Avoiding high speed rejected takeoffs due to EGT limit exceedance

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1 | Introduction

Unnecessary high speed rejected takeoffs are experienced from time to time due to high Exhaust Gas Temperature (EGT).
The goal of this article is to explain that a too high EGT overlimit must not lead to abort a takeoff at high speed.
The first part will provide some technical background on EGT and will outline the operational recommendations and Aircraft Maintenance Manual procedures in case of limit exceedance.
The second part will describe maintenance and operational procedures, which minimize EGT over limit occurrences.

2 | EGT is a good indicator of engine health

As engines accumulate cycles, their performance tend to deteriorate due to various reasons, e.g.:

- Dust/dirt ingestion and further accumulation on fan blades/compressor airfoils.
- Increasing tip clearances on compressor / turbine blades and seal clearances due to rub.
- Other mechanisms such as erosion of airfoils and seals, hot section oxidation and increased air gas path air seal wear.

The High Pressure (HP) compressor and the HP turbine are generally the main contributors to deterioration. On some higher bypass ratio engines, the low pressure (LP) compressor may also be a significant contributor.

The appropriate indicator of the overall performance of the engine (compressors and turbine) is based on the core flow temperature, which is measured at the turbine exit and is referred to either as EGT or TGT, for Turbine Gas Temperature on Rolls-Royce engines.

The above temperature is measured in the gas path, either at the Low Pressure (LP) turbine inlet (on CFM, EA, GE and RR engines) or at the LP turbine exit (on PW and IAE engines).

3 | Demonstration of EGT operational limit

To protect turbine hardware, an operational limit on EGT (called "EGT red line") is demonstrated during endurance tests required for FAR 33/JAR-E/EASA engine certification.

During such tests, the engine is run for 25 stages of 6 hours each. For each stage, the engine spends up to one hour cumulative time at max takeoff regime, with average EGT at redline conditions.

Moreover, FAR 33 engine certification requires the engine to run for 5 minutes with N1 and N2 at red line levels and with EGT at least 42°C above the red line. After the run, the engine is disassembled and the turbine assembly must be within serviceable limits.

4 What is takeoff EGT margin and how is it calculated?

EGT Margin is an estimate of the difference between the certified EGT redline and a projection of engine EGT to full-rated takeoff at reference conditions.

The observed EGT is projected to a standard reference condition of takeoff full power, on a flat-rate temperature day at sea level, using characteristics derived from the Engine Manufacturer's thermodynamic model for the engine rating. This projected temperature level represents the expected EGT if the takeoff actually occurred with the reference conditions. The projected EGT level is then subtracted from the certified EGT redline for the particular engine rating in order to produce an estimated takeoff EGT margin.

Therefore the EGT margin is not just the difference between recorded EGT at takeoff and the EGT redline, since it is very unlikely that the takeoff data were recorded at the reference power level, temperature day, and bleed level.

5 Use and limitations of EGT margin projections

EGT margin is routinely used to monitor the health of installed engines through the ECM tool (Engine Condition Monitoring), together with cruise performance trends, takeoff EGT margin trends are used to detect shifts in performance for each engine, which can indicate the need for inspections and/or maintenance. The EGT margin trends are also used to forecast an average remaining time on-wing, if engine removal is due to takeoff EGT margin shortage.

However:

- Calculated EGT margin should not be used as sole criterion for engine removal. Apart from the Life Limited Parts constraints, it should be considered with other factors such as cruise trends, number of EGT over limit occurrences and the associated maintenance tasks requested by AMM prior to an engine removal decision.
- Takeoff EGT margin has a limited accuracy, driven by:
  - the accuracy of recorded flight conditions and engine parameters,
  - the fact that the performance model included in the ECM tool is representative of the average behaviour of production engines, but not of every single engine.

Further, recall that EGT margin is calculated for a reference condition, typically a full-power takeoff, on a flat-rate temperature day, at sea level. This condition is not necessarily the most severe condition; the worse condition can be different for different engine models. So, EGT margin is frequently not projected for the worst case. However, this representative condition permits trending takeoff margin on a consistent basis. Factors such as ambient temperature, amount of derate, time since previous operation of the engine, altitude of the runway can impact the actual peak-EGT during any given takeoff. Therefore:

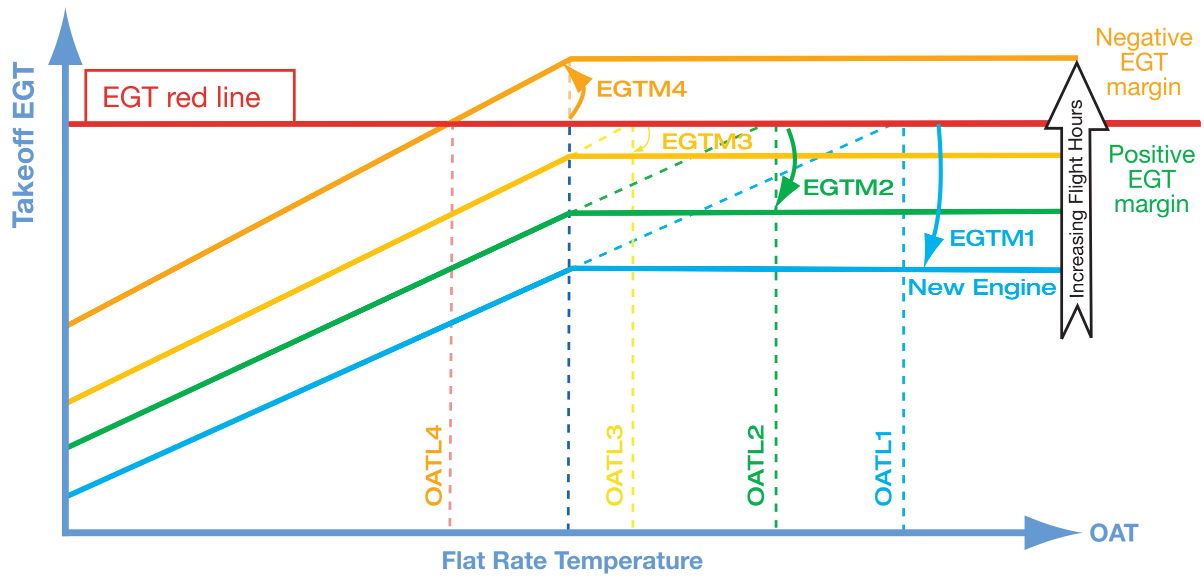
- An engine with a slightly positive takeoff EGT margin may experience EGT over limit at takeoff
- An engine with a slightly negative takeoff EGT margin may not necessarily experience EGT over limit at takeoff.

6 What is OATL?

(Outside Air Temperature Limit)

For the engines whose takeoff EGT is nearly constant with increasing Outside Air Temperature (OAT) beyond Tref (flat rate temperature), OAT Limit (OATL) is another related indicator of engine health for takeoff. OATL is a projection of the highest ambient temperature at which an engine should be able to produce full flat-rated thrust without exceeding EGT redline. Thus, this parameter describes an engine's takeoff performance capability in operational terms that can be used directly by Flight Operations. Note that OATL and EGT margin are similar measures of performance based on takeoff data; these parameters are not independent assessments of the temperature limitations for an engine. For instance, when the OAT Limit equals the flat-rated temperature for an engine, the EGT margin is zero.

As the engine accumulate cycles, EGT margin (EGTM) and OATL decrease



- **OAT Limit (OATL) is a projection of the highest OAT at which an engine should be able to produce full flat-rated takeoff thrust without exceeding EGT redline.**
- **When OATL is below the Flat Rate Temperature (i.e.EGT margin is negative), EGT over limit may occur during a full rated takeoff.**

Fig 1: Engine Deterioration Effect on EGT margin and OATL

7 | Operational recommendations:

An EGT over limit due to normal engine wear does not affect the engine thrust, safe continuation of the takeoff is therefore possible.

Below 80 knots, an ECAM caution will trigger and the takeoff may be aborted.

Above 80 knots, ECAM caution is inhibited, no crew action required.

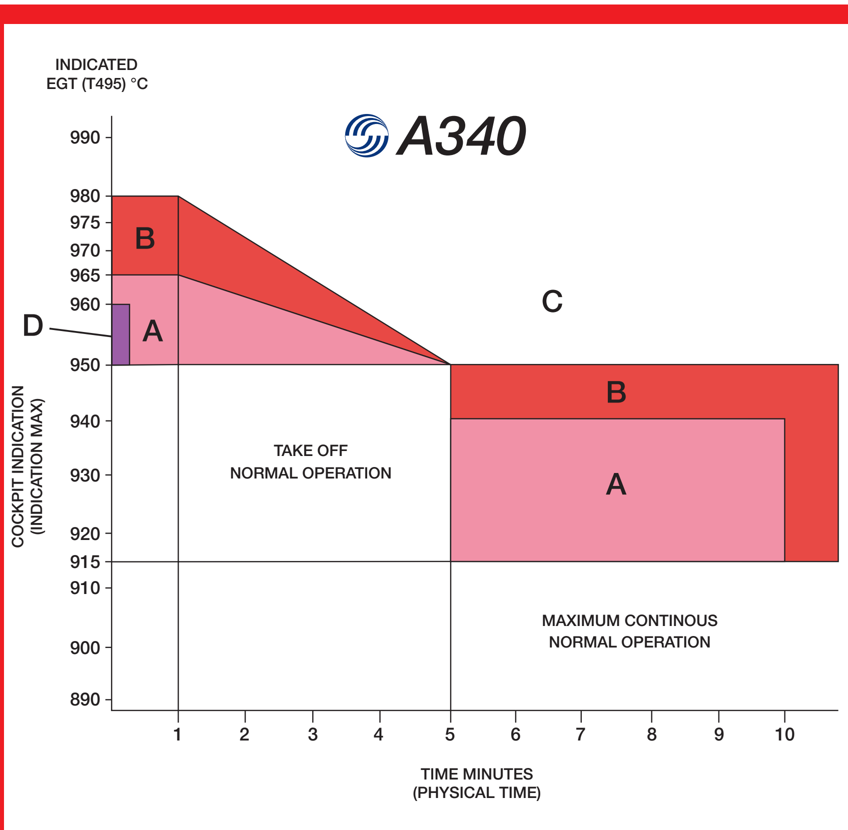
During flight phase 4, from 80 knots to lift-off, the Flight Crew Operating Manual (FCOM) procedure in case of EGT over limit calls for continuation of the takeoff. On all fly by wire aircraft, EGT over limit ECAM cautions are inhibited during this flight phase whereas the EGT indication will become red as EGT goes beyond the red line. The intent is to avoid distracting the pilot during a critical flight phase with information that might cause inappropriate crew response.

After lift-off, the ECAM procedure should be applied when the appropriate flight path is established and the aircraft is at least 400 ft above the runway. Pending the magnitude of the EGT over limit, the ECAM will call for different procedures, as illustrated in the following figure.

8 | Aircraft Maintenance Manual procedures in case of EGT over limit:

To increase the operator's flexibility for engine removal and allow the aircraft to fly back to its main base whenever possible, maintenance tasks have been defined according to the magnitude of the EGT over limit and its duration. Those tasks range from a visual inspection up to a required engine removal and overhaul. As a reminder, this latitude given to operators is not a means of extending on-wing life for EGT limited engines, but aims at offering flexibility, to avoid Aircraft On Ground (AOG) situations at other stations than the main base.

The chart below shows an example of AMM chart for the CFM56-5C:
In this particular example, three areas referred to as, A, B and C, were originally defined according to the magnitude of EGT over limit and the duration of the event. To each area corresponds a specific maintenance action.
At a later stage, it was decided that within A, occurrences implying EGT over limit of less than 10 degrees Celsius with a duration of less than 20 seconds did not call for any maintenance action.
This particular area is referred to as D.



Allowance for CFM56-5C EGT over limits

In order of gravity:

- **Area D**
  EGT over limit of less than 10°C and during less than 20 seconds are permitted, without any requested maintenance action
- **Area A**
  Inspection and troubleshooting required.
  Maximum of 20 over limit occurences allowed before engine removal
- **Area B**
  Inspection required.
  If root cause not identified, borescope inspection required.
  20 over limit occurrences in area A & B combined or 10 in area B allowed before engine removal
- **Area C**
  Remove the engine and return to shop.
  One non-revenue flight allowed if no damage beyond serviceable limits.

9 | Maintenance/Operational procedures to minimize EGT over limit occurrences:

Follow-up of engine performance with the Engine Condition Monitoring tool allows focussing attention and efforts on engines with limited takeoff EGT margin.

Within each operator's constraints, operations on most demanding routes of aircraft equipped with such EGT limited engines should be avoided.

The following recommendations should be applied in priority to those engines.

Engine wash:

Each engine manufacturer has issued recommendations on intervals between two washes. Each operator, based on their various constraints, e.g., environmental, may tailor those intervals. Average EGT margin recovery based on operators' feedback to engine manufacturers is around 7°C (up to 15°C).

Air conditioning selection:

- Full rated takeoff operations:
  On twin engine Airbus aircraft, the EGT level is quite similar regardless of air conditioning selection (bleed ON or OFF). Power setting decrement associated to bleed selection is designed to achieve that result.

On quad engine Airbus aircraft, the power setting decrement is designed to reach the same EGT level with bleed ON as with bleed OFF, when one engine feeds one air conditioning pack (failure case). EGT levels at full rated takeoff are thus lower with bleed ON than with bleed OFF.

- Flex takeoff operations:
  At constant takeoff weight, switching OFF the engine bleed allows operation of the engines at higher flex temperatures than with bleed ON. This leads to lower EGT level.

Example:
To illustrate this point, let us consider an A340-300 equipped with CFM56-5C4 engines, taking off from an airport at 8 600 feet altitude , with a 10°C OAT:
With air conditioning ON (on the engine) and Tflex = 17°C, aircraft TOW= 225 tons.
Same TOW with air conditioning OFF (or ON but from the APU) is achievable with Tflex = 23°C, leading to EGT 10°C lower than with bleed ON.

Engine warm-up time:
Cold engine takeoff can lead to higher peak EGT values than with warm power plants.
The FCOM recommends a minimum engine warm-up time to avoid engine damage.
Extending the engine warm-up time beyond this minimum recommended will lower peak EGT values at takeoff.

Example:
The A340/CFM56-5C FCOM quotes a 2-minute minimum engine warm-up time before takeoff.
Increasing this warm-up time to:
- 10 minutes provides an average 9°C lower peak EGT,
- 15 minutes provides an average 12°C lower peak EGT.

Note: Extending the warm-up time show more benefit on takeoff peak EGT for engines with single stage HP turbines than for those with two-stage HP turbines.

10 Conclusion

- To minimize EGT over limit occurrences, use engine trend monitoring and consider the following actions for aircraft equipped with reduced EGT margins:
  - Avoid operations on demanding routes
  - Conduct regular water wash.
  - On quad engine aircraft, privilege bleed ON for full rated takeoff and bleed OFF for flex takeoff operations.
  - Consider longer warm-up time to reduce EGT peak level at takeoff.

- **Operations of engines with very low takeoff EGT margin may lead to a risk of unnecessary high speed rejected takeoff. This risk increases as ambient conditions and power setting get closer to the worst-case conditions (full power, day temperature at or above flat rate temperature).**
  If an EGT over limit occurs when the aircraft speed is above 80 knots, the pilot should continue the takeoff and wait for the flight path to be established, at an altitude of at least 400 feet above the runway; before applying the appropriate ECAM procedure.

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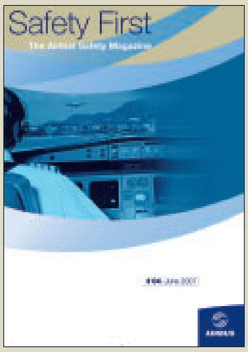

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