OPTIMIZED 10 TON CLASS COMMERCIAL AIRCRAFT ENGINE

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The CFM56 engines family, designed to power aircraft of 110 to 200 passagers, short, medium or long range, has been defined to produce 18 000 to 28 000 pounds of thrust depending on the version considered. Figure (1) compares the first two models of the CFM56 family : the CFM56-2 certificated at 24 000 pounds and now in production compared to the 20 000 pounds for the CFM56-3.

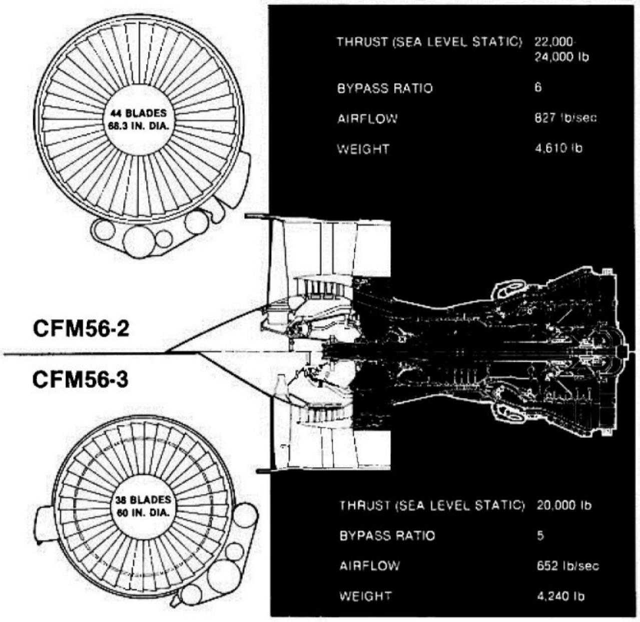

Figure 1 - CFM56 engine family

The CFM56 program had its start about eleven years ago when studies conducted at SNECMA and GENERAL ELECTRIC concluded that the core of the F101 engine would provide the best core engine for the new 10 ton class turbofan. The first full CFM56-2 engine went to test in 1974 followed by an extensive development program conducted for the last eight years. In March 1979 this engine was selected as the powerplant for re-engining the DC8 series 60 aircraft after a very thorough competitive evaluation made in March 1979 by a group of major American carriers including UNITED AIRLINES, DELTA and FLYING TIGERS. An extensive extra-severity development program has been conducted since the first engine went to test and, perhaps the most noteworthy of this was the installation of 4 of these engines on a BOEING 707 and the flight test of that aircraft in late 1979 and early 1980 under a joint program conducted by the BOEING COMPANY and CFM INTERNATIONAL. The results were very impressive including demonstration of the engines capability to meet its altitude performance specifications and the demonstration of the low noise objectives lower than the latest FAR-36 stage 3 (amendment 8 and 9) requirements for new type design aircraft.

Low noise qualities of the CFM56 have been recently confirmed early this year on a Mc DONNELL DOUGLAS DC8-60 aircraft as part of the DC8 re-engining certification program which came to a successful conclusion early this year. Re-engined DC8-60 entered revenue service late April. In 1980, the U.S. AIR FORCE selected the CFM56-2 for its KC-135 tanker fleet re-engining program the first flight of the CFM56 powered KC-135 will occur in August 1982. Last year one of the most significant milestone in the history of the CMF56 program has been the announcement by the BOEING COMPANY of the launching of a new derivative of the 737 family identified as the 737-300 aircraft which is powered by CFM56-3 engines. For CFM INTERNATIONAL, it was the birth of a family of derivative engines based on a majority of common parts. As it can be seen on figure (2) the commonality reaches approximately 90% between the CFM56-2 and CFM56-3 making this engines's development an extension of the CFM56-2 program.

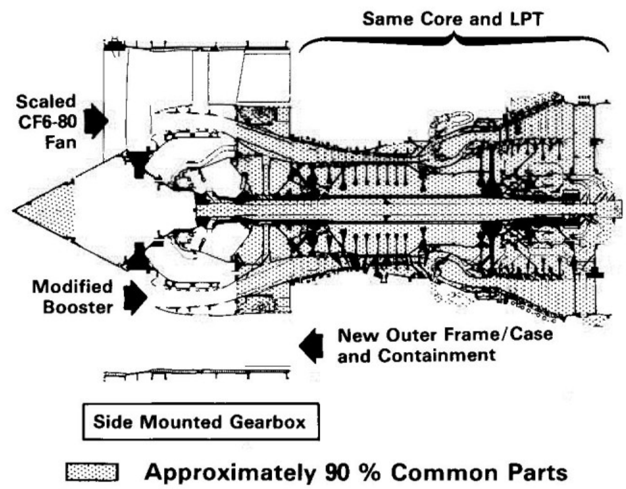

Figure 2 - CFM56-3 commonality with CFM56-2

Thousands of factory and flight test hours and endurance cycles will contribute directly to reduce the time required for the CFM56-3 certification program. Since the weight and performance of CFM56-2 are already established high confidence can be placed in the CFM56-3 specification. Figure (3) shows the milestones of the 2 programs. It should be noted that by the time the CFM56-3 is certified the CFM56-2 will have more than a year of revenue service.

- **CFM56-3 Development is an Extension of CFM56-2 Development**

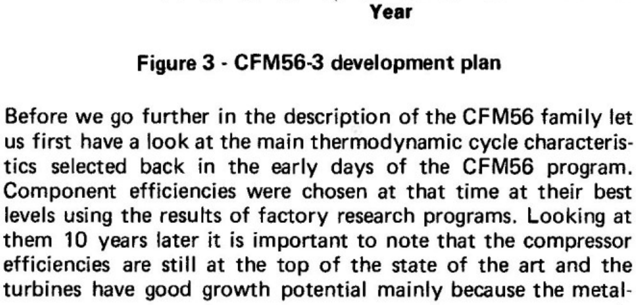

Figure 3 - CFM56-3 development plan

Before we go further in the description of the CFM56 family let us first have a look at the main thermodynamic cycle characteristics selected back in the early days of the CFM56 program. Component efficiencies were chosen at that time at their best levels using the results of factory research programs. Looking at them 10 years later it is important to note that the compressor efficiencies are still at the top of the state of the art and the turbines have good growth potential mainly because the metallurgical progress has made it possible to reduce blade and nozzle cooling allowing a cleaner neater airfoil. Quite surprisingly the cycle maximum temperature of competitor product has not changed in 10 years demonstrating that the level selected for CFM56 family was pretty advance for the time. The final optimization is to choose the optimum between fan pressure ratio, overall compression ratio and by-pass ratio. Exhaust nozzle expansion ratio has not a big margin of freedom given jet noise limit and reasonable primary nozzle sizes. This resulted in a choice among a series of fan with pressure ratios going from 1.55 to 1.75 and by-pass ratios from 4.5 to 6.5. Even nowadays these numbers are still valid and the difference would show only in overall compression ratio that went from 25-30 to 1 to 35-40 to 1. However the higher the pressure ratio the bigger the number of compressor/turbine stages, meaning weight, complexity and higher engine price.

Once the thermodynamic cycle is defined the question is how to split the primary compression/expansion system between the low pressure spool and the core engine. This problem rapidly boils down to the key question : one single high pressure turbine stage versus two. Either choice has its own advantages : two stages would allow a better transition between high and low pressure turbines and would permit to reduce the loading of the high pressure turbine all of this resulting in a better turbine efficiency ; however the compressor would have a 13 or 14 stages, highly sophisticated but prone to stall margin problems requiring an increased number of variable stators.

The CFM56 features a single stage HP turbine which allows a much simpler mechanical design :
- reduced cooling flow,
- HP turbine disc weight saving,
- no critical speed problems for low pressure system,
- no bearing/structure under the combustor,
- higher rotational speed.

It is clear that single turbine stage core engines have definite advantages in terms of stability and mechanical technology. Further it can be feared that the theoretical efficiency advantage of the twin stage turbine would vanish or at least decrease considerably when the needs and difficulties encountered during development make necessary to introduce design changes. On the contrary, the existing hardware of the CMF56 core is the result of extensive factory test programs of two engines CFM56-2 and the F101. As it can be seen on figure (4), the CFM56 hot section has significant operational temperature margins which will assure maturity and service reliability.

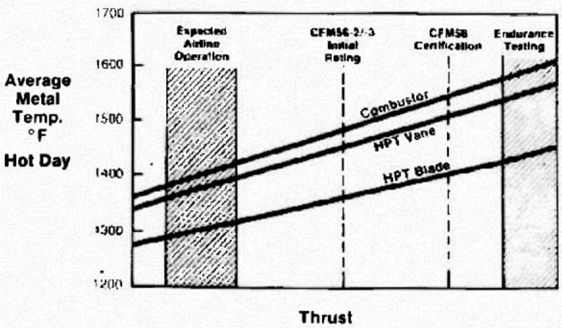

Figure 4 - CFM56 hot section has significant operational temperature margins

In terms of performance and degree of technology the CFM56 core engine shows a number of means that makes it a modern and competitive system such as :

- low clearance compressor with rotor temperature control,
- variable stators on first 4 stages : allows an additional variable geometry parameter but limits the complexity to 4 stages,
- high speed HP turbine,
- high pressure turbine active clearance control by selectively directing 5th and 9th stages cooling air to the HP shroud support permits the use of closer running clearances.

As a result engine performance is better, deterioration is reduced and tip rubs -a major contributor to HPT blade replacement- are reduced.

To meet the competition of the 80's and 90's it has been decided to work continuously on the hot section in order to improve regularly its component efficiencies. This program had its start back in 1979 when the CFM56-3 was first laid out. Thanks to an extensive test and research program it has been made possible to acquire with high accuracy the temperatures distribution and cooling patterns. High energy X rays such as figure (5) have been used extensively to size the running clearances to optimum values.

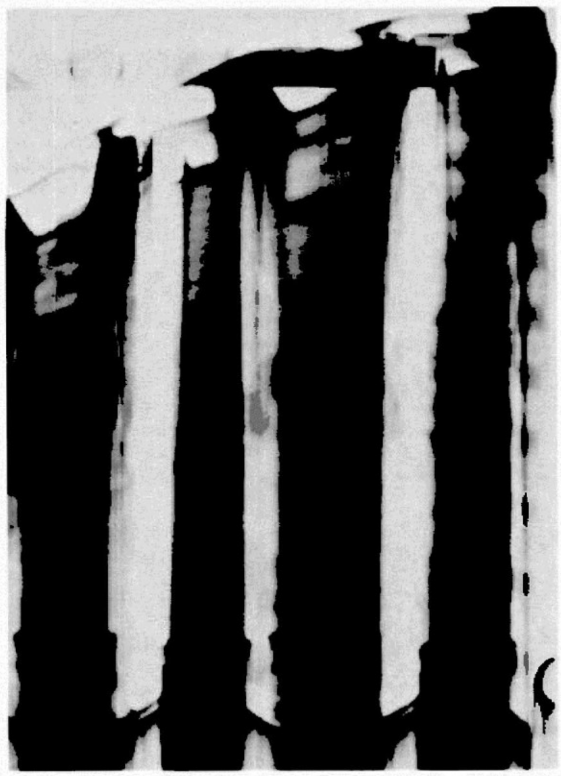

Figure 5 - High energy X rays

The low pressure turbine module shown on figure (6) features a great deal of items that make it favorably comparable with other modern engines. The one-piece turbine casing is cooled so that close clearances can be maintained under all operating conditions in order to maximise LPT efficiency. Cooled LPT stage 1 nozzle, with use of this air to keep the turbine disc temperature lower and vent/pressurize the turbine rotor cavity. As part of the performance improvement effort a very careful survey of the temperature map and cooling system has resulted in an improved efficiency thanks to extensive testing and high energy X rays campaigns.

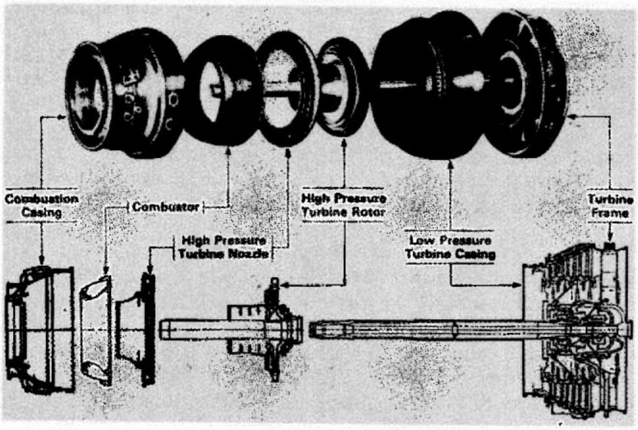

Figure 6 - CFM56 hot section

A second improvement program of the hot section started last year with the following groundrules :

- keep a large number of existing parts to retain reliability and ensure a mechanically successful product ;
- learn from the extensive CFM56's development program where to change what in order to improve component efficiencies ;
- introduce new design techniques, now available such as heat insulation coating, advanced turbine material, aero redesign, low power SFC optimization, etc...

A continuous effort is spent on the core engine and hot section resulting in step improvements in specific fuel consumption. In the meantime the fan/booster system is optimized for each specific application.

The 44 tip-shrouded fan blades of the CFM56-2 have thick leading edges to provide excellent resistance to bird ingestion and other foreign object damage figure (7). Another noticeable feature is the composite material/aluminium spinner whose conical shape is designed to prevent ice build-up and make it unecessary to design engine anti-icing system. The CFM56-2 is the first commercial engine to use this device.

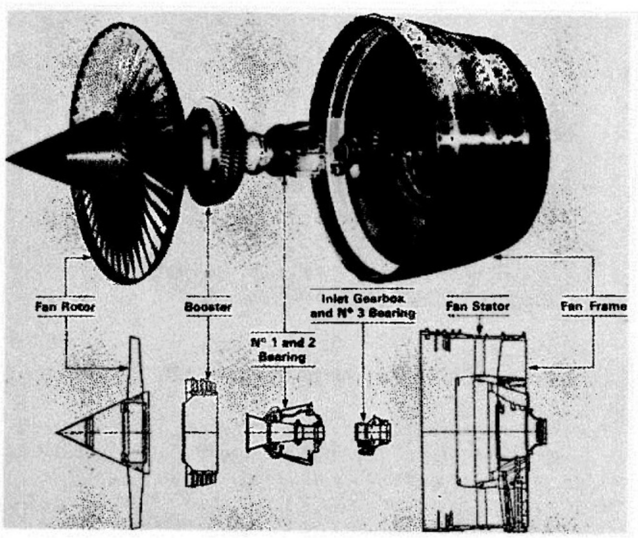

Figure 7 - CFM56 fan and booster

Chart (8) describes the change in the fan design of the CFM56-3 engine. With its smaller fan diameter, the fan tip speed of the CFM56-3 engine is significantly reduced from the CFM56-2 and because of this reduction and with the same RPM it has been possible to use a scaled CF6-80 design both for optimization of fan efficiency at these tip speeds and for blade ruggedization. It is very important to note that the CF6-80 having successfully passed its bird strike tests, similar CFM56-3 fan blade tests are expected to go without major difficulties.

- **Same LP Rotor Speeds**
- **Lower Fan Tip Speeds**
- **Scaled CF6-80 Design**
  - **Low Risk**
  - **High Efficiencies at These Tip Speeds**

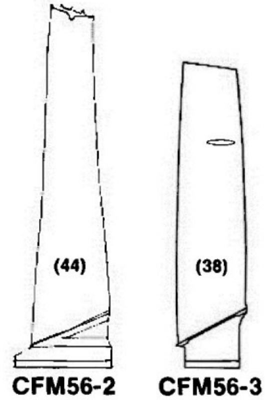

Figure 8 - Fan blade

Figure (9) shows an advanced version of the CFM56 family making the most of the hot section development programs and featuring a low speed fan.

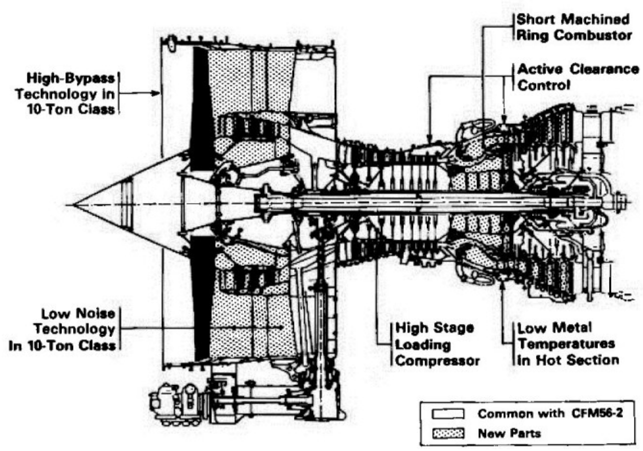

Figure 9 - Advanced CFM56 technology

As it can be seen the commonality with the CFM56-2 is very high -over 60%- and would ensure a development program free of major mechanical problems. Together with mature mechanical hardware the new series of CFM56 advanced engines would show a number of refinements and characteristics that would make them leaders in terms of technology : wide chord low speed fan, compressor and turbine active clearance control, advanced digital electronic fuel control, high strength titanium alloy, composite materials, advanced turbine material. These advanced components would allow specific fuel consumption to be reduced more than 5% compared to current engines. As it can be seen on figure (10) the CFM56 family specific fuel consumption is continuously improving.

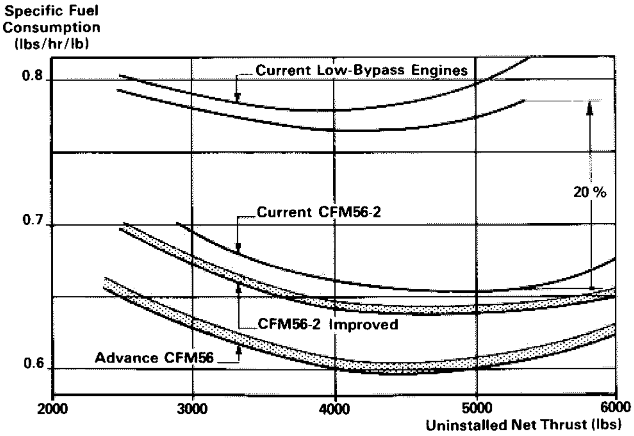

Figure 10 - CFM56 cruise performance

At the time when an advanced CFM56 can be put to test the factory test program conducted on CFM56-2 & CFM56-3 will have completed 60,000 accelerated endurance cycles and about 24,000 hours on complete engines which are being tested and continue to be developed as part of our on-going post-certification and fleet leader development program.

As far as revenue service experience as it is shown on figure (11) the CFM56-2 engine will have about three years of commercial service on the re-engined DC8 and there will be about 2.5 million engine flight hours (about 1 million flight cycles) on the CFM56-2 when the CFM56-3 will enter revenue service. Because of its high commonality with CFM56-2 and CFM56-3 the advanced CFM56 will benefit of this impressive experience in service putting a lot of confidence in the realization of performance objectives.

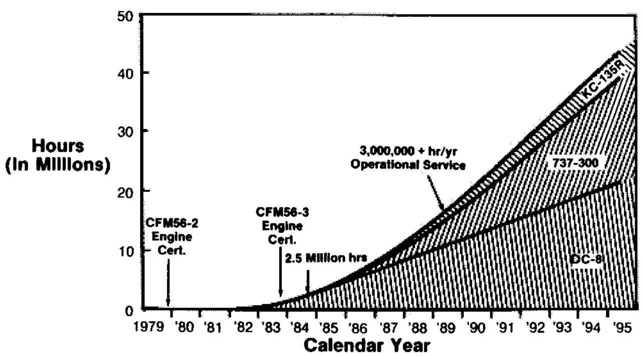

Figure 11 - CFM56 cumulative engine operating hours

As a matter of fact, even with a careful design during the development phase of past engine programs, unexpected problems have arisen that were solved by reinforcements or changes in design conducting to performance penalties. Those problems ranged from fan blade increase thickness for birds strike to increased cooling to cure a thermal problem. All resulted in additional losses and degraded specific fuel consumption forcing the introduction of new changes to improve performance back to the original objectives. The CFM56 performance has been demonstrated after the incorporation of development fixes, giving high confidence.

The only way to avoid those mechanical "surprises" is to use as many developed and service-proven parts as possible.

As shown on the attached curve figure (12), this situation is particularly true for the CFM56 family. Taking for instance the CFM56-3 which demonstrated the objective SFC early this year the final developed stage is expected to be reached without any major redesign because this engine has extensive common parts with its "big brother" CFM56-2 already in-service on DC8-70 series. The same rationale applies to more advanced CFM56 derivatives which will retain their mechanical advantages while they show about 10% reduction in cruise SFC.

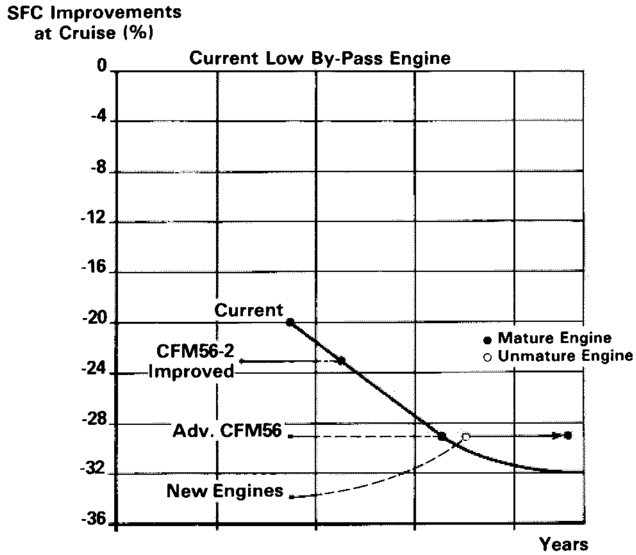

Figure 12 - SFC trend for mature engines

Starting from scratch it is theoretically possible to define a cycle that would show better SFC than an advanced CFM56. However it is feared that this supposed advantage will never come true because of the mechanical problems and the corrective measures to solve them. And the product you get at the end is not yet mature. An additional development time has to be accounted before the new engine turns into a mature powerplant, unless there is the time, like for the CFM56-2, to take advantage of a 10 year development program. Studies have been conducted with several aircraft manufacturers showing that advanced CFM56's would provide more than 90% of the fuel burn saving expected from a new generation engine. Considering this result it is estimated that the best choice is to rely on CFM experience. The case for the CFM56 family is therefore easy to make : demonstrate high performance efficiency while retaining mechanical durability and service endurance.