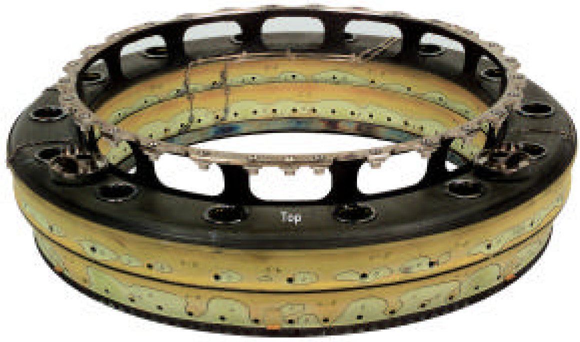

Fig. 5: Thermo colours pattern after the rig test

Furthermore, the described design of the fuel conditioning system leads the a very stable combustion (LBO > 300 kg-air / kg-fuel) which is needed in the case of high deceleration of the engine.

6.3 Compressor Turbine

The increase of the specific power as well as the reduction of the engine weight can be achieved by reducing the numbers of stages in the turbomachinery components. Therefore, the change from the traditional two-stage turbine to a single stage design was chosen at the very beginning of the development. The technology of a transonic single stage turbine [2] with a pressure ratio of 3.6 for small turboshaft engine applications (Fig. 6 was developed within a demonstrator programme which was partly sponsored by the Ministry of Technology of the Federal Republic of Germany.

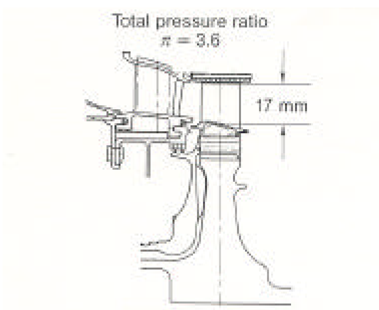

Fig. 6 Single stage transonic high pressure turbine

The key aspects which are mainly to be handled are on one hand the high aerodynamic loading with su-

personic Exit Mach Numbers for the blading. This leads to compression shocks including additional shock-boundary layer interactions with the combined complexity and sensitivity to geometrical deviations.
Much attention was given therefore to the aerodynamic design. On the other hand the minimisation of necessary airfoil cooling flows and the optimisation of the tip-clearance are important to get the best result with respect to the engine operation line.

The compressor turbine design including the interturbine duct was also affected by the mechanical boundary conditions with very high temperature and stress levels for life limiting parts. This shows the excellent interaction between the necessary technical disciplines.

Fig. 7 shows the loss contributors in this class of engine size in comparison with a large engine. It is evident that tip clearance and cooling losses are of the same order as aerodynamic losses and have to be taken careful into account.

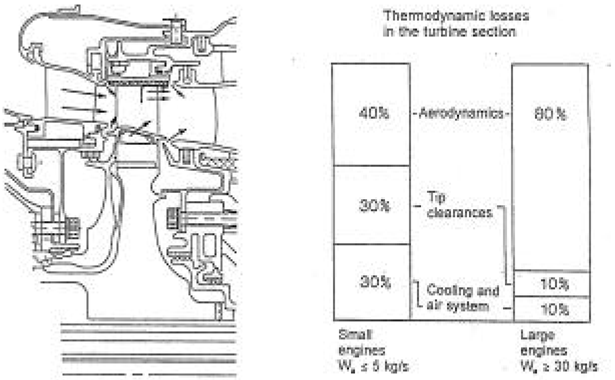

Fig. 7: Thermodynamic losses in the turbine module

In Fig. 8 published results of several tip clearance investigations are plotted together with rig and demonstrator engine data from MTU.

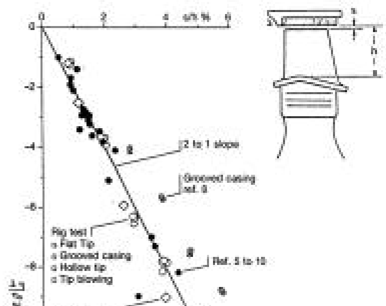

Fig. 8 Influence of tip clearance variations on stage efficiency

As blade height is only 17mm, a tip clearance of 0.1mm results in an efficiency change of 1 point.

Fig. 9 highlights the impact of tip clearance on the radial efficiency distribution for 1, 2 and 3 % relative radial gap(s/h). The efficiency is affected down to 50% blade height.

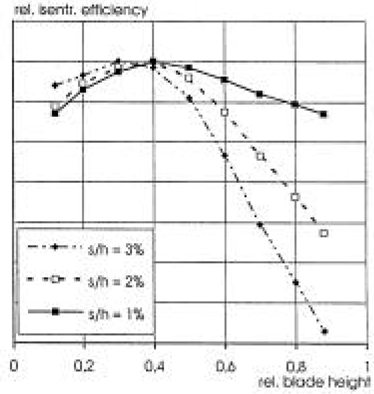

Fig. 9: Influence of tip clearance variation on the radial efficiency distribution

Therefore, an efficient system was chosen with liner segments hung into a casing of low thermal expansion and controlled by forced cooling. The short and rigid gas generator rotor contributes to the efficient tip-clearance control.

In order to minimise the cooling air both nozzle and vane are of single crystal material which permits high temperatures. The blade cooling configuration was developed to minimise the amount of air and the detrimental effects of secondary flows re-entering the gas path.

6.4 Power Turbine

The power turbine is a two-stage uncooled design. The philosophy behind this module was to ensure ease of maintainability and repair whilst achieving a low cost reduced weight yet reliable design. Several features were key in this achievement.

The power turbine is easily replaced in field through the removal of a series of retaining bolts on the power turbine case together with the curvic bolts. The module then simply slides rearwards and clear from the engine. The power turbine bearings and air/oil system are retained within the core engine module. The power turbine can be replaced without the need to re-test the engine.

The curvic coupling, mentioned previously, transmits the torque to the engine reduction gearbox. This curvic coupling allows accurate re-assembly of the power turbine, reducing the susceptibility of the module high speed balance to wear at this interface.

To ensure Foreign Object Damage (FOD) tolerance a single crystal material and equi-axed material was chosen for the first and second stages respectively. The materials chosen offer impact resistance at a relatively low density. This is an important consideration with the cantilevered power turbine design when assessing the highly unlikely event of a blade loss and the associated out-of-balance moment that is generated. The power turbine foreign object damage (FOD) tolerance was optimised and demonstrated during the development programme.

The power turbine rotates in the reverse direction to the engine core. This reverse rotation minimises the 'turning' required by the PT1 NGV to ensure acceptable entry conditions to the first stage of blade. This contributes to the high overall efficiency of the power turbine.

The efficiency is further improved by the absence of an exhaust diffuser and its associated discharge losses. Overall module weight is also reduced.

7. FADEC CONCEPT

The engine control system is essentially based on a FADEC (full authority digital engine control) developed from the background acquired over more than 10 years flight experience on other turboshaft engines applications. This concept allows a great simplification in the hydromechanical units most of which are grouped in the accessory gearbox module.
It provides carefree engine operation, control and monitoring.
It is essentially a single channel with electric manual back up and analogue overspeed protection.

The control function provides basically automatic start sequence, rotor run up, and then maintains the Rotor at the nominal value.
In flight the engine is protected against limit exceedance, surge and flame out for a minimum of pilot workload.

Many other functions are also available like training mode which simulate an engine failure for pilot training and automatic relight in flight in case of flame out.

A lot of work has been done including several altitude tests for optimisation of engine transient accelerations and decelerations.
The result of this optimisation is one of the key elements enabling TIGER aircraft impressive manoeuvrability.

The FADEC also provides maintenance help functions:

- Built In Test: monitors the defect of the Control Unit, all the accessories and aircraft interfaces electrically linked to the Control Unit.
  After a defect is detected the pilot is informed of the consequences if any on the engine operation and complementary localisation information helps the maintenance personal to repair after the flight.
- Engine Performance Check: monitors that the minimum specified power is available.
- Limit Exceedance Monitoring: records potential limit exceedance duration and peak values of main parameters (torque, turbine temperature, gas generator and power turbine speeds) in order to define the maintenance actions.
- Life Usage Monitoring: computes the life consumption of the life limited parts (impellers, disks, …)

8. MODULARITY AND MAINTENANCE

The engine consists of four separate, interchangeable modules, including the FADEC can be changed without the need to retest the engines, nor are any special checks or adjustments required on module change.

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.

A minimised toolkit is required for first line maintenance, consisting of just a few hand tools. All line replaceable units (LRU) can be removed by one operator, in an average time of 15 minutes, and there is no wire locking.

9. TEST EXPERIENCE

During the programme, a total 17.700 hours of engine running have been completed. Development bench running of 10200 hours has been accumulated, including 1500 hours of endurance testing and 1.800 hours of AMT. Flight engines have logged up a total 6500 hours, 5800 hours in the Tiger, and 700 hours in the Panther FTB.
The engines in the flight programme have proved to be very reliable. In the 6500 flight hours there has been 1 unplanned „in flight“ shutdown, caused by a design 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.

10. GROWTH POTENTIAL

The MTR390 features a power growth capability of 50%:

- a first growth step of 10% could be achieved by increasing the turbine entry temperature; up to level already tested on other programme;
- a second growth step of 20% could be achieved by modifying the compressor 1st stage such as to increase the air mass flow within the same size;
- additional steps could be envisaged later on by means of further temperature increase and / or deeper compressor modifications.

11. SUMMARY

The MTR390 has now finished a successful development test and flight programme. This leads to production of the engine for the Tiger attack helicopter due to begin in 2001. 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.

12. LITERATURE

[1] F. Joos, B. Simon, B. Glaeser, S. Donnerhack
Combustor Development for Advanced Helicopter Engines
ISABE 1991

[2] H.-J. Dietrichs, F. Malzacher, K. Broichhausen
Aerodynamic Development of an HP-Turbine for Advanced Turboshaft Engines