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GP7000: MTU Aero Engines' Contribution in a Successful Partnership

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Abstract

Because of globalization and opening of national markets, airlines are facing a constantly increasing cost pressure. Therefore, a close cooperation between airframe and engine makers is essential to seek for new approaches. In particular, it is the expectation that a significant contribution to the reduction of Direct-Operating-Cost is coming from the engine manufacturer. As a result engine designers are working on new concepts for the next generation of jet engines which increase component efficiency and power as well as improve environmental sustainability and, at the same time, reduce production and development cost.

The new super Airbus A380 requested just such a new generation of jet engines, see Fig. 1.


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Fig. 1: The GP7200 on wing of the A380

As a consequence, two of the leading engine makers, General Electric and Pratt & Whitney joined to form the Engine Alliance in order to develop the GP7000 engine family with a thrust range of 70.000lb to 82.000lb. Additional partners are MTU Aero Engines, Snecma, and Tech Space Aero. The GP7000 competes with Rolls-Royce's Trent 900 engine designed as a derivative of the Trent family.

The Engine Alliance together with MTU Aero Engines as a partner hereby guarantees best results for the customer, because of:

- The use of the best mix of talented engineers of each company
- The availability of a profound experience base in commercial engine development such as the GE90- and PW4000-product families
- The long time, stable working relationship and trust between airlines, airframer and engine maker.

Because of this approach, the best technical concept can be achieved in less time and at low risk by making use of all partner companies technology platforms.

The GP7000 engine which is to power the A380 aircraft is an example of a very successful multi-partner development to which MTU Aero Engines had a substantial contribution.

Introduction and GP7000 Overview

The GP7000 engine architecture is based on the highly successful GE90 and PW4000 engine families with a combined service experience of over 250 million hours. Its core draws on the GE90 whereas the low spool is derived from the PW4000. The approach was to make use of significant legacy experience, while at the same time introducing new technologies to meet the technical challenges. Fig. 2 shows a picture of the GP7000 engine and contains a table of the engine module split between Pratt & Whitney (low spool) and General Electric (core engine).

1) Swept Fan
2) 5 stage Low Pressure Compressor
3) Gear Box
4) 6 stage Low Pressure Turbine
5) 9 stage High Pressure Compressor
6) Single Annular Combustor (SAC)
7) 2 stage High Pressure Turbine
8) FADEC III (Full Authority Digital Engine Control)

Fig. 2 GP7000 engine and module split

Table 1 summarizes the most important engine specifications as certified in December 2005.

Takeoff-Thrust (SLS, ISA) flat rated to 30°C……………:		70.000lb/311kN
Cruise-Thrust (35.000ft/10668m; 0,85Mn; ISA)….........:		12.633lb/56kN
Noise (A380):	LHR Departure…......…:	QC2
	LHR Arrival…...…......:	QC1
	Margin to Stage ¾…....:	23/13 EPNLdB
OPR (Max Climb)……………………….:		45,6
BPR (Cruise)……………………………:		8,7
Thrust Setting Parameter……………..……..:		N1
Length…………………………………..……..:		187in/474cm
Diameter…………………………………:		124in/316cm
Fan Diameter……………………………:		116in/295cm

Table 1. GP7270 key technical specifications

The GP7000 engine is also certified for a thrust level of 77.000lb named GP7277.

The Partnership arrangement of the Engine Alliance in this program is such that General Electric and Pratt & Whitney both have a 50% share.

Main Risk & Revenue Sharing Partners (RSPs) are Tech Space Aero, Snecma and MTU Aero Engines. MTU Aero Engines is a RSP on both sides of the alliance with a total share of 22.5% which makes MTU Aero Engines the 3rd largest contributor on the program.

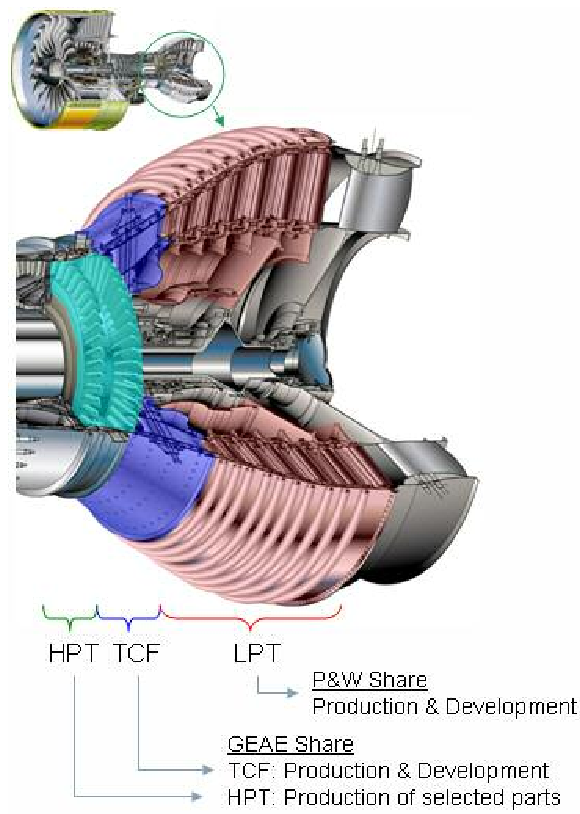

Fig. 3 illustrates MTU Aero Engines' development and production share

For the first time, MTU Aero Engines was assigned development responsibility for the Turbine Center Frame (TCF) by GEAE, which is the frame structure located between high and low pressure turbines and supports the rear high spool bearing. In addition MTU has production responsibility of selected High Pressure Turbine (HPT) parts. Fig. 3 summarizes MTU Aero Engines' production and development share of the GP7000 engine.

On the P&W side, MTU Aero Engines has development responsibility for the Low Pressure Turbine (LPT) as in previous joint P&W/MTU programs (PW2000, PW4000, PW6000).

The LPT is based on legacy experience on commercial applications like the PW2000, V2500, and PW4000 Growth Family PW4084/90/98, incorporating continuous improvements and new developments. Fig 4. shows a cross section of the GP7000 LPT.

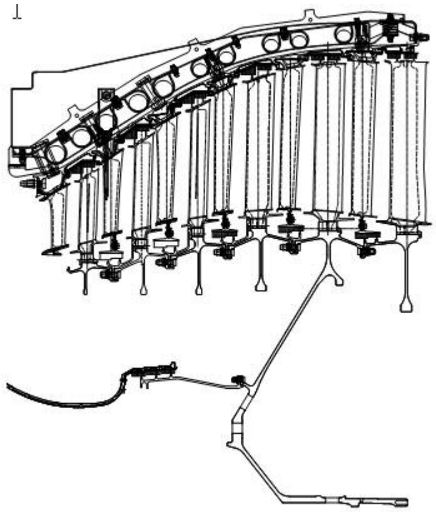

Fig 4. GP7000 Low Pressure Turbine cross section

The LPT has six stages with 3D aerodynamic design and additional technologies targeted at improving efficiency. Active clearance control improves the efficiency even further. While the design makes use of significant field experience regarding reliability and maintainability, a major focus area was the achievement of a weight optimized design. New design concepts and additional new technologies like high lift blading were introduced.

A major customer requirement for the GP7000 was the noise characteristic. To achieve the requirements, a cut-off design was introduced, where airfoil numbers are chosen such that low pressure turbine noise is minimized.

The high pressure rear bearing structure is located between high and low pressure turbine as in the GE legacy engines. This structure, the Turbine Center Frame (TCF) is a star like static structure (Fig. 5), for which the load carrying struts are protected from the hot gas path by aerodynamic optimized fairings, see Fig 6. The TCF also provides oil to and from the bearing and cooling air to HPT and LPT. Fig. 7 shows a cross section of the TCF.

While this frame was a major challenge with respect to size and specification, MTU Aero Engines was able to draw on its significant experience on similar structures (e.g. turbine exit casings on PW2000 and

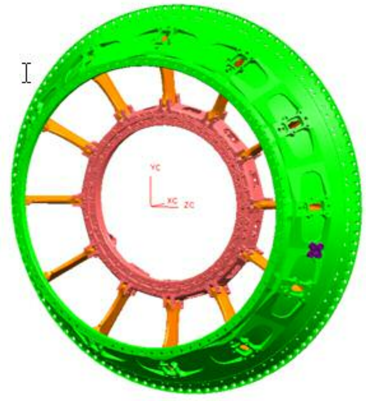

Fig. 5 GP7000 Turbine Center Frame 3D model

PW4000 as well as the turbine mid frame in the MTR390). In addition, working closely with GEAE ensured that General Electric legacy experience on this structure was fully taken advantage of. By designing the TCF and the LPT MTU Aero Engines was able to ensure an optimized interface between HPT and LPT and optimum inlet conditions for the LPT with an overall benefit in SFC.

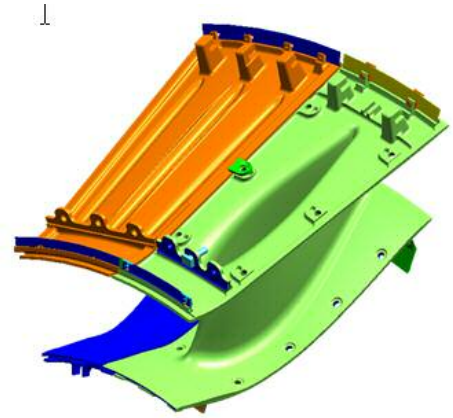

Fig. 6 GP7000 Turbine Center Frame fairings

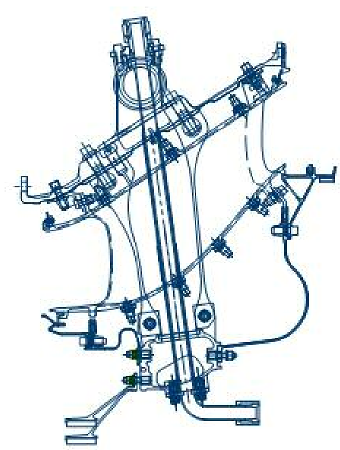

Fig. 7 Turbine Center Frame cross-section

Challenges

Today's highly competitive environment clearly translates into the need to achieve aggressive technical goals within very short development cycles to meet equally aggressive cost targets. Therefore, the key challenges for the GP7000 were:

- Technical and cost targets
- Schedule and industrial delivery
- Multi partnership environment

Technical and Cost Targets

The GP7000 engine had to exceed world class technical goals for specific fuel consumption, weight and noise in order to successfully penetrate the market while being environmentally friendly and superior in maintainability. Those technical goals turned into high temperatures in order to achieve world class component efficiencies and an aggressive light weight design simultaneously.

For best-in-class LPT efficiency, optimization of flow path geometry and airfoil count was performed stringently using 3D-Navier-Stokes simulation technology.

Today the GP7000 LPT is a best in class LPT being 10% lighter than the PW4000 LPT and significantly better in component efficiency while meeting aggressive noise targets.

For the TCF architecture, the search for the lightest design meant increasing transition duct slope without an increase in pressure loss. At the same time the structure had to withstand high temperatures without active cooling.

Of course, the technical targets had to be achieved at the lowest development and production manufacturing cost.

Schedule and Industrial Delivery

Crucial for the success of the development program was and still is to meet the highly demanding schedule driven by the customer:

- FETT March 2004 - achieved
- FAR33: FAA Engine cert December 2005, EASA April 2007 - achieved
- 1st compliance engine Bill-of-Material freeze a couple of months after FETT – achieved
- 1st flight w/ GP7000 engine August 2006 - achieved
- *FAR 25, Airframe w/engine cert December 2007 - planned*
- *Entry into Service September 2008 - planned*

In order to meet this schedule the 1st compliance engines Bill-of-Material had to be frozen only a couple of months following FETT. As a consequence, the engine and the component designs had to be first-time-right, just going through validation rather than allowing design iterations of major components within the engine development plan.

Multi Partnership Environment

Dealing with several major partners at the same time at various locations of course is a challenge. It requires a distributed development approach for which stringent processes and discipline in executing and integrating the design work are key. This approach is highly demanding regarding the organizational setup and communication tools.

Key Success Parameters

There are a number of key success criteria that need to be taken care of in order to make such a challenging project as the GP7000 successful. Some of these are necessary when performing a project within one company, and some additional requirements driven by the complexity of working successfully within several different companies (GEAE, P&W, MTU Aero Engines and others).

These criteria can be roughly grouped into 'Preparation', 'Execution' and 'Organization'.

Some discussion already went into the first aspect of 'Preparation', which is to make extensive use of ***legacy experience***. In the GP7000, this meant exploiting GE90 experience on the core and PW2000, V2500, PW4000 and PW6000 experience on the low spool. Each partner company including MTU Aero Engines contributed to this aspect with its own experience to ensure best design maturity and the use of lessons learned from previous programs.

An aspect related to this is the ***consistent use of standard work***. Standard work determines the tasks that need to be executed in the design phase as well as how to execute these tasks. Legacy experience and lessons learned need to be incorporated into standard work and it needs to be execution ready prior to the start of detailed design. Having standard work ready for execution means having the tools used to perform the standard tasks available and people trained in those tools.

The third aspect of 'Preparation' involves ***technology readiness***. It is important to follow a stringent technology readiness process by which a certain maturity level of new technologies needs to be demonstrated in order to introduce these technologies in the engine. The technology might be demonstrated in other engine program, engine demonstrators or engine rigs depending on the technology and the associated risk to the engine and the program.

An example of this approach can be seen in the extension of the aerodynamic design space in the direction of higher lift and the execution of a 3D aerodynamic design. A stringent technology introduction process was executed which culminated in the successful run of a full scale LPT cold flow rig prior to detailed design, see Fig. 8.

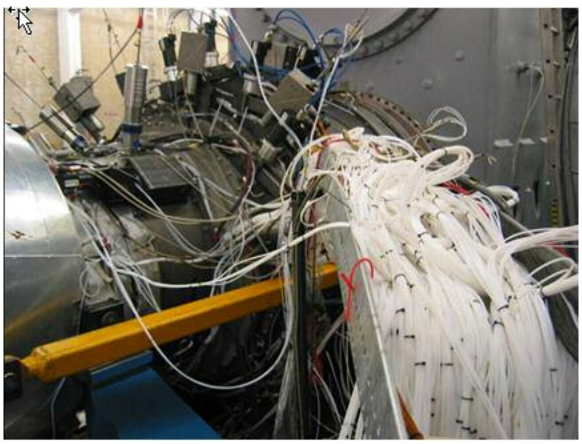

Fig. 8 GP7000 full scale LPT cold flow rig

The aerodynamic technologies introduced into the LPT and the predictions of the 3D Navier-Stokes simulations were verified and demonstrated, which allowed the introduction into the final design.

Another example of a technology introduced to address the weight challenges of the GP7000, was the light weight single crystal LEK94. The tasks to make this airfoil material available for the GP7000 ranged from material characterization and casting trials all the way to the successful runs of blades made from this material in a demonstrator engine, see Fig. 9. In this example, the technology readiness process was followed stringently and the necessary maturity levels were demonstrated prior to the completion of detailed design.

Correspondingly, the introduction of new technologies in the GP7000 went flawlessly and no design iterations related to new technologies were required.

Fig. 9 Light weight single crystal LEK94 blade 1

Big contributors to the successful engine development are items related to 'Execution'. One item can be summarized under ***industrial management***, which consists of several important aspects. Industrial management takes care of everything that drives hardware availability and execution of the engine validation plan all the way to certification. Part of this consists in the monitoring of crucial milestones in the hardware supply chain. However, it is a process that if executed stringently will go far beyond the aspect of monitoring and will drive the way and the order in which tasks are being performed. Industrial management will drive early supplier integration, which is important in order to embark in concurrent engineering from the start with the suppliers closely involved. It will also highlight the value of design and production maturity at FETT, which is an important issue to avoid costly changes and learning during the validation phase. Equally, it is important to have a thorough and complete risk analysis, which identifies the potential risks in the engine development plan, and the corresponding risk mitigation plan, which identifies how to react to possible scenarios including the potential needs for redesign and hardware availability. Ultimately, an analysis of this kind will drive the execution of the engine validation and the test and instrumentation requirements.

Important aspects to be taken care at 'Execution' relate to managing the needs at the boundaries of teams and components. Stringent **interface management** and **dependency management** become key. Interfaces can be physical or functional definitions of component boundaries and dependencies describe anything that needs to defined by one team/ component for the other team/ component to proceed. Of particular importance is that interface definition and dependency need dates get defined and that monitoring the execution of these become part of the industrial management process.

The aggressive goals of an engine development program like the GP7000 cannot be met without a very ***stringent execution of details*** in the engineering work and without making sure that the boundaries set by standard work are fully exploited. In addition to the introduction of the appropriate technologies, this meticulous attention to detail becomes crucial. As an example, the significant weight reduction of the LPT relative to legacy experience owes its success to the detail design work, in which every radius and every wall thickness was investigated and challenged while staying within the boundaries set by structural and life requirements as well as manufacturability. Also, this had to be achieved within the limits defined by standard work and available technologies.

Finally, a big part of the success relates to 'Organization'. ***Strong leadership*** is a key requirement, as is an organization, in which ***roles and responsibilities*** are clearly defined. This is important at every organizational level. In addition, achieving the high technical challenges and the cost targets in a multi-partnership environment requires very stringent processes and a highly efficient organization. For MTU Aero Engines, this also meant positioning strong engineering leadership together with the functional integration teams at both partner companies, Pratt & Whitney and General Electric. This approach of ***on-site management capability*** enabled MTU Aero Engines to actively participate in the highly demanding integration process while being able to support real time decision finding.

With MTU Aero Engines North America in Connecticut, MTU was adequately positioned to support MTU Aero Engines' strategy of strong on-site presence with engineering capability and support beyond just the integration management teams. This allows quick response and efficient participation in the engine integration where, the component needs have to be represented while trying to achieve a system optimum.

A final aspect of 'Organization' lies in the management skill of selecting people. It is the people that determine the success. Therefore, selecting the right people is a crucial success criterion. In particular, it is important to choose a balanced ***mix between an experienced and a young talented workforce***. This enables to draw on experience while at the same time creating an environment which is challenging for individuals and in which creativity is honored.

Summary

The GP7000 is a from the start very successful aircraft engine which was developed in a multi-partner environment and which had to satisfy aggressive goals: technical, cost, and schedule. The stringent execution of crucial success criteria enabled the overall success of this program in which MTU Aero Engines had a substantial role and major contribution in developing the Turbine Center Frame for General Electric and the Low Pressure Turbine for Pratt & Whitney.