



MTR 390

A NEW GENERATION TURBOSHAFT ENGINE

BY

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Summary

The design of the MTR390, a new turboshaft engine in the 1000 kW range, is the result of combining the strength of MTU, Turbomeca and Rolls-Royce. The engine is designed both mechanically and aerodynamically to meet the requirements expected of a modern engine. Results of advanced components technology programmes, started years before the engine development, provide an early design verification.

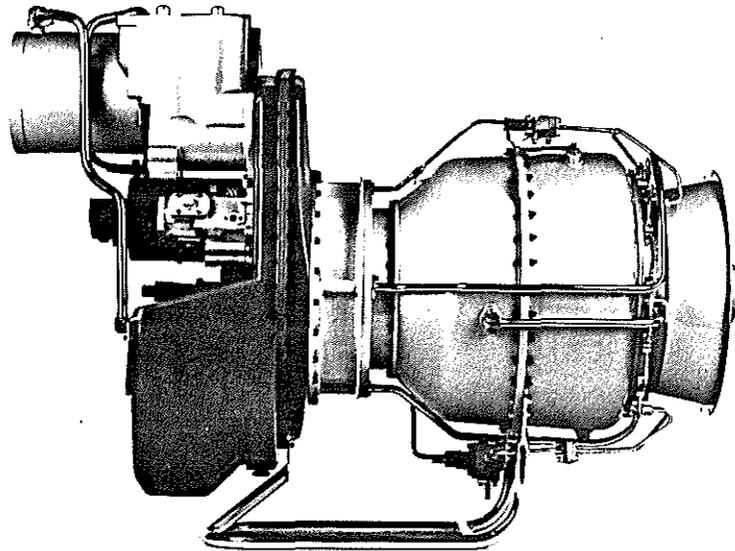


Fig. 1 MTR390

1. Introduction

The MTR390, Fig. 1, under development by MTU, Turbomeca and Rolls Royce, is the designated engine for the Franco-German anti-tank and support helicopter HAP-PAH/HAC (ref. 1). The engine design is based on the large experience of the three partner companies in the aero engine field as well as on their latest technical achievements. The engine, although it has to fulfill very specific requirements for its first application, is suitable for a wide range of other applications.

2. Requirements

The requirements the engine has to meet in its first application are laid down in detailed specifications which are based on civil and military standards, for example:

- JAR-E (for airworthiness and certification requirements)
- MIL-E-8593A
- others (AIR, BCAR, FAR, Defence Standard 00-971, ...)

The main requirements are listed in Fig.2.

SHAFT POWER (ISA 0/0)		OPERATION	
. Max continuous	: 873 kW	. Combat mission with a high number of accels and decels as basis for	
. Take-off (5 min)	: 958 kW	- life	: 6000 h
. Emergency (30 s)	: 1160 kW	- reliability	
. Growth potential		mission failure rate	: 1/1000 h
short term	: 20 %	. Acceleration 0 - 95 % TOP	: < 3 s
long term	: 50 %	. Manoeuvre loads	: 2,5 rad/s + 1 g
INSTALLATION		MAINTENANCE	
. Front drive		. on condition	
. Output shaft		. electronic health and usage monitoring	
- speed	: 8000 to 8320 RPM		
- displacement rel. to engine CL	: 125 mm		
. Installation attitude:	$\pm 15^\circ$ roll		
. Self-contained oil system			
ECONOMY			
. low fuel consumption			
. low weight			
. low production cost			
. low maintenance cost: modular design, good maintainability, high performance retention			

Fig. 2 Main Design Requirements

The functional requirements outlined above (shaft-power-, installation-, operation- and maintenance-requirements) determine the engine size and define its outward appearance. The gearbox and compressor air inlet design are dictated by the installation requirements of the engine's first application, the HAP-PAH/HAC.

The economic requirements do not have such a clearly visible influence on engine design. Since each of these requirements, taken separately without regard to the others, would lead to quite a different design solution, it depends on the skill of the designer, and the technology base available to him, to find the best compromise between these diverging requirements within the design frame generated by the functional requirements - i.e.: the design solution that gives minimum "Life Cycle Costs" (LCC) or "Direct Operating Costs" (DOC). Design to min. LCC has to take into account that the impact of fuel consumption on LCC is approx. twice as high as the impact of each of the other 3 elements (ref. 2). Low SFC, therefore, plays a predominant role in the design optimisation process.

3. Engine Design

3.1 Thermodynamic Cycle and Architecture

Engine fuel consumption is dependent on component technology and on engine size. The smaller the engine - or more specifically: the dimensions of its turbomachinery components - the bigger the unfavourable influence of Reynolds-Numbers, secondary flows, seal clearances and geometric tolerances on engine performance. Thorough investigations of these dependences have been made and published (ref. 3, 4). For an advanced 900 kW engine, ref. 4 found thermodynamic cycle parameters that would yield min. SFC around a pressure ratio of 13 and a turbine inlet temperature of 1450 K. Such investigations formed the basis for advanced components research and development work and led consequently to the choice of cycle parameters for the MTR390 engine as shown in Fig. 3.

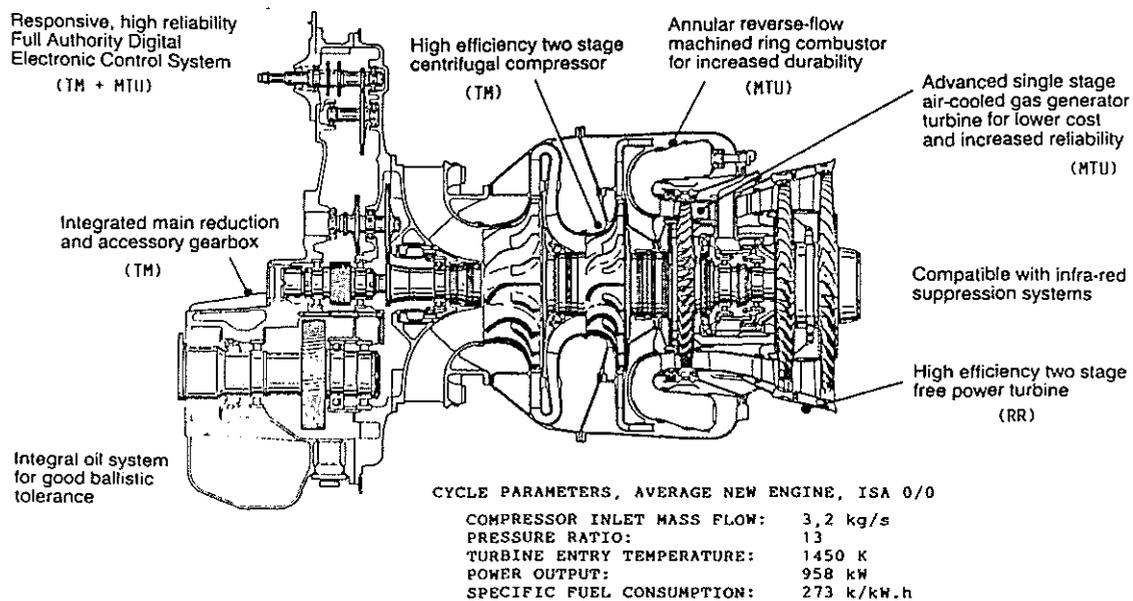


Fig. 3 Engine Design

The choice of engine architecture also is the result of an optimisation study, commonly carried out by the 3 partner companies MTU, Turbomeca and RR. The main design features, as shown in fig. 3, and the reason for their choice are:

- 2 stage radial compressor, chosen for its outstanding performance, its simplicity (no variable guide vanes required), its ruggedness and insensitivity to FOD, ice and sand ingestion. It was found that for engines in the 1000 kW power-class a double centrifugal compressor offers the best solution to comply with reliability and economic requirements.
- Reverse flow annular combustion chamber, chosen for its advantages regarding the whole engine architecture. Best adapted to the radial compressor design it minimizes engine length, provides good accessibility to fuel nozzles and allows a close coupling between the compressor and the compressor turbine, thereby reducing the gas generator length.

- Single stage cooled compressor turbine, chosen primarily for its weight and cost advantage relative to a two stage turbine. It could be demonstrated (ref. 2) that, though a single stage turbine evidently must have a lower aerodynamic efficiency than a 2 stage turbine, this disadvantage is offset by the lower cooling air requirement of a single stage turbine, so that overall engine performance is not affected.
- 2 stage uncooled power turbine, connected to the reduction gearbox at the front end of the engine by the power turbine shaft which runs inside the gas generator rotor. For efficiency reasons a 2 stage power turbine was selected.
- Integrated reduction gearbox, accessory gearbox and oil tank. The accessories are attached to the front end of the accessory gearbox and are easily accessible.
- Short and stiff gas generator rotor, composed of 3 rotor elements, tied together via 2 curvic couplings by a central tiebolt and supported by one bearing at either side. Favoured by the choice of the combustion chamber and the single stage compressor turbine this stiff rotor design enables the gas generator to run at subcritical rotor speeds and minimizes rotor deflections under manoeuvre loads - a major condition for performance retention especially in a combat mission environment as specified for this engine.
- 2 main bearing chambers - the front one, with power turbine and gas generator thrust bearings, integrated into the gearbox, the rear one, with 1 gas generator and 2 power turbine roller bearings, situated between gas generator and power turbine as part of the interturbine housing.

A special feature which needs to be looked at more closely is the design of the interturbine housing. Twin engine helicopters of today, especially military helicopters operating near the ground, require engines with an emergency power capability. In an OEI-condition (one engine inoperative) the remaining engine has to provide an emergency power - immediately after failure of the other engine - of up to approx 25 % above take-off power for up to 30 sec, followed by a contingency power (take-off level or slightly above) for up to 30 min. Consequences of the emergency power requirement for engine design have been discussed in ref. 5. There seems to be agreement among helicopter operators that special means - like water injection into the flame tube - are not acceptable for safety, reliability and economic reasons. So emergency power is created simply by a "throttle push". Because of the short duration of max. 30 sec the resultant high gas temperatures will not cause an engine failure, even if the material temperatures are raised close to its limits, but there may be distortions which could cause - in the case of the interturbine housing - measurable out-of-roundness and eccentricity of the hot gas path.

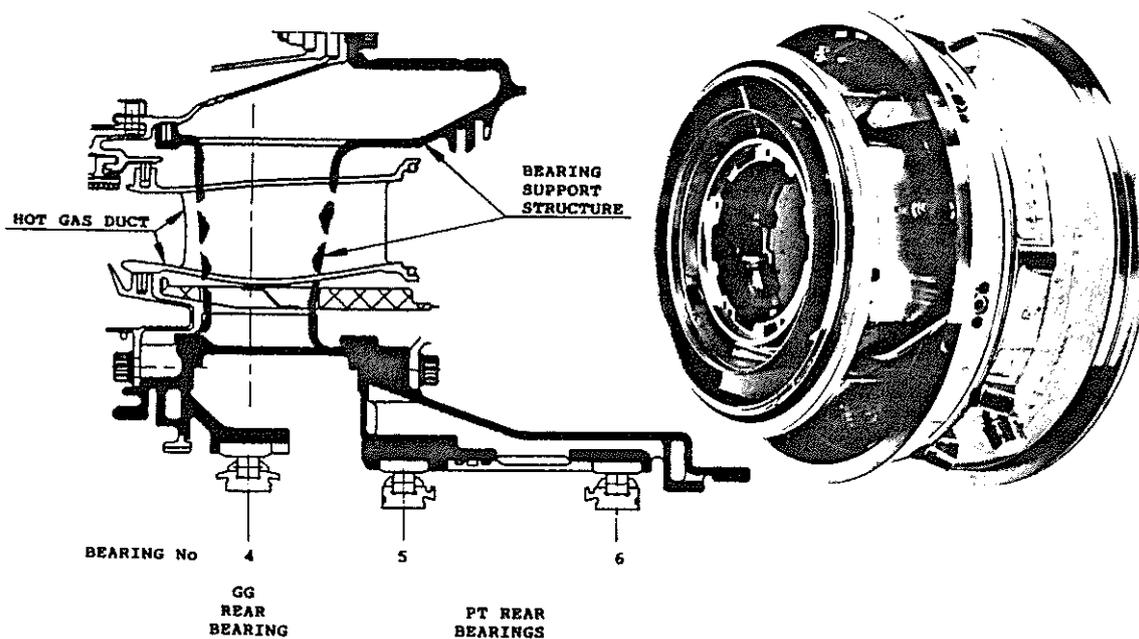


Fig. 4 Interturbine Housing

In order to fulfill the second part of the requirement - 30 min contingency power - it is essential, however, to avoid any misalignment of rotors and bearings relative to the casings. For the MTR390 interturbine housing therefore the bearing support structure and the hot gas duct have been separated as shown in Fig. 4 This design - though not as simple as comparable interturbine housings of other engines - provides a more reliable solution and the potential for a repeated use of emergency power without immediate maintenance action afterwards.

3.2 Engine Control and Maintenance

3.2.1 Engine Control and Monitoring System (ECMS)

The engine governing system is essentially based on a digital concept developed from the experience acquired over some years on other turboshaft engine applications. This concept allows a great simplification in the hydromechanical units limited to the following elements, most of which are grouped in the accessory gearbox module:

- LP and HP fuel pumps
- filter
- metering valve
- start valve, stop valve and those for Purging of injectors.

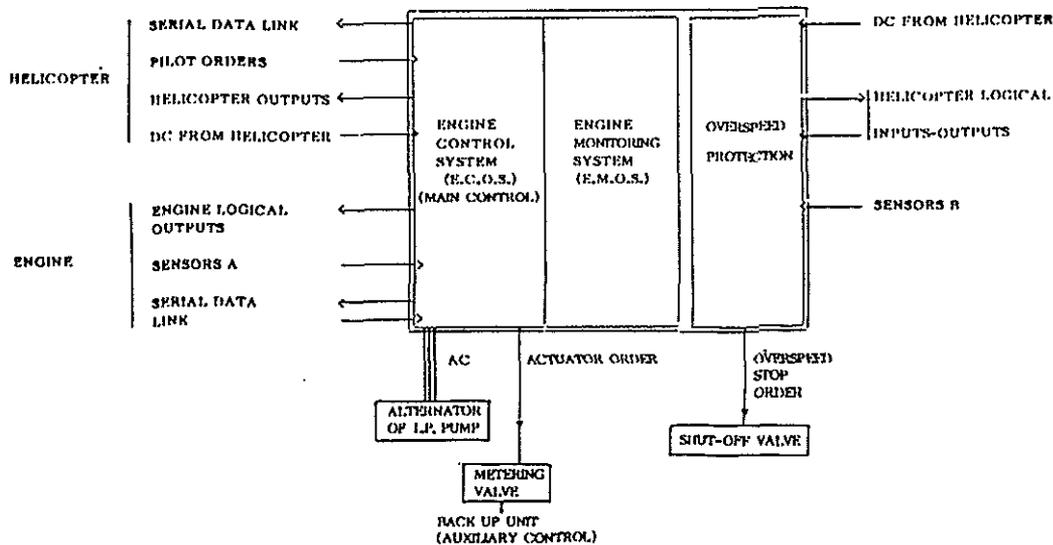


Fig. 5 Control and Monitoring System

The electronic unit is mounted in a separate box which can be installed either directly on the engine, or in the helicopter equipment compartment (in the case of the HAP, PAH2/HAC application). The essential principles which govern the system design are:

- Full Authority, ensuring the control of all ratings and all powers, from stop to maximum authorized ratings.
- Deletion and correction to control system failures, to minimise their effect on mission reliability and on the work load of the pilot.
- Safety of operation resulting from the incorporation of auxiliary emergency loops, with electronic or manual control.
- Autonomous electrical supply from the engine (except for starting).
- Pilot assistance provided by
 - * the supply of parameters for engine surveillance
 - * simulation of failure cases in training (school function)
- Maintenance aid
 - * of the system itself, with the help of the failure self-detection and its modular break-down.
 - * of the engine by:
 - Performance control
 - limit excedence control
 - calculation of life utilisation (counting of cycles)

3.2.2 Maintainability

The engine is designed to a modular concept. The modules are

- Gearbox
- Gas Generator
- Power Turbine
- Electronic Control and Monitoring System (ECMS)

Maintenance actions will be required "On condition" only.

In addition to the maintenance aid system integrated in the control system electronic box, the engine is equipped with devices for monitoring of mechanical health:

- Indicators of oil and fuel filter pre-clogging and blockage.
- Magnetic plugs for the detection of metal particles at several points of the oil system.
- Ports for boroscope inspection.
- Vibration pick-ups (optional)

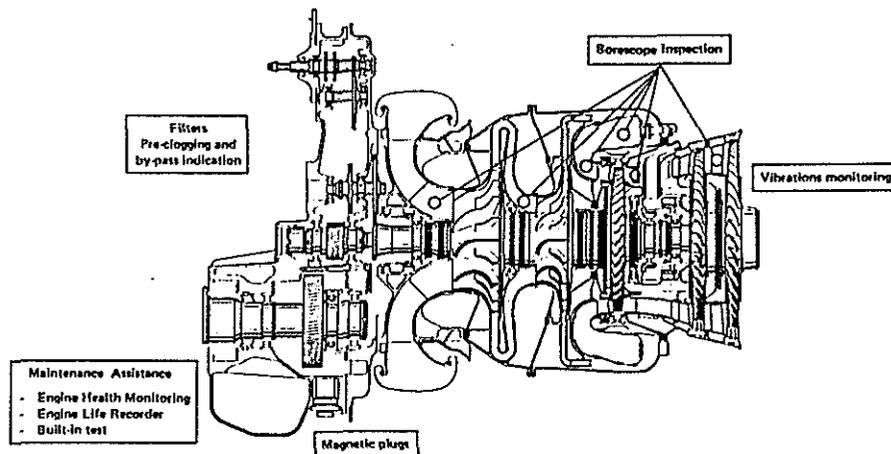


Fig. 6 Maintainability - "On Condition" Maintenance

From the very beginning of design, maintainability studies have been carried out to facilitate maintenance operations on the installed engine, and in the shop. These studies have been conducted on mock-ups and have been taken into account during the engine definition. All these actions will ensure a high availability rate and a reduction in the user's operating costs.

4. Component Design and Technology

Engine development programmes of today have to be carried out in a stringent time and cost frame with guarantees given to the customer right from the start of the programme. This, of course, can only be done on a sound and broad technology base, established well in advance of the actual programme start. In other words: The development work on the main components of a new engine will have to start years before the complete engine programme is launched.

The MTR390 design is based on proven component technology. The components are either derivatives from earlier developed engines, updated to the technical standard of today, or newly developed. In the latter case development work started 7 years ago on the basis of considerations such as described in ref. 3, 4. Full rig and/or demonstrator test evidence was available at the time of the MTR390 programme start.

4.1 Reduction gear - Accessory gearbox

The complete gear system has been grouped in a single module located at the front of the engine:

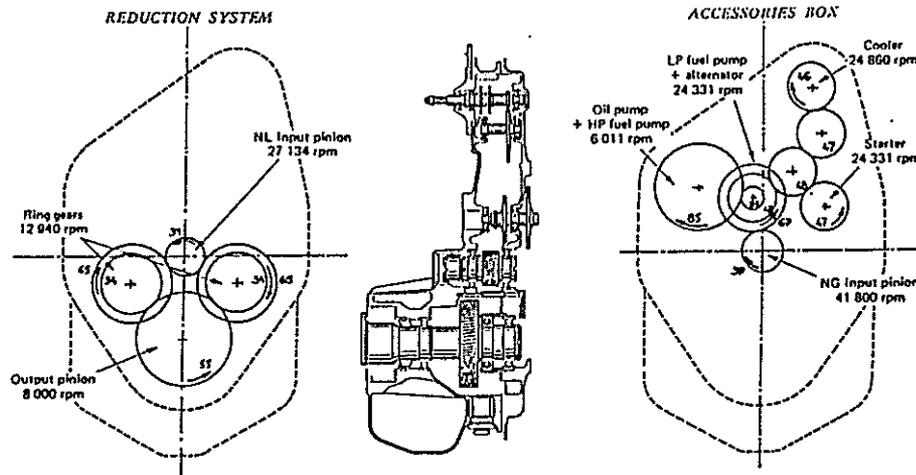


Fig. 7 Gearbox

It includes two operational units:

- In the lower part of the module, the reduction gear, which reduces the rotational speed of the power turbine (27000 rpm at take off rating) to the output speed specified by the helicopter manufacturer (8000 rpm). The reduction system comprises two intermediate trains on which the load is distributed and balanced by a hydraulic system which also provides torque measurement.
- In the upper part of the module, the accessory gear box which provides the support and drive for engine equipment
 - * LP and HP fuel pumps
 - * oil pumps
 - * oil cooling system
 - * electrical starter

The reduction gear, the accessory gear box and the engine oil tank are housed in common aluminium cast casings, the unit constituting a separable module of reduced dimensions and weight, capable in the overall dimensions of a power increase in the region of 20 % without major redesign.

4.2 Compressor

The compressor is a 2 stage centrifugal system the present design of which results from a development initiated in 1982. Results of preliminary parametric studies have shown that compared with the axial-centrifugal version envisaged at the outset of the programme, there are significant performance advantages (efficiency - flow - pressure ratio) obtained at a second stage circumferential speed lower than that of the centrifugal compressor of the axial-centrifugal version.

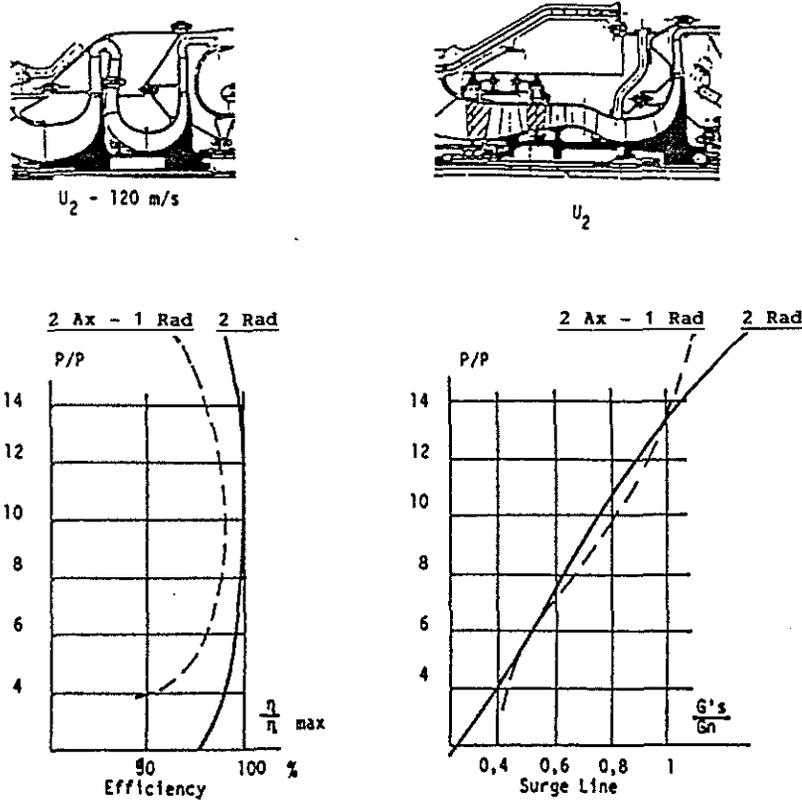


Fig. 8 Compressor Performance

The tests carried out on a test rig with experimental units of reduced scale have confirmed these predictions by giving results in agreement or better than targets, for example (at nominal speed):

	target	obtained
Flow (kg/s)	2,5	2,25
Pressure ratio	14	14,4
Efficiency	0,8	0,814

The structure of the compressor unit consists of:

- an air intake in cast light alloy, including on integrated washing system.
- an external casing in welded Inconel material.
- internal casings in cast steel.
- stators in steel and titanium machined from castings and assembled by brazing.
- two forged rotors in titanium, assembled by curvic-coupling.

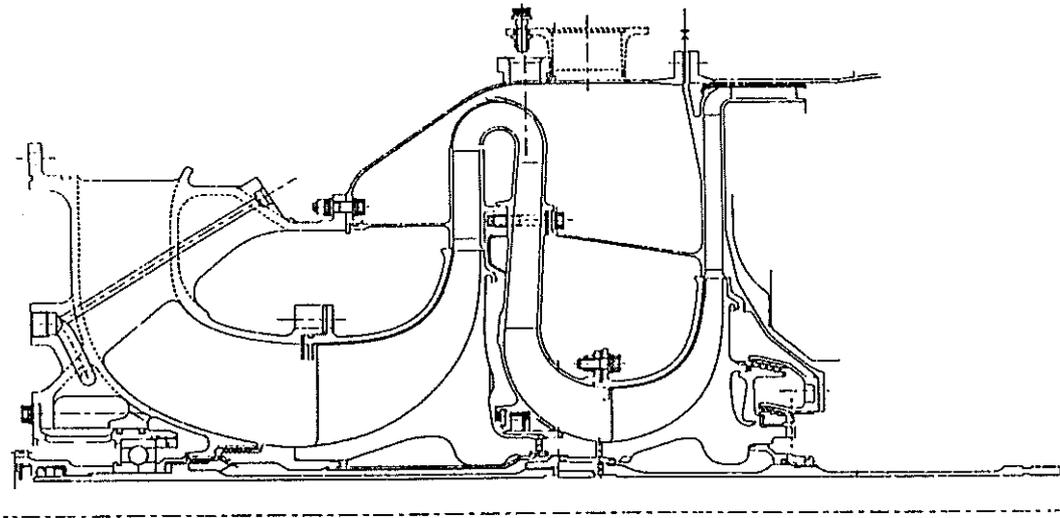


Fig. 9 Compressor Architecture

The choice of this design structure with casings and static parts with thin walls, together with the extensive use of titanium, leads to a very favourable balance between dimensions and weight.

4.3 Combustion Chamber

The advantages of a reverse-flow combustion chamber have already been discussed. This type of combustor, however, has one disadvantage: its large flametube wall area, which needs cooling, compared to the relatively small air mass flow that can provide cooling.

This disadvantage has been overcome in the MTR390 by a fuel injection and flame stabilisation system which was developed using air blast atomizers and two counterrotating primary zone vortices (see Fig.10).

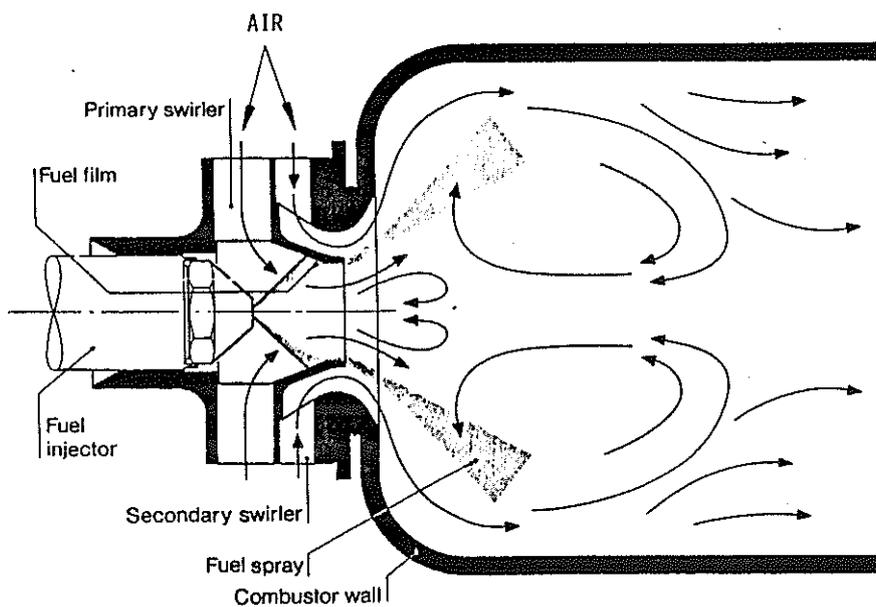


Fig. 10 Combustion Chamber-Schematic View

This system concentrates the burning process in the centre of the primary zone, thus avoiding contact of the hot burning products with the flametube walls.

The principle of the air blast atomizer and the vortex flow pattern in the primary zone is shown in Fig. 10. Immediately after leaving the nozzle the secondary swirler airstream turns in the vertical direction, forming a layer on the flametube back-plate. Recirculation is directed towards the centre of the flametube, where burning takes place. Air for wall-cooling and the air needed for the burning process are separated and do not interfere with each other, so that a high wall-cooling efficiency is attained.

The flametube, designed 7 years ago, originally had a greater axial length, based on the experience gained with earlier flame tubes (ref. 2). One objective of the development programme was to reduce that length, in order to

- reduce the flame tube wall area
- improve access to the rear bearing chamber
- reduce weight.

The attempts to shorten primary and dilution zone by introducing a new pattern of air injection holes turned out to be very successful. It could be shown by gas analysis that the burning process was terminated roughly 25 mm upstream of the original flame tube exit plane, as shown in Fig. 11.

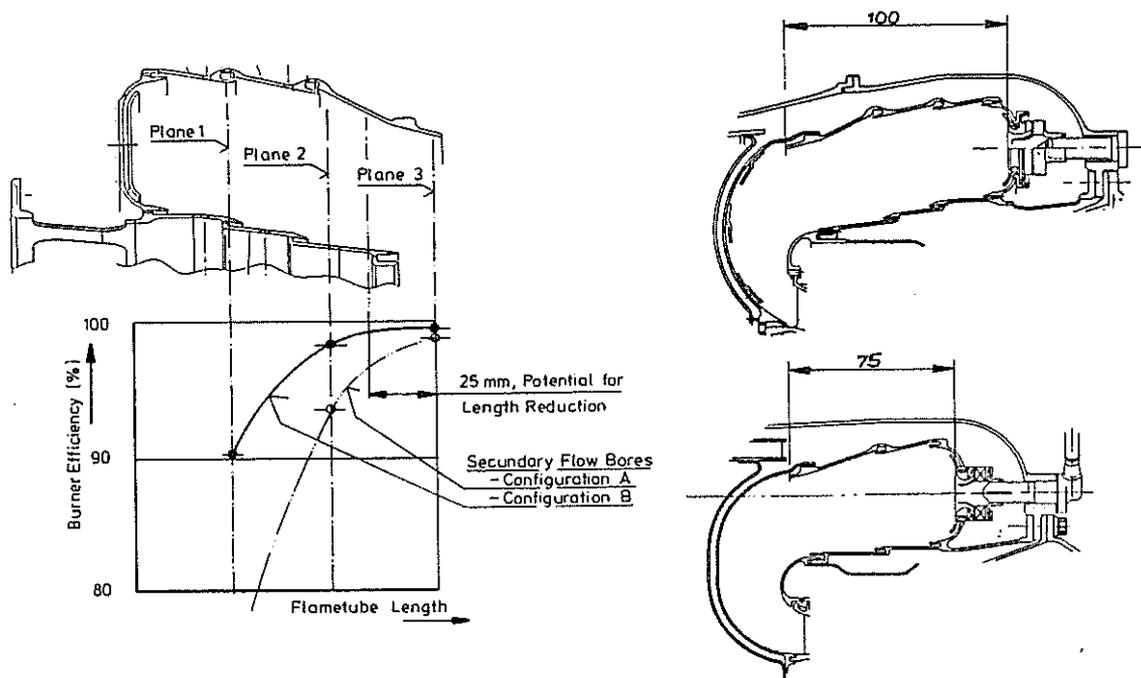


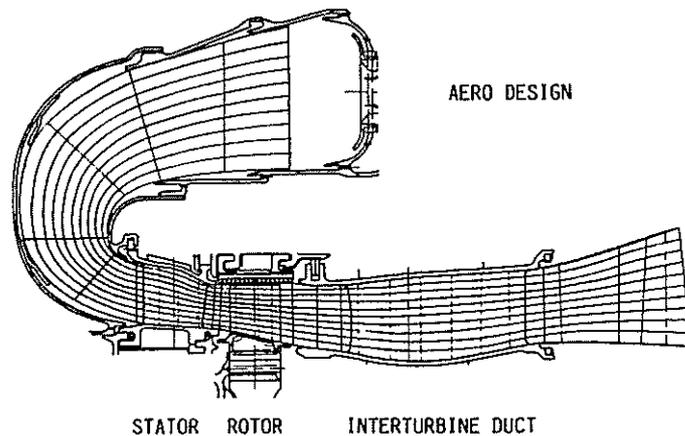
Fig. 11 Combustion Chamber Length Reduction

Testing with the new shorter flame tube for the MTR390 started end of last year with water analogy rig test to finally optimise the air injection hole pattern. Full scale burning tests, starting June 88, confirmed the good results obtained with the longer flame tube thereby justifying the reduction in length.

4.4 Compressor Turbine

Marked progress in turbine aerodynamics based on refined analytical design methods and test results, as well as the availability of improved materials - powder metal (PM), directionally solidified (DS) and single crystal (SC) materials - paved the way to change from a traditional 2 stage turbine in this power class to a 1 stage design (ref. 2). Development of this transonic turbine with cooled vanes and blades was started in 1982.

In the aerodynamic design of the compressor turbine, which included the interturbine duct ((Fig.12), attention has been paid especially to the reduction of secondary flow losses. The flow path design in the stator area - favoured by the application of a reverseflow annular combustion chamber - results in a low radial pressure gradient at the stator outlet minimizing boundary layer flows in the radial direction. Reduction of work extraction close to the rotor blade tip aims at a reduction of the sensitivity of turbine efficiency to blade tip clearance. The potential for a reduction of tip clearance sensitivity, however, turned out to be limited, as explained in (6). So an effective tip clearance control was one of the major development objectives for this component.



AERO RESEARCH & DEVELOPMENT

- LARGE SCALE WATER MODEL	2 BUILDS	
- TRANSONIC 2D-CASCADE	3 BUILDS	2 CASCADES
- ENGINE SIZE ANNULAR CASCADE	2 BUILDS	2 CASCADES
- ENGINE SIZE TURBINE RIG	20 BUILDS	4 TURBINES
- GNT1 - DEMONSTRATOR	21 BUILDS	2 TURBINES

Fig. 12 HP Turbine Aerodynamics

Turbine aerodynamics were optimized on the basis of an extensive rig programme (Fig.12). 4 different aero design standards were investigated in 20 builds of a cold flow aero rig, including studies of cooling air and blade tip clearance effects on turbine performance.

The mechanical part of the turbine development programme concentrated on two main areas:

- materials
- demonstrator testing

The characteristics of the new materials (PM, DS, SC) had to be investigated, data bases for design and certification to be established. Moreover a new life concept - based on crack propagation rather than crack initiation - for highly stressed parts had to be developed. The theoretical background and results of the extensive research programme which was initiated at MTU are described in ref. 7 (Fig.13). Today the most important part of the programme has been carried out and sufficient evidence for the viability of the mechanical design is available.

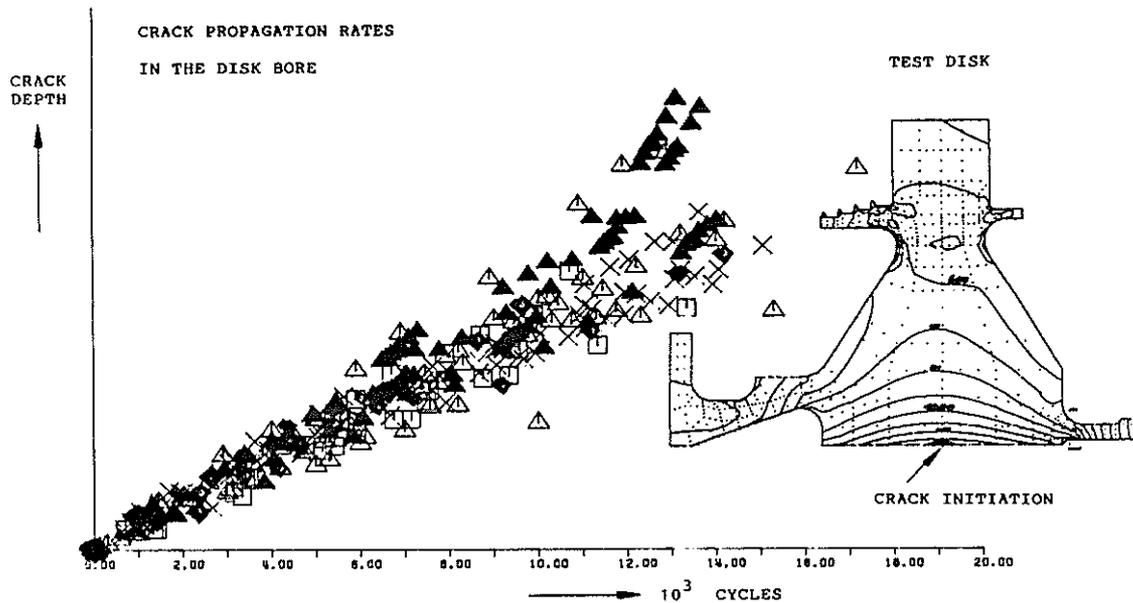


Fig. 13 HPT Disk Technology Programme

Development of hot components cannot rely on rig tests only. Investigation of their performance in a real engine is essential. Therefore a demonstrator was built at MTU which in the gas generator configuration was especially dedicated to combustion chamber and HP-Turbine development. This demonstrator, called GNT1 and described in ref. 4, made it's first run in 1984.

One of the major objectives of the demonstrator programme was cooling optimisation of hot components. As an example Fig.14 shows 5 different blade cooling configurations which have been tested. The configuration chosen for the MTR390 is similar to that of the first configuration shown on fig. 14. This configuration has two major advantages relative to the originally designed system (similar to the last configuration and described in ref. 2):

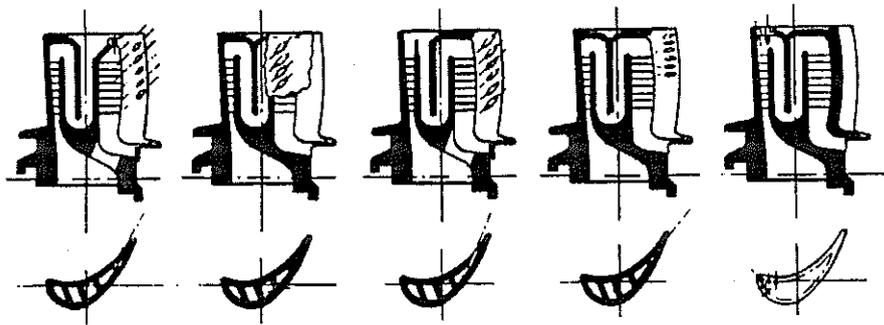


Fig. 14 HPT Blade Cooling Variations

- better growth potential; the blades can easily be adapted to higher gas temperature by simply adding cooling holes without changing the casting
- positive influence on turbine efficiency, because a high percentage of the cooling air is expelled at the blade tip (ref. 4).

One of the most important objectives of the demonstrator programme was the development of an efficient blade tip clearance control. Turbine efficiency is heavily dependent on blade tip clearance as shown in ref.4, and since blade height is only 16 mm, a tip clearance change of 0,1 mm results in an efficiency change of 1.3 %, or a fuel consumption change of 1.6 % at max. continuous.

Since the thermal response of the rotor can hardly be influenced blade tip clearance control has to be done by proper casing and liner design. The first, simple design, featuring an integral liner ring (ref. 8) was abandoned in favour of a more sophisticated, but significantly more efficient design featuring liner segments hung into a casing of low thermal expansion material (ref. 4). Tip clearance variation between cold start and take-off is shown on Fig.15. The segmented liner design has proved to provide the tight tip clearances necessary to fulfill the low fuel consumption requirement for the MTR390.

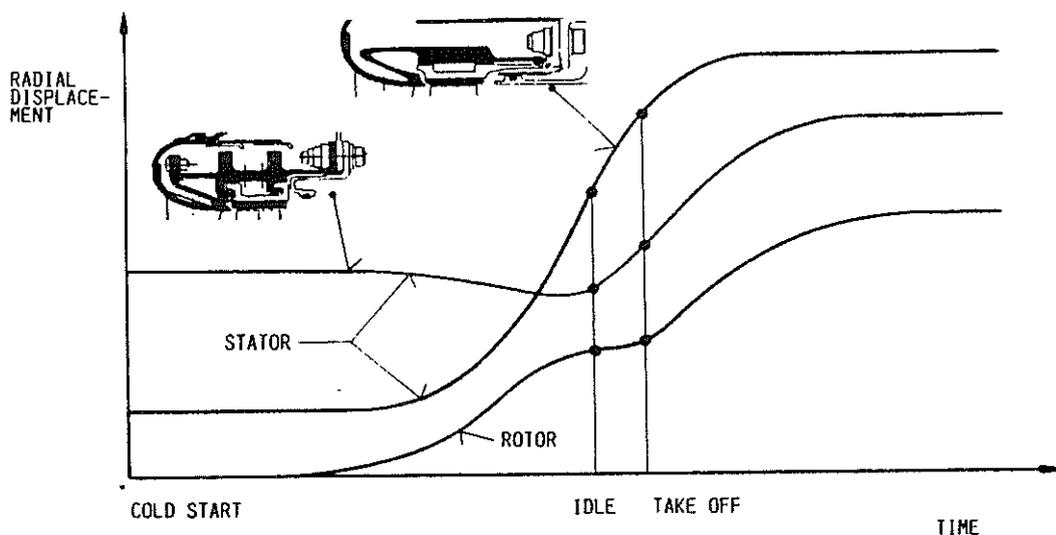


Fig. 15 HPT Blade Tip Clearance

4.5 Power Turbine

The power turbine is a conventional 2 Stage uncooled design, giving high efficiency over the full operating range of the engine. Careful optimisation of stage aerodynamics design gives a 'flat' efficiency characteristic having virtually no change of performance between cruise and emergency power conditions. The blading design is based on the RTM 322 size (ref. 9).

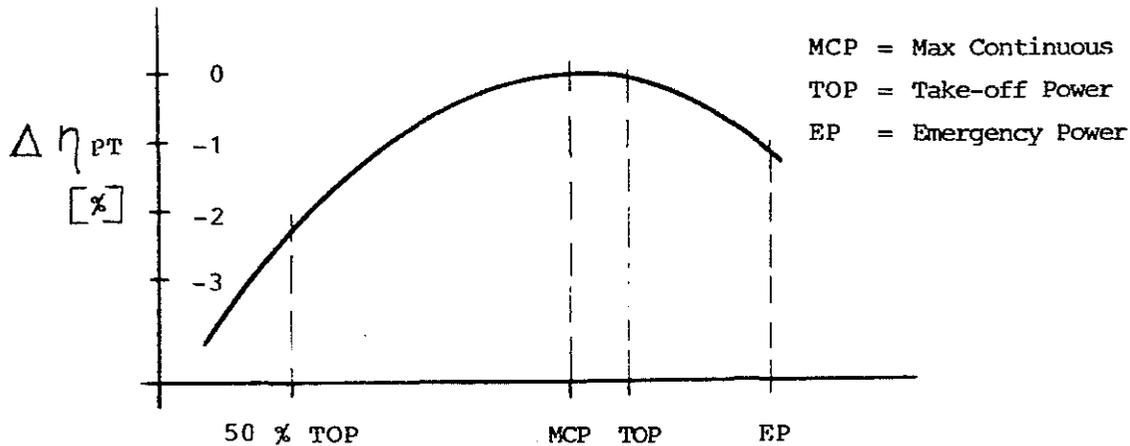


Fig. 16 Power Turbine Efficiency

The power turbine shaft contra-rotates with the gas generator shaft to take advantage of the exit whirl angle of the gas from the gas generator turbine, reducing the amount of "turning" of the gas in the first stage power turbine nozzle. This gives an estimated 1 % efficiency benefit relative to a co-rotating design.

The mechanical design of the power turbine follows existing well proven routes, using one piece castings for both nozzles to give maximum durability and low cost. The finned shrouded blades use honeycomb seals to control "over tip" leakage and knife seals on the underside of the blade platforms to minimise disc air bleed requirements. Stage 1 blade material is single crystal chosen for maximum creep life potential.

The power turbine shaft drives forward through the centre of the gas generator to the reduction gearbox, is located by a ball bearing at the front of the engine and runs on two roller bearings at the rear. The design uses a separate splined stub shaft which allows the power turbine module to be removed without exposing the rear bearing chamber to ingress of dirt or contamination.

Overspeed control for the internal shaft failure case is provided by a reference shaft inside the power turbine shaft. If the main shaft fails for any reason, the reference shaft will still rotate at rotor speed long enough to give the required indication to the control system.

5. Programme Status

The engine design phase is now complete and parts are being manufactured and assembled for the first engine test, due at the end of this year.

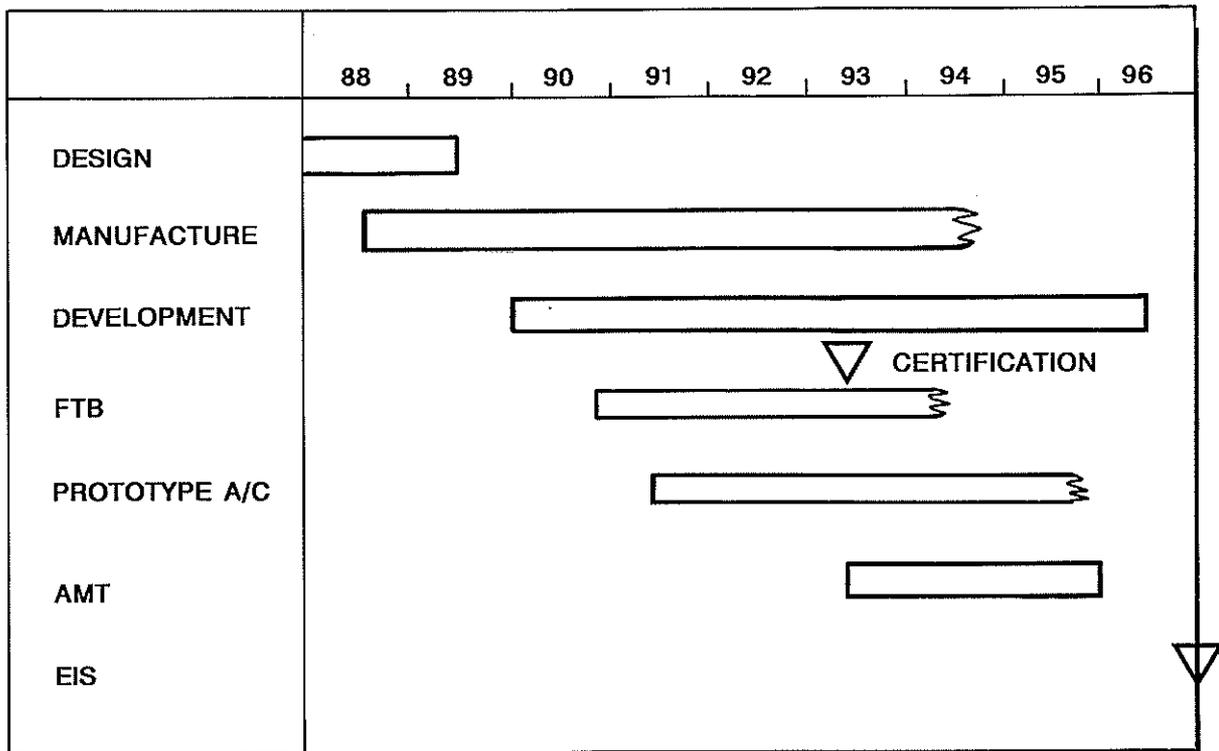


Fig. 17 MTR390 Programme to EIS

The development/certification programme is planned to run for 6000 hours with an additional 2400 hours accelerated mission testing before entry into service.

A flying test bed programme will commence in late 1990 to confirm handling and performance characteristics in advance of delivery of prototype PAH/HAP-HAC helicopter engines scheduled for 1991.

Bench testing will be shared between the three companies, with each partner basically responsible for qualification of its own parts. As far as possible, test facilities are designed to be common to ease transfer of engines between sites.

MTU, Turbomeca and Rolls-Royce have set up a joint company - MTU TURBOMECA ROLLS-ROYCE GmbH (MTR) - to coordinate the development, production, marketing, sale and support of the MTR 390 engine and to act as contractor for the German and French Governments and other customers.

It is the declared goal of MTR and the three Partner Companies to develop and produce an engine, which is capable of meeting all challenges of the market in this power class in the next 20 to 30 years.

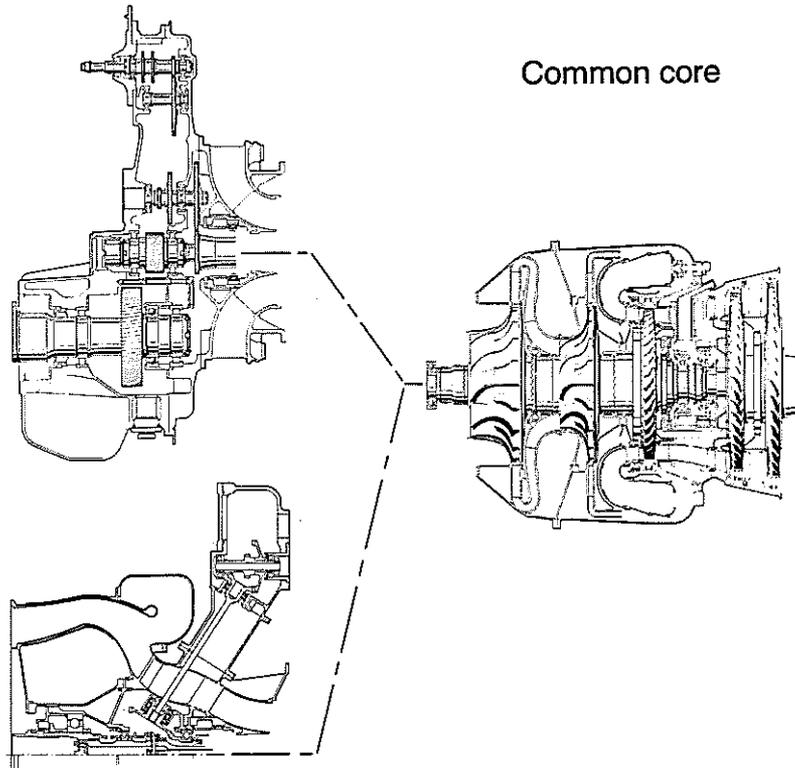
Joint reviews in all major functions are regularly held to ensure, that the best available technology and the combined experience from all partners are used throughout.

Design studies have been extended to examine derivatives for other applications. A 6000 rpm drive version can be offered simply by changing four gear wheels in the main reduction gearbox. A direct drive version has also been defined.

Adaptable drives and
intake configuration

MTR 390
Low speed drive
8000 rpm and
6000 rpm

MTR 390T
High speed drive
27 000 rpm



Common core

Fig. 18 MTR390 Derivatives

Conclusion

It has been possible to present the main features of the new MTR390 engine programme. The engine configuration chosen is particularly suitable for "nap of the earth" manoeuvrability and survivability in hostile battlefield environments. The principle design concepts incorporated are shown to have taken advantage of the best technology available from each of the three partners to produce a simple competitive rugged engine suitable for a large number of applications.

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