RB199 Maintenance Recorder: an application of “on condition maintenance methods” to jet engines

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Abstract

Maintenance on-condition concepts have been applied for many years in maintenance of RB199 engines installed on Italian Air Force TORNADO aircraft. A system based on networked computers has been developed to calculate life consumption of life limited components of this engine.

Engine parameters recorded during the mission are stored in a database for on-ground, post-flight processing. This approach has populated the database with up to 40,000 TORNADO missions, a unique database with a mix of training flights, Sardinia, Norway and Canada marshalling, missions in Kuwait. The database is continuously updated by collecting data from the bases as soon as they are made available.

This system has shown the advantages in term of:

- better usage of whole components life
- engine performance trend monitoring
- ad-hoc engine assembly and configuration
- post-flight analysis and fault location.

This program, due to its maturity and the acquired large database, has clearly demonstrated the advantages of condition maintenance approach.

The paper gives an overview of the approach applied to the TORNADO aircraft and will focus on:

- the architecture of the system
- the effectiveness of the method used
- the cost saving in maintenance activity
- engine test and maintenance optimization

trying to show the guidelines and new concepts for the next generation of maintenance stations for aircraft engines.

1. Introduction

The need to provide safe operation of aircraft engine as well as their cost-efficient maintenance policies is mandatory in today’s scenario. Since the beginning of 1990s, governments have tried to strongly reduce military expenses. Demands are for aircraft with reduced life-cycle costs, emphasizing durability for longer interval between overhaul, high reliability for minimal unscheduled maintenance and maintainability for simple and fast maintenance operations. In response to such demands, several years ago the Control System departement of FiatAvio started the development of a ground station to apply modern *Maintenance On-Condition* concepts to RB199 engines installed on TORNADO aircraft.

The original station served as a bench to validate the applied concepts: the adopted system showed benefits in engine performance and maintenance costs. Moreover, benefits have been found in logistic support to Italian Air Force (IAF).

This paper will describe the system used for the validation of the approach and the architecture of the new station under development. Moreover, benefits will be introduced and discussed to show the real advantages in terms of costs and timesaving.

2. Maintenance on-condition concept

Since the beginning of the operation of the RB199 engines on TORNADO aircraft, the analysis of the life usage of critical components[1] during missions was faced by the engineers. The Nations Air Forces (RAF for UK, GAF for Germany and IAF for Italy) identified different strategies. Such strategies led to different solutions of the problem, and ad-hoc systems, based on the requirements of the individual military agency, were developed by industries.

Replacing the scheduled overhaul with “when needed” operations is the target of the maintenance on-condition approach. To get this goal, the exact consumed life, based on cycles, shall be calculated. The knowledge of the residual life of each component is then monitored to warn the operators when maintenance of the engine become necessary. Therefore, component life is better used while maintaining the same safety margin.

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[1] Engine components are defined as *critical* when they are *life limited.* Life is usually measured in *cycles.* As they are life limited, knowledge of the residual life is essential, because this has an impact on the flight safety.

Two main algorithm to evaluate components life consumption during a mission exist:

- <u>calculation via the *exchange factors*</u>
  it is a statistical mean to convert the engine running hours into stress cycles

- <u>analysis of engine data during the mission</u>
  engine parameters (temperature, speed…) are analyzed to calculate stress cycles

IAF together with FiatAvio chose the second approach: engine parameters measured during the mission are recorded on magnetic tape for post-flight processing (by the MaReMOTO ground station). In the author opinion this method shows a great advantage compared to the other one: it is based on analysis of the real engine mission. In fact, different missions[2] may produce different damages[3] of engine components even if they last the same time (according to the first method, consumed components life is calculated by multiplying the mission duration by the *exchange factors*). This could never be taken into account with an *exchange factor* approach.

As an additional benefit of this technique, the post-processing method allows storing flight data and collecting them for further analysis: anyway, the mechanical tape recorder installed on the aircraft as well as the magnetic tapes themselves show maintenance troubles. The on-board analysis equipment installed on GAF TORNADO (OLMOS system) overcomes those problems, as a microprocessor-based equipment is installed on board. Anyway, any update of the system (hardware or software) requires that the operations of the entire fleet be suspended until the update is completed (from the experience, about one year is necessary to complete the task).

For clearness, it shall be highlighted that the core of this approach is the exact calculation of the component life consumption during a mission. It has to be noted that the key issue to perform the damage evaluation is the knowledge of the *stress laws*, that is the algorithm to derive component stress from engine parameters. Those algorithms shall be supplied by the engine manufacturer or be calculated from the lifing experts. The lack of knowledge about those *stress laws* makes it impossible to apply the described concepts. The same way, once the stress algorithm are known, it is necessary to collect the engine data to feed the algorithm. Obtaining those data can be a troublesome job, due to different reasons, for example a suitable device has to be installed on the engine and connected to sensors, the data shall be stored in a secure and easy-to-get way, the sensors supplying data shall be reliable.

3. Italian maintenance on-condition system

The current MR-AGS (Maintenance Recorder – Automatic Ground Station) is based on a Digital VAX-VMS computer. It was developed with the goal of proving the *maintenance on-condition* concept, its correctness and effectiveness.

The core of the system is a server computer, containing the database acting as a repository for all information related to the items (components, modules and engines). One station is installed for each IAF base. Within each base, a LAN network allows client terminals to access the central database. A WAN network connects computers of different bases each other to exchange data between bases.

The whole set of items stored in the database is shared between bases, but each base can write only to a sub-set of them (that is, a *signature* exists to identify the owner of each component, module, engine). Each base has full access on its items, but can just read items own by other bases: Fig. 1 shows an overview of this architecture. An overnight *replication mechanism* is scheduled to *synchronize* the databases: this leads to a complete duplication of the database content into all stations.

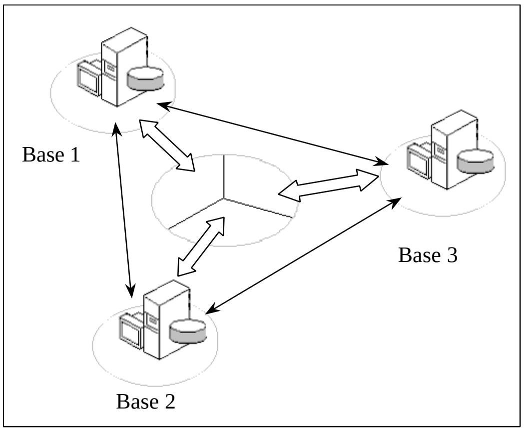

Fig.1 – Networked stations for the replication of the database

This solution shows three major advantages:

- each server computer in each base contains the complete database, hence allowing personnel to virtually access any data of the entire fleet

[2] "Different missions" means completely unsimilar ways of employing the aircraft, for example "transferring an aircraft from a base to another" and a "war attack" or a "training flight". Those missions can take the same flight time, but the life consumption of the engine is very different.

[3] Throughout this paper, *damage* of a component is used as *life consumption* of the component during a mission.

- each server computer in each base contains the complete database, so no need of backup is required to technicians because data are replicated in any database
- as the WAN is designed to allow connection between any computer, if a connection between two computers should fail, the communication between other stations will be anyway guaranteed.

Two major tasks are assigned to personnel in the bases:

- updating the database with flight data after missions.
  Just after an aircraft lands from a mission, or after an engine test on a test bench facility, the magnetic tape containing the engine parameters recording shall be read by the station and the flight data analyzed. Based on those engine parameters, stress damage of each critical component is evaluated through stress laws and stored in the database.
- building up engines with components and modules after overhaul operations.
  The station shows functions to build up an engine by allocating components and modules; also, special checks are implemented to verify the engine configuration in order to assure that correctly assembled engines only are inserted in the database.

The exact calculation of the component life consumption during a mission is the main issue on which the Italian maintenance on-condition approach as is based. The three major items to be considered for the development and the management of the concept are the *stress laws*, the engine *data recorded during the flight* and the *system used for elaboration of data*. Therefore, the key issue to perform the damage evaluation is the knowledge of the *stress laws*, that is the algorithm to derive stress from engine parameters. Those algorithms shall be supplied by the engine manufacturer or be derived from the lifing experts.

4. Benefits of the Maintenance on-condition concept

The former version of the Maintenance Recorder Station was used to demonstrate the *maintenance on-condition* concept. The development of the new station was used to better address the lacks of the previous system, in order to provide an improved product including hints and needs as suggested by IAF operators.

The extensive usage of the station in all IAF bases owning TORNADO aircraft allowed the collection of nearly 40,000 missions: this makes the MR-AGS the widest database containing TORNADO data. Recordings come from training flights in Sardinia (Italy), from marshalling in Norway and Canada and from operating missions.

The processing of such amount of engine data results in benefits in three major areas:

- *increase of components operating life*
  The knowledge of the exact damage accumulated during the engine mission allows correct calculation of the residual life of each component. Therefore, this method permits the better usage of each component, because they can be removed from the engine just few hours before their life is over. By using this approach, it can be taken advantage of almost whole components operating life. In the other way (statistical approach by means of *exchange factors*), components with a residual life were usually sent to the store. After the system was successfully proven, estimations have been made on the data stored in the database: they showed that nearly half the components set aside were recovered because of the useful residual life still available.
- *engine performance trending*
  When the aircraft is on the run-away waiting for the “green light” from the control tower,

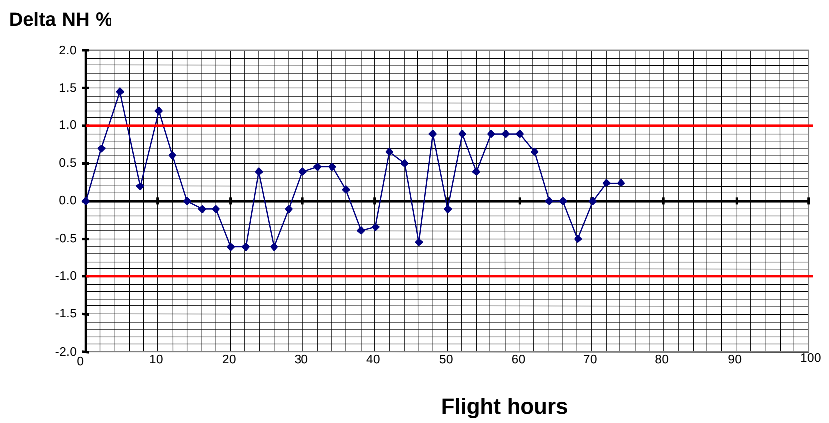

Figure 2 - Engine performance trending

just before the take-off, pilots are requested to perform engines special maneuvers: as all engine parameters are recorded on the magnetic tape, engines behavior during those maneuvers are stored as well.
The post analysis of those data gives information about the engine performance. Based on the results of processing of most sensitive engine parameters, technicians get an indirect measure of the engine thrust. Charts are automatically produced with the trends of performance of different engines versus the time. Technical personnel can decide when the minimum thrust level is reached and unload the engine for the necessary overhaul operations. Figure 2 shows an example of the trend of the engine speed recorded over several missions. Other diagrams like that one are produced by the station, for different engine parameters.
Before this procedure became operative, engine tests to measure thrust were scheduled at defined time intervals (75 running hours). The new method pushed those scheduled operations up to two times the current time, and decreased maintenance costs in term of fuel saving, man-hour and aircraft grounding time.

5. Discussion

The key factors of the success of the concept and the system implementing it are the easy-of-use and the integration with the Customer during the prototype station testing phase. A big effort has been put in the development of the system in order to design a simple and effectiveness user interface, made by user friendly windows to simplify the job of the operators. Manual tasks that can lead to errors due to the repetitiveness of the job have been automated, and checks have been added to control the quality of data stored to the database.

As stated above, the **tight interaction** between the team and the Customer during the on-filed testing of the station allowed an effective tuning of the system, by collecting and discussing the exact needs of the personnel and by adding proper functionality to cope with those requests.

The database architecture defined above (Figure 1) shows a secondary effect impacting on **logistics**. The central logistic department, which is in charge of managing distribution and purchase of components for all bases, has an overall view of the components and

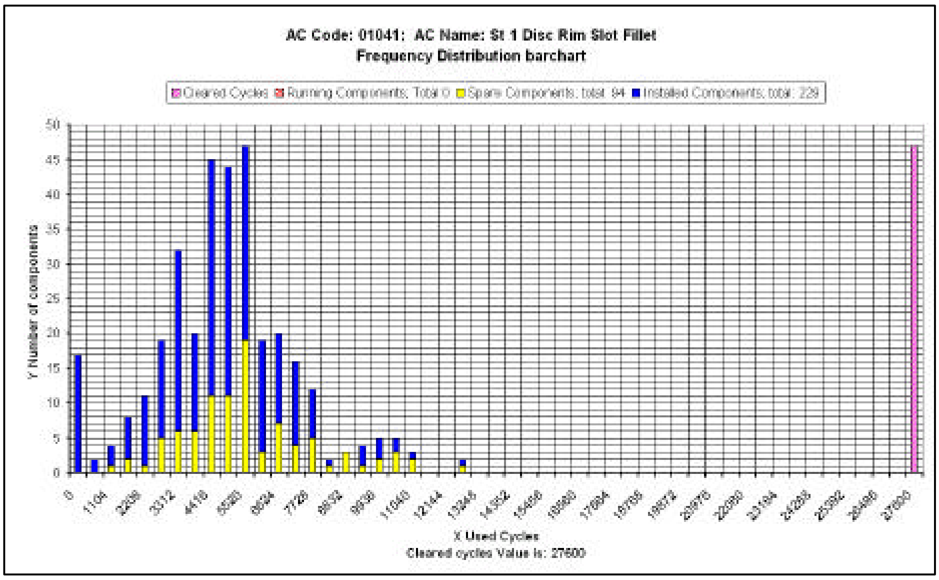

Fig.3 – Compressor disk life distribution

➢ *driven engine configuration*
As the system "knows" the exact residual life of each component in the database, a driven engine configuration wizard helps the operators to build a new engine by using components with similar residual life. This function allows building an engine with equally aged components and avoids the necessity of unloading an engine due to a prematurely component expiration.

modules availability in the fleet. Additionally, information about the status of each single component (residual life, status, location…) are stored in the database.
Figure 3 shows an example of the life distribution of the components of one type (Compressor Disc). Most of the components has a large residual life (the limit is the bar at the right side of the chart). Colors differentiate between installed and spare components.

Even if everybody in the base can access those information, special dedicated functions have been developed for logistic personnel to perform those queries in the database they need: as an example, life prediction of components installed on different engine standards can be simulated to check their better usage.

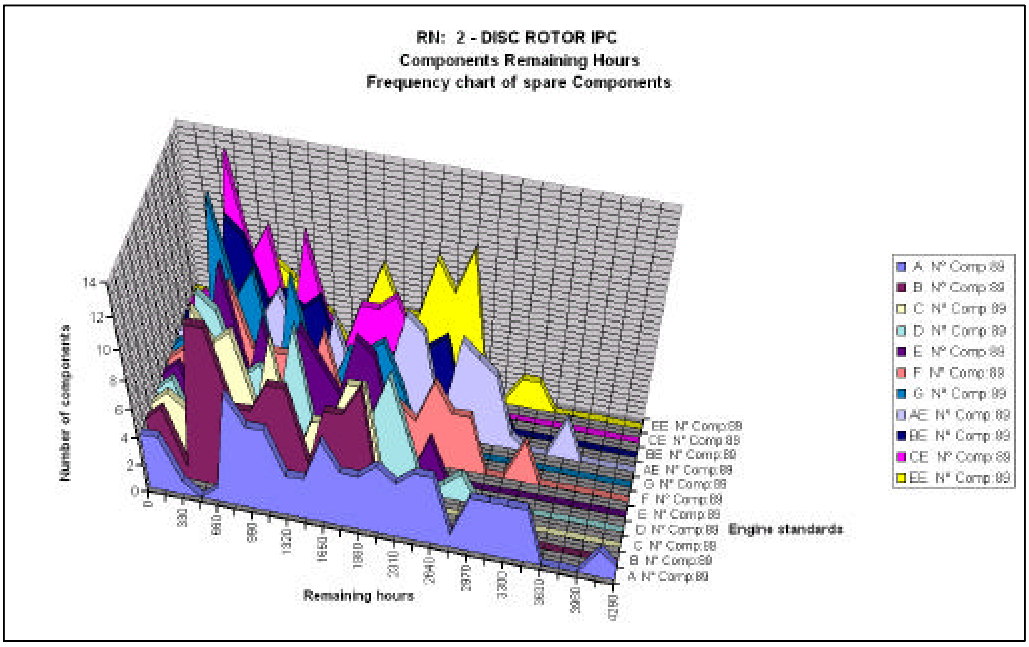

Fig.4 – Compressor disk residual life distribution simulation

The Figure 4 shows an example of such life prediction simulation for one component type (Compressor Disc), depending on the engine standard: the 89 spare discs residual life will be distributed as shown in the figure depending on the engine standard they will be installed (i.e., if the disk is installed on an engine set as standard A – the frontmost area of the figure – most of components will show a residual life between 660 and 3600 hours – the center part of the area).

Beside the huge database discussed in the previous chapter, the off-line post-processing approach shows a great advantage in term of data collection. In fact, before storing data in the repository, engine recordings read out from the magnetic tape are analyzed by means of a tool developed for **post-flight analysis and fault location** to check their correctness: this analysis allowed discovering several malfunctions related to engine/aircraft sensors. Corrective action was therefore suggested to maintenance personnel. Stored flight data will be processed with a dedicated tool in order to analyze the engine operations during the mission. Figure 5 shows a view of the tool: engine parameters are represented in an animated window.

Operators can stream thorough the entire mission recording file to look at the simulation of the flight: this tool has been very useful to investigate engine problems, because it allows to correlate engine and aircraft data, in order to find out any impacts of aircraft operations on engine performance.

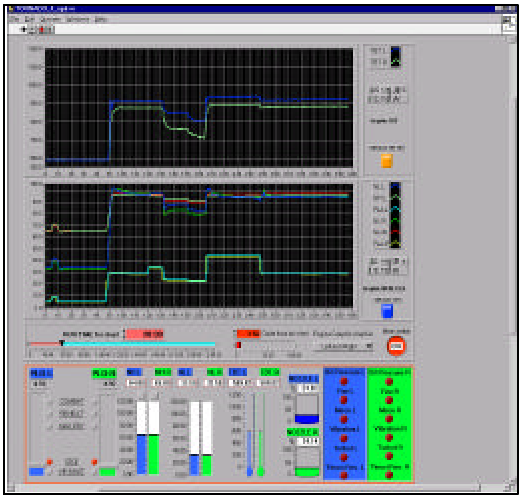

Fig.5 – Flight Data analysis tool

6. The future

In the above discussion, the GAF maintenance on-condition approach has been mentioned; it has been underlined that aircraft are equipped with an on-board system performing the engine data analysis during the operation and supplying results at the end of the mission. This approach does not allow post-processing, because flight data are not available.

For the future, a feasibility study is on going to investigate the potential of the integration of the two systems, the recording and off-line processing with the on-board analysis. The target is the development of a system that

- calculates components damage during the mission, to have information available as soon as possible when the aircraft lands
- supplies recorded data for post flight analysis for fault location, troubleshooting …

to integrate the two concepts into a system collecting the benefits of both of them.

Engine data could even be transmitted via the aircraft telemetry to the receiver in the military bases, in order to save space, weight and power consumption on the aircraft. This would be an alternative system to replace the tape recorder actually installed on TORNADO.

7. Conclusions

The Maintenance Recorder Station is a successful product. As already stated, the key factors for its success are the easy-of-use and the integration with the Customer during the prototype station testing phase.

The current computer technology allows development of powerful systems: for example, the modern *database replication* permitted the creation of the distributed architecture described in this article, with a minimum effort.

The concept herein described shown good results during both the testing phase and the following operative usage. It shall be highlighted that those results have been achieved on the TORNADO aircraft, which is an old fashion machine (the design started in the seventies). Modern aircraft are based on the state-of-the-art technology, and maintainability and testability concepts are considered since the beginning of the development. Under those assumptions, for future systems we could expect even better results than the ones got in the past with the Maintenance Recorder Station program.