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OPERATION CONDITIONS OF THE MTR390 TURBOSHAFT ENGINE ON ALTITUDE TEST FACILITY

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The specification of the MTR390 turboshaft engine requires satisfactory engine operation under different ambient conditions. To verify compliance with the specification various engine tests have been carried out on the altitude test facility. For the qualification of the engine, the following tests are mainly of interest: checking of the engine starting and restarting envelope, qualification of the auto-relight function, verification of usage of different fuels, investigation of engine performance in the flight envelope and demonstration of icing effects on engine operation.

The result of these tests have revealed that the MTR390 engine fulfills the specification requirements. On the basis of these qualification tests, among others, the engine has achieved civil and military certification. Production investment activities are on going to prepare the engine for serial production.

In this paper the altitude test facility configuration and the procedures of the above-mentioned qualification tests are presented. Furthermore, the results of the tests are described and discussed.

NOMENCLATURE

ALT	Altitude
ATF	Altitude test facility
CEPr	Centre d'Essais des Propulseurs Saclay/France
FTB	Flying test bed
N_G	Gas generator rotational speed
N_{PT}	Power turbine rotational speed
P_{s0}	Ambient pressure
P_{t0}	Engine inlet pressure
PW	Shaft power
SFC	Specific fuel consumption
T0	Ambient temperature
T_{45}	Power turbine inlet temperature
TIT	Gas generator turbine inlet temperature
T_{s0}	Ambient temperature
T_{t0}	Engine inlet temperature
δ	P_{t0} [kPa] / 101.325
θ	T_{t0} [K] / 288.15

INTRODUCTION

The MTR390 is a turboshaft engine in the 1000 kW category for application in the German/French military helicopter Tiger and in other helicopters with a take-off weight of 5.5 to 6.0 tons [1,2,3]. MTR390 is produced jointly by the companies MTU, Turboméca and Rolls-Royce. Figure 1 shows the MTR390 engine ready for use in the helicopter. The main components of the engine are:

- Two-stage centrifugal compressor
- Reverse-flow annular combustion chamber
- Single-stage gas generator turbine with inter-turbine duct
- Two-stage power turbine with exhaust diffuser (for the test bed)
- Gearbox
- Digital control and monitoring unit.

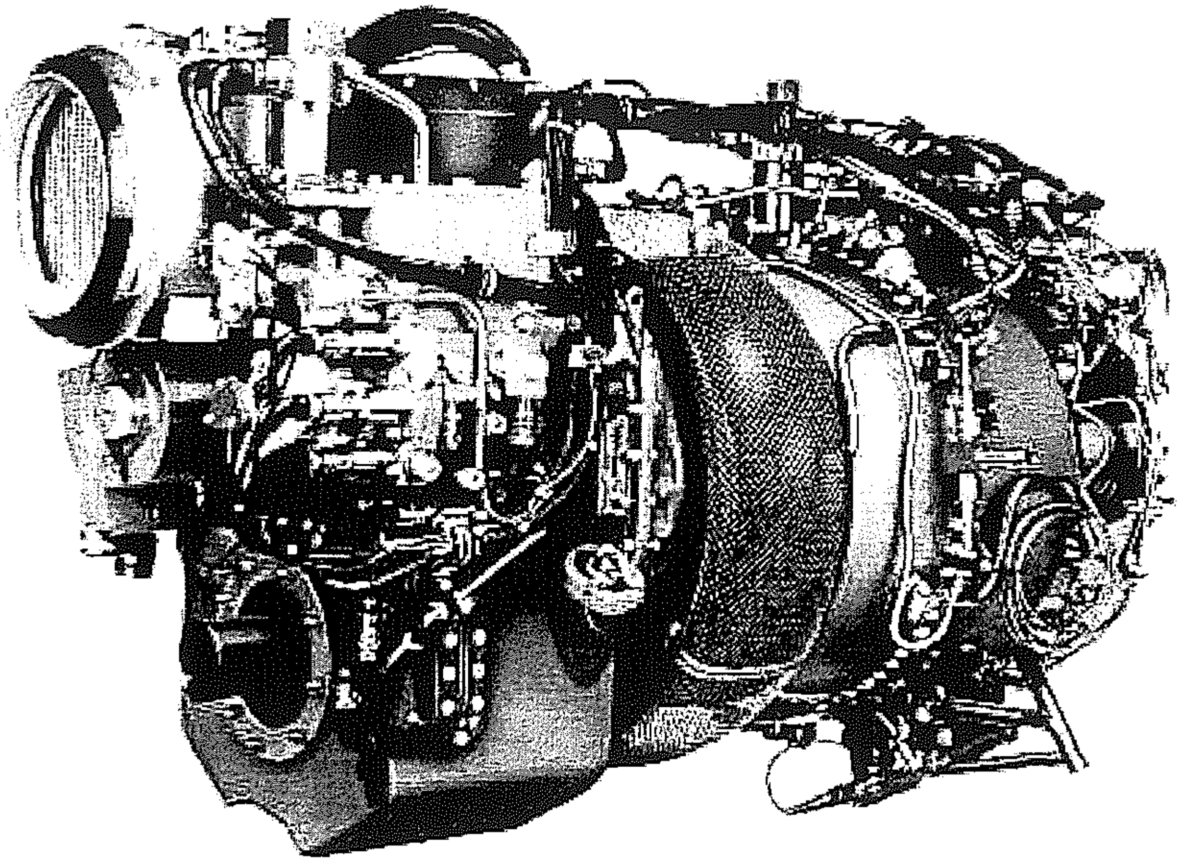

Figure 1: The MTR390 turboshaft engine

The certification programme of MTR390 for the Tiger started officially with the signature of the main development contract followed by the first engine run in December 1989.

Within the certification process more than 11000 test bed hours and 6000 flight hours have been accumulated so far without significant development problems. The successful demonstration of the certification requirements based on the military specification MIL-E-8593 and civil aviation regulation JAR-E change 6 resulted in the military type certification issued by the Military German Airworthiness Authorities in 1996, and the civil type certificate was granted by the German Civil Airworthiness Authorities in 1997.

Important steps in achieving the various qualification milestones were the test campaigns performed on the altitude test facility (ATF) at Centre d'Essais des Propulseurs (CEPr) in France. Within several test phases more than 700 hours on the ATF were accumulated for the following major qualification justification:

- 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.

ALTITUDE TEST FACILITY

Apart from engine tests on the sea level test bed it is necessary to carry out tests within the whole flight envelope. These tests may be done on the altitude test facility as well as on the flying test bed (FTB) simulating the engine inlet conditions: P_{t0} and T_{t0}, as defined by the ambient conditions P_{s0} and T_{s0},

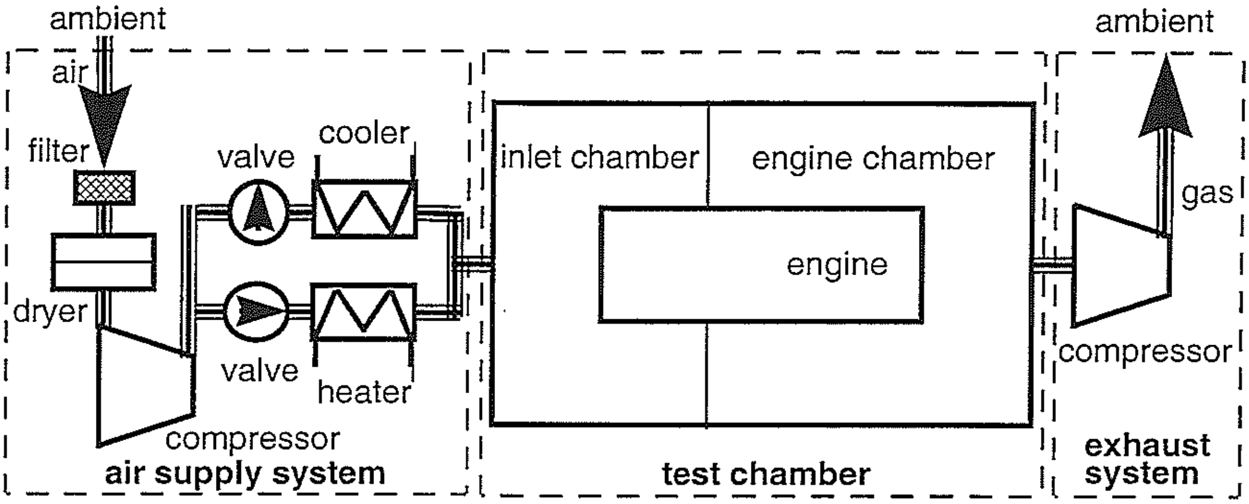

Figure 2: A schematic layout of an altitude test facility

and by the flight Mach number. The ATF has the following major differences versus FTB's:

- There is no risk of a crash
- Contrary to the FTB, the engine under test is visible from all sides
- The whole flight envelope may be tested at the same place
- The ambient conditions may be varied independent of each other
- Certain engine inlet conditions may be reproduced exactly
- Extensive instrumentation of the engine is possible, as for example the measurement of the airflow is possible on the ATF but not on the FTB.

The ATF, as shown in Figure 2, consists of the main components: air supply system, the test chamber with the inlet chamber and engine chamber, and the exhaust system. To simulate the desired P_{s0}, T_{s0} and flight Mach numbers, the airflow is prepared in such a way that the corresponding P_{t0} and T_{t0} are obtained at the engine inlet. The preparation of the air principally happens as follows: It is sucked in by a compressor through a filter, passes a dryer and then a heater or cooler depending on the required air temperature. After being thus prepared, the air enters into the inlet chamber. From there the air flows through an air-meter to the engine inlet, or it reaches the engine as free stream. By extracting of the exhaust gases a compressor ensures that the static pressure in the engine chamber is controlled to the desired flight altitude. More details about altitude test facilities can be found, for example, in [4] and [5].

Pressure range	5 to 150 kPa abs
Temperature range	-70 to +150 °C
Maximum flow rate Without filter with filter	 75 kg/s 50 kg/s
Shaft power absorption at max. rpm of 8000 at max. rpm of 24000	 1000 kW 2200 kW
Fuel supply pressure conditioning temperature condition. max. flow	 15 to 500 kPa abs -55 to +80 °C 2000 l/h

Table 1: Main capacities of the ATF of CEPr

Measurement type	**Number**
Pneumatic pressure	500 measurements
Hydraulic pressure	48 measurements
Temperature	480 thermocouples 48 resistance detectors 10 BST
Period meter	24 TF pulse
Dynamic	80 measurements
Remote monitoring	5 cameras

Table 2: Main equipment of the ATF of CEPr

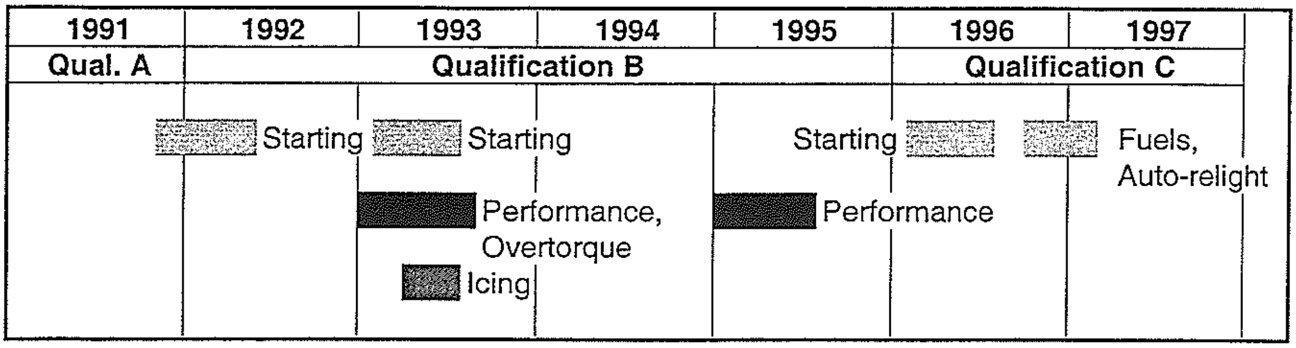

Figure 3: Time schedule for MTR390 qualification tests on the altitude test facility

The altitude test facility of CEPr, on which the MTR390 engine was tested, has the main capacities shown in Table 1. Hence it appears that a wide range of flight conditions can be simulated which covers the flight envelope of MTR390. Table 2 shows the types and the amount of instrumentation which are available on this test bed. The ATF of CEPr is also equipped with a powerful data acquisition system which allows the registration of 2500 measured and calculated parameters in steady-state engine operation, and 800 parameters during transients. Accordingly, extensive registration of the operating data of MTR390 engine was possible.

CERTIFICATION MILESTONES

The MTR390 qualification programme was divided into three major parts with milestones named Qualification A, B and C, see Figure 3. Qualification A covered the clearance of MTR390 for the flying test bed and for the Tiger. Apart from other certification requirements on the sea level test beds, i.e. endurance tests, vibration investigation and over-speed tests, an engine was built for starting investigations on the ATF, where the requirements according to JAR-E500 and JAR-E700 were successfully demonstrated. Based on the results achieved, the MTR390 prototype engines were cleared for flight tests within the specified engine operating envelope.

The primary intention of Qualification B, representing the Military Type Certificate, was to show compliance with the Airworthiness regulations. During this qualification step the starting envelope was tested again to optimise the starting procedures, and in addition, quick acceleration and deceleration manoeuvres were performed to test the transient behaviour of the engine. But the basic investigation on the ATF was concentrated on the contractual performance requirements, where measurement points of specific flight conditions were tested and certified. The icing condition demonstration and over-torque test according to JAR-E780 and JAR-E830, respectively, completed the main ATF investigation during Qualification B.

Test type	Regulation
Stating & restarting	JAR-E500, JAR-E770
Auto-relight	JAR-E910
Performance	JAR-E40, JAR-E500
Fuels	JAR-E560
Oils	JAR-E570
Icing	JAR-E780

Table 3: Main demonstrated tests on ATF

The aim of the Qualification C milestone was the completion of the development contract considering specific customer requirements and their certification. Apart from repetition of the performance demonstration with the production engine build standard within the specified operating envelope, the auto-relight behaviour and the starting capabilities with the specified fuel and oil brands

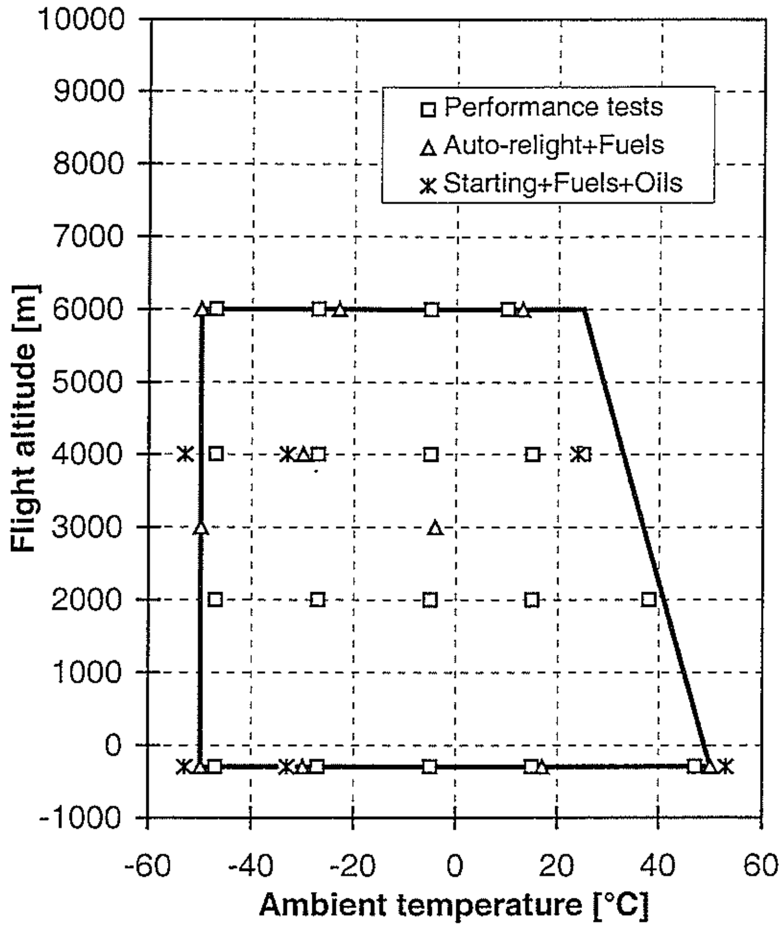

Figure 4: Test points in the flight envelope (Qualification C)

were tested. Table 3 shows the most important tests performed on the ATF with the corresponding regulation. In the following chapter these tests are discussed in detail.

STARTING AND RESTARTING TESTS

As is generally known starting or restarting is initiated as soon as the pilot actuates the engine start button and it ends with the stabilization at idle, where the five phases, cranking, purging only for re-starting, ignition, light-round and acceleration to idle, follow each other. The general requirement is that the starting or restarting process is completed reliably and as quickly as possible with different fuels and oils for the whole operational envelope without excessive overheating of the engine hot parts. A more detailed description of the start process can be found, for example, in [5].

The starting or restarting process was one of the most demanding work during the development of the MTR390. The ATF tests were necessary to optimise and verify the starting and re-starting procedures, and to furnish evidence that specification requirements are fulfilled. During the start and restart test campaign the engine was tested more than 130 hours on the altitude test facility. Figure 4 documents the main start and restart tests at different ambient conditions, which cover the whole operational envelope. These tests showed that the engine can be started even at very low ambient temperatures T_{s0} of around -50 °C without additional measures, i.e. oil and/or fuel heating.

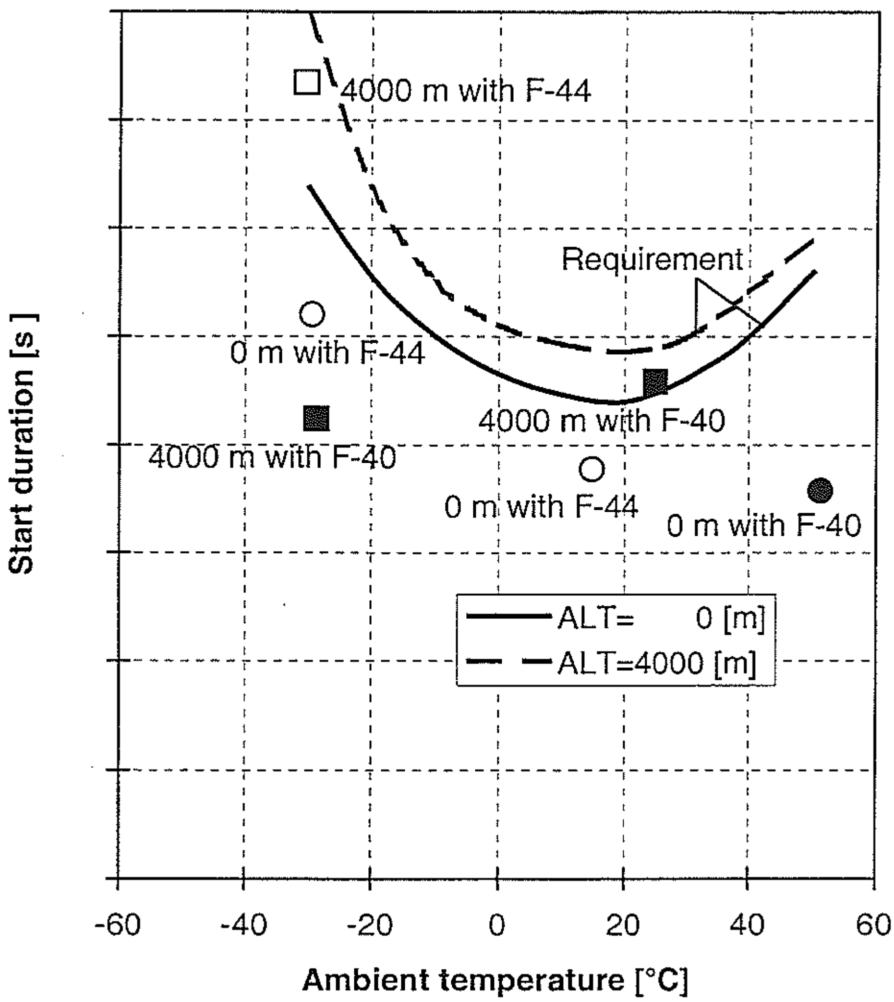

Figure 5: Start duration requirements and their fulfillment

The comparison between the starting duration measured on the ATF and the required times in Figure 5 shows that the specification is fulfilled. The start duration in Figure 5 also includes the rotor start time.

AUTO-RELIGHT TESTS

The digital control and monitoring unit of the MTR390 features an automatic relight function. In the event of engine flame-out the igniter plugs will be activated automatically, and the fuel flow will be adjusted to achieve optimal relight conditions. Based on the specified auto-relight envelope various test conditions were defined. Prior to the test campaign on the ATF, the function of the algorithm created for the auto-relight was checked, and adjustment work on the auto-relight system for preventing excessive thermal stress of the engine hot parts was done on the sea level test bed. The tests of the auto-relight function were then continued on the ATF, where more detailed investigations were possible. Figure 4 shows the main auto-relight test points on the ATF.

In order to simulate an engine flame-out, a magnetic fuel valve was installed in the fuel feed line to the main fuel burners. Through activating this valve the fuel flow was interrupted to cause flame-out. Figure 6 shows, as an example, the trace of the performance parameters N_{PT}, N_G and T_{45}, as well as the magnetic valve activation and deactivation during an auto-relight test at ALT = -300 m and T_{s0} = -30 °C. These parameters decrease after the valve has been activated, and they increase when the valve is deactivated.

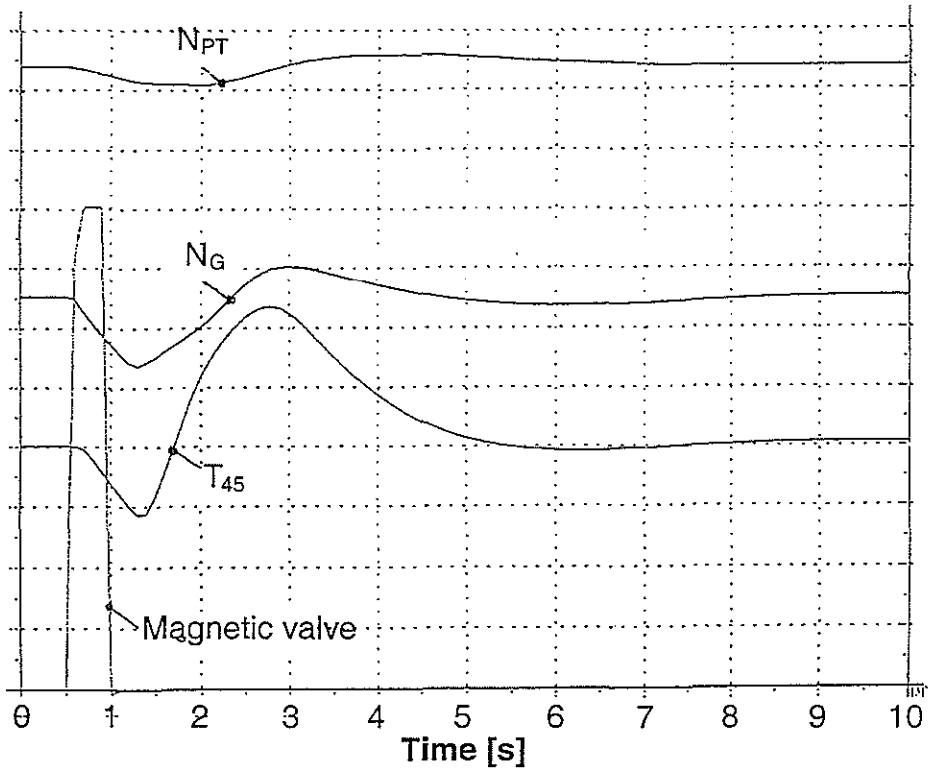

Figure 6: Demonstration of the auto-relight system function at ALT = -300 m and T_{s0} = -30 °C

In all, the test results show that the auto-relight system works reliably with the specified fuels as per Table 5 and at all ambient conditions defined.

PERFORMANCE INVESTIGATION

The performance investigation of the MTR390 also required extensive engine testing on the ATF. It served the verification of the engine performance synthesis model [6] and the demonstration of the engine specification requirements. Moreover, the ATF test data were used to check the speed schedules for operation with the control system.

The verification of the synthesis model is important, because it is the basis for:

- Customer Deck used for calculation of flight performance.
- Engine Performance Check [2] used for monitoring of engine performance in flight.
- Calculation of the exponents κ, and γ used for correction of the engine parameters, like the shaft power PW to standard day $PW/(\theta^{\kappa} \bullet \delta^{\gamma})$, which is necessary for performance comparison of different engines and for engine pass-off.

This verification includes a comparison of measured data gained from engine tests on the ATF with the data calculated from the engine model. In order to obtain representative measurement data, various test points of the flight envelope were chosen. Figure 4 also shows the investigated test points for a certain engine test campaign (Qualification C), where a test point represents a specific ambient condition, at which a complete engine operating line is measured by power tapping.

At the beginning of the engine development, the performance synthesis model was mainly based on rig test results, and later it was refined in line with the knowledge gained in the course of engine development.

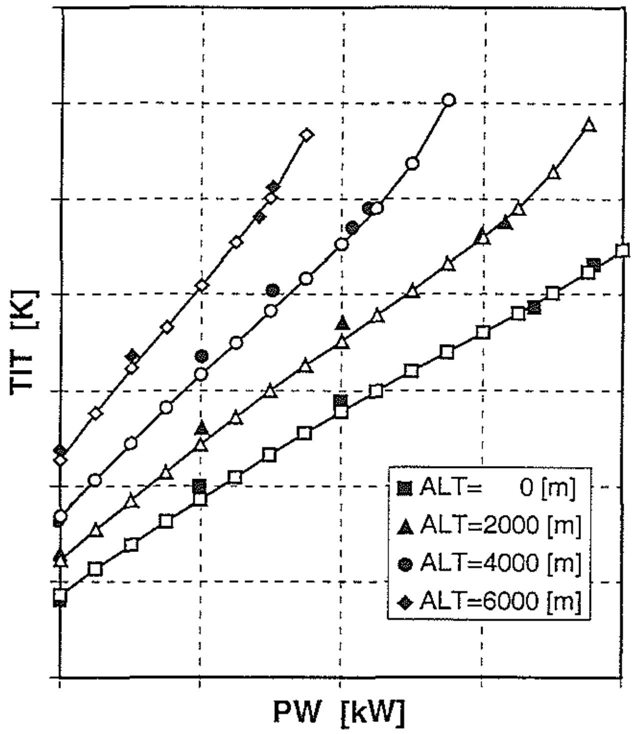

Figure 7: Model and test data at T_{s0}=-10 °C from Qualification B

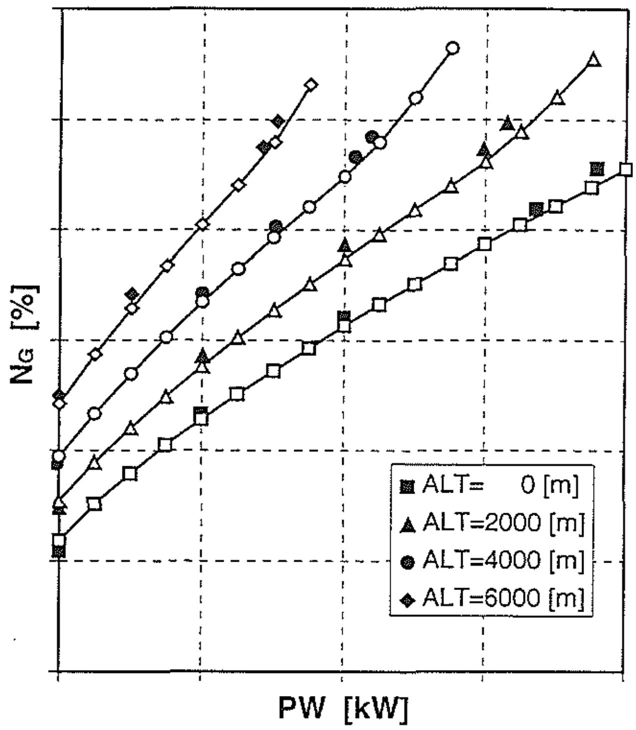

Figure 8: Model and test data at T_{s0}=-10 °C from Qualification B

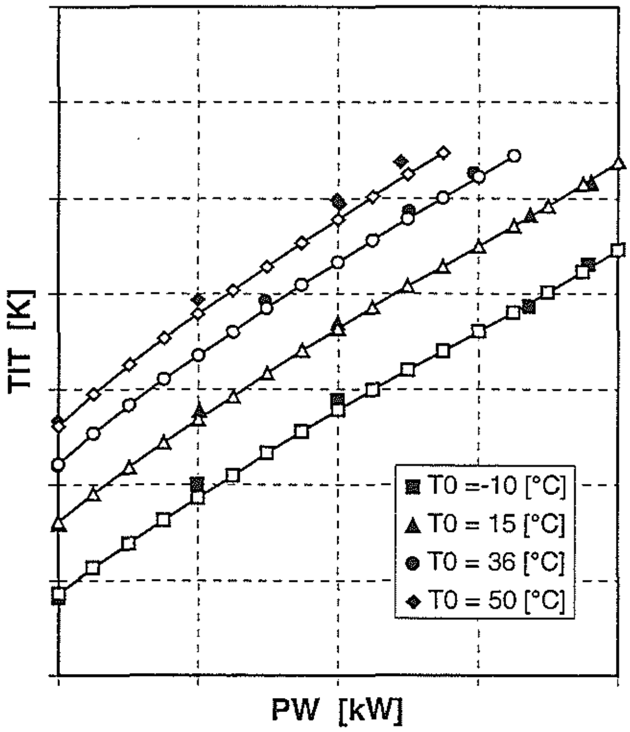

Figure 9: Model and test data at ALT=0 m from Qualification B

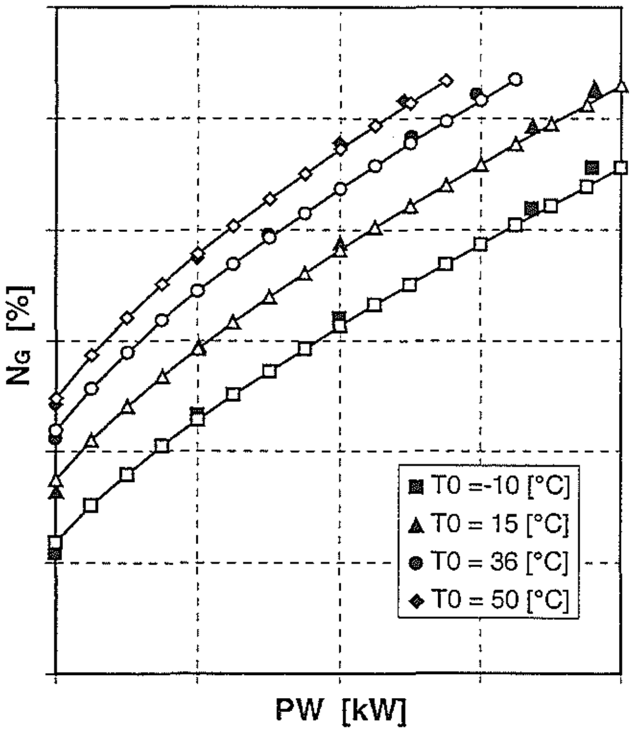

Figure 10: Model and test data at ALT=0 m from Qualification B

Power rating	sea level static normal condition		1000 m 25 °C static		1500 m static normal condition		2000 m static normal condition	
	SFC	TIT	SFC	TIT	SFC	TIT	SFC	TIT
Super Emergency Power (30 seconds)	fulfilled	fulfilled	-	-	fulfilled	fulfilled	-	-
Maximum Emergency Power (2.5 minutes)	fulfilled	fulfilled	-	-	fulfilled	fulfilled	-	-
Emergency Power (30 minutes)	fulfilled	fulfilled	-	-	-	-	fulfilled	fulfilled
Take-Off Power (5 minutes)	fulfilled	fulfilled	fulfilled	fulfilled	-	-	-	-
Maximum Continuous Power	fulfilled	fulfilled	fulfilled	fulfilled	-	-	-	-
50% Take-Off Power	fulfilled	-	-	-	-	-	-	-

Table 4: Performance requirements and their fulfillment

For the configuration of the test engine, the model was especially prepared in terms of the secondary air assumptions and assembly tip clearances of the compressor and turbines to predict the performance, which had to be compared with the test data. The following performance global parameters were mainly of interest for the comparison:

- Engine shaft power PW
- Turbine inlet temperature TIT
- Gas generator speed N_G.

If the values of these parameters measured in tests are approximately in accordance with those calculated, the model is representative of the test engine. In Figures 7 to 10, representative data of ambient conditions for TIT and N_G are plotted versus PW. As can be seen, the test data fit the calculated data quite well, both in tendency and quantity.

In order to demonstrate the fulfillment of the specification requirements, the ATF test data at certain ambient conditions are compared with those specified. For this comparison it was necessary that for a given engine shaft power the specified specific fuel consumption (SFC) and the maximum allowed inlet temperature (TIT) were not exceeded. The results are presented in a general form in Table 4. With the fulfillment of the performance requirements, the engine development maturity was demonstrated so that the series production phase could be launched.

Fuel type	NATO code	Specification
JP-4 JET B	F-40(1)	MIL-PRF-5624S DEF STAN 91-88 DERD 2454
JP-5	F-44(1)	MIL-PRF-5624S DEF-STAN 91-86 DERD 2488
JP-8	F-34(1)	DEF-STAN 91-87 MIL-T-83133D Amen. 1
JP-8+100	-	JP-8+100
JET A JET A1	F-35(2)	ASTM-D-1655 DEF-STAN 91-91 MIL-T-83133D Amen. 1
-	F-43(2)	DERD 2498
-	F-18(3)	DERD 2475 MIL-G-5572E
-	F-54(3)	DEF-STAN 91-9
-	F-57(3)	BS 4040 MTGAS

Table 5: Cleared fuels for MTR390
(1) Primary fuels without any restriction
(2) Alternative fuels used at T_{s0} > -15 °C
(3) Emergency fuels usable for a min. period of 6 h

Oil type	NATO code	Specification
AEROSHELL 560 CASTROL 5000 EXXON 2380 MOBIL JET OIL II TN600(NYCO)	0-156[(1)]	MIL-PRF-23699F DEF STAN 91-101
AEROSHELL 555 CASTROL 599 EXXON ETO 25	0-160[(1)]	DEF STAN 91-100
EXXON 2389	0-148[(2)]	MIL-PRF-7808L
TURBONYCOIL	0-150[(2)]	-

Table 6: Cleared oils for MTR390
(1) Oils with a viscosity of 5 cSt
(2) Oils with a viscosity of 3 cSt

FUELS AND OILS VALIDATION

For operation of the engine the viscosity of the fuel and oil is of essential importance. The following relationship is given: The viscosity of kerosene, diesel and oil increases over-proportionally with decreasing temperatures. With kerosene and diesel this may lead to poor fuel atomization during injection into the combustion chamber. The ignition capability may then be reduced. With oils the resistance of the bearings may be increased resulting in a deterioration of the engine starting behaviour.

In the MTR390 specification it is required that the engine runs with different types of fuels and oils at specified ambient conditions. Tables 5 and 6 show the types of fuels and oils cleared for the MTR390. The ambient conditions, at which these fuels and oils were tested, are shown in Figure 4.

ICING TEST

Flying through clouds and fog at a temperature below 0 °C may cause ice deposits on the aircraft and on the engine inlet. The consequences for the engine should be explained briefly. Under such circumstances, a helicopter engine may have ice on the protection grid at the engine inlet, which might block the inlet. A blockage leads to an increase of the pressure loss at the inlet and to an unevenly distributed airflow, which adversely affects the compressor operation. Consequently, the engine looses performance. Detached ice deposits may enter into the engine and cause erosion of the engine components. It may also cause flame-out of the combustion chamber. More details about icing effect on engine performance can be found, for example, in [5].

The MTR390 engine underwent extensive icing tests on the ATF using a special water spraying device to produce ice. The engine was run under the following specified test conditions:

- Ambient temperature -30 to 0 °C
- Altitude 0 to 4000 m
- Water concentration in air 0.2 to 2.5 g/m³
- Engine shaft power idle to Take-Off
- Simulated helicopter speed 0 to 275 km/h
- Water droplet size 20 to 25 µm
- Test duration 30 minutes

The test results show that neither the engine components were damaged, nor a flame-out of the combustion chamber occurred. The performance loss of the engine due to icing was far less than the specification value. Because of the special construction of the engine inlet grid complete blockage by ice is prevented.

SUMMARY

The MTR390 engine underwent various tests before attaining military and civil certification. In this paper, the major tests on the altitude test facility are reported. They include starting and re-starting tests, autorelight demonstration, engine performance investigation, fuels and oils validation, as well as icing tests.

These and, of course, all other qualification tests not discussed here, like the overtorque demonstration, were successfully passed by the MTR390 which thus met the requirements of the engine specification.

Production investment work is underway. The delivery of the first serial production engine is expected in early 2001.

ACKNOWLEDMENT

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REFERENCES

[1] SPIRKL A.
MTR390, the new generation turboshaft engine
AGARD 1993

[2] RICHTER K., ABDULLAHI H., BROEDE J., MÖHRES W.
Monitoring the MTR390 engine
20th European Rotorcraft Forum, 1994

[3] ABDULLAHI H., KURPJUHN B., REISER M., SPIRKL A.
Sand ingestion tests on the MTR390 turboshaft engine
24th European Rotorcraft Forum, 1998

[4] NOWATZKY P.
Einsatz eines Höhenprüfstandes in der Triebwerksentwicklung und kritische Bewertung der Schubmessung
DGLR 1998

[5] WALSH P.P., FLETCHER P.
Gas turbine performance
Bristol 1998

[6] ABDULLAHI H.
Synthese model with neural network for operating behaviour simulation of a turboshaft engine
DGLR-JT98-219, 1998