CFM56-3 series specifications

The CFM56-3 series is ratings between 18,500lbs and 23,500lbs thrust. Its specifications & EGT margin performance are examined.

The CFM56-3 is the second of five series of the CFM56 engine model, and was the first to sell several thousand units. Certified in 1984, the CFM56-3 ceased production in 1999, after some 4,500 units had been built. As the sole powerplant for the 737-300/-400/-500, the CFM56-3 will continue operating in large numbers for another 20 years on account of the aircraft's popularity.

Configuration

The CFM56 family has a two-shaft design and provides a range of engines rated between 18,000lbs and 34,000lbs thrust across five series. The -3 series was derived from the initial -2 series utilised to re-engine the DC-8-60 series.

The CFM56-3 has a 60-inch fan diameter, and the three variants have bypass ratios between 4.8:1 and 5.1:1. The engine's high-pressure (HP) system has a nine-stage high-pressure compressor (HPC) and single-stage high-pressure turbine (HPT). The low-pressure (LP) system has a three-stage low-pressure compressor (LPC) and four-stage low-pressure turbine (LPT).

There are three main variants: the -3B1 rated at 18,500lbs and 20,000lbs thrust; the -3B2 rated up to 22,000lbs thrust; and the -3C1 rated up to 23,500lbs thrust (introduced in 1988, it is the only variant available at all four thrust ratings).

The 737-300 can be configured with the -3C1 or -3B1 variant rated at 20,000lbs and 22,000lbs, while the largest 737-400 can be equipped with the -3C1 rated at 22,000lbs and 23,500lbs, or powered by the -3B2 rated at 22,000lbs. The smallest -500 can be configured with the -3C1 rated at 18,500lbs or 20,000lbs, or with the -3B1 rated at 18,500lbs *(see table, page 11)*.

Because each aircraft model uses at least two thrust ratings, and all four ratings are applied across the three aircraft variants, the CFM56-3C1 can be re-rated to different thrust ratings to satisfy airlines' operational requirements. The ability to re-rate is also useful when an engine has used its exhaust gas temperature (EGT) margin at a high rating, and can regain some margin by being de-rated to a lower thrust. This process gains additional on-wing time.

Life limited parts

The CFM56-3 comprises five main modules: the fan, booster, HPC, HPT and LPT. The CFM56-3 has 19 LLPs.

These LLPs include three in the fan and booster module of the LP system: the fan disk, booster spool and and fan shaft. CFMI's intention is for all these LLPs to have lives of 30,000EFC. These have a list price of $305,000.

There are another seven LLPs in the turbine module of the LP system: the four disks for the four LPT stages; the stub shaft; the main LPT shaft; and the conical support. CFMI is aiming for all these LLPs to have lives of 25,000EFC. These have a list price of 485,000.

There are just nine LLPs in the HP system: the HPC front shaft; 1-2 HPC spool; 3 HPC disk; 4-9 HPC spool; CDP seal; HPT forward shaft; front air seal; HPT disk; and HPT rear shaft. CFMI's long-term intention is for these parts to have uniform lives of 20,000EFC, but some parts have shorter limited lives. These have a list price of $755,000.

EGT margin

The maximum EGT permitted on the CFM56-3 series is 930 degrees centigrade. The number of times that this 'red-line' temperature can be exceeded, before removal for a shop visit is required, depends on several factors.

At maximum thrust, the EGT increases at a constant rate as outside air temperature (OAT) increases *(see chart, page 11)*. This is because the power management schedule on the aircraft is programmed to provide a constant take-off thrust with rising OAT. Air becomes thinner as OAT rises, so constant thrust is maintained by increasing throttle, resulting in an increase in EGT. The gradient of this increase is 3.2 degrees of EGT for every 1 degree of OAT. Thus, at maximum power, the engine's EGT is 32 degrees higher at an OAT of 20 degrees compared to an OAT of 10 degrees.

In the case of the CFM56-3, constant maximum engine thrust is maintained up to an OAT of 30 degrees centigrade. The power management schedule is then programmed to keep the EGT constant for OATs higher than this 30-degree 'corner point' *(see chart, page 11)*. The EGT is kept constant by reducing engine thrust as OAT rises beyond this point. This process of flat rating provides the engine with some EGT margin at high OATs. EGT margin is the difference between the maximum permitted EGT and the actual EGT of an engine at maximum thrust at the corner-point OAT at sea level conditions *(see chart, page 11)*. In the case of the CFM56-3, the EGT margin is quoted for a standard OAT of 30 degrees centigrade and sea level atmosphere conditions. EGT margin is obviously larger for lower OATs.

The EGT is also lower for lower thrusts, and so lower-rated engines have higher EGT margins. A new CFM56-3 rated at 18,000lbs thrust has an EGT margin of about 116 degrees centigrade at the standard OAT of 30 degrees centigrade. The -3 rated at 20,000lbs thrust has an EGT margin of 92 degrees centigrade, while an engine rated at 22,000lbs thrust has an EGT margin of 65 degrees, and an engine at the highest rating of 23,500lbs thrust has an EGT margin of 45 degrees. The EGT lines of engines with different thrust ratings are parallel *(see chart, page 11)*.

SLOATL

While flat rating keeps EGT constant above an OAT of 30 degrees centigrade, EGT would continue to increase at a constant rate as OAT rises if maximum power were maintained *(see dotted line, chart, page 11)*. The OAT at which EGT reaches the maximum allowed level of 930 degrees centigrade is referred to as the sea level outside air temperature limit (SLOATL), which is the highest sea level OAT at which EGT margin becomes zero at maximum thrust.

SLOATL is calculated by adding the corner-point temperature of 30 degrees centigrade to the engine's EGT margin at standard temperature, divided by the gradient constant of 3.2. A CFM56-3 rated at 23,500lbs thrust with an initial EGT margin of 45 degrees therefore has a SLOATL of 44.06 degrees *(see table, page 11)*. An engine rated at 22,000lbs thrust with an EGT margin of 65 degrees has a SLOATL of 50.3 degrees, an engine rated at 20,000lbs thrust with an EGT margin of 92 degrees has a SLOATL of 58.9 degrees, and an engine rated at 18,500lbs thrust with an EGT margin of 116 degrees has a SLOATL of 66.2 degrees. Engines rated at 22,000lbs and 23,500lbs thrust are clearly more sensitive to high OATs.

An engine's SLOATL is higher than

the corner-point temperature for an engine with positive EGT margin *(see chart, this page)*. Since EGT is actually kept constant above the corner-point temperature by reducing engine thrust, take-offs can be conducted for any OAT above this point while the engine still has EGT margin. By calculating SLOATL, the actual highest permitted thrust setting for a given OAT can be determined.

An engine's EGT margin increases at OATs lower than the corner-point temperature of 30 degrees. The increase in EGT margin is 3.2 degrees for every drop of one degree centigrade in OAT below 30 degrees. An engine will thus have an additional 32 degrees of EGT margin when operating at an OAT of 20 degrees at sea level.

Take-off de-rate

Engines are rarely used at full thrust rating, and usually have a level of de-rate for take-off power, which reduces EGT, and consequently increases EGT margin. EGT reduces by about 3.6 degrees for each 1% de-rate on the CFM56-3. De-rates of 5% and 10% will reduce EGT, and increase EGT margin by about 18 degrees and 36 degrees respectively. De-rating can be used if aircraft take-off weights are less than the permitted maximum take-off weight (MTOW), a long runway is available, or OATs are relatively low. Take-off de-rating prolongs on-wing engine life because of reduced EGT. EGT margin reduces at a rate of about 3.5-4.0 degrees per 1,000EFC, and so an average 5% de-rate during operation can add several thousand EFCs to on-wing intervals.

Engine degradation

Engine turbomachinery deteriorates during operation, as a result of which clearances around the blade tips increase, therefore leading to a rise in EGT, and decrease in EGT margin.

Engines only recover about 70% of their original EGT margin after the first shop visit. The restored EGT margin for an engine rated at 23,500lbs thrust is about 30 degrees, about 40 degrees for a 22,000lbs thrust-rated engine, about 80 degrees for an engine rated at 20,000lbs, and about 90 degrees for an engine rated at 18,500lbs.

After the first shop visit, engines rated at 23,500lbs and 22,000lbs lose about 15 degrees of EGT margin in the first 2,000EFC on-wing, with EGT margin deteriorating at about four degrees per 1,000EFC. EGT margin will therefore be reduced to about 15 degrees, and SLOATL will fall to 34.7 degrees for the highest-rated engine after 2,000EFC. This engine may only be expected to have an on-wing interval of 5,000-6,000EFC before all EGT margin is used.

An engine rated at 20,000lbs will have an EGT margin of about 25 degrees and SLOATL of 37.8 degrees after the first 2,000EFC following a shop visit. The total interval can be expected to be about 9,000EFC.

The low EGT margins and SLOATLs

CFM56-3 SERIES VARIATION OF AVAILABLE EGT MARGIN & OAT

Engine with EGT margin of 15 degrees centigrade

SLOATL = 34.69 deg C

OAT deg C	0	10	20	30	35	40	45
EGT margin deg C EGT margin with 5% de-rate	111	79	47	15	N/A		

Engine with EGT margin of 35 degrees centigrade

SLOATL = 40.94 deg C

OAT deg C	0	10	20	30	35	40	45
EGT margin deg C EGT margin with 5% de-rate	131	99	67	35	19	3	

Engine with EGT margin of 45 degrees centigrade

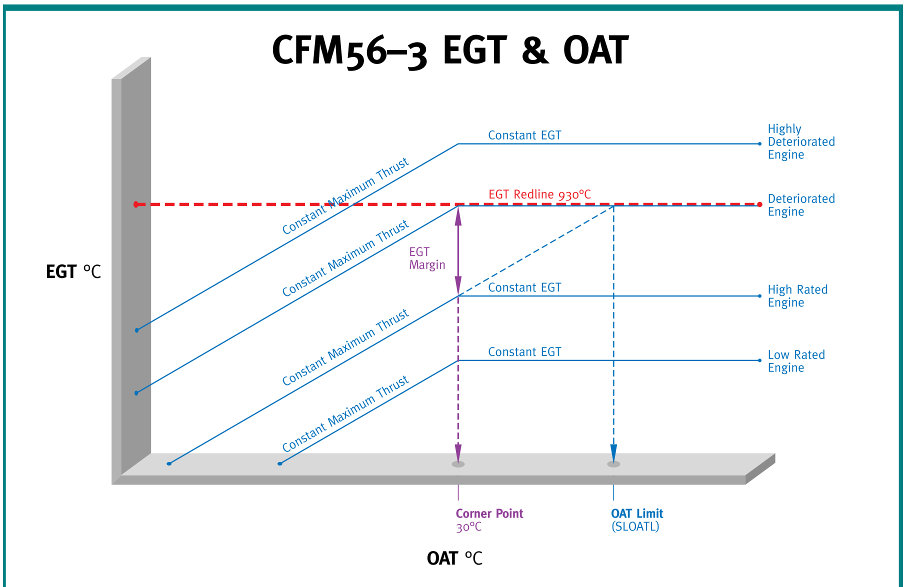
SLOATL = 44.06 deg C

OAT deg C	0	10	20	30	35	40	45
EGT margin deg C EGT margin with 5% de-rate	141	109	77	45	29	13	0

Engine with EGT margin of 60 degrees centigrade

SLOATL = 48.75 deg C

OAT deg C	0	10	20	30	35	40	45
EGT margin deg C EGT margin with 5% de-rate	156	124	92	60	44	28	12



There are large differences in the EGT margin between CFM56-3s rated at 18,500lbs thrust and those rated at 22,000lbs & 23,500lbs thrust. Higher rated engines have EGT margins of 30-40 degrees centigrade. This can severely limit on-wing removal intervals, and so all possible measures should be taken to maximise EGT margin and minimise its rate of deterioration.

of these high-rated engines give a strong incentive for installing CFMI's advanced upgrade kit, which improves EGT margin by 15-20 degrees centigrade *(see CFM56-3 Modification programmes, page 13).*

A deteriorated engine with zero EGT margin at the corner-point OAT of 30 degrees also has zero EGT margin for higher OATs, but still has EGT margin at maximum thrust for lower OATs *(see chart, page 11).* The engine can only be rated at maximum power for OATs up to 30 degrees.

An engine with an even higher level of deterioration can have negative EGT margin at the standard OAT of 30 degrees. In this case the SLOATL is less than 30 degrees *(see chart, page 11).* The engine can still have some EGT margin at maximum power for low OATs, however *(see chart, page 11).*

EGT margin vs OAT

Available EGT margins at maximum thrust for different OATs and SLOATLs for several standard EGT margins can be calculated. Available EGT margins for take-off de-rates of 5% can also be approximated *(see table, page 11).*

A new CFM56-3 rated at 23,500lbs thrust and an EGT margin of about 45 degrees will have zero available margin at a SLOATL of 44 degrees, but will have an available margin of about 77 degrees at an OAT of 20 degrees *(see table, page 11).* It will only have a margin of about 13 degrees at OAT of 40 degrees, one of the highest temperatures an aircraft is likely to experience. EGT margins are increased where a 5% de-rate is possible.

A deteriorated engine with an EGT margin of 35 degrees will have a SLOATL of about 41 degrees, and so will only have an available margin of about 3 degrees at an OAT of 40 degrees. The available margin will increase to about 21 degrees, however, with a 5% de-rate. This point illustrates the need for engines operating in hot environments, with OATs of about 40 degrees, to be removed as a result of performance degradation, even though they have 35-50 degrees of EGT margin remaining.

In the other extreme, an engine with an EGT margin of 45 degrees has an available margin of 77 degrees for an OAT of 20 degrees, the margin also increasing with take-off de-rate. An engine operating in a cool environment of about 10 degrees will have an EGT margin of more than 100 degrees at maximum power.

Lower-rated engines with an EGT margin of 60 degrees will have an available margin of about 90 degrees when operating at an OAT of about 20 degrees.

The variation of available EGT margin with OAT, take-off de-rate and thrust rating means that lower-rated engines have relatively high EGT margins and SLOATLs. This means they will be able to use maximum power, even in hot operating conditions. Low-rated engines also have high EGT margins in moderate climates *(see table, page 11)*, and also still have available margins of 28-45 degrees in the hottest conditions. This means they can achieve relatively long on-wing intervals for most operating temperatures.

Engines with low EGT margins of about 35 degrees will be restricted to maximum power SLOATLs of about 40 degrees. The SLOATL will fall to about 35 degrees and then still further as EGT margins deteriorate in operation *(see table, page 11).* The relatively low EGT margins also mean that their on-wing intervals will be limited by performance degradation.

CFM56-3 production

More than 4,500 CFM56-3s were produced, powering more than 1,900 737-300/-400/-500s still in service and providing spare engine back-up. The -3C1, introduced in 1987, is the most numerous, powering about 900 operational aircraft of all three variants.

The -3C1 fleet is split between all three 737 models, and 390 are used on the 737-400. Only 22 of these aircraft are in North America, while 178 aircraft are based in Europe.

There are 167 aircraft in the Asia Pacific and China, another 14 aircraft in Africa and seven in Latin America. These 188 aircraft are powered by the -3C1, which is capable of a thrust rating of 23,500lbs, and is most sensitive to high OATs and low EGT margins. Only a small number are operated in the Middle East and India, regions that experience some of the highest peak and average ambient temperatures in the world.

The -3B1, the first into service, is the second most numerous variant, powering a total of more than 700 aircraft. Although the engine is rated at 18,500lbs and 20,000lbs thrust for the 737-500 and -300, the -3B1 also powers a small number of -400s for Alaska Airlines. The majority of -3B1s are used on the 737-300, since most -500s are equipped with the -3C1.

The -3B2 is used on only just under 300 aircraft, split between 235 -300s, and 64 737-400s. AC