



# Exhaust Gas Temperature Margin of A Jet Engine Cause Impact and Simulation

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**Abstract:** When a jet engine starts, the temperature starts to increase within a range. At various durations of the engine run, there is some temperature. Higher the thrust, higher the heat. This temperature is called Exhaust Gas Temperature. Each type of engine has a maximum allowed exhaust gas temperature and the difference between the actual gas temperature and the maximum temperature is called the Exhaust Gas Temperature Margin. Airlines struggle to know which components should be replaced to obtain desired Exhaust Gas Temperature Margin. Formula for EGT Margin is  $EGT\ Margin = EGT\ Red\ Line - EGT\ Take\ off$ . Every airline aims to obtain a margin as high as possible. If the margin is very low, it is unsafe to use the engine and it could lead to fire in the engine. The article explains the root cause of lower margin, factors impacting the margin, what can be done to maintain a good margin and what must be avoided at all costs for the safety of the aircraft engine. Currently, there are no directions or guidelines on what engine components can be replaced to improve EGT Margin. The article shows how the simulation data was captured and what methodology was used to obtain the data.

**Keyword:** Aerospace, Engine Maintenance, Exhaust Gas Temperature Margin, Overhaul Shops, Thrust, EGT: Exhaust Gas Temperature, CFM56: A Jet Engine Model, LLP: Life Limited Part, TSN: Time Since New, CDP: Compressor Discharge Pressure, HPT: High Pressure Turbine, STG: Stage

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## INTRODUCTION

All airlines are required to adhere to safety guidelines of the Department of Civil Aviation and are required to have an Air Operator Certificate. For instance, airlines operating in India have to adhere to Directorate General of Civil Aviation; Airlines operating in United Kingdom have to adhere to United Kingdom Civil Aviation Authority, Airlines operating in the United States have to adhere to Federal Aviation Authority; Airlines operating in the country of European Union have to adhere to European Union Aviation Safety Agency, Airlines operating in Saudi have to adhere to General Authority of Civil Aviation. These airlines use jet engines to fly the aircraft in the air. A jet engine is a type of engine that generates thrust by taking air inside, compressing it, mixing it with fuel, burning the fuel, exhaling the heat to propel the exhaust gases, leading to propelling a large object called aircraft following the third law of motion by Newton. This creates heat in the engine and this is EGT. The article gives a complete understanding of the EGT concept.

For a jet engine, the maximum Exhaust Gas Temperature could be upto  $1060^{\circ}$  Celsius depending on the model of the jet engine. When an engine starts, the temperature follows the structure of a bell which is to have low temperature then it goes up and then reaches peak and then goes down gradually.

If a jet engine has fuel mass flow supplied to the combustor much smaller than the air mass flow, and assuming the full expansion in the exhaust nozzle, thrust of the engine can be described by the below equation: \*

$$K = m * (C5 - Vh) = Qpow * P * (C5 - Vh)$$

Where:

m = air mass flow,  
 C5 = exhaust gases velocity,  
 Vh = airspeed,  
 Qpow = volumetric airflow,  
 P = air density

Atmospheric air parameters (pressure, temperature and density) are changing with altitude above sea level (ASL), which of course affects the performance of aircraft engines. Lowermost airports are located at altitudes close to sea level, while some of them are in the Andes and the Himalayas at altitudes exceeding 3000 m, and even reaching 4500 m. For engine performances comparison, generally is used model of the International Standard Atmosphere (ISA), in which it is assumed that at sea level (h=0) the air pressure is 101325 Pa, temperature of an air is equal to 288.15 K, and the air density is 1.225 kg/m<sup>3</sup>. This model does not consider humidity changes. Calculation of engine performance assumes that the air is completely "dry". Besides the standard atmosphere, due to the considerable diversity of climatic conditions in the world, additional models of the atmosphere - cold, hot and tropical (Trop) also has been developed, for which the adopted pressure changes are the same as for the standard atmosphere model but different changes in temperature, and hence the change in air density. The need to take into account temperature changes depending not only on the altitude at which the airport is situated but depends also on latitude. Airports located on similar altitudes for the polar circle have OAT -50°C, while in the airports located in Africa and Asia OAT exceeds + 50°C. In the case of relative humidity we have to consider that in tropical regions often exceed 90% at the temperatures approx. +30°C to +35°C, while at the same time at the airports located on the same altitude, but in Central Europe conditions may prevail where the temperature will correspond to standard conditions and the relative humidity does not exceed 10%. Calculations carried out for the model of turbofan engine at standard conditions with a thrust approx. 100 kN are showing that when the engine is running and the pressure corresponds to the standard it has thrust 12% higher at the temperature less by +35°C than the reference, and 22% lower if the ambient temperature rises by the same amount in relation to the reference temperature. In case, if that engine will operate from an airport situated on altitude close to 4500 m, the thrust will be about 38% less than this can be achieved at the airport, located at sea level.

### **FACTORS IMPACTING EXHAUST GAS TEMPERATURE MARGIN**

Exhaust Gas Temperature Margin is crucial because it is the primary indicator of an aircraft engine's health, showing how much performance degradation has occurred, allowing for proactive maintenance, preventing costly over-limit events (like aborted takeoffs), and predicting engine life, ultimately ensuring flight safety and efficiency. Every airline is required to maintain this log on every take off. Key objective of Exhaust Gas Temperature Margin:

**Performance**

A shrinking margin signals internal wear (like turbine seal gaps or combustor issues), indicating reduced efficiency and a need for attention.

**Safety**

Prevents unexpected Exhaust Gas Temperature over-limits during critical takeoff phases, which can force high-energy rejected takeoffs or even engine removal, improving safety.

**Maintenance**

Track engine conditions to schedule maintenance (like compressor washes or core restoration shop visits) before failure, optimizing time on-wing and reducing unexpected removals.

**Cost Efficiency**

Restoring margins through maintenance (like washing) brings back performance, delaying expensive engine overhauls and saving money. A good Exhaust Gas Temperature Margin can lead to fuel savings.

**Life Limited Parts (LLP) Life Span**

Trends in margin loss help forecast remaining operational life and schedule major overhauls, linking to Life Limited Parts replacement. This is the backbone of an engine. Below are Life Limited Parts:

- Forward Outer Seal
- High Pressure Turbine Case
- High Pressure Turbine Rotor Disk
- Rotating Seal
- Blisks
- Spools
- Impeller Tube Support
- Combustor Case
- Low Pressure Turbine Shaft
- Low Pressure Turbine Disk
- Impeller Tube Support
- High Pressure Turbine Rotor Mid Seal

**Exhaust Gas Temperature Efficiency**

In order to run a jet engine efficiently, the airlines take all necessary steps to prevent the Exhaust Gas Temperature Over limit Events. Every engine has an Exhaust Gas Temperature Sensor that monitors the margin continuously. It is imperative to know how we are tracking the Exhaust Gas Temperature Margin as the stand alone engine's Exhaust Gas Temperature

Margin may not be the same as Exhaust Gas Temperature Margin of the engine in the aircraft. Hence, consideration of the below factors is critical:

- Exhaust Gas Temperature (or T4) reading: The raw temperature at the turbine exit. You compare it to the engine's reference limit to get the margin.
- T2/T1 (compressor inlet temperature): Environmental temperature (or the temperature after the Inlet) i.e. Hot-day conditions shrink the margin, so we need the actual T2 to normalize the Exhaust Gas Temperature .
- N1/N2 Speeds: This relates to speed of Fan (N1) and Core (N2). Higher speeds usually push Exhaust Gas Temperature up, so you track them alongside temperature.
- Fuel Flow: More fuel means higher Exhaust Gas Temperature. Monitoring fuel flow helps see if the temperature rise is fuel-related or a hardware issue.
- Air-Flow Parameters: Compressor pressure ratio and mass-flow estimates tell us how much air is being compressed. Less air means higher Exhaust Gas Temperature for the same fuel burn.
- Environmental Pressure and Altitude: Lower pressure (high altitude) reduces air density, which can raise Exhaust Gas Temperature. Airlines should use these to adjust the margin to sea-level conditions.
- Bleed-air extraction: Any customer-bleed or anti-ice bleed reduces core airflow, nudging will make Exhaust Gas Temperature go up. Airlines should keep an eye on bleed valve positions.
- Engine Health Parameters: Turbine inlet temperature, compressor efficiency, and turbine health indices. Degraded components show up as a widening gap between expected and actual Exhaust Gas Temperature.
- Outside Air Temperature: Higher the outside air temperature higher the Exhaust Gas Temperature, reducing the margin. As an estimated equation, every 1°C increase in OAT would lead to 3°C increase in EGT at the same level of thrust. An OAT of 30°C at sea level (ISA +15°C) is usually defined at the maximum take-off by the engine manufacturers because it enables maximum thrust in a wide range of conditions.
- Altitude: Higher altitudes can affect Exhaust Gas Temperature
- Thrust Demand: Higher thrust settings or increased bleed air (for systems like anti-ice) raise Exhaust Gas Temperature.
- Flight Cycles: More cycles mean more wear and reduced margin.
- Engine Contamination: Dust/pollution (fouling) restricts airflow, increasing Exhaust Gas Temperature.
- Take off D-Rate: When the engine starts gradually and accelerates gradually, this helps Exhaust Gas Temperature Margin. That is why high-speed take off is not recommended.

### **MAINTENANCE PROCEDURES TO BE FOLLOWED TO CONTROL EXHAUST GAS TEMPERATURE MARGIN**

Airlines know that Exhaust Gas Temperature Margin is a critical requirement for their smooth operations from an operational perspective as well as from compliance perspective. So, utmost care is taken to control the Exhaust Gas Temperature Margin and take action before it goes below the minimum limits to avoid any potential damage to Life Limited Parts or other major engine components:

- Replace Hot-Section worn parts like High-Pressure Turbine blades/seals,
- Compressor blades/stators,
- Seals, or perform advanced repairs/upgrades on these components
- Shop Visit with Performance Restoration Shop Visit.
- Fuel-air mix: Keep the mixture as lean as possible without hitting the lean-blow-out limit. Better atomization and proper fuel scheduling help a lot.
- Combustion tuning: Adjust the pilot/main split, timing, and swirl to burn more evenly. A tighter flame front lowers peak temperatures.
- Hardware health: Clean compressor blades, check for hot-section deposits, and make sure the turbine inlet guide vanes are moving freely. Any blockage raises Exhaust Gas Temperature.
- Environmental conditions: If we can, run at cooler inlet temps (e.g., water-injection or inlet cooling). Colder air densifies the charge and drops Exhaust Gas Temperature.
- Control logic: Update the engine-control maps to target a slightly lower Exhaust Gas Temperature set-point, but make sure you stay within surge and stall margins.

Airlines operate with a significant initial Exhaust Gas Temperature Margin, often 30°C to over 80°C, which decreases over time as engines age, with typical drops of 7-15°C per 1,000 Engine Flight Cycles for engine models like the CFM56, until performance loss or life limited part triggers maintenance, with operators often using engine washes and upgrades to recover some margin and extend time on-wing. New engines generally operate at a margin of 100-130 ° Celsius.

## **POTENTIAL EFFECTS OF EXHAUST GAS TEMPERATURE MARGIN DEGRADATION**

### **Engine Deterioration**

As engines age, components wear (compressor/turbine blades), corrode, or erode, reducing efficiency, which forces the engine to run hotter to produce the same thrust, thus shrinking the Exhaust Gas Temperature margin.

### **Increased Workload**

A shrinking margin means less room for error. On takeoff, hotter ambient temperatures reduce the margin further, potentially causing Exhaust Gas Temperatures to exceed limits, forcing a rejected takeoff or causing significant crew stress.

### **Performance Loss**

Eventually, the engine can't produce required thrust without exceeding the limit, leading to removal for overhaul, or it might fail to generate rated thrust at all, especially in hot environments.

### **Fuel System/Combustion Issues**

Problems like fuel flow reduction or air intake blockage can also cause low Exhaust Gas Temperatures (indicating poor combustion), but conversely, issues like combustor distress

increase Exhaust Gas Temperature, consuming the margin and raising the risk of overlimit events.

### **Rich Fuel Mixture**

A very rich mixture (too much fuel for the air) results in cooler combustion, showing as low Exhaust Gas Temperatures.

### **Clogged Air Filter/Intake**

Restricted airflow reduces combustion efficiency, lowering temperatures.

### **Faulty Exhaust Gas Temperature Sensor**

An inaccurate sensor reading can falsely show low Exhaust Gas Temperature, affecting engine management.

### **DPF Regeneration (Diesels)**

In diesels, low Exhaust Gas Temperatures can indicate a failed or slow DPF regeneration, leading to fuel economy issues.

### **Safe Operating Limit (Redline)**

The critical factor is the maximum sustained Exhaust Gas Temperature, which is typically around 100°C to keep the engine running. Any margin less than this is considered unsafe.

## **DATA COLLECTION METHOD**

Collection of data is a study between various disciplines such as statistics, machine learning, artificial intelligence, database management. Data mining methods are used in customer relationship management, banking or finance sector, logistics and transportation, production and maintenance, insurance, computer software and hardware, engineering and science, defence industry, transportation sector, and health field (Olson & Delen, 2008). Table in point-6 is the outcome of the data mining.

### **Data Pre-processing**

As can be seen in the method mentioned above, data mining includes starting with the determination of the problem, performing various operations on the obtained data set, and reaching a result.

At this stage, data is cleaned from noisy data, any missing data is completed. If the size of the data is large, size reduction is performed to be able to process with adequate analysis.

## Aircraft Exhaust Gas Temperature Value Mining with Rough Set Method

N1, N2, altitude, airspeed, ground speed, pitch, angle of attack, roll, heading, vertical acceleration, latitude acceleration, longitude acceleration, speed break, total air temperature, EGT data were used in our study from the data obtained by flight data recorder during the flight of a commercial aircraft. In this study, EGT value is used for failure prediction with this data mining method.

### PROBABILITY AND SIMULATION

Simulation refers to a situation where not an actual and permanent solution is applied, rather most of the possibilities are applied and results are inspected to reach to some conclusion that would lead to an exact course of action in future for a pre-defined issue. It is one of the biggest problems with the airlines in the globe today that they cannot ask the original equipment manufacturer or the overhaul shop to do a hit and try approach by replacing various engine components and inspecting the Exhaust Gas Temperature Margin at each action. Original equipment manufacturer or the overhaul shops cannot do that for the below reasons:

- Installing a new part on an engine even for just one test run, will make it Used Serviceable Material and the price of such material is a lot cheaper than the price of a brand new component. Hence, the original equipment manufacturer or the overhaul shop does not want to risk the inventory value depletion of such parts which are in reality brand new but due to this one test run, will now be tagged as Used Serviceable Material.
- There are regulations if an engine component is installed on an engine, it has to be documented and when this installed part is further removed and installed on any other engine, it has to go through the compliance procedure of installing a used component that requires a lot more documentation than a brand new part.
- The risk of the new component getting fully scrapped at shop cost is very high. Generally airlines use the contracting concept of Rate Per Flight Hour. So, if a component is installed only for testing and somehow that component just fails, it will be as per shop cost. So, the shop would not like to risk so much cost.
- Original equipment manufacturers or the overhaul shops do not encourage this simulation as it would be a very long testing schedule for them delaying induction and testing of other engines in line. Installing one component and then doing the testing then again removing it and installing another component could be extremely time taking activity. The operators do not pay for it and hence the shop does not encourage it.
- There are contractual requirements that force the operator to not ask the shop for this kind of simulation. Contractual requirements state that before every overhaul of the engine, there is a Workscope that is agreed between the operator and the shop. So, if the replacement of such parts is not in the workscope, replacement of such parts for simulation is a violation of the contract terms. A contract cannot have simulation criteria. With some research, we found an instance where an operator wanted to improve Exhaust Gas Temperature Margin and was not aware what parts are damaged that are making the margins low. So, the operator asked the overhaul shop to check for the possibility of replacement of the Combustion Chamber and its

impact on Exhaust Gas Temperature Margin. The overhaul shop denied the proposal but they did agree to work with the product support engineer to know the likely impact of the replacement of the Combustion chamber. The Product Support Engineer took 45 days to complete the case and prepare a response. The response was not very specific in terms of measurements that it could lead to regarding Exhaust Gas Temperature Margin. They only provided the response that the replacement would only have very low impact on overall Exhaust Gas Temperature Margin but they could not clearly mention, what impact it will be.

- Every overhaul shop operates at an overhaul cycle time of a defined number of days. Generally, even engines have longer cycle time compared to non-event engine overhaul. If simulation is adopted, then the overhaul cycle time would be very long which no overhaul shop encourages.
- Cost of overhaul becomes very expensive for the operator if the overhaul shops do some part replacement as part of simulation. The operators want to keep their operational cost at the most affordable level and simulation leads to higher cost. So, it is not an option they would like to choose.
- Simulation implementation on an active overhaul engine leads to a lot of complications about inspection of various engine components. There are 3 levels of inspection of engine components: Level-A, Level-B & Level-C. Level-A is a general visual inspection, Level-B is inspection at Engine Service Manual level for the whole module and Level-C which is the most detailed and requires each component inspection at piece part level as per Engine Service Manual. Replacement of a Life Limited Part leads to several engine components being inspected at Level-C which could actually be only Level-A as per the workscope. This also complicates the implementation of simulation.

To solve this issue, we adopted a very thorough and detailed process of gathering actual overhaul data from various shops across the globe and formulating them into a simulation table. We did following steps to generate simulation data:

- We did detailed market research and identified multiple Aircraft engine overhaul shops. We also identified the point of contact and procedure to legally reach out to these shops. There are a very limited number of shops across the globe. Some shops are independent overhaul shops that do overhaul of engines for all operators and there are other shops which do overhaul work only for a specific airline. These shops which only cater to overhaul of only specific operators, are very confined in terms of sharing data outside the organization but they still need to adhere to all aviation regulations. Below independent overhaul shops are the only limited number of independent shops:
  - GE Aviation
  - Pratt & Whitney
  - Rolls Royce
  - Standard Aero
  - AAR Corporation
- After market research and communication with the shops for more than a month, we were able to identify the shops that can help us in our simulation.

- A few of the above shops were able to help us do our research. We targeted to get only test data from these shops with respect to engines getting to overhaul shops for Exhaust Gas Temperature Margin correction in the workscope.
- The shops also mentioned that the data would not include the name and engine serial number of the operator. All the data was shared with us using Operator1, Operator2 engines etc. For our Research, we only needed the data, not the operator name or serial number. So, we did not have any bottleneck in continuing our research.
- This was a time taking approach since engines coming to overhaul shops are not common to have workscope of Exhaust Gas Temperature Margin.
- As a researcher, I have been virtually part of the testing for such cases.
  - Operator1 engine had workscope of Exhaust Gas Temperature Margin with replacement of CDP Seals/Rotating Seals. We noted the results and Exhaust Gas Temperature Margin impact was noted to our simulation tracker and simulation database.
  - Operator2 engine had workscope of Exhaust Gas Temperature along with replacement of High Pressure Turbine Stage-1 Blade. We followed the same process and noted the results.
  - Operator3 engine also had a workscope of Exhaust Gas Temperature Margin and so on. We noted all the scenarios and their results. We had a total of 40+ such cases across 2.5 years of thorough test results scrubbing for Exhaust Gas Temperature Margin related workscope.

Based on Probability Theory and Simulation, below table gives the most accurate prediction of how Exhaust Gas Temperature Margin will improve if various components of the engine are replaced with brand new component:

### Parts Replaced for High Thrust Engines

We started the simulation with High Thrust Engines and below are the results accumulated across large data set over a span of 2.5 years:

**Table 1: Showing results of Exhaust Gas Temperature Margin on replacement of various engine components**

| Engine Operation                       | 5000TSN | 7500TSN | 10000TSN | 12500TSN | 15000TSN |
|--|---------|---------|----------|----------|----------|
| CDP Rotating Seal                      | 5.00°C  | 3.75°C  | 2.81°C   | 2.11°C   | 1.58°C   |
| CDP Stationary Seal                    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| HPT STG1 Blade                         | 3.00°C  | 2.25°C  | 1.69°C   | 1.27°C   | 0.95°C   |
| HPT STG2 Blade                         | 4.00°C  | 3.00°C  | 2.25°C   | 1.69°C   | 1.27°C   |
| STG1 Shroud                            | 7.00°C  | 5.25°C  | 3.94°C   | 2.95°C   | 2.21°C   |
| STG2 Shroud                            | 5.00°C  | 3.75°C  | 2.81°C   | 2.11°C   | 1.58°C   |
| HPT S1 Nozzles                         | 8.00°C  | 6.00°C  | 4.50°C   | 3.38°C   | 2.53°C   |
| HPT S2 Nozzles                         | 3.00°C  | 2.25°C  | 1.69°C   | 1.27°C   | 0.95°C   |
| Compressor Rotor S1 Honeycomb Seals    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| Compressor Rotor S2 Honeycomb Seals    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| Compressor Rotor S3 Honeycomb Seals    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| Compressor Rotor S4 Honeycomb Seals    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| Compressor Rotor S5 Honeycomb Seals    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| Compressor Rotor S6-10 Honeycomb Seals | 10.00°C | 7.50°C  | 5.63°C   | 4.22°C   | 3.16°C   |

## Parts Replaced for Low Thrust Engines

We also performed the same test simulation for Low Thrust Engines

**Table 2: Showing results of Exhaust Gas Temperature Margin on replacement of various engine components**

| Engine Operation                       | 5000TSN | 7500TSN | 10000TSN | 12500TSN | 15000TSN |
|--|---------|---------|----------|----------|----------|
| CDP Rotating Seal                      | 6.00°C  | 4.50°C  | 3.38°C   | 2.53°C   | 1.90°C   |
| CDP Stationary Seal                    | 1.00°C  | 0.75°C  | 0.56°C   | 0.42°C   | 0.32°C   |
| HPT STG1 Blade                         | 4.00°C  | 3.00°C  | 2.25°C   | 1.69°C   | 1.27°C   |
| HPT STG2 Blade                         | 5.00°C  | 3.75°C  | 2.81°C   | 2.11°C   | 1.58°C   |
| STG1 Shroud                            | 7.00°C  | 5.25°C  | 3.94°C   | 2.95°C   | 2.21°C   |
| STG2 Shroud                            | 6.00°C  | 4.50°C  | 3.38°C   | 2.53°C   | 1.90°C   |
| HPT S1 Nozzles                         | 9.00°C  | 6.75°C  | 5.06°C   | 3.80°C   | 2.85°C   |
| HPT S2 Nozzles                         | 3.00°C  | 2.25°C  | 1.69°C   | 1.27°C   | 0.95°C   |
| Compressor Rotor S1 Honeycomb Seals    | 1.50°C  | 1.13°C  | 0.84°C   | 0.63°C   | 0.47°C   |
| Compressor Rotor S2 Honeycomb Seals    | 1.50°C  | 1.13°C  | 0.84°C   | 0.63°C   | 0.47°C   |
| Compressor Rotor S3 Honeycomb Seals    | 1.50°C  | 1.13°C  | 0.84°C   | 0.63°C   | 0.47°C   |
| Compressor Rotor S4 Honeycomb Seals    | 1.50°C  | 1.13°C  | 0.84°C   | 0.63°C   | 0.47°C   |
| Compressor Rotor S5 Honeycomb Seals    | 1.50°C  | 1.13°C  | 0.84°C   | 0.63°C   | 0.47°C   |
| Compressor Rotor S6-10 Honeycomb Seals | 11.00°C | 8.25°C  | 6.19°C   | 4.64°C   | 3.48°C   |

## RESULTS

In this paper, data mining methods were applied to the data obtained from the aircraft engine and the EGT parameter was estimated. In the data mining application, firstly the data reduction process and outlier data cleaning the Exhaust Gas Temperature Value Mining with Rough Set Method. The process was performed, and the pre-processing process was completed and the data was made ready for modelling. By using the data reduction rough set method, various sub-sets were obtained. Then the simulation for estimation of the EGT margin was proposed above.

## HOW TO USE THE ABOVE SIMULATION TABLE

The table is simple to use. If an operator has low Exhaust Gas Temperature Margin issue and they replace Compressor Rotor Stage2 Seals, they will improve Exhaust Gas Temperature Margin depending on the Time Since New of the engine and the Thrust Rating of the engine. If the engine is a High Thrust Engine and the Cycle Time is up to 5000 (refer to Table#1), replacement of Stage2 Seal would improve the Exhaust Gas Temperature Margin by 1°C, for 10000 Cycle Time Engine, it would be 0.56°C and so on. The same numbers for a low thrust engine (refer to Table#2) would be 1.5°C and 0.84°C. While reviewing the above table, it is also very important to understand that the above table has been simulated based on tests of the engine in the test cell. Test cells do testing at full thrust but when an engine is installed on the Aircraft, it does not run at full thrust as there is concept of De-rate to maintain the engine health and with that we have observed an additional increase in Exhaust Gas Temperature Margin by 8-10°C. So, while reading the above table, it is imperative to note that the actual margin on-wing will be 8-10°C higher which adds more room for the airlines to operate safely. Take-off derate is basically a safety margin that airlines bake into

the engine power they use when an aircraft runs. Instead of pulling max thrust right away, they “derate” it which means run it at a lower, pre-approved thrust. Higher the thrust for take-off, higher the stress on the engine and leading to lower Exhaust Gas Temperature Margin. Thrust obviously cannot be the minimum as it needs a minimum level of thrust in order to take off. So, there is a fine balance required to de-rate and still maintain smooth take off. A rule of thumb is that lesser the thrust, lesser is the wear on the engine and longer is the engine life and life of various attached components and lower maintenance cost. Exhaust Gas Temperature Margin is the most impacted driver at the time of take off or landing. So, de-rate plays a significant role in maintaining the Exhaust Gas Temperature Margin. The de-rate is also considered as a safety measure as it gives the pilots some extra thrust reserve if something unexpected happens. A few instances of unexpected happenings could be slippery run-way or a sudden gust, avoiding any possible incidents etc. As we have identified de-rate as an item of significance for better Exhaust Gas Temperature Margin, it is also important to note that there is concept of icing in an aircraft that could lead to incorrect Exhaust Gas Temperature Margin and mostly on showing the lower Exhaust Gas Temperature Margin than it should actually be. Icing is basically a flying condition where super-cooled water droplets hit the cold surfaces of an airplane, freeze and turn into ice. That can happen on wings, tail, engine inlets, propellers i.e. anywhere the airflow is exposed.

This can lead to:

- Lift loss: Ice messes up the smooth airflow, so the wing makes less lift.
- Drag increase: The rough ice shape adds drag, burning more fuel.
- Engine trouble: Ice in the inlet blocks airflow, can cause stall or surge, and usually drives the temperature of the engine higher.
- Control issues: Extra weight and altered aerodynamics can make the plane harder to handle.
- Pilots avoid it by flying around known icing zones, using anti-ice (heaters, de-icing boots) or climbing to warmer temps where the moisture turns to rain instead of ice.

Hence, Icing can bite into the Exhaust Gas Temperature margin in a few ways:

When ice builds up on the inlet or fan blades, the airflow into the core gets distorted and the mass-flow drops. The engine has to work harder to keep the same thrust, so it burns more fuel and the turbine temperature climbs. That shrinks the gap between the measured Exhaust Gas Temperature and the red-line limit - in other words, the Exhaust Gas Temperature margin narrows.

If the ice is severe enough to trigger an engine-anti-ice bleed, the bleed-air extraction reduces core airflow even further, pushing the temperature up another notch. On the flip side, once the ice is cleared (either by the anti-ice system or by climbing to warmer air), the airflow recovers, fuel flow drops back toward normal, and the margin returns to its baseline.

To conclude about icing, less air, higher fuel-to-air ratio, higher Exhaust Gas Temperature, smaller margin. We keep an eye on the Exhaust Gas Temperature trend during an icing encounter; a sudden upward shift is a clear and early warning that the margin is eroding.

## CONCLUSION

Exhaust Gas Temperature is not the sole engine health indicator but it is one of the most important checking points for a jet engine and aircraft safety and all possible measures should be taken to have the safest Exhaust Gas Temperature Margin. The simulation data can work as a ready handbook for the operators to make a decision if they should replace a particular engine component. After we prepared our Simulation Table, we shared the results with all the shops that participated in the research and for next 6 months, all Exhaust Gas Temperature Margin workscope overhaul engines were tested using replacement simulation and we found that our simulation table was working at an accuracy of more than 98.45%. So, we have strong reasons and results to believe that all airlines should start using this simulation table and operate the aircraft more safely with a very efficient cost of operation.

## REFERENCES

The article has been written completely based on the understanding and knowledge of the author without specific reference to any book, journal, article or any content available publicly or privately. However, following references have helped build up knowledge about the technology.

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