PAPER Nr.: 119

MONITORING THE MTR390 ENGINE

BY

K. RICHTER, H. ABDULLAHI, J. BROEDE, W. MÖHRES

MTU MOTOREN- UND TURBINEN-UNION MÜNCHEN GMBH
MUNICH, GERMANY

TWENTIETH EUROPEAN ROTORCRAFT FORUM
OCTOBER 4 - 7, 1994 AMSTERDAM

Printed by the Technical Highschool Haarlem

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K.Richter, H.Abdullahi, J.Broede, W.Möhres
MTU Motoren- und Turbinen-Union München GmbH
Munich, Germany

Abstract

An advanced monitoring system is being developed for the MTR390/Tiger turboshaft engine. Besides increasing safety, the system will reduce operating costs and pilot workload by automatically monitoring

- *limit exceedances*
  with respect to specified speed, torque and temperature limits
- *engine performance*
  providing torque and turbine temperature margins, achieved by comparison of the measured values with the specified minimum torque or maximum temperature, respectively
- *life usage*
  to log accurately the life consumption of individual critical parts by means of realtime computation of thermal, stress and fatigue models

The system supplies to the flight and maintenance crews information about engine deterioration, required inspections and mission impact after excessive engine operation. Furthermore, detailed information about engine parts' treatment and margins are provided to the logistic crew for optimised maintenance scheduling and in-time provision of spare parts.

The system is described and the benefit to the aircraft operators is explained.

Abbreviations

CM	torque
CM0	minimum torque to permit a performance check
ECMS	Engine Control and Monitoring System
ECMU	Engine Control and Monitoring Unit
EMOS	Engine Monitoring System
HP	High Pressure
NG	gas generator speed
NTL	power turbine speed
PIU	contingency power rating
PMD	take-off power rating
PMU	max contingency power rating
PSU	super emergency power rating
T45	power turbine inlet temperature

STATUS SUMMARY AT JULY '94

- 7000 total hrs completed to date
- 1400 flight hrs on Tiger and Flying Testbed
- 28 engines now running in the programme
- 9 "qualification"schedule endurance tests completed
- 4000 m and +/-50 °C starting and relights demonstrated
- 6000 m flight envelope proven
- Engine basic qualification requirements met mid '93 on schedule
- Full certification due end '94
- 2 AMT engines will accumulate 2400 hrs total running time by '96
  - (first engine running - 400 hrs completed)

Fig. 1 MTR390 Development Status

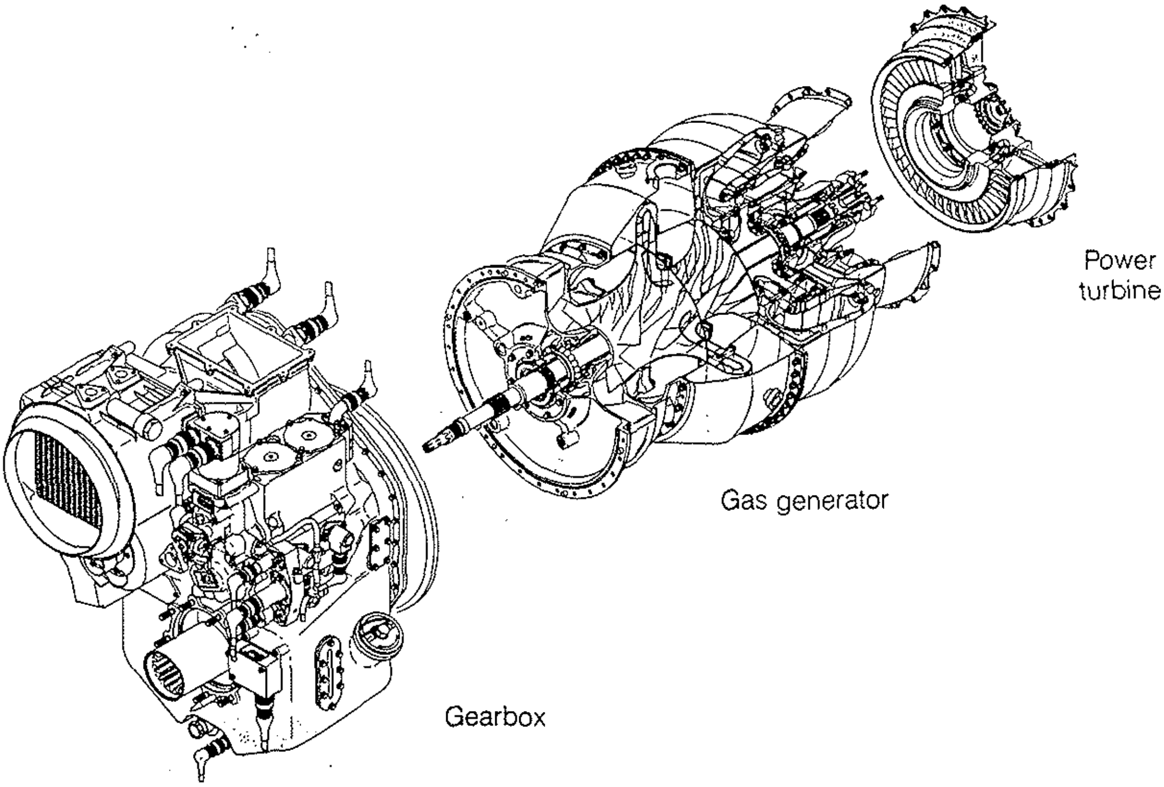


Fig. 2 MTR390 Engine Modules

1. Introduction

MTR390 is a turboshaft engine in the 1000 kW range to power Tiger [1, 2, 3]. It is being developed by MTR, a joint company of MTU, Turboméca, and Rolls-Royce. Fig. 1 gives an overview on the MTR390 development status.

The engine is fully modular and comprises four easily changeable modules (Fig. 2):

1) Gearbox
2) Gas generator
3) Power turbine
4) Engine Control and Monitoring Unit (ECMU) - not shown

The Engine Control and Monitoring Unit (ECMU) is the main part of the Engine Control and Monitoring System (ECMS), Fig. 3. It includes all functions necessary to safely operate the engine and to minimize engine related pilot workload.

The monitoring functions realized in the ECMU are an important prerequisite for the efficient and low cost "on-condition" maintenance concept of the engine. How they meet this goal is detailed in the following.

Further devices installed for easy maintenance are

- indicators of oil and fuel filter preclogging and blockage
- magnetic plugs for detection of metallic debris
- ports for boroscope inspections
- vibration pick-up (optional)

2. Engine Monitoring Concept

2.1 System Integration

Hardware Integration

Because the engine monitoring functions are housed in the same hardware box as engine control, safe communication is ensured and a low weight system is achieved.

Helicopter Integration

For simple handling by the operators, the ECMS has been designed as a part of the TIGER integrated helicopter supervisory and health monitoring system (Fig. 3).

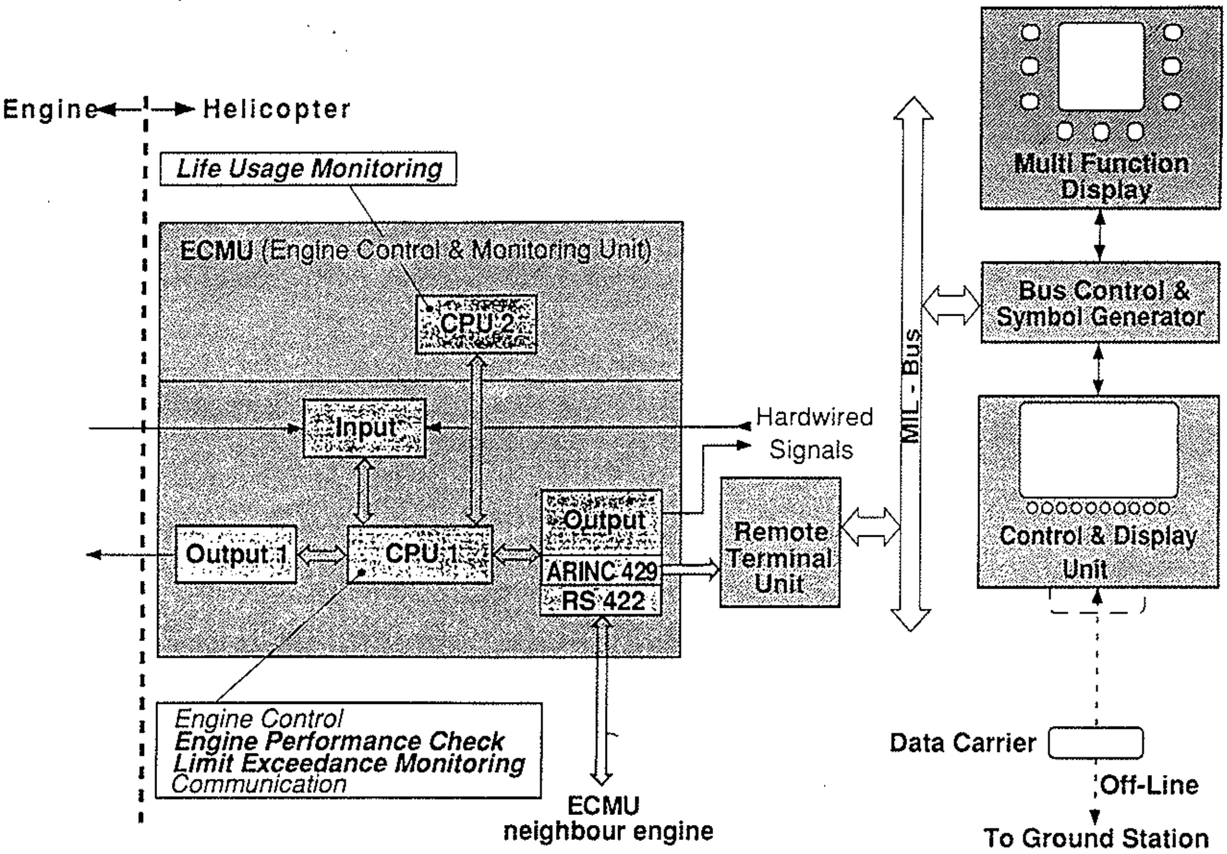


Fig. 3 Engine Monitoring System

This means, communication between the user and the ECMS is performed solely via the common indication and data transfer facilities (Fig. 4):

- *Alert information* is transmitted hard-wired to the cockpit Warning Panel.
- *Mission-relevant information* is displayed to the flight crew on the Multi Function Display.
- *Maintenance information* is available from the Control and Display Unit.

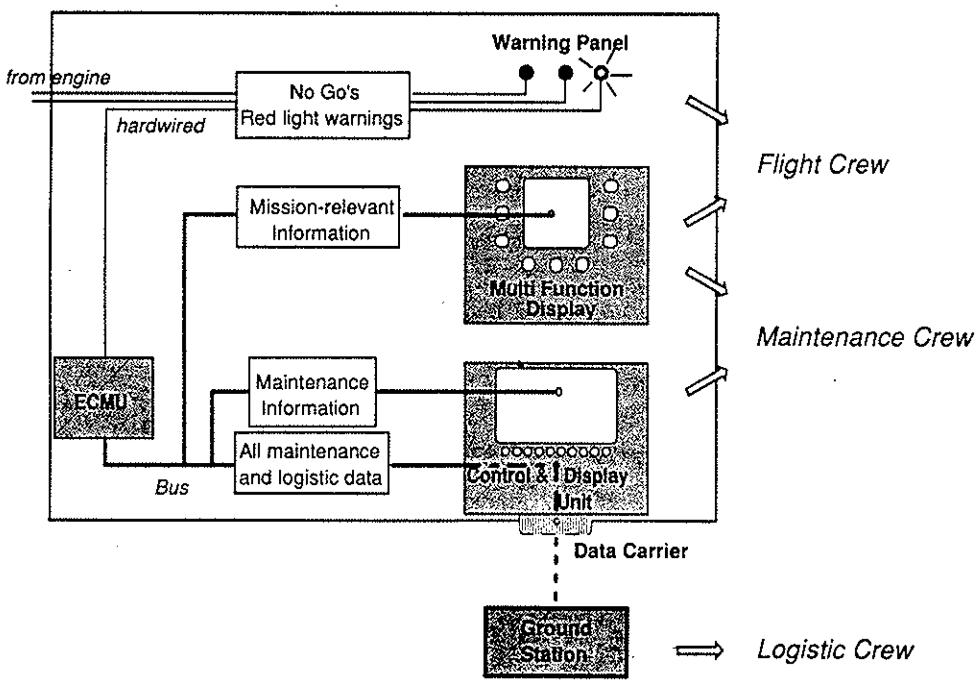


Fig. 4 Engine Monitoring Output Devices

Engine Performance Check	Engine power availability, engine health and efficiency → *Rejection of a deteriorated engine* → *Hint whether gas generator or power turbine is involved* → *Trending and performance forecast (fault prediction)*
Limit Exceedance Monitoring	Exceedances of engine speed, torque or temperature limits → *Detection of exceedances reduces failure probability* → *Classification of mission impact* → *Initiation of a specific inspection*
Life Usage Monitoring	Remaining life and life consumed per flight (individually for each monitored part) → *Indication of engine life exhaustion: engine removal* → *Identification of life-expired modules, parts, areas* → *Maximum availibility of each part* → *Optimisation of maintenance actions* → *Remaining life statistics of monitored parts (installed engine, spare)* → *Parts to be ordered (e.g. per flight base)* → *Life consumed by specific missions ("mission severity")*

Fig. 5 Engine Monitoring Results

- *Detailed data* are transferred to the Ground Station via the common removable solid-state data store carrying all helicopter maintenance data.

No additional ground equipment is required.

The initiation of a performance check has been left up to the pilot's authority, whereas the other monitoring functions are always activated automatically at an engine run up. It should be noted that all monitoring functions are activated in both, the standard automatic engine control mode, and the manual control mode.

2.2 System Output

The engine monitoring system satisfies the user's requirements for on-condition maintenance information. The output and benefit from all functions are summarised in Fig. 5. Additionally, the Engine Control and Monitoring System is fitted with a built-in test. It localizes failures to electronic sub-module level and takes appropriate action according to the failure severity:

- severe failure: "No-Go"
- minor failure: compensated by recovery function
- failure without effect: due to redundancy

By the following, the attention is focussed on the three engine monitoring functions.

3. Engine Performance Check

3.1 Objectives

On most present helicopters, performance checks can only be carried out by dedicated flights, and by pilot manual recording of cockpit gauge readings.

The MTR390 EMOS will perform this function in a wide power range and is fully automatic. Engine shaft power and turbine temperature will be checked at :

- *Pre Take-Off Conditions*
  in order to provide information to the crew prior to mission commencement
- *Routine Flight Conditions*
  for a regular assessment of engine performance data for on-ground trending and maintenance planning
- *Test Flight Conditions*
  which are specified for most accurate results

3.2 Conditions

Performance will be checked on pilot request, if the monitoring system has confirmed that the minimum conditions necessary for reliable checking are satisfied. The satisfaction of rigorous Test Flight conditions will be separately flagged.

The following constraints have been defined :

- *Exceedance of a minimum torque level (CM0)*
  The torque (CM) will be measured via the hydraulic oil pressure. Due to the features of the system, the accuracy is degraded at low torque levels. For Pre Take-Off conditions CM0 has been specified according to the highest torque which can be tolerated by the helicopter without take off when carrying no load.

- *Engine stabilized*
  Sufficiently stabilized conditions are a prerequisite for accurate checks. However routine checks shall be possible within a normal mission without special instructions having to be considered. In particular, the minimum stabilisation time has been defined such that no extension of the time from engine start until take-off is necessary.

- *Rigorous criteria for Test Flight conditions*
  For Test Flight conditions the minimum torque prescribed (CM0) shall be close to the maximum torque possible in flight with both engines operating. The pre-history of several minutes will be analysed to identify full thermal balance.

- *Customer bleed*
  The customer bleed has to be identified as being closed.

Further restrictions might be imposed to further improve the check accuracy.

3.3 Models

Two models are employed to permit torque and temperature checks :

- The first model describes the torque of an uninstalled engine providing the minimum torque which can be accepted (minimum guarantee power).
- The second describes the maximum accepted turbine temperature at the same conditions.

Each model consists of a set of schedules which are functions of the power turbine speed NTL, the gas generator speed NG and the ambient temperature, and a pressure correction term.

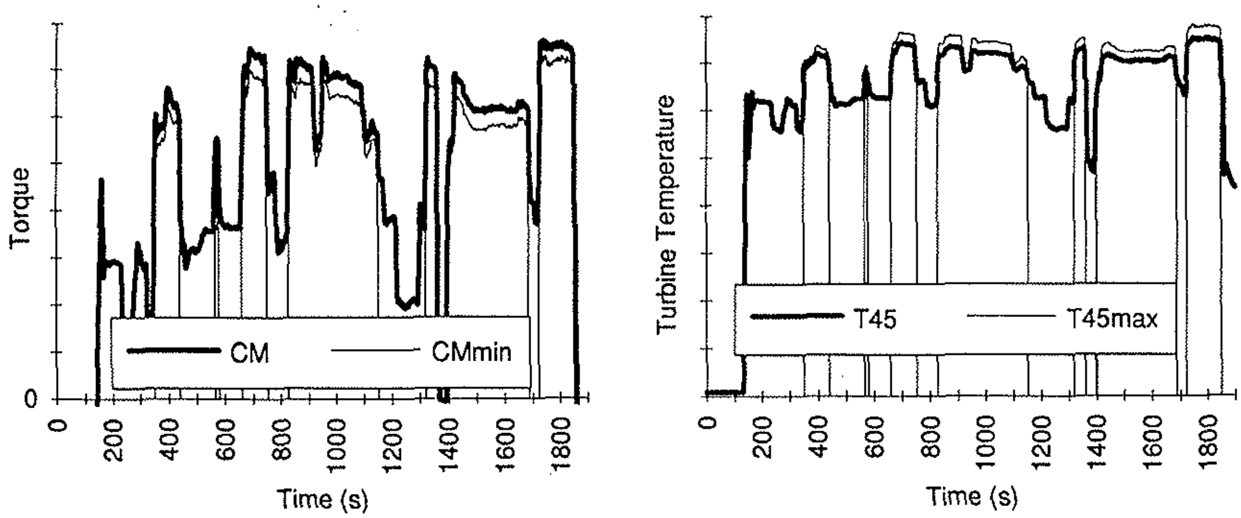
The helicopter Bus Control and Symbol Generator will complete the check after having received the data by compensating installation effects on performance. Presence of a sandfilter in the airflow inlet and the operation of this filter will be automatically sensed and the requirements individually adapted. The torque and temperature margins and the accuracy status, will be indicated in the cockpit. All results together with the engine parameters will be transmitted to the Ground Station via the removable data carrier.

On ground both parameters will be analysed. The information, whether the torque or the temperature margin is exhausted first supports failure localisation to module level. On-going engine deterioration can be monitored and pre-estimated by an appropriate trending procedure.

3.4 Results

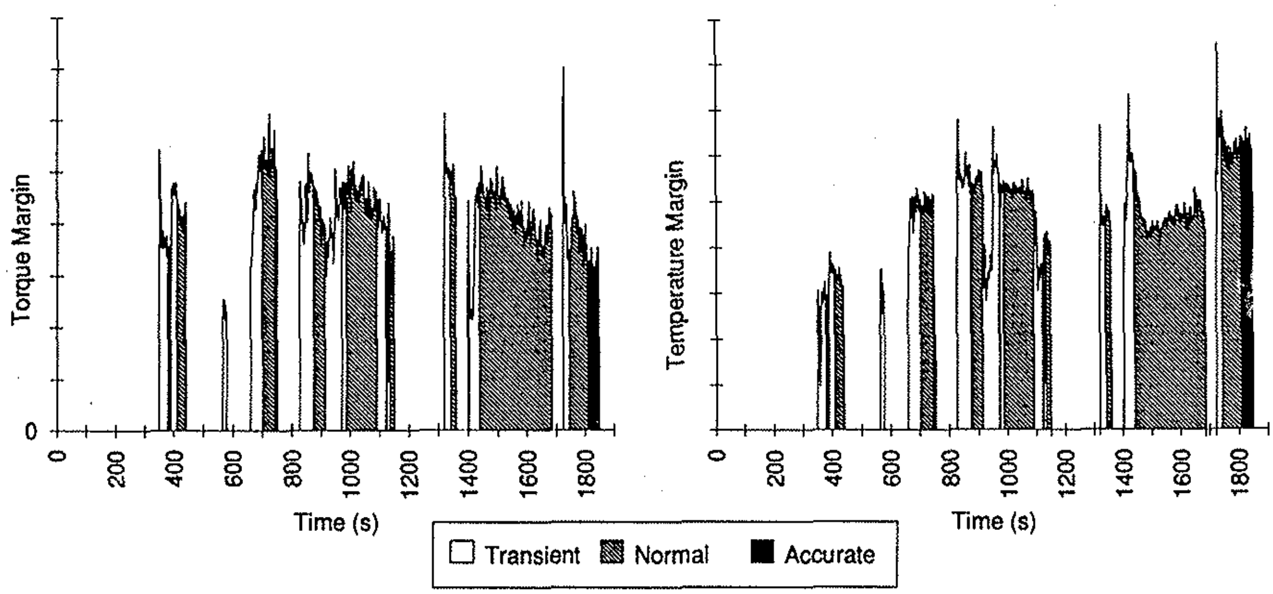
Recorded parameters have been evaluated by a development software, aimed to verify algorithms and test criteria at any condition. For this reason, checks are continuously performed as long as CM0 is being exceeded.

Results from an evaluation of a Tiger test flight are shown in Figures 6 and 7. Preliminary minimum torque and maximum temperature models were available, which were adapted to the test flight engine



a) Torque *b) Turbine Temperature*

Fig. 6 Measured Parameters and Limit Values



a) Torque *b) Turbine Temperature*

Fig. 7 Margins

standard and could be used for algorithm development.

Fig. 6 shows the torque and turbine temperature signals together with their respective limit values during the first phase of a test flight.

For analysis the corresponding torque and the turbine temperature margins are plotted in Fig. 7. The space below the lines is shadowed as a function of the stability status identified, which is either "transient", "normal", or "accurate".

The data showing the highest and lowest margin levels are not shadowed, indicating that these results would not be computed but discarded. For the different stabilised conditions, the torque and temperature margins vary in a comparatively small range close to the specified aging margins as this engine was almost new.

4. Limit Exceedance Monitoring

4.1 Constraints

Flight conditions may appear where an increased power relative to the maximum continuous power is required. Engine manufacturers specify higher power ratings which are permitted under certain conditions. By accurately checking whether restrictions have been exceeded, engine maintenance actions can be initiated which will reduce the probability of consequential damage and cost.

The following ratings have been defined :

a) both engines operative
- max continuous power (PMC) for unlimited use
- take-off power (PMD) for 5 min

b) one engine inoperative
- contingency power (PIU) for 30 min
- max contingency power (PMU) for 2.5 min
- super emergency power (PSU) for 30 s

Fig. 8 gives an example for the set of the respective limit values. For MTR390 the limit levels for take-off power and for contingency power coincide. To protect the engine, the control system will limit NG, NTL, T45, and CM to either PMD/PIU, PMU, or PSU as released by the pilot via selection switches. The duration of a selection, and the selection of a rating will not be compromised by the control system, however, for the pilot's flexibility.

4.2 Design

The scheme of defined limit values requires that the following exceedances have to be identified
- time exceedances of the ratings PMD, PIU, PMU and PSU
- exceedances of parameters beyond their released limit

Furthermore the resulting maintenance request priorities are determined.

To enable the detection of time exceedances the engine operation time spent at each rating has to be accumulated. A rating is considered as achieved and the respective counter is activated as long as at least one parameter has exceeded a limit value of the lower rating, either the steady state limit for longer than 10 seconds - or the transient one.

4.3 Interpretation of Results

The occurrence of a high priority maintenance request is messaged to the flight crew, since flight safety might be concerned by an increased failure probability and the mission is affected : only a single or even no engine restart may be permitted.

Other status messages transmitted to the Ground Station will raise less urgent actions by the maintenance personnel. It will be possible to realize the on-condition maintenance concept by scheduling individual inspections depending on the parameter and the level achieved, e.g. power turbine shaft inspection after excessive torque levels.

Parameter	Gasgenerator Speed NG [%]		Powershaft Speed NTL [%]		Powershaft Torque CM [%]		Turbine Temp. T45 Offset [K]	
Rating	a	b	a	b	a	b	a	b
PSU	104	104	112	112	133	133	+96	+96
PMU	100	101	106	112	108	113	+34	+50
PMD/PIU	98	101	106	112	100	113	0	+50
PMC	96	101	106	112	91	113	-34	+50

Fig. 8 Scheme of Engine Limits (preliminary relative values)
a - steady state (may be exceeded for less than 10 sec)
b - transient (should not be exceeded)

Monitored Part	Damage Mechanism
Gas Generator Module :	
Compressor	Low Cycle Fatigue, Thermal Fatigue
HP Turbine Disk	Low Cycle Fatigue (safe life concept and damage tolerant concept)
HPT Cover Plate	Low Cycle Fatigue
HP Turbine Blades	Creep, Thermal Fatigue
Power Turbine Module :	
Power Turbine Blades	Creep
Power Turbine Assembly	Low Cycle Fatigue

Fig. 9 Monitored Parts and Damage Mechanisms

5. Life Usage Monitoring

5.1 Motivation

The striking argument to adapt a life usage monitoring system for MTR390 was that extra operation time without an increase in failure probability can be offered, which means reduced life cycle costs for the user.

Simple time-based models rely on a "typical" mission severity, which does not exist for a military engine, and scattering engine mission severities do not compensate to an estimated mean severity over an engine's life time. The user either wastes a significant portion of the parts' life potential, or puts up with an increased average failure probability, or even both.

The gain in engine operation time has been quantified [5, 8] for the military RB199 jet engine fitted with a similar lifing system [6]. For this study more than 300 engines and some ten thousand engine runs were investigated. With this system installed the parts' average use could be increased by some 125 %.

5.2 Parts to be Monitored

There are two important criteria to select a life-limited part for being monitored :

1. Fracture-critical parts are to be life monitored for safety reasons, since a failure may lead to the loss of the helicopter.
2. Additional parts are life monitored for economic aspects, e.g. if they are valuable or difficult to replace.

The monitored parts and the damage mechanisms taken into account are listed in Fig. 9. The monitored areas are shown in Fig. 10. Monitored areas coincide, if different damage mechanisms are used at the same place.

5.3 Procedure

Among the MTR390 monitoring functions, Life Usage Monitoring is the most extensive one. It is performed on a separate processor board CPU2 (see Fig. 3), which is a Motorola 68020, fitted with 256 Kbyte ROM and 64 Kbyte RAM.

The philosophy is to assess the damaging impact of actual engine operation individually at all areas of a monitored part, which might first reach its life limit. For this, models are applied which have a limited deviation from the full design tools, which are Finite Element Methods and state of the art models for part life predictions.

The method applied was already presented [7]. Fig. 11 gives a pictorial overview on the main principle of computation.

Every time step a new iteration is performed which starts with an update of the temperature distribution, required to derive thermal stresses and temperature-

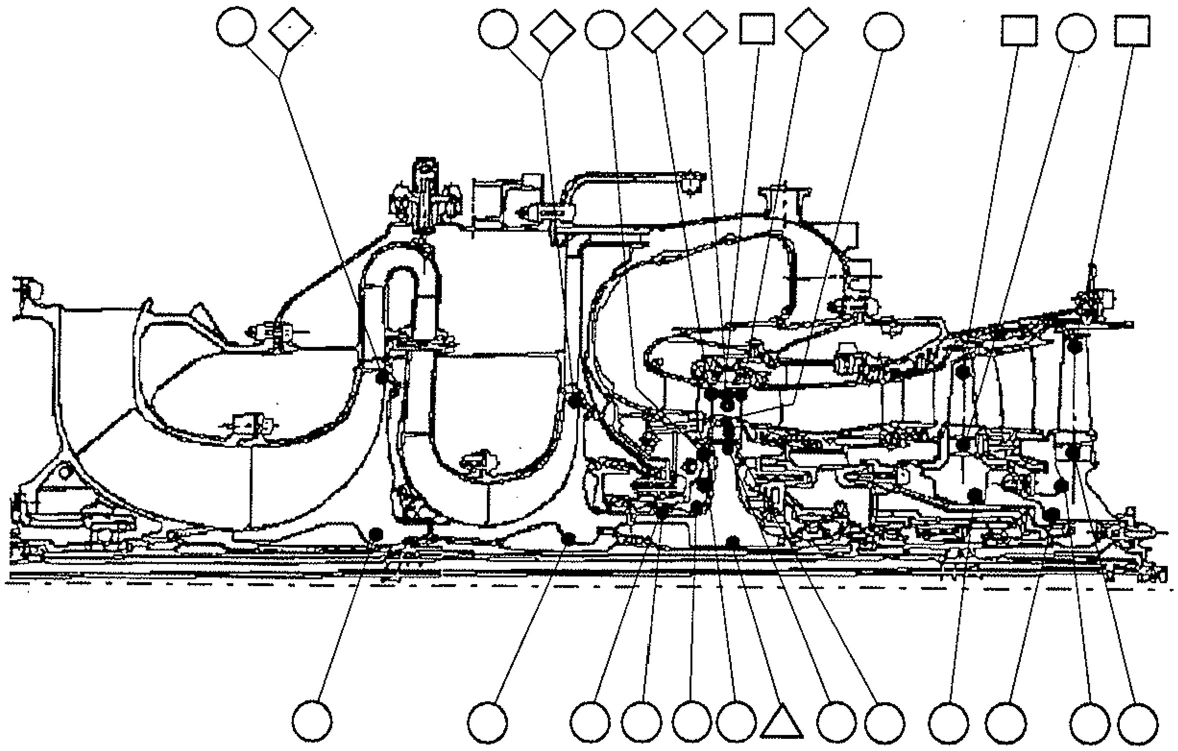


Fig. 10 MTR390 - Initial Life Monitored Areas

○ Low Cycle Fatigue (technical crack length) □ Creep

Δ Low Cycle Fatigue (crack growth) ◊ Thermal Fatigue

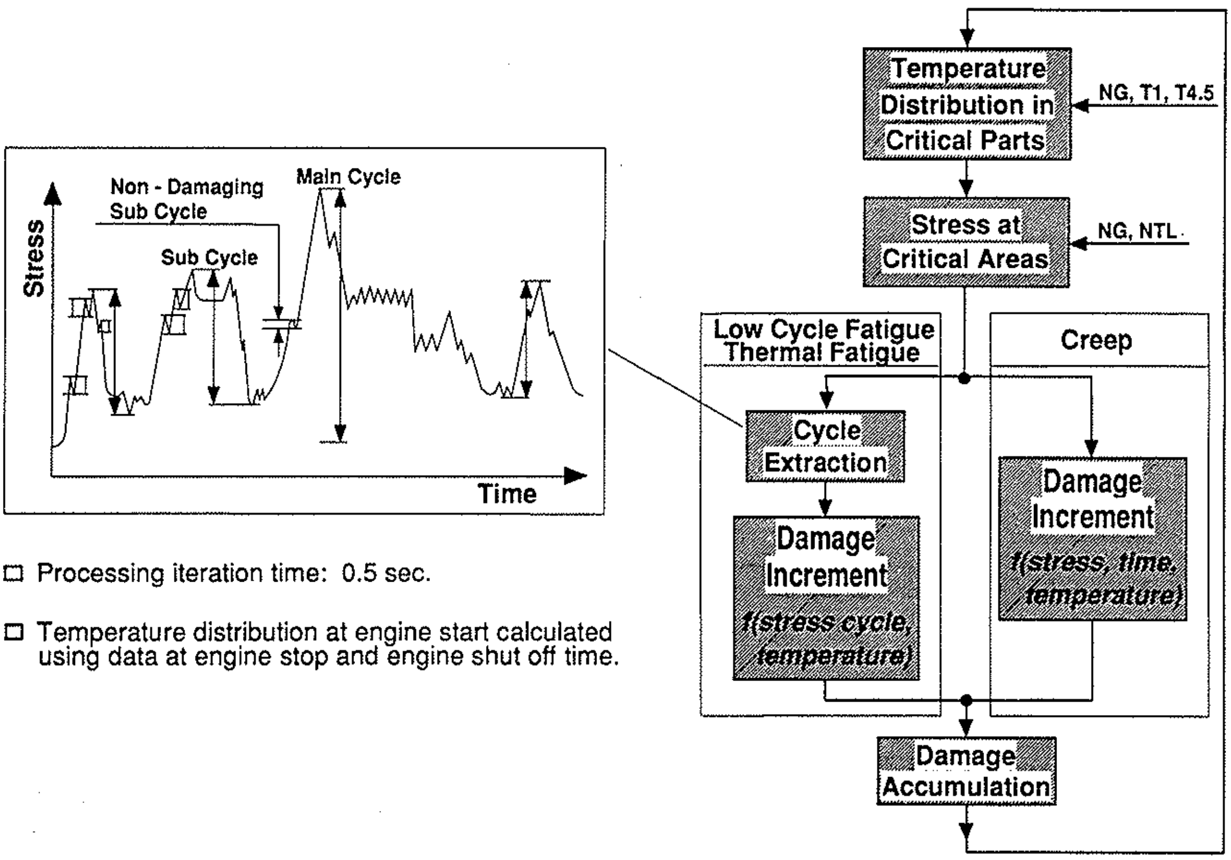


Fig. 11 Computation of Life Usage

dependent material properties. Then the total stresses at each monitored area are determined. Creep life usage can be derived from the stress level. Fatigue methods require extracted stress cycles instead. For the damage tolerant concept applied on an HP turbine disk area, the crack increment is additionally a function of the current crack length itself.

5.4 Results

Fig. 12 shows the life usage derived from

- a 60 min Flying Testbed flight
- a 40 min Tiger prototype mission (the same as used for para. 3.4)
- and from a 30 min ground bench engine run

Each life usage is related to that one received from the 160 min design mission. For the HP turbine disk area no. 1 - treated by a damage-tolerant concept - a range of damage ratios has been derived which corresponds to the range of possible crack lengths. For some areas no ratios are shown, because increments from the missions are negligible. These areas might be removed from monitoring in future, but not before having gained sufficient experience with a large number of operational missions at a wide spectrum of mission types.

Fig. 12 also shows that

- life usage is far from being proportional to the engine run duration
- life usage of different areas procedes individually as a function of the mission characteristics

Some life increments from the evaluated tests are negligible compared to those derived for the design mission, others even exceed this mission. The evaluated ground bench engine run includes a 15 min stay at the contingency power rating simulating one engine inoperative conditions (see para. 4.1). For this run the design mission life consumption is surpassed by a factor of about 20 at one HP turbine blade section, although the design mission level is not reached for some other areas.

These results stress the arguments for individual monitoring detailed in para. 5.1; the system user will benefit from individual accurate lifing of the monitored areas at any mission type :

- Flight safety will be increased. The impact of a certain mission on particular areas will not be underestimated.
- At the same time life potential of other areas, which are less affected by the same mission, will not be overestimated. Unnecessary replacements are avoided and economic long-term use is ensured.

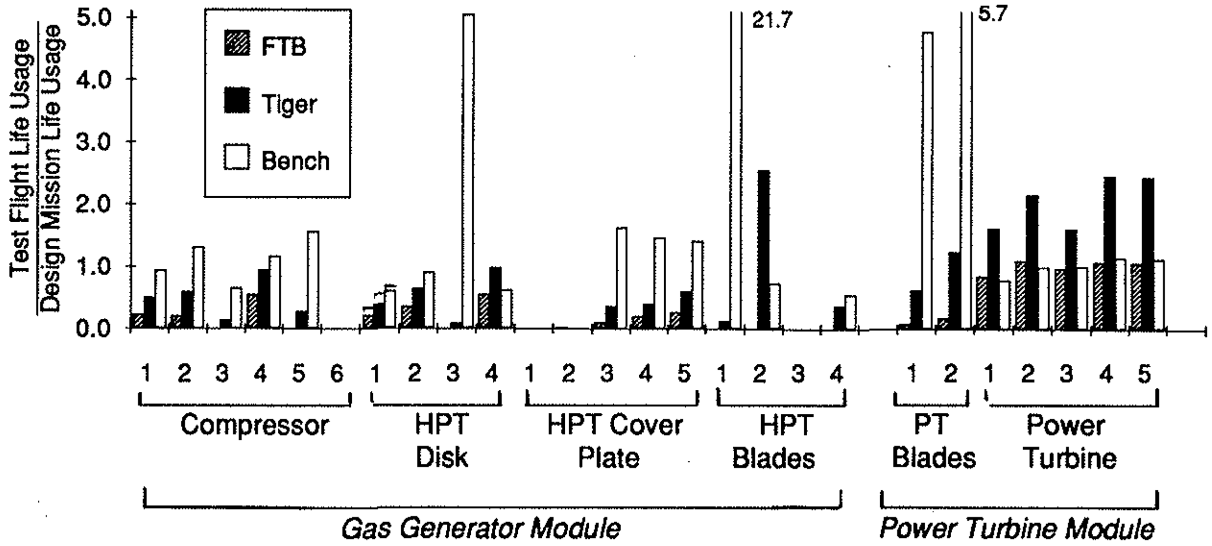


Fig. 12 Engine Test Life Usage Related to the Design Mission Life Usage

6. Conclusions

The MTR390/Tiger Engine Monitoring System represents the latest state of the art in engine technology.

The particular monitoring system design takes advantage of the detailed knowledge of the MTR engine manufacturers and will therefore enable the operator to fully exploit engine performance and life potential.

It will be easy to handle and will not require extra data readout since it is fully integrated to the common helicopter monitoring and supervisory facilities.

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Further information on the MTR390 engine is available from:

MTR GmbH, attn.: Mr. Roy Sanderson
Inselkammerstr. 5, D-82008 Unterhaching
Germany
Tel 49-89-614494-17, Fax 49-89-6149526