Overview

CFM56 General

Technical Features

Engine Certification & Testing

Operational Characteristcs

EGTMargin, OATL

Reduced TakeOff Thrust

Normal Operating Considerations

Flight phases, ops recommendations

cfm

THE POWER OF FLIGHT

CFM is a Joint Company of
Snecma, France
And
General Electric Co., U.S.A.

cfm

THE POWER
OF FLIGHT

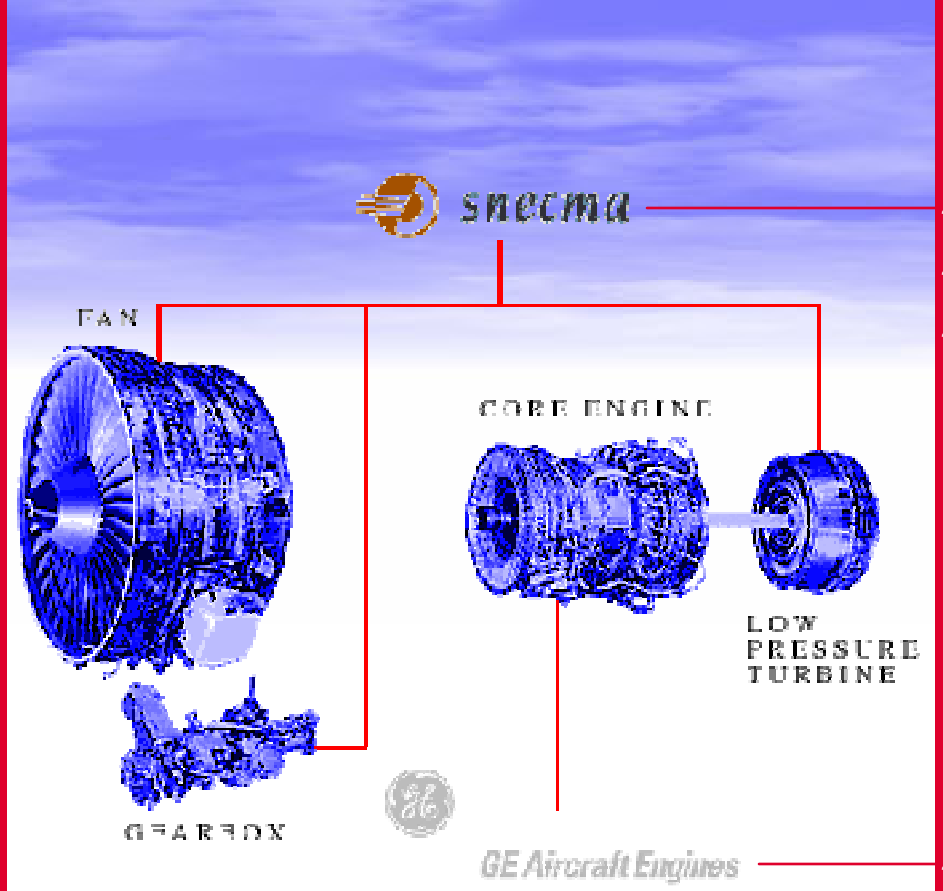
CFM General

A jointly owned company

EFECTIVE 50/50

WORK SPLIT

An effective division of labor dictates exactly how the companies allocate their manufacturing resources. This work split acknowledges the technological achievements of both Snecma's and GE Aircraft Engines' respective organizations



- *LP system*
- *Installations*
- *Gearbox*
  - *Controls and accessories*

- *Core engine*
- *System integration*
- *FADEC/MEC systems*

The CFM56 core is based on the GE F101 engine (developed for the B-1 bomber) and employs a single-stage high-pressure turbine to drive a nine-stage compressor. Correspondingly, a Snecma advanced four- or five-stage, low-pressure turbine drives the Snecma fan and booster.

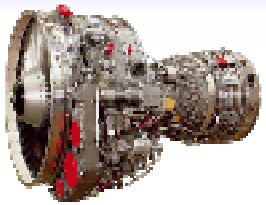
cfm
THE POWER OF FLIGHT

CFM General

CFM56-2 (1979)
22 / 24 Klb

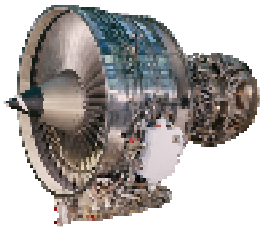
- DC8
- KC-135 FR
- C-135 FR
- E-3 (AWACS)
- KE-3 (Tanker)
- E-6

CFM56-3 (1984)
18.5 / 20 / 22 / 23.5 Klb



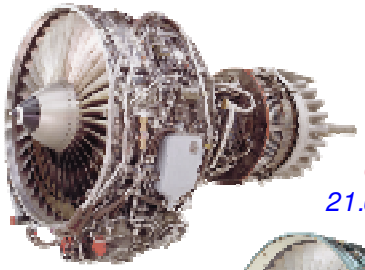
BOEING 737
300 / 400 / 500

CFM56-5A (1987)
22 / 23.5 / 25 / 26.5 Klb



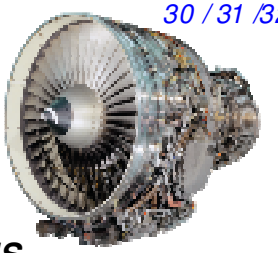
AIRBUS
A319 / A320

CFM56-5C (1991)
31.2 / 32.5 / 34 Klb



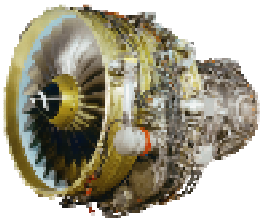
AIRBUS
A340

CFM56-5B (1993)
21.6 / 22 / 23,3/ 23.5 / 27
30 / 31 /32 Klb



AIRBUS
A318 / A319 / A320 / A321

CFM56-7B (1996)
19.5 / 20.6 / 22.7
24.2 / 26.3 / 27.3 Klb



BOEING 737
600 / 700 / 800 / 900

… 18 KLB TO 34 KLB …
GROWTH CAPABILITY WITH COMMONALITY BENEFITS

CFM General

CFM56 Family Today

as of July 31, 2005

- ***Around 20,000*** *CFM56 on commitment (options & spares included)*
- ***536*** *Operators / Customers & VIP*
- ***6,012*** *A/C /* ***15,066*** *engines in service*
- ***294*** *million Engine Flight Hours &* ***173*** *million Engine Flight Cycles*
- *1 aircraft departure every* ***4*** *seconds*

THE WORLD'S MOST POPULAR ENGINE

CFM General

Engine Fleet Status

as of July 31, 2005

EVERY four seconds, every single day, an aircraft with our engines takes off. CFM56 engines power more planes to mores places than any other engine in their thrust class; they've logged more than 247 million flying hours and nearly 60 billion miles. Reliably. Efficiently. Cost-effectively. Every four seconds, every single day.

CFM General

cfm
The Power Of Flight

Reliability Rates
(Rate/Number of events)

as of July 31, 2005

		Unpl. Removal**				Shop Visit**			
		Total*		Engine		Total*		Engine	
CFM56-2C	DC8-70	.069	9	.065	8	.051	14	.047	13
CFM56-3	B737-300/400/500	.038	130	.030	102	.099	332	.093	310
CFM56-5A	A319/320	.030	98	.025	81	.098	320	.094	306
CFM56-5B	A318/319/320/321	.011	7	.008	5	.024	16	.022	15
CFM56-5C	A340	.024	110	.021	97	.065	300	.061	280
CFM56-7B	B737NG	.015	133	.012	106	.013	115	.011	97

12-Month Rolling Rate

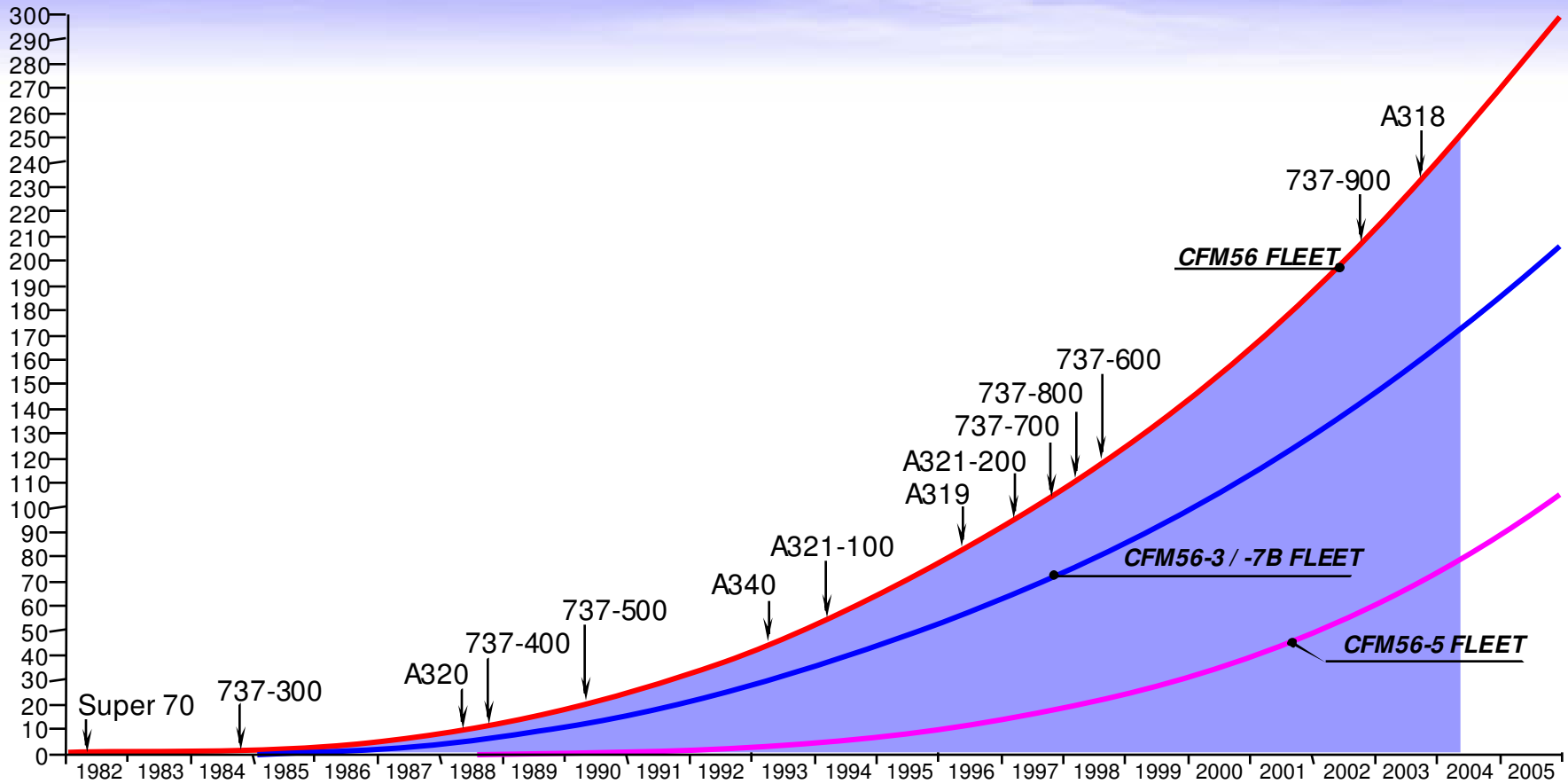
		I.F.S.D.**				A.T.O.***				A/C DEP. REL. %			
		Total*		Engine		Total*		Engine		Total*		Engine	
CFM56-2C	DC8-70	.054	15	.018	5	.154	5	.062	2	99.96	13	99.99	4
CFM56-3	B737-300/400/500	.003	34	.002	21	.012	42	.004	13	99.97	1000	99.99	522
CFM56-5A	A319/320	.005	15	.005	13	.019	16	.010	8	99.89	879	99.92	648
CFM56-5B	A318/319/320/321	.001	7	.001	5	.016	22	.007	9	99.95	712	99.96	484
CFM56-5C	A340	.009	37	.005	20	.146	23	.025	4	99.61	623	99.81	300
CFM56-7B	B737NG	.002	18	.001	9	.010	26	.003	7	99.96	1113	99.97	815

EVERY four seconds, every single day, an aircraft with our engines takes off. CFM56 engines power more planes to mores places than any other engine in their thrust class; they've logged more than 247 million flying hours and nearly 60 billion miles. Reliably. Efficiently. Cost-effectively. Every four seconds, every single day.

*(Total includes engine cause and other related engine events such as FOD, Customer Convenience,...)
**(Per 1,000 EFH)
***(Per 1,000 Departures)

CFM General

Experience and Forecast



100M EFH IN 1997 … 200M IN 2002 … 300M IN 2005

A CFM-POWERED AIRCRAFT TAKES OFF EVERY 4 SECONDS

CFM56 Engine High Times

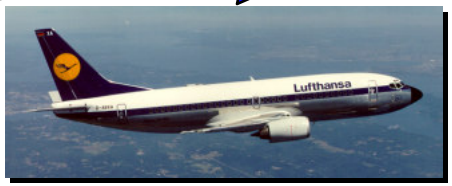
As of December 31, 2003

ENGINE	High Time Engine		Highest on Wing life*	
	TSN	CSN	EFH	EFC
CFM56-5A	41,247	30,684	30,631	15,300
CFM56-5B	22,761	19,966	22,628	13,985
CFM56-5C	48,300	9,345	31,899	6,491
CFM56-2C	50,775	19,985	22,614	8,541
CFM56-7B	24,500	13,945	24,500	12,571
CFM56-3	56,850	56,178	40,729	20,000

CFM56 engines built around the ***single stage HPT concept***

PROVEN OVER 242M EFH

40,729 hours / 17,504 cycles
First engine removal on Sept. 05, 2003

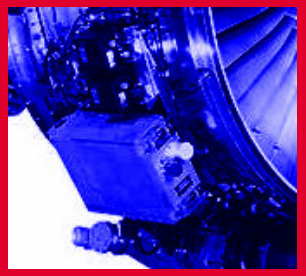


20,000 cycles

WORLDWIDE RECORD FOR CFM56-3
on-wing life without removal

World records for high cycle operations * Longest intervals achieved on wing without removal

NEW ENGINES BUILT ON CFM56 RECORD-SETTING ON-WING EXPERIENCE



CFM56 General

Technical Features

Engine Certification & Testing

Operational Characteristics

EGTMargin, OATL

Reduced TakeOff Thrust

Normal Operating Considerations

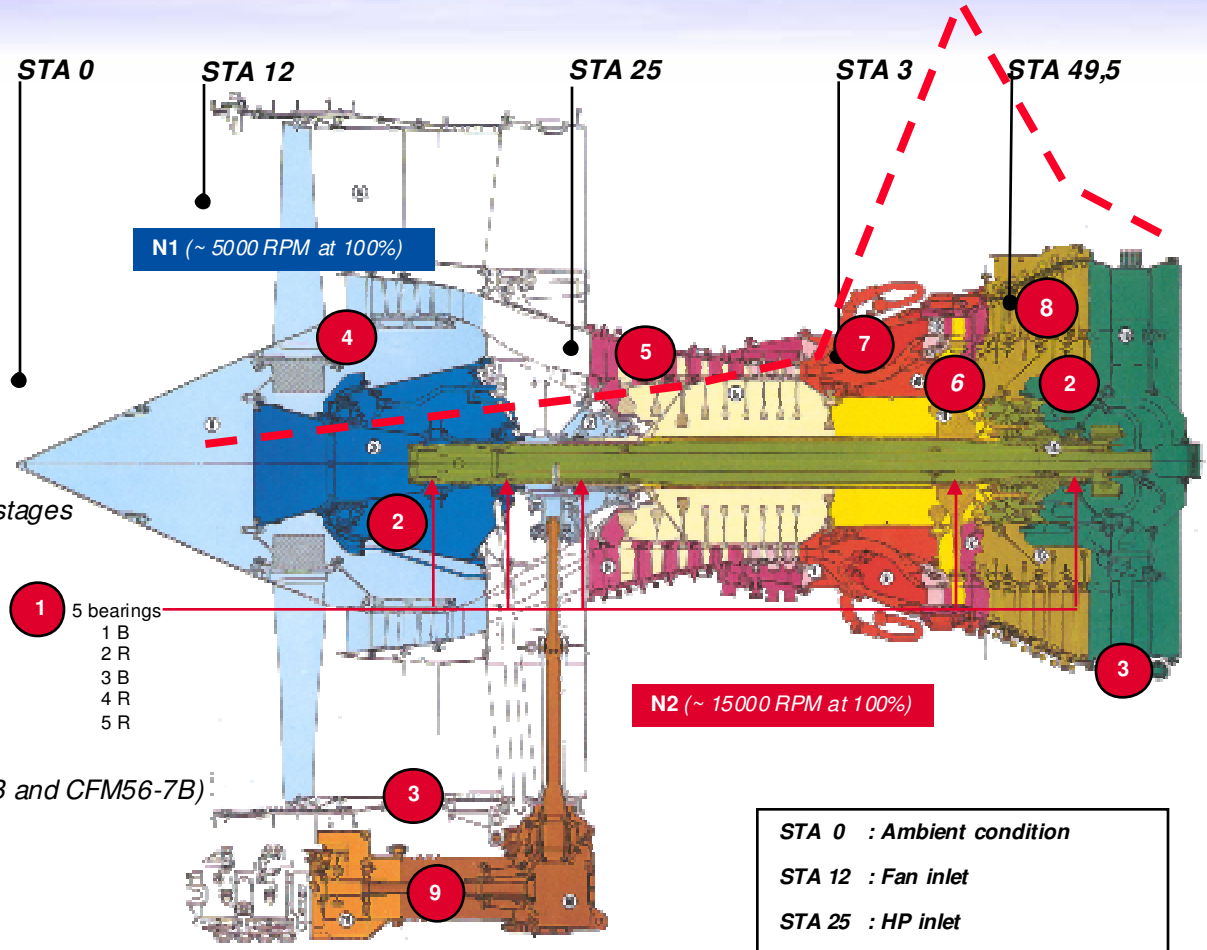
Flight phases, ops recommendations

THE POWER OF FLIGHT

CFM56 Common Architecture

All CFM56 engines have

1. ***5 bearings***
   - *Ball (B) bearings absorb axial loads*
   - *Roller (R) bearings absorb radial loads*
2. ***2 sumps***
3. ***2 frames**: Fan frame and turbine rear frame*
4. ***LPC**, Low Pressure Compressor*
   - *1 fan stage*
   - *3 or 4 booster stages*
5. ***HPC**, High Pressure Compressor*
   - *9 rotor stages, 4 variable stages, 5 fixed stator stages*
6. ***HPT**, High Pressure Turbine*
   - *Single-stage turbine nozzle*
   - *Single-stage turbine rotor*
7. ***Combustor***
   - *Single annular combustor*
   - *Dual annular combustor (optional on CFM56-5B and CFM56-7B)*
8. ***LPT**, Low Pressure Turbine*
   - *4 or 5 stages*
9. ***3 gearbox** arrangements*
   - *Inlet, transfer, accessory*



STA 0	***: Ambient condition***
STA 12	***: Fan inlet***
STA 25	***: HP inlet***
STA 3	***: HP compressor discharge***
STA 49,5	***: EGT mesuring plane***

Flow path air temperature rise

CFM56-5A Family

Engine Ratings & Applications

		-5A1 25 Klbs	-5A3 26.5 Klbs	-5A4 22 Klbs	-5A5 23.5 Klbs
A320					
A319					

SAME ENGINE FOR 2 A/C APPLICATIONS

CFM56 -5B

1. Coniptical Spinner
Minimizes ice accretion
Maximizes hail ingetion capability

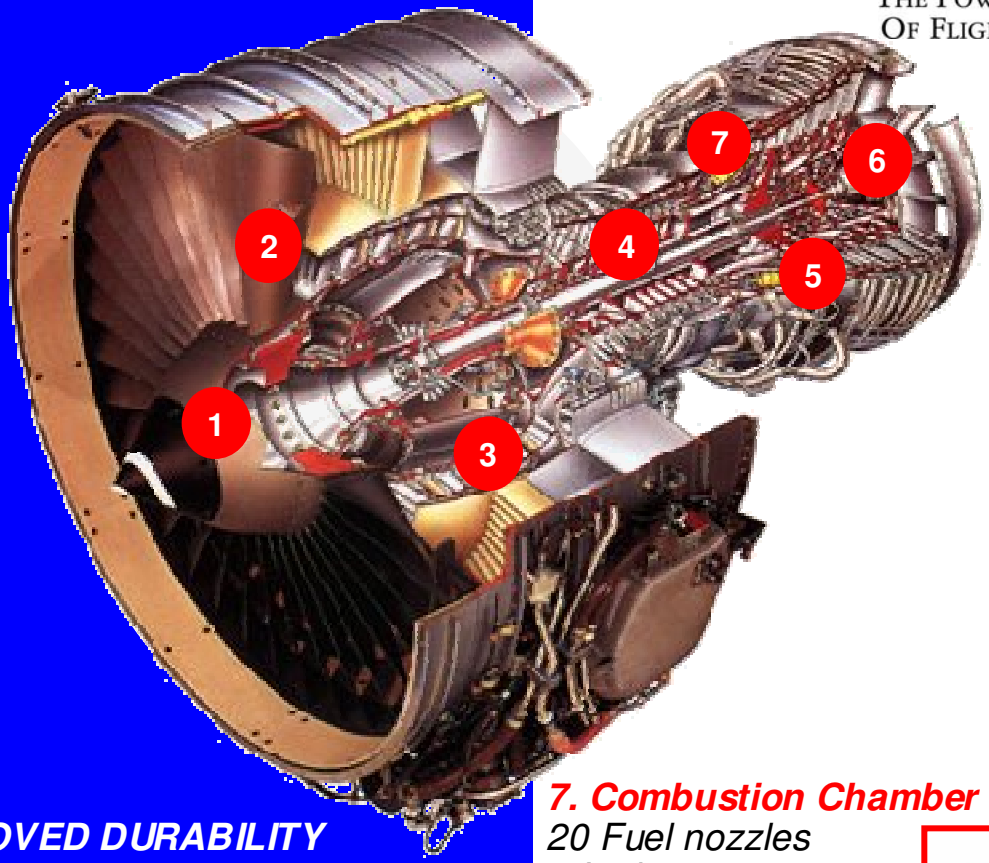
2. Fan
36 titanium fan blades
3D aero design ⇒ efficiency 90%

3. Booster
4 stages
New 3D aero design

4. HPC
High Pressure Compressor ed
Hard coated blades
HIGH PERFORMANCE
LOW DETERIORATION DESIGN

5. HPT
High Pressure Turbine
ECU optimized HPTCC
IMPROVED EFFICIENCY & IMPROVED DURABILITY

6. LPT
Low Pressure Turbine
LPTACC modulated cooling flow
IMPROVED PERFORMANCE & INCREASED T° CAPABILITY



7. Combustion Chamber
20 Fuel nozzles
2 Igniters
Burner Staging Valve

DAC option
40 fuel nozzles
LOWER EMISSIONS

THE POWER OF FLIGHT

IMPROVEMENTS
CFM56-5B/P

THE POWER OF FLIGHT

Key Changes

1. HPC

3-D aero HPC compressor

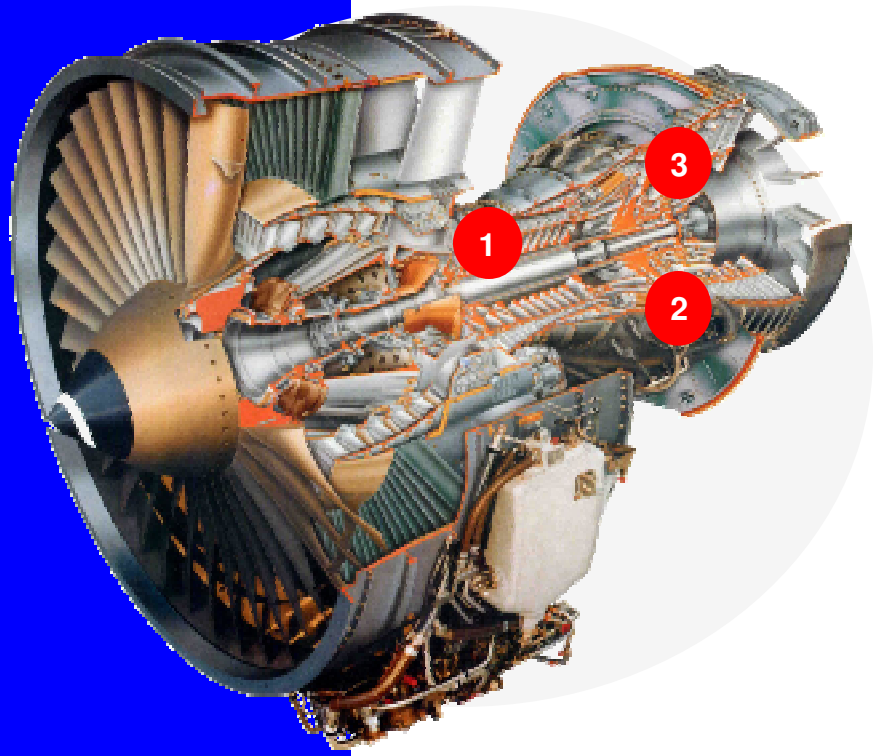
2. HPT

Latest HPT blade design

- *Increased cooling*

3. LPT

Redesigned New LPT stage 1 nozzle



CFM56-5B Family

Engine Ratings & Applications

		-5B1/P 30 Klbs	-5B2/P 31 Klbs	-5B3/P 32 Klbs	-5B4/P 27 Klbs	-5B5/P 22 Klbs	-5B6/P 23.5 Klbs	-5B7/P 27 Klbs	-5B8/P 21.6 Klbs	-5B9/P 23.3 Klbs
A321										
A320										
A319										
A318										

Thrust rating

CFM56-5BX/P CFM56-5BX/2P

DAC option

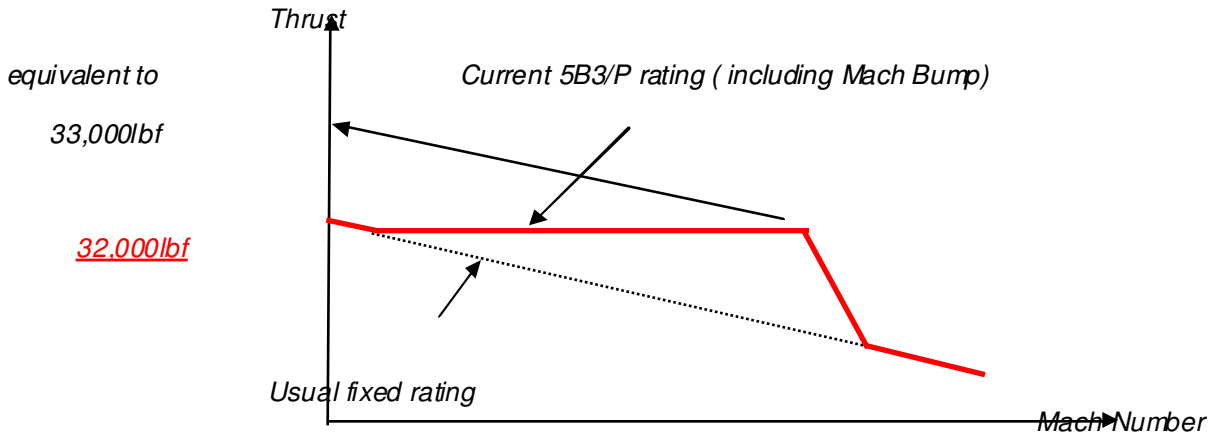
New 3D aéro design

SAME ENGINE FOR 4 A/C APPLICATIONS

CFM56-5B3/P Nameplate

- The reference certified thrust level at Take Off for CFM56-5B3/P is 32,000lbf (nameplate)
  - It corresponds to a sea level static thrust level

- The CFM56-5B3/P thrust rating has a Mach Bump to maximize aircraft performance



- To emphasize the real capacity of the engine during T/O phase, CFM marketed its CFM56-5B3/P engine as an equivalent 33,000lbf T/O thrust engine.

CFM56-5A vs –5B Design

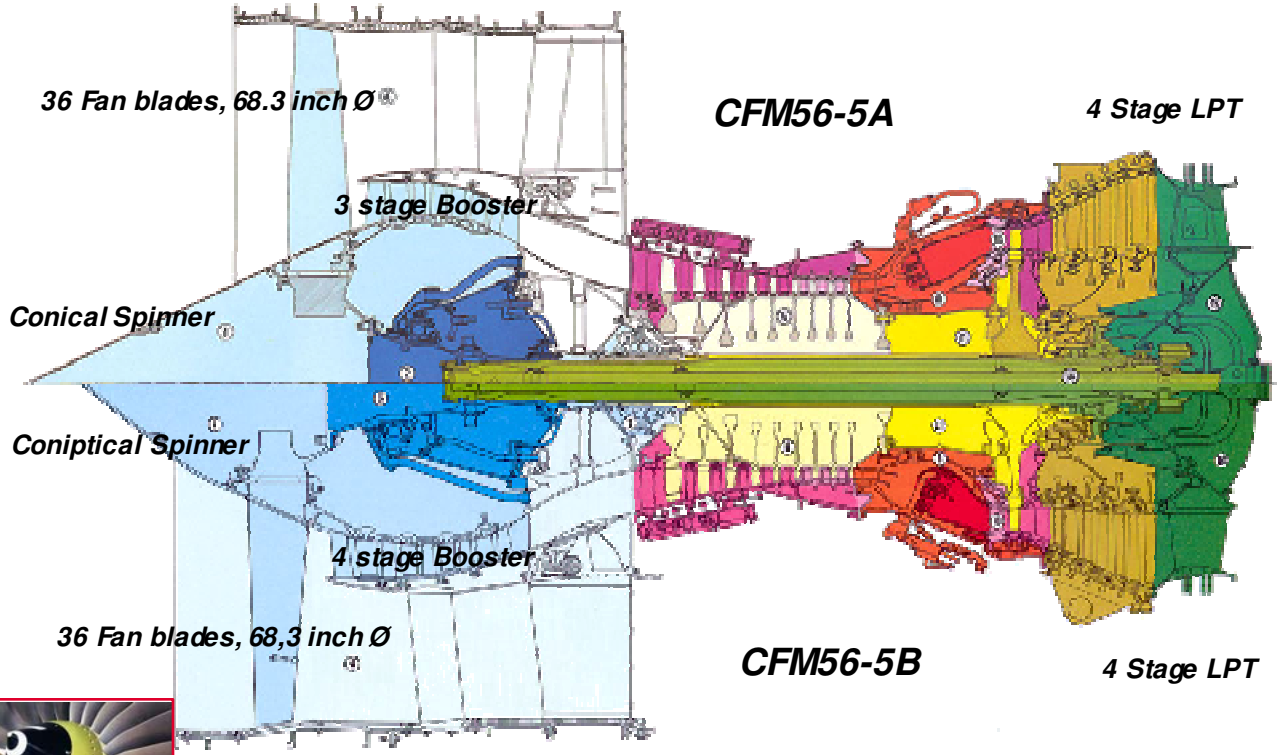
Spinner shape

- ***Conical***: *Provides best ice accretion characteristics (minimizes)*
- ***Elliptical***: *Provides best hail ingestion capability*
- ***Coniptical***: *A compromise between ice accretion characteristics and hail ingestion capability*

Conical

Elliptical

Coniptical



Engine Control System

FADEC (Full Authority Digital Engine Control)

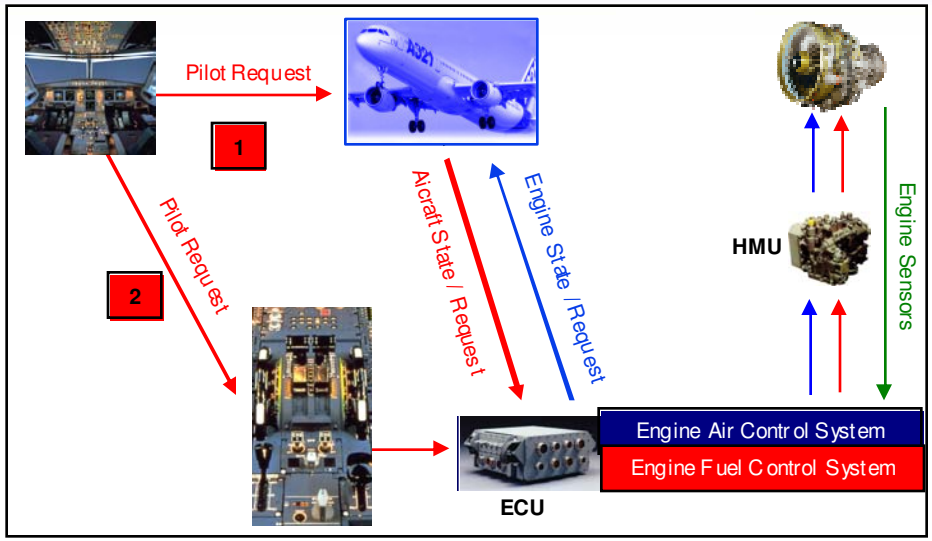
- No mechanical connection cockpit to engine
- Analogous to "fly by wire" aircraft control system

Consists of

- Dedicated alternator and power supplies
- Electronic control unit (ECU) - "brains"
- Hydromechanical unit (HMU) - "muscle"
- Sensors for control, monitoring and feedback
- Cables and connectors

More than just fuel control functions

- Start
- Ignition
- Variable geometry (VSV's and VBV's)
- Clearance/cooling control
- Reverse thrust
- Fault detection



FADEC is Full Authority Digital Engine Control. It is the name given to the most recent generation of electronic engine controls currently installed on a variety of high-bypass turbofan engines. FADEC systems are more responsive, more precise, and provide more capability than the older mechanical controls. They also integrate with the aircraft on-board electronic operating and maintenance systems to a much higher degree. The FADEC enhanced engine is not only more powerful and efficient than its mechanically controlled counterpart, it is simpler to operate, and easier to maintain.

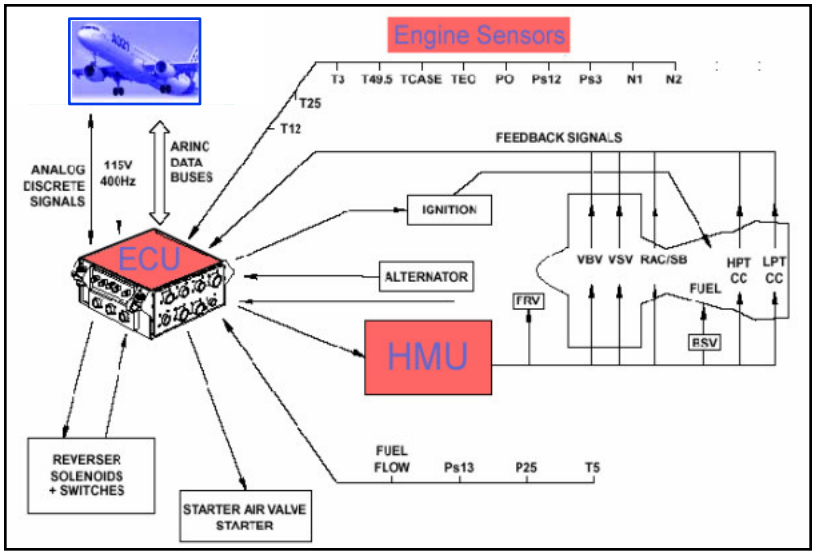
Engine Control System

FADEC components

ECU: *Engine Control Unit*
- Containing two identical computers, designated ChA and ChB.
- Performs engine control calculations
- Monitors the engine's condition

HMU: *Hydro-Mechanical Unit*
which converts electrical signals from the ECU into hydraulic pressures.

ENGINE SENSORS
Used for control and monitoring.



Engine Control System

FADEC Philosophy

EEC Functions:

- Performs input signal validation & processing
- Governs the engine forward & reverse thrust
- Performs automatic regulation
- Provides information to airplane (N1,2 red line / EGT red line, Max Cont, Start red line / ENG FAIL)

EEC Architecture:

- Dual channel
- Cross-channel communication
- Fault tolerant
- Dual control sensors for critical inputs and feedback
- Dual source airplane system inputs cross-connected to both channels

Self-tested and fault tolerant

- FADEC is a BITE system ⇨ Built In Test Equipment

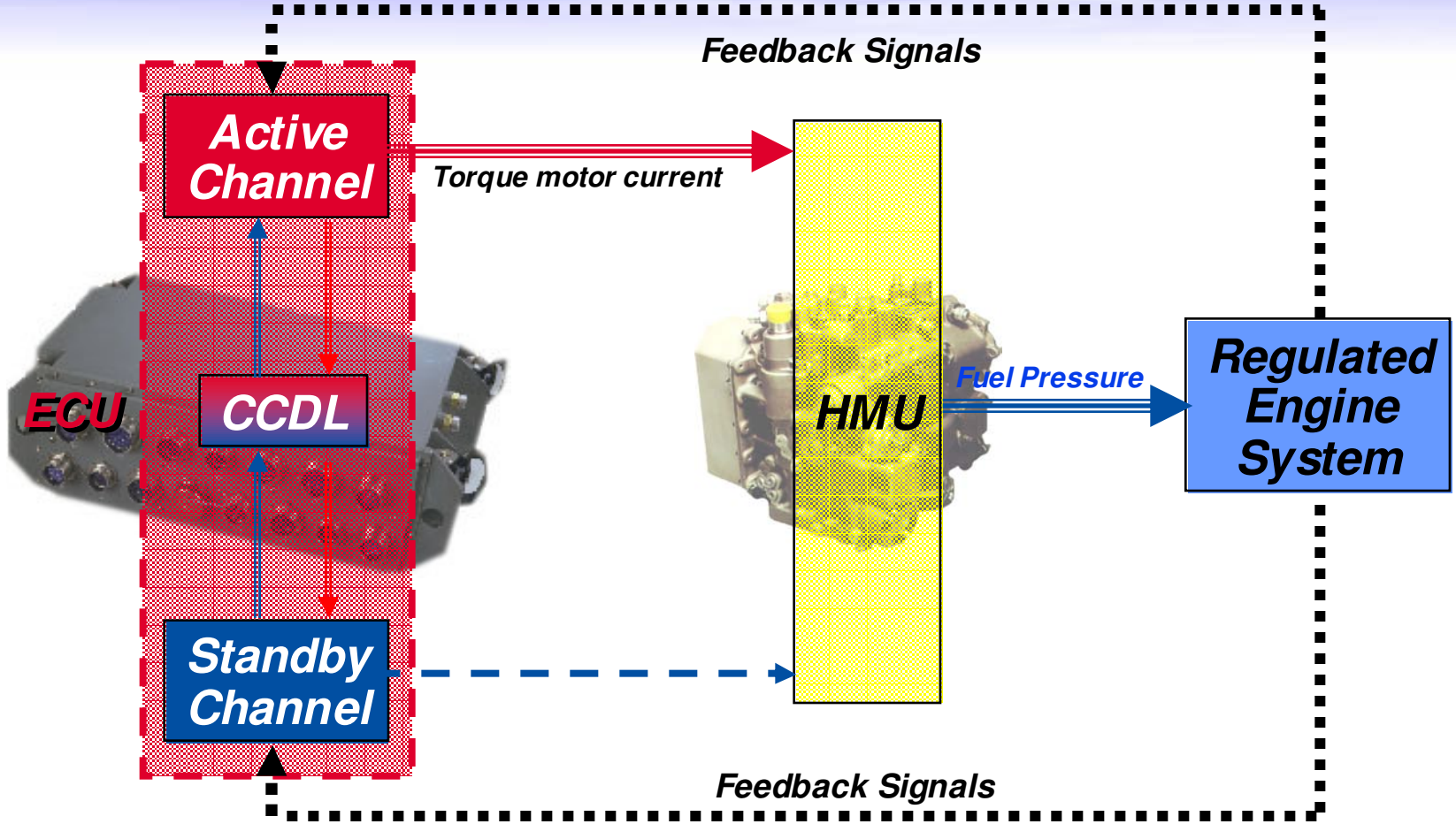
- It detects and isolates failures or combinations of failures in order to determine the channel health status and to transmit maintenance data to the aircraft. Each channel determines its own health status. The healthiest channel is selected as the active channel.

- The selection is based upon the health of each channel. Active / Stand-by channel selection is performed
  - At EEC power-up and during operation.
  - At every engine start if equal health status exists ,as soon as N2>70%.

- If a channel is faulty and the channel in control is unable to ensure one engine function, this controlled function is moved to a fail-safe position.

Engine Control System

FADEC Philosophy

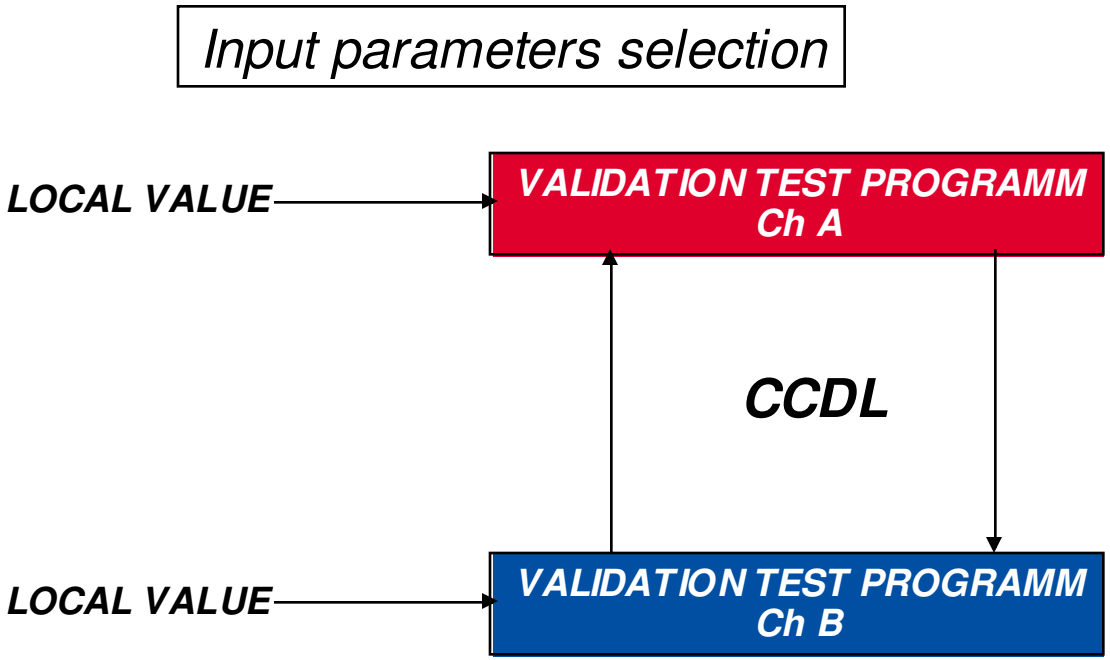


Designed with a dual-redoundant architecture

Engine Control System

FADEC Philosophy

All electrical inputs, sensors and feedback signals are dual



Value selected:

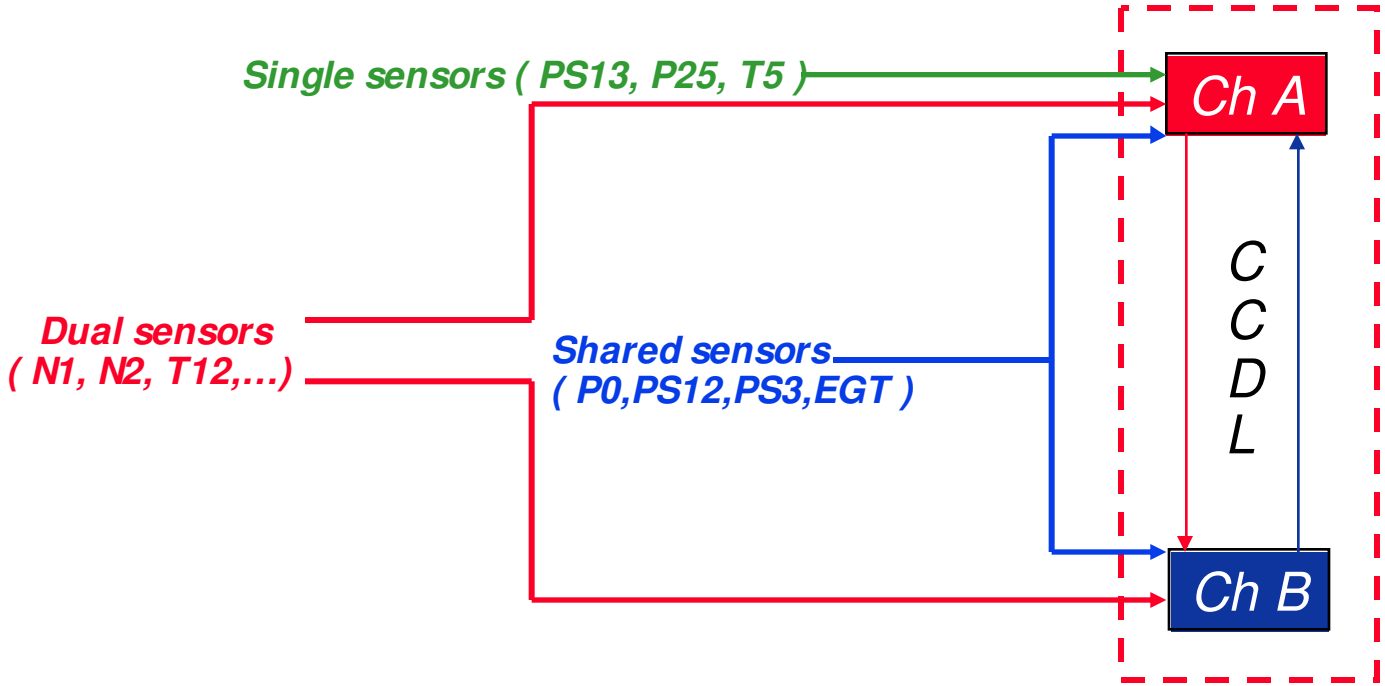
- *Average*
or
- *Local value*
or
- *Cross channel value*
or
- *Engine Model*
(N1, N2, PS3, T25, T3, FMV, VSV & VBV feedback position)
or
- *Failsafe Position*

A lost of parameter does not generate an ECU channel change as long as the CCDL is operative

Engine Control System

FADEC Philosophy

All electrical inputs, sensors and feedback signals are dual



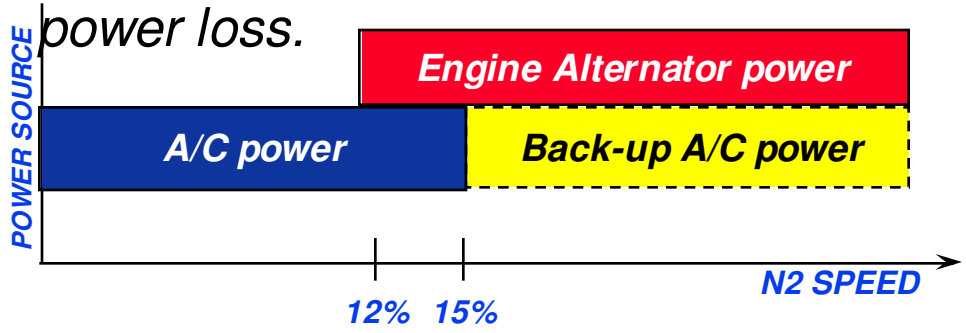
Engine Control System

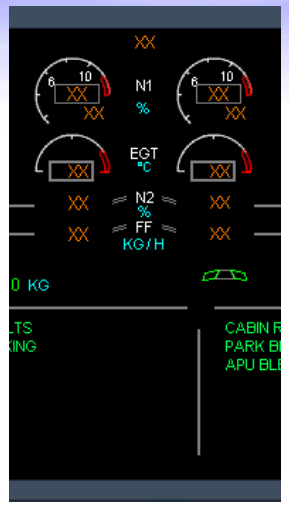
ECU: Electronic Control Unit

ELECTRICAL POWER SUPPLY

- Engine control alternator:
  - engine start up ⇨ when N2 > 15%.
  - engine shut down ⇨ until N2 < 12%.

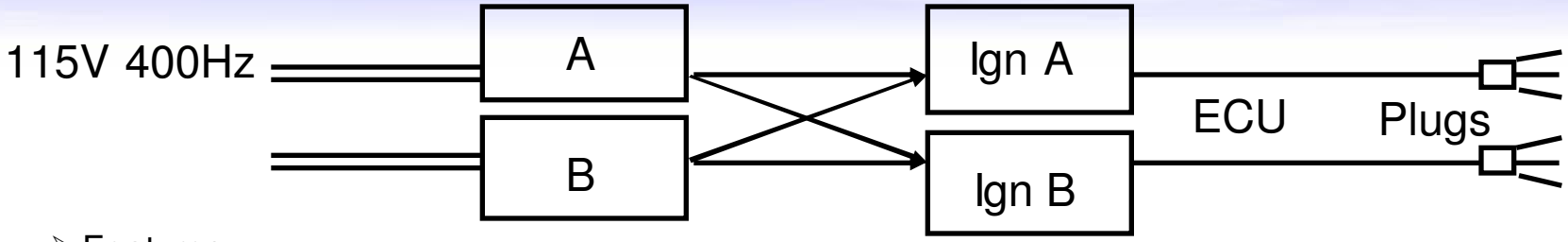
- Aircraft 28 v:
  - Engine is not running
  - engine start up ⇨ until N2 > 15%.
  - engine shut down ⇨ when N2 < 12%.
  - Back up power supply in case of alternator power loss.





ECU automatically powered down on ground through the EIVMU 15 min after shutdown or AC power up, unless MCDU used

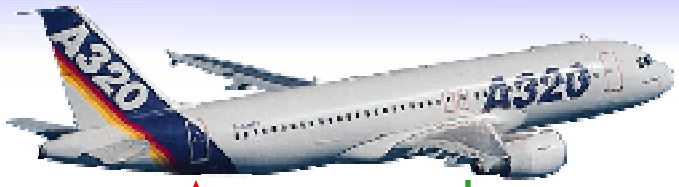
CFM56-5 Ignition System



- Features
  - Two independent systems per engine
    - Automatically alternated every two starts
  - Ignition on - slightly before fuel
  - Delayed ignition logic
  - Either channel can control both ignition boxes
  - Ignition off when N2 >50%
  - Auto message if either ignition delayed/failed
  - Auto relight if “flame-out” sensed
  - Pilot can select continuous ignition
  - Both ignitors on for all air starts and manual starts on the ground
  - Ignitors located at the 4 and 8 o’clock position on combustion case

Fuel Control System

Fuel distribution



10 Fuel Nozzles (Staged)

10 Fuel Nozzles (Unstaged)

BSV

Engine Oil Back To Oil Tank

Engine Oil From Scavenge Circuit

T<100 °C

SERVO FUEL HEATER
Raises the T° of the fuel

Fuel nozzle Filter

MAIN OIL/FUEL HEAT EXCHANGER
(cools the engine scavenge oil)

FRV

LP PUMP

FUEL FLOW TRANSMITTER

Servo Fuel Pressure

VSV
VBV
TBV
HPTCC
LPTCC

Metered Fuel

Fuel Filter

HP PUMP

IDG FUEL/OIL COOLER

Fuel Control System

Fuel distribution

MAIN OIL/FUEL HEAT EXCHANGER
Fuel coming from LP pump cools the engine scavenge oil. The cooled engine oil returns to the oil tank.

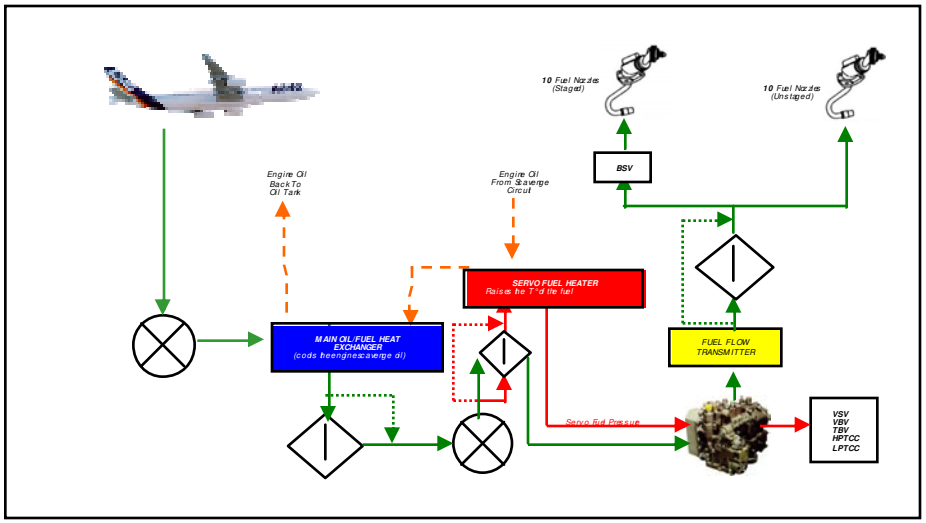
FUEL FLOW TRANSMITTER
Signals are created and sent to:
Ch A & Ch B of the ECU ⇨ **ENGINE CONTROL**

The DMCs for ECAM display in the flight deck ⇨ **INDICATING**

The FWCs for warning activation and display on ECAM ⇨ **INDICATING**

16 standard fuel nozzles (8 staged / 8 unstaged)

4 wider spray pattern fuel nozzles placed adjacent to the igniters to help engine operation during start and adverse weather conditions.(2 staged / 2 unstaged)



SERVO FUEL HEATER
Raises the T° of the fuel to eliminate ice in the fuel before entering the control servos, inside the HMU.
Catch particles in suspension in the oil circuit, before the oil is coming back to the oil tank.

Fuel Control System

BSV

- The BSV « Burner Staging Valve » controls fuel flow to the 10 staged fuel nozzles.

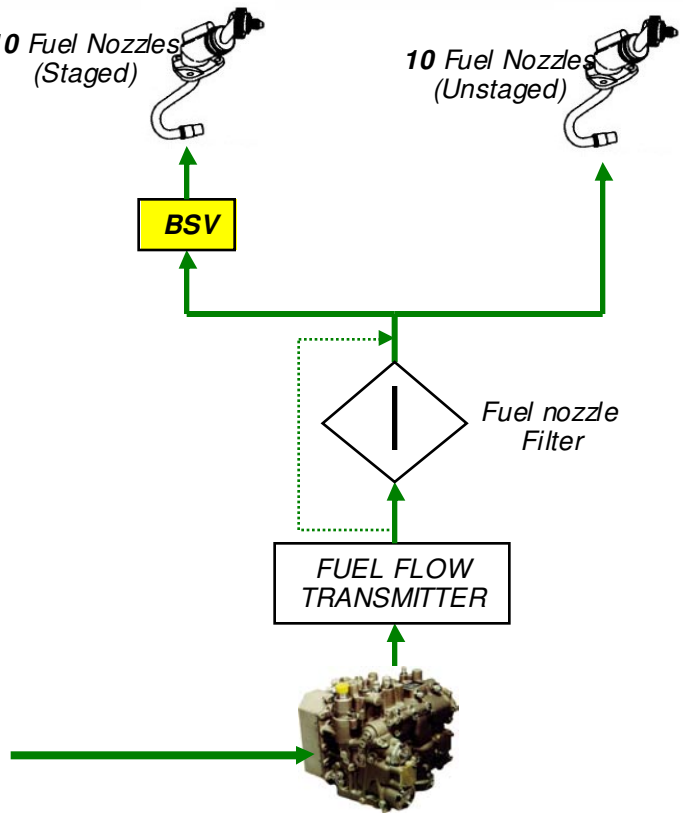
- The BSV will close in decel to keep the Wf above the lean flame out limit.

- With BSV closed, a stronger flow of fuel goes to the unstaged fuel nozzles. This makes a stronger flame pattern in the combustion chamber wich helps to provide a better flameout margin at low power.

- At higher power, the BSV opens and lets fuel flow to the staged nozzles.

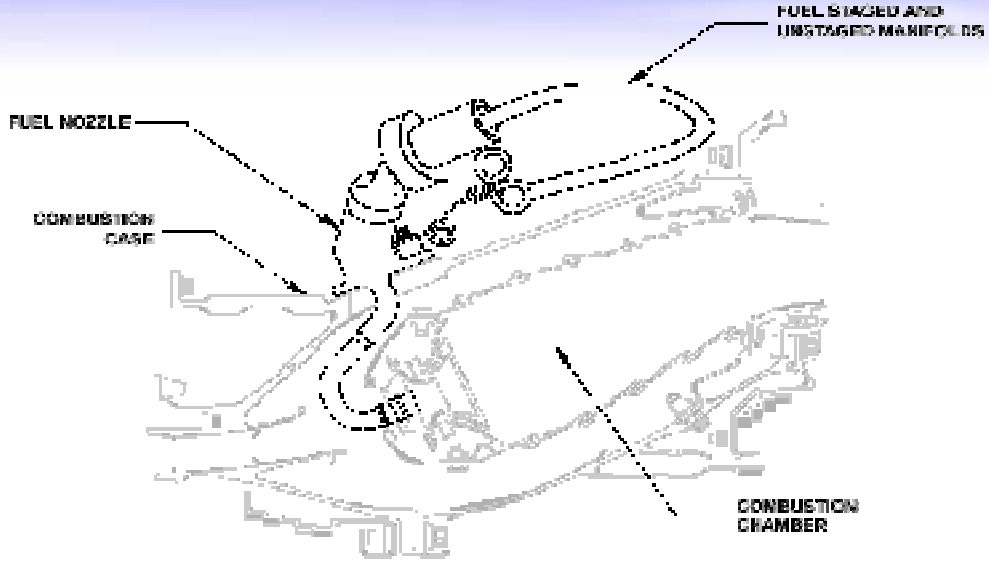
- **BSV is remains open for these conditions:**

  - Engine at steady state on the ground
  - ECU cannot read the BSV position

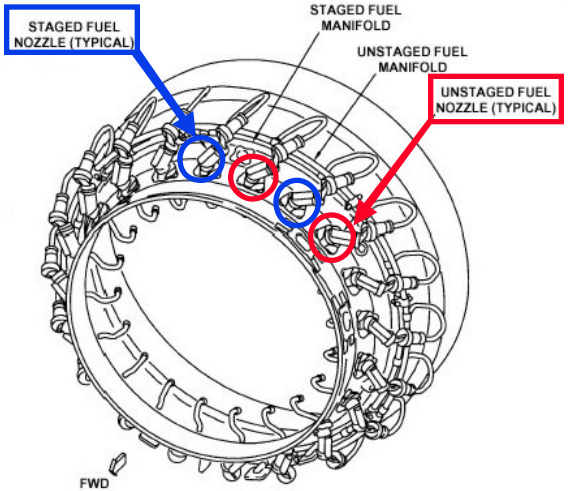


Fuel Control System

FUEL NOZZLES



FUEL NOZZLE



FUEL DISTRIBUTION - FUEL MANIFOLD

16 standard fuel nozzles (8 staged / 8 unstaged)

4 wider spray pattern fuel nozzles placed adjacent to the igniters to help engine operation during start and adverse weather conditions.
(2 staged / 2 unstaged)

Fuel Control System

HMU by-pass Fuel flow / Oil Cooler

IDG *Cooling System & FRV*

FRV

The ECU controls

The fuel return flow to the aircraft through the FRV according to the oil T°

The Modulated Idle to create a higher fuel flow
(more dissipation of IDG oil T°)

IDG oil T° = Engine oil T° * 0.7

The FRV selects *3 levels of returning fuel flow*

Zero Flow
Low Flow
High Flow

Fuel Control System

IDG Cooling System & FRV

- *The IDG cooling logic performs two functions:*
  - *The **control of the FRV***
  - *The **control of the mini N2***
- *Both functions cool the IDG oil by cooling the fuel that goes into the IDG oil/fuel heat exchanger.*
- *The **FRV system returns hot fuel back to the aircraft fuel tanks**. This enables cooler fuel to be pumped to improve the IDG oil cooling.*
- *The **mini N2 controls the temperature by increasing the idle speed** of the engine. The fuel T° ⇩ because of the additional flow, due to the N2 increase.*

Fuel Control System

IDG Cooling System & FRV

Fuel Return Flow:

Low return = 300 Kg/h hot fuel + 200 Kg/h cold fuel
High return = 600 Kg/h hot fuel + 400 Kg/h cold fuel

GROUND → oil T° > 90°c → Low Return until oil T° < 78°c

FLIGHT → oil T° > 90°c → Low Return until oil T° < 78°c

FLIGHT → oil T° > 95°c → High Return until oil T° < 85°c then Low Return

Fuel Control System

IDG *Cooling System & FRV*

IDG Modulated Idle:

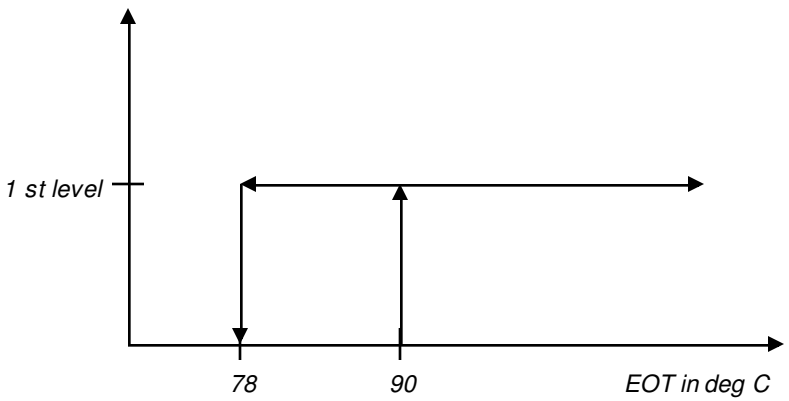
GROUND → No Modulated Idle

FLIGHT → oil T° > 106°c → N2% ⇗ from 54 up to 77%
(oil T° from 106 up to 128°c)

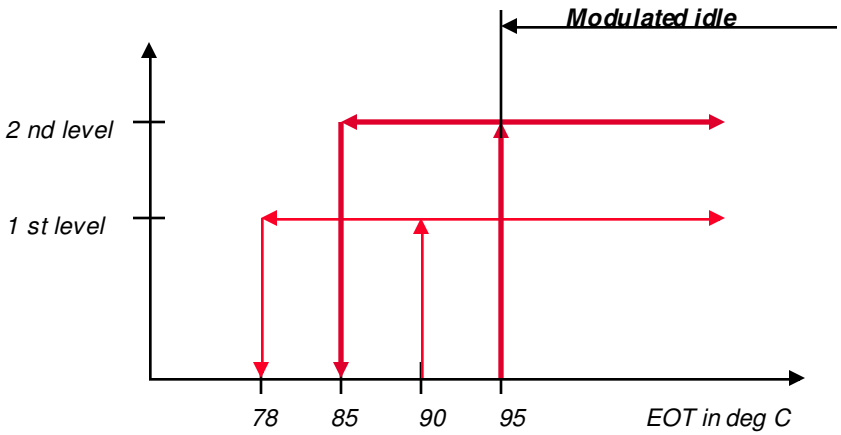
Fuel Control System

➢ FRV Operation:

Ground



Flight



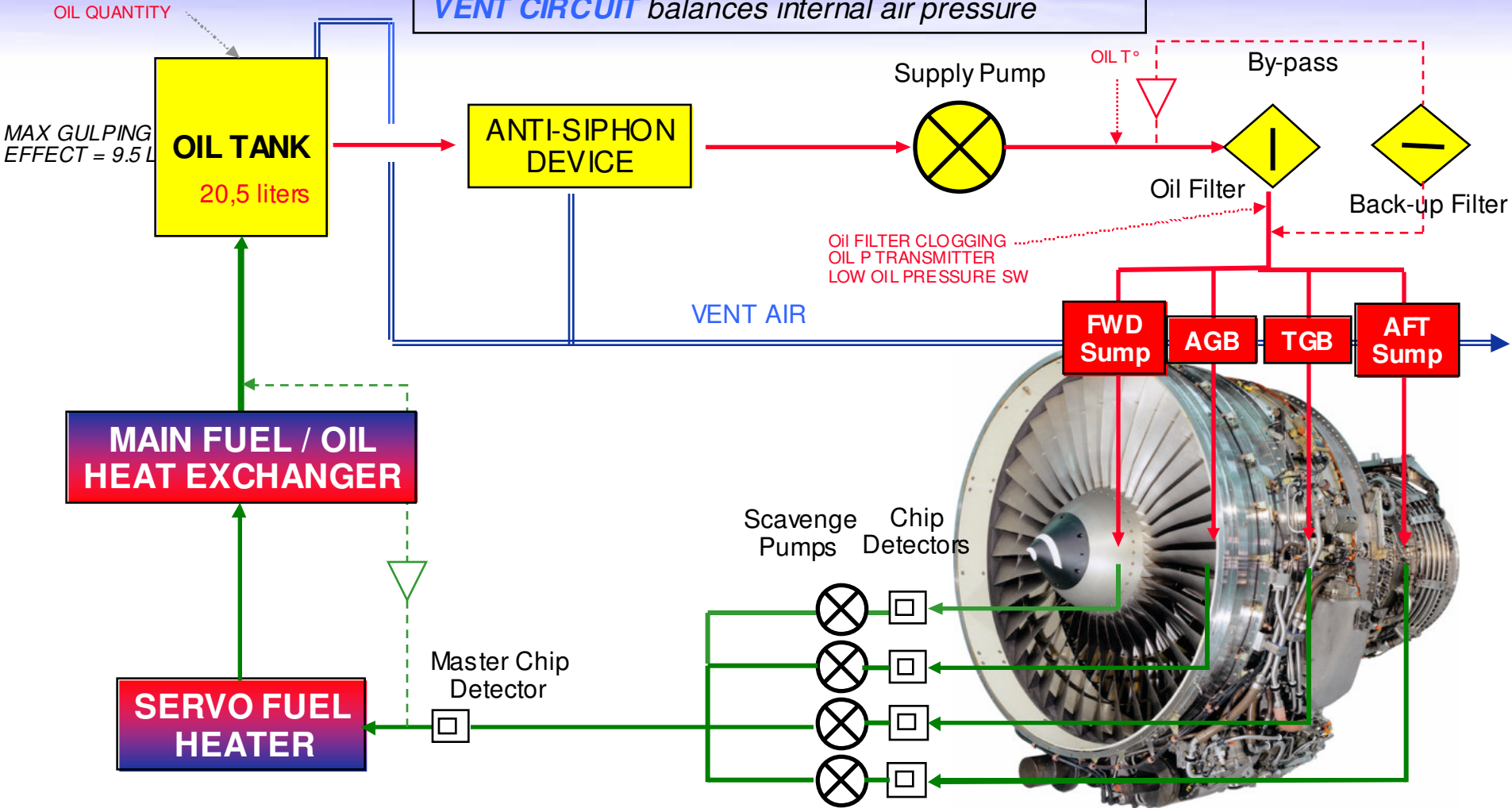
Fuel Control System

- ***FRV will be closed:***

  - *if N2 < 50% during engine start*
  - *at engine shut down (Master Lever Off)*
  - *During take off and climb (Fuel Flow reference)*
  - *if wing tank level < 280 Kg*
  - *if fuel over flow in surge tank*
  - *if fuel feed is by gravity only*
  - *if fuel T° > 52°c in the wing tank (in flight)*

Oil System CFM56-5B

SUPPLY CIRCUIT lubricates Bearings & Gears
SCAVENGE CIRCUIT: Oil back from engine to tank.
VENT CIRCUIT balances internal air pressure



Air Control System

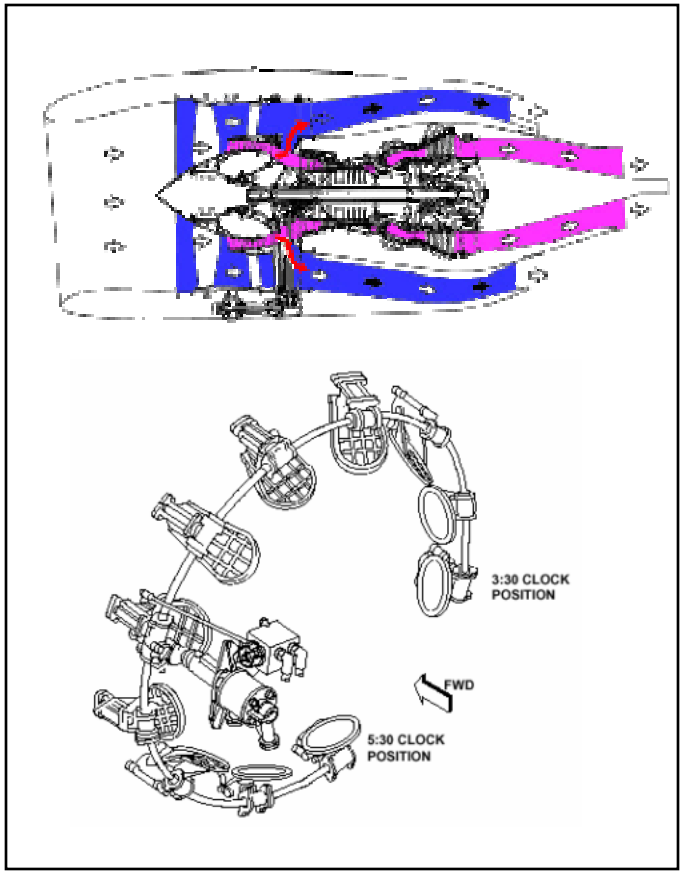
Compressor Airflow Control → **VSV**, **VBV**

Engine Clearance Control → **TBV**, **HPTCC**, **LPTCC**

Air Control System

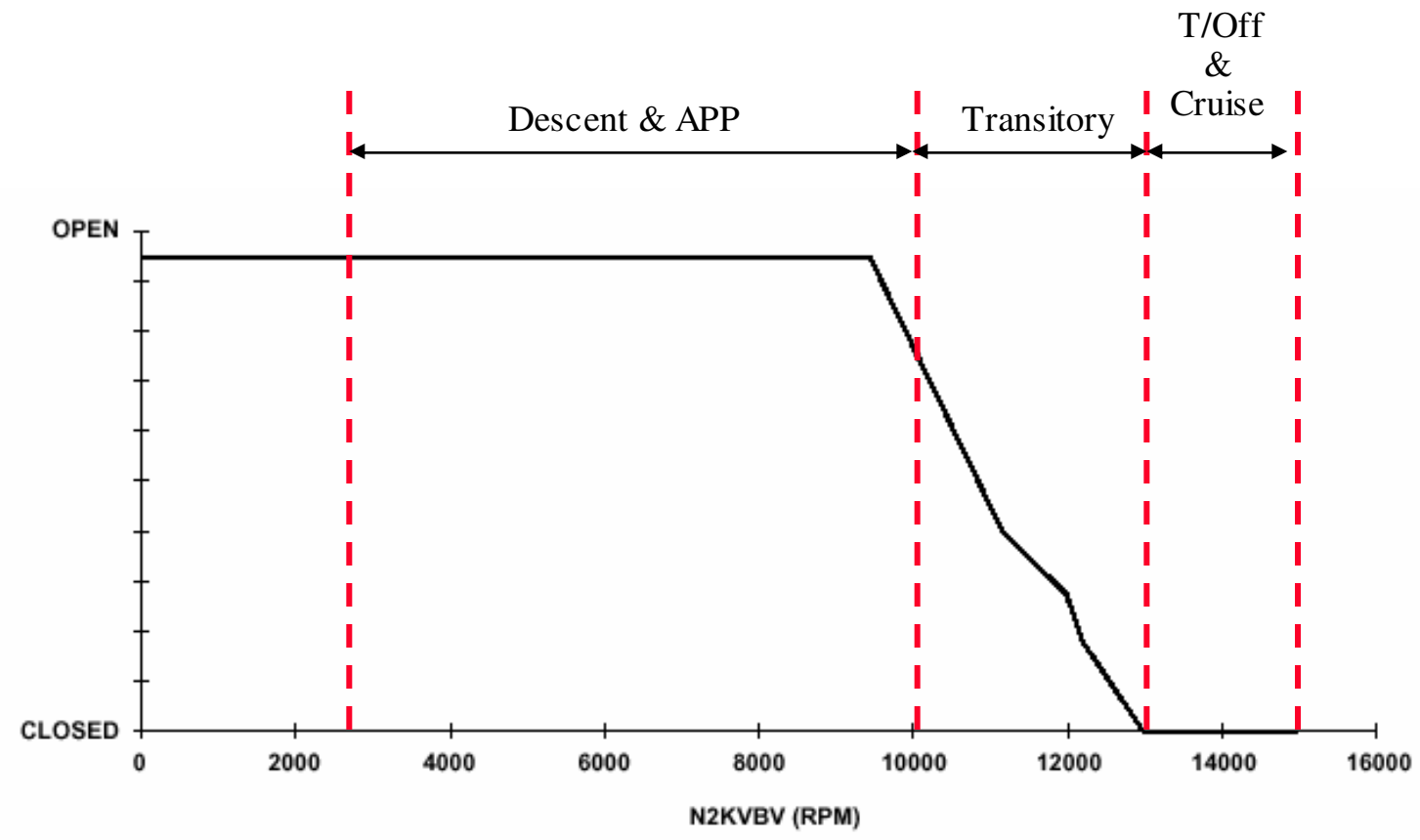
VBV: Variable Bleed Valve

- The VBV system controls the LPC discharge airflow.
- The VBV system bleeds the LPC air out into the secondary airflow to prevent stalls, reduce water and foreign object damage ingestion into the HPC.
- The ECU uses the HMU to control the VBV system.
- The HMU sends servo fuel pressure to move the VBV actuator.
- The actuator sends an electrical position feedback signal to the ECU.



Air Control System

Variable Bleed Valve



Air Control System

Variable Bleed Valve

1 Acceleration Schedule

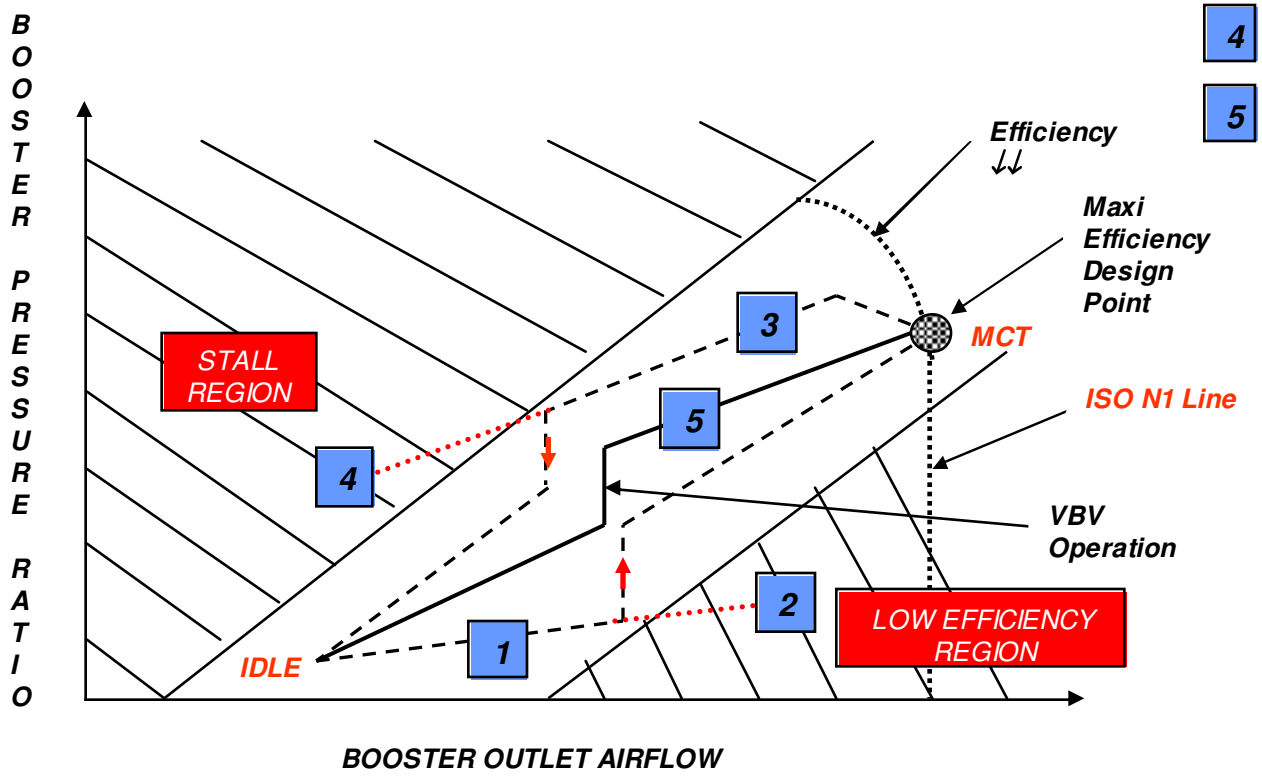
2 If VBV not closed

3 Deceleration Schedule

4 If VBV not open

5 Operating Line

Typical LPC flow chart



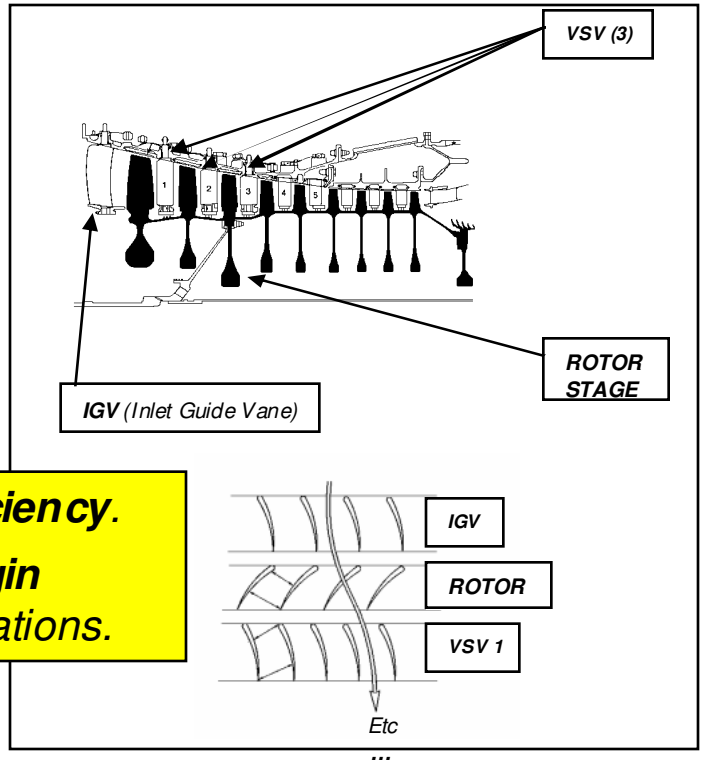
- **Low speed or Deceleration ⇒ VBV OPEN**
- **High speed or acceleration ⇒ VBV CLOSED**

Air Control System

VSV: Variable Stator Vanes

- The VSV system controls the HPC inlet airflow.
- The VSV system gives the correct quantity of air to the HPC.
- The ECU uses the HMU to control VSV system.
- The HMU sends servo fuel pressure to move 2 VSV actuators.
- The 2 actuators move th variable stator vanes.
- Each actuator sends an electrical position feedback signal to the ECU.

- **VSV optimise HPC efficiency**.
- **VSV improve stall margin** for transient engine operations.



Air Control System

VSV: Variable Stator Vanes

Transient if:
App idle is selected or, either FMV or VSV parameter is invalid or, N2 Accel or Decel rate changed or, actual N2 < N2min + 100 rpm with N2 < 10875 rpm

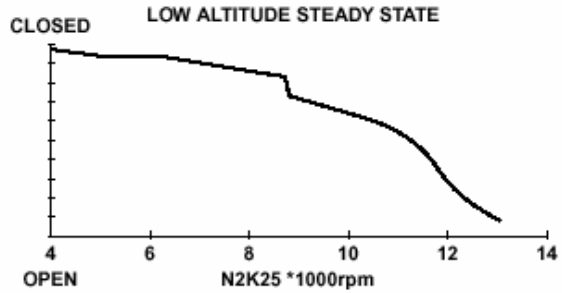
Steady

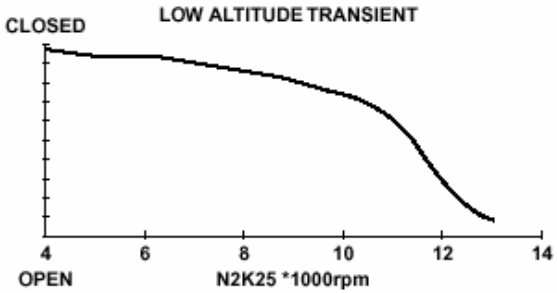
Transient

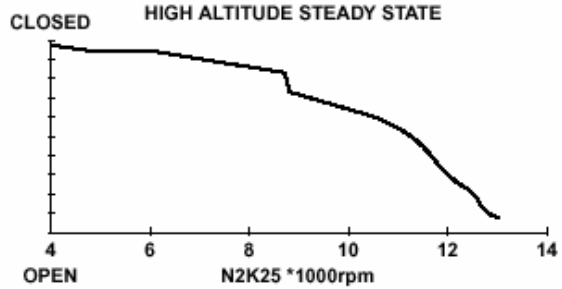
Low Z < 17500 ft

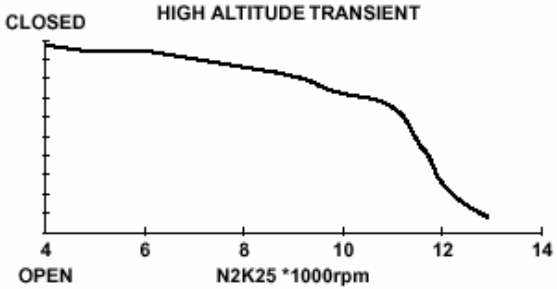
If between, the previous selected position is confirmed

High Z > 25000 ft









Air Control System

Variable Stator Vanes

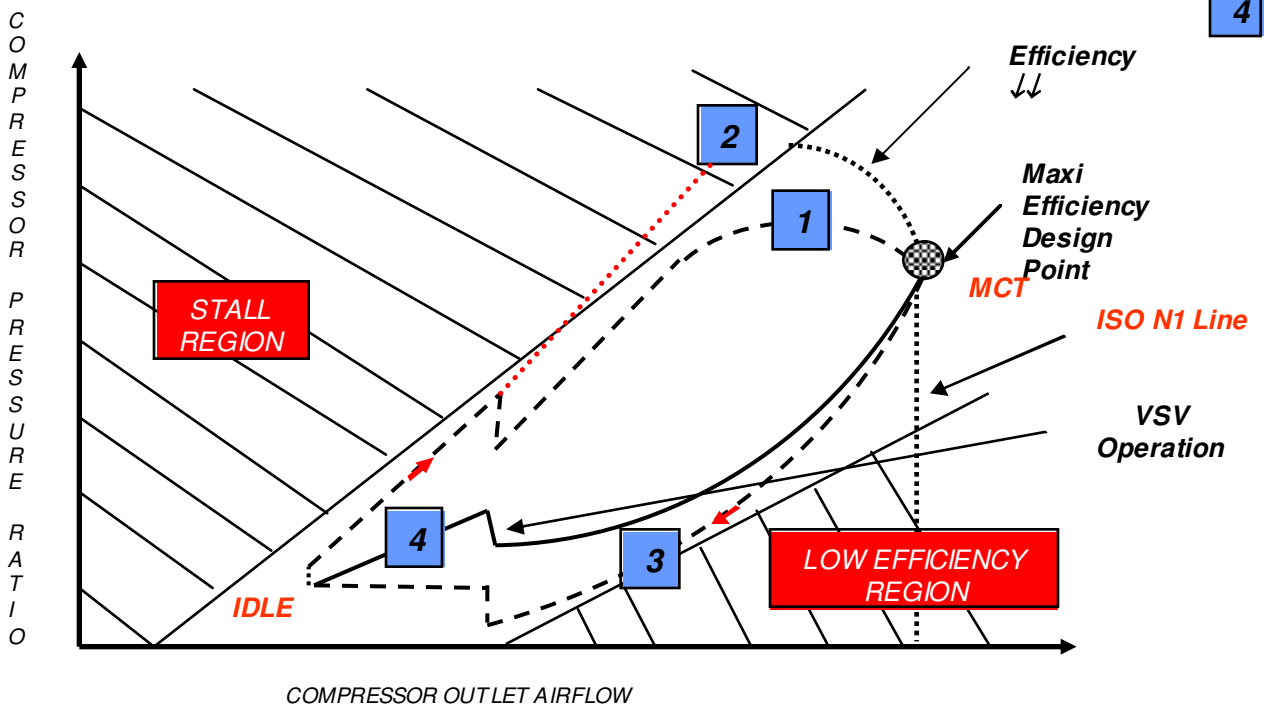
1 Acceleration Schedule

2 If VSV not open

3 Deceleration Schedule

4 Operating Line

Typical HPC flow chart

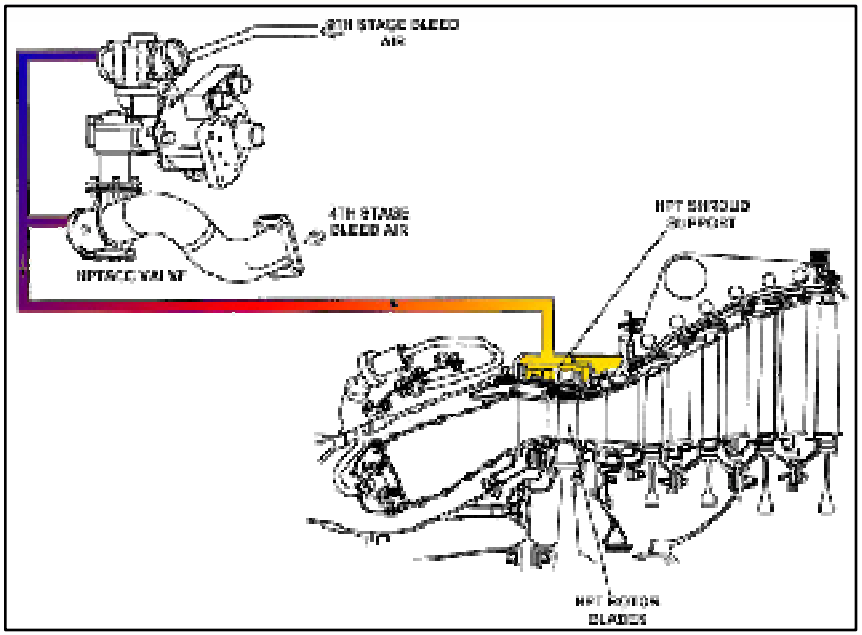


- **Low speed or deceleration ⇒ VSV CLOSED**
- **High speed or acceleration ⇒ VSV OPEN**

Air Control System

HPTCC: High Pressure Turbine Clearance Control

- The High Pressure Turbine Clearance Control system controls the HPC 4th stage (-5A, 5th stage) & 9th stage air send to the HPT shroud support.
- The air flows through an HPTCC Valve.
- The ECU uses the HMU to control the position of the HPTCC Valve.
- The HMU sends servo fuel pressure to move the HPTCC valve actuator.
- The HPTCC actuator sends an electrical position feedback signal to the ECU.

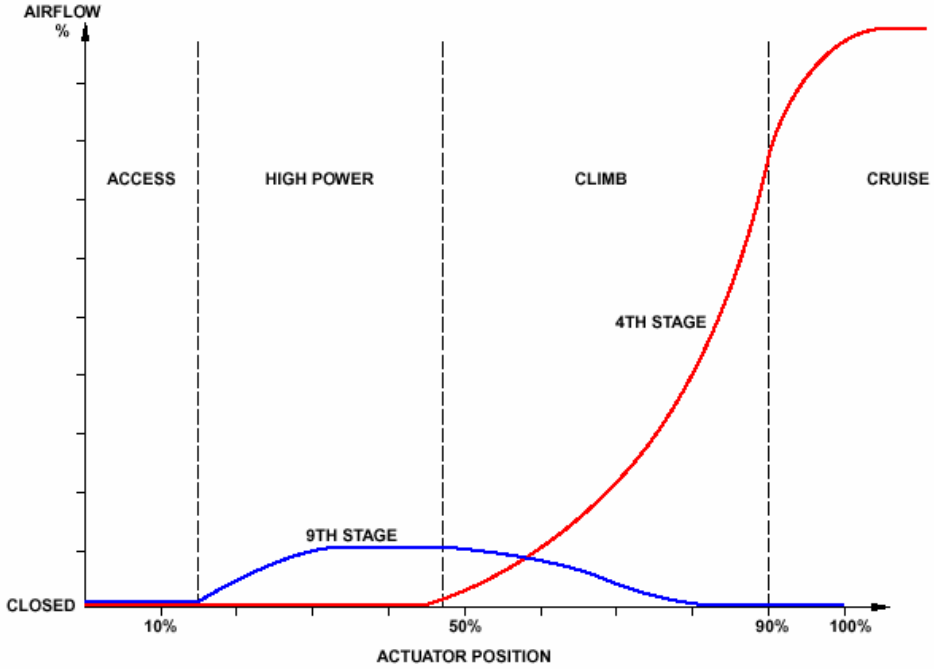


Tighter clearance
⇩
SFC ↘↘

Air Control System

HPTCC: High Pressure Turbine Clearance Control

NO AIR	-	BOTH BUTTERFLIES CLOSED	-	FAILSAFE POSITION
9th	-	9th STAGE BUTTERFLY OPEN	-	IDLE, TAKE-OFF, START BLEED
MIXED	-	BOTH BUTTERFLIES OPEN	-	CLIMB
4th	-	4th STAGE BUTTERFLY OPEN	-	CRUISE



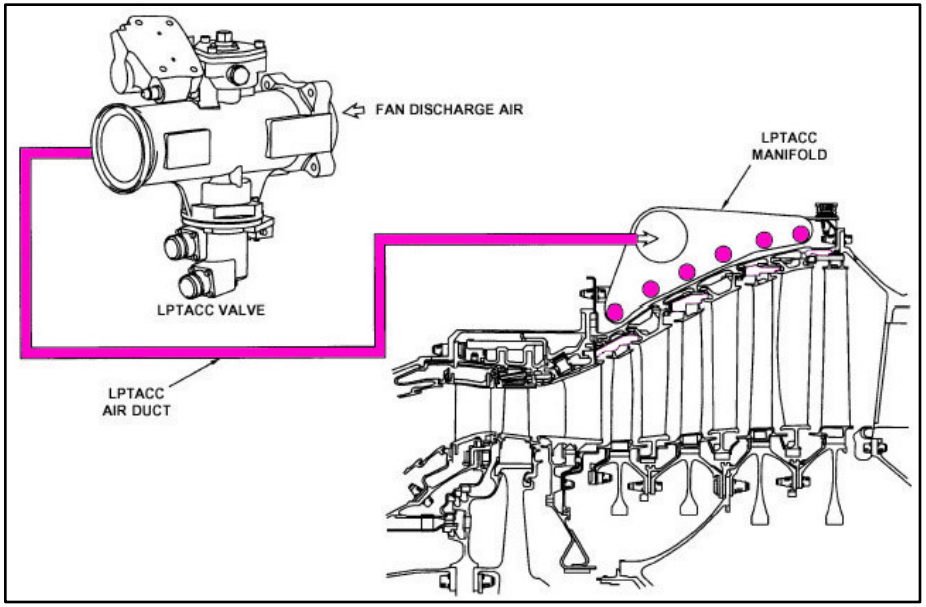
HPTCC OPERATING SCHEDULE

1-140-00

Air Control System

LPTCC: *Low Pressure Turbine Clearance Control*

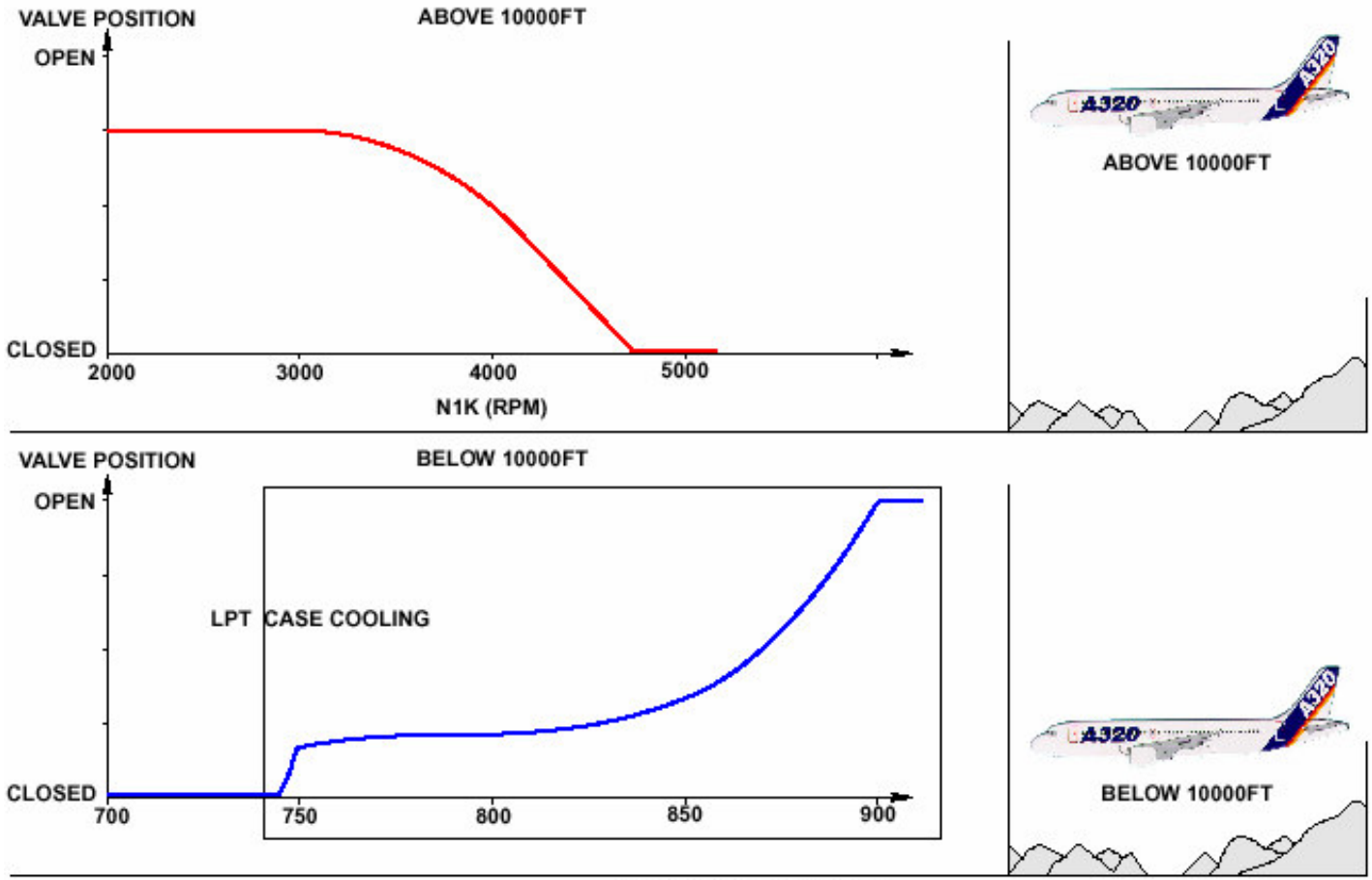
- *The Low Pressure Turbine Clearance Control system controls the amount of Fan discharge air that goes to the LPT case.*
- *The air flows through the LPTCC valve.*
- *The ECU uses the HMU to control the position of the LPTCC valve.*
- *The HMU sends servo fuel pressure to move the LPTCC valve actuator.*
- *The LPTCC actuator sends an electrical position feedback signal to the ECU.*



Tighter clearance
⇩
SFC ↘↘

Air Control System

LPTCC: *Low Pressure Turbine Clearance Control*

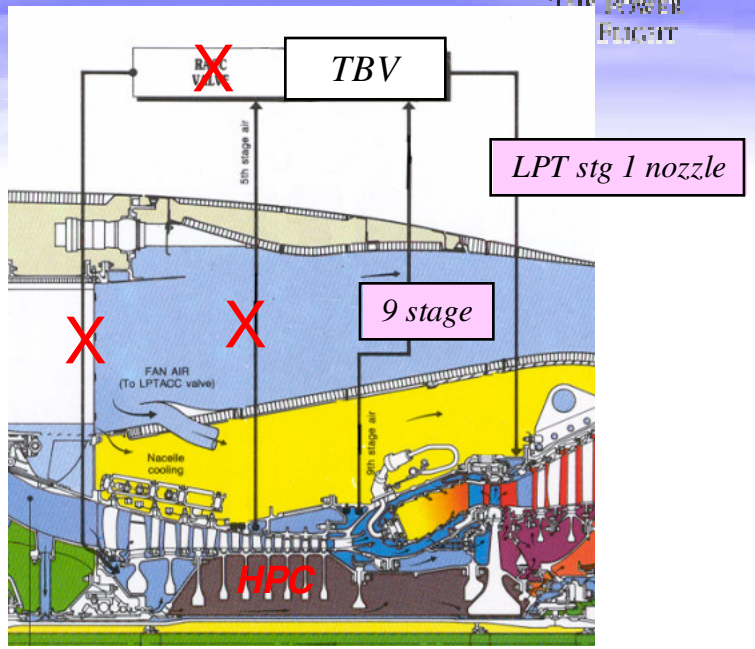


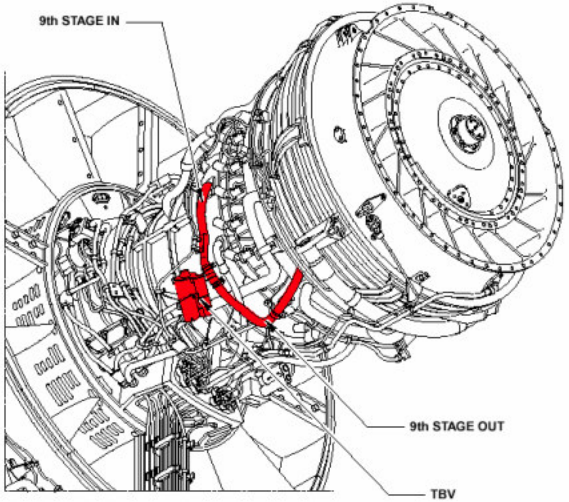
LPTC SCHEDULES

Air Control System

TBV: Transient Bleed Valve

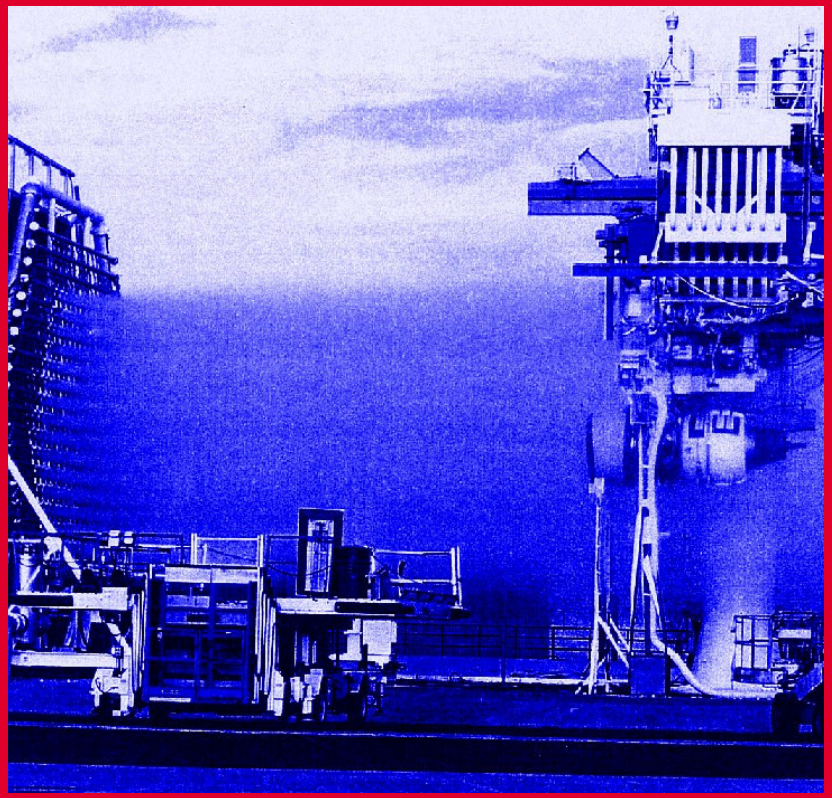
- The TBV system improves HPC stall margin during engine start and acceleration
- The air flows through the TBV.
- The ECU uses the HMU to control the position of the TBV.
- The HMU sends servo fuel pressure to move the TBV actuator.
- The TBV actuator sends an electrical position feedback signal to the ECU.





TBV SYSTEM LOCATION

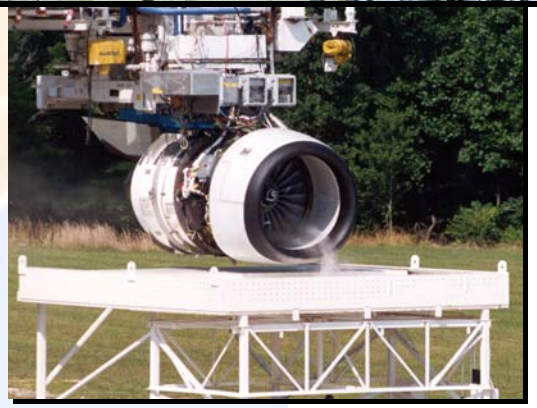
Engine Certification & Testing



- Block test
- Vibration test
- Blade containment
- Ingestion tests
  - Water
  - Hail
  - Ice slab
  - Hail stone
  - Birds (medium & large)
  - Mixed sand & gravel
- Induction system icing test
- Overtemperature test

Engine Certification

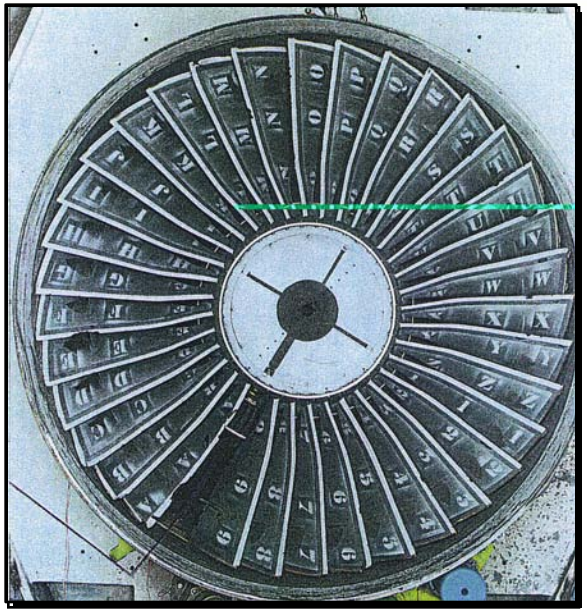
A variety of development and certification tests are conducted on CFM56 engines. Ground testing is primarily accomplished by GEAE's Peebles Test Operation in Peebles, Ohio and by comparable SNECMA facilities in France like Saclay. Flight testing is accomplished by GEAE's Flight Test Operation in Victorville, California.



This presentation summarizes some of these tests and test facilities used.

Engine Certification

Blade containment test



Test Objectives

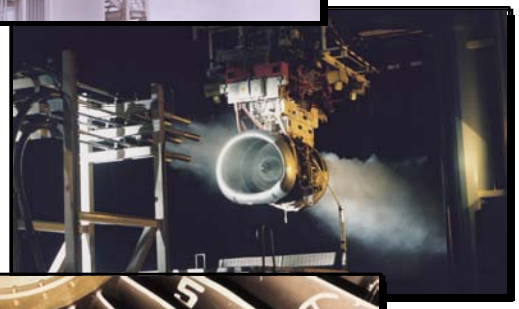
- Demonstrate fan blade containment inside casing
- No fire accepted
- Engine mounting attachments must not fail
- Engine shut-down capacity within 15 sec.

Main goal is to show no hazard to the aircraft

Test description

- Engine running at or above maximum allowed fan speed
- 1 fan blade released : explosive in shank of released blade.

Engine Certification



Ingestion tests

To demonstrate the capability of the engine to operate satisfactorily while ingesting simulated foreign object.

- *<u>with no substantial thrust loss</u>*

- water : 4% (in weight) of total airflow
- hailstones : 25 x 2 " + 25 x 1" stones within 5 seconds
- ice from inlet : 2 x (1"x4"x6") slabs

- *<u>with less than 25% thrust loss</u>*

- medium birds : 3 x 1.5 lb. +1 x 2.5 lb. (core) in volley within 1 second and operate for a 20 minutes period
- mixed sand and gravel : 1 ounce for each 100 in. of inlet area

- *<u>with no hazard to the aircraft</u>*

- large bird : 1 x 6 lb. at most critical fan blade location.

Overtemperature test

A319/320/321 FLIGHT CREW OPERATING MANUAL	ABNORMAL AND EMERGENCY POWER PLANT	3.02.70 SEQ... P 13 REV...

ENG 1(2) EGT OVERLIMIT

- **Max pointer indications:**

  EGT above 915°C (or 950°C at take off power) and below 990°C :

  - THR LEVER (of affected engine) …….. .BELOW LIMIT

  Normal operation may be resumed and maintained until next landing.
  Report in maintenance logbook.

- **Max pointer indications:**

  EGT above 990°C :

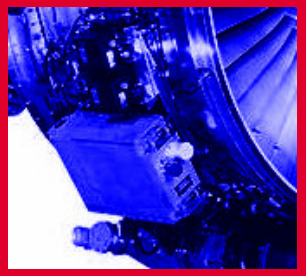
  - THR LEVER (of affected engine) ……IDLE
  - ENG MASTER (of affected engine) ……OFF

  If conditions do not permit engine shut-down land as soon as possible using the minimum thrust required to sustain safe flight.

ENG 1(2) SHUT DOWN

Apply after ENG SHUT DOWN procedure.

Demonstrate, by engine test, the ability to **operate for 5 minutes at 42°C / 75°F above declared limit** (N1, N2 at red line) with post-test inspection showing engines parts within serviceable limits.



CFM56 General

Technical Features

Engine Certification & Testing

Operational Characteristcs

EGTMargin, OATL

Reduced TakeOff Thrust

Normal Operating Considerations

Flight phases, ops recommendations

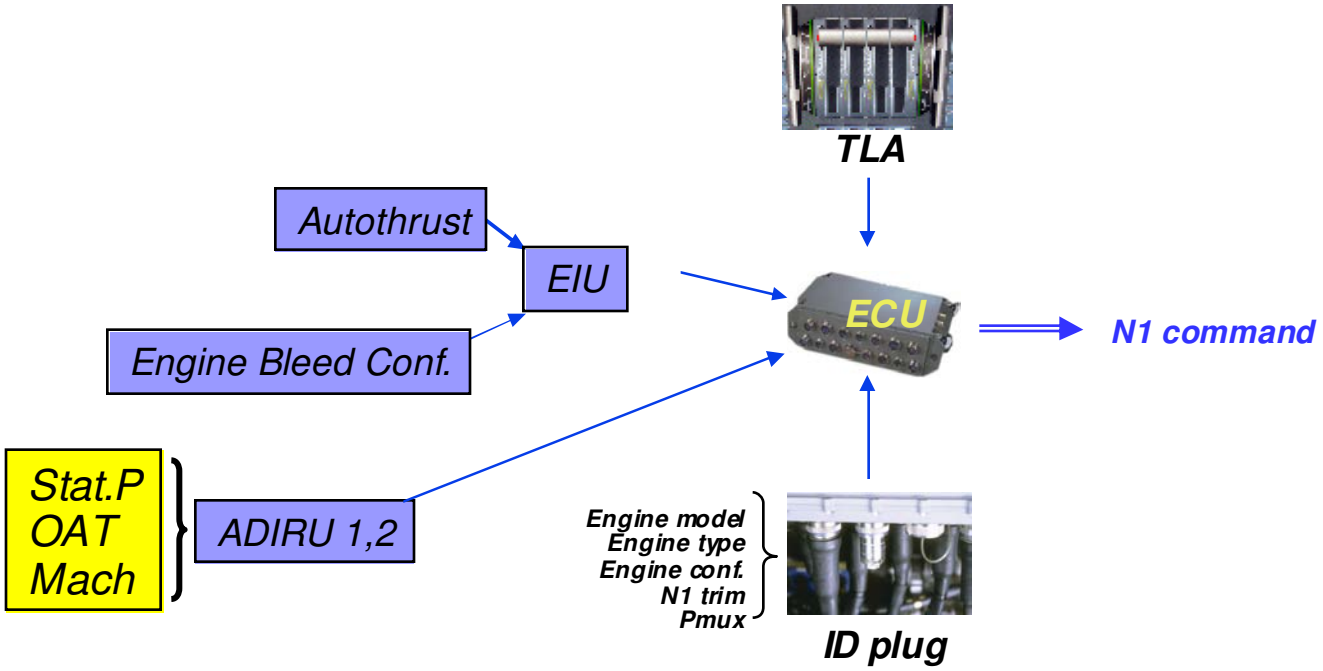
THE POWER OF FLIGHT

Power Management

The Power Management computes the N1 necessary for a desired thrust.

The FADEC manages power, according two thrust modes:

- Manual mode
- Autothrust mode



Power Management

Idle Control

- At engine idle speed, the **bleed pressure** must be at, or above the aircraft demand.
  (Including **flame out protection** in bad weather)

- At engine idle speed, the N2 must satisfy:
  - Mini engine permissible core speed (N2=58.8%)
  - Mini accessories speed
  - Mini speed for IDG oil T° control

- Engine idle speed must comply with **Modulated Idle**
  - In flight, Flaps < 20° and Landing Gear retracted
  - On the ground to minimize the time to accelerate to maxi reverse

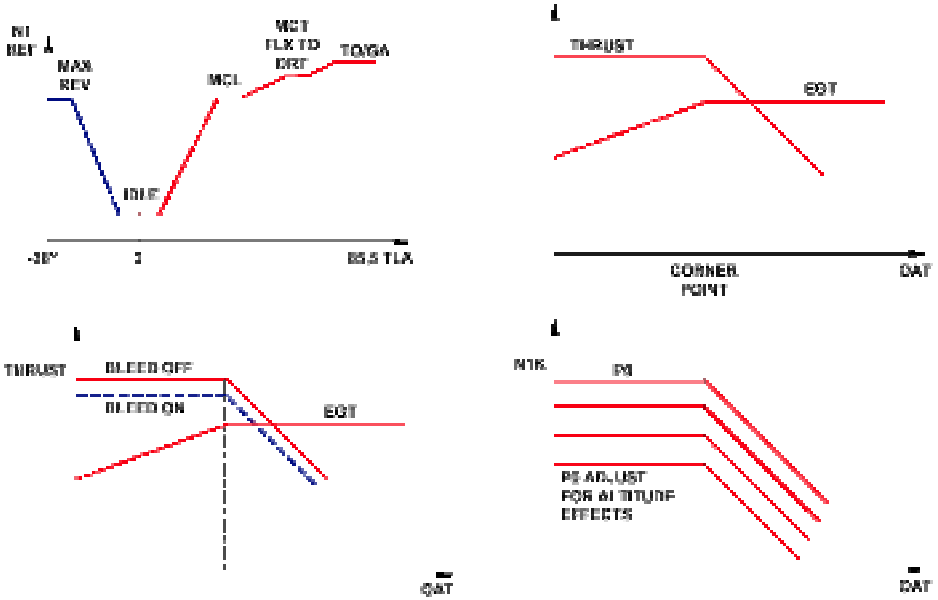
- Engine idle speed must comply with **Approach Idle**
  - Approach idle is the mini engine power possible when the mini Modulated Idle is not active.
  - The approach idle enables the engine to achieve the GO AROUND THRUST within 8s.

Power Management

The 8 baseline thrust ratings are calculated by the FADEC:

- ***MTO/GA*** *Maxi Take off / Go Around*
- ***DRT*** *Derate Take off*
- ***FLEX*** *Flexible Take off*
- ***MCT*** *Maxi Continuous*
- ***MCL*** *Maxi Climb*
- ***DCL*** *Derated Climb*
- ***IDLE*** *Idle Level*
- ***MREV*** *Maxi Reverse*

Each rating sets a fan speed N1, and each baseline rating is associated with a throttle flat. Thrust levels between these baseline ratings are set by interpolation depending on TLA.



Power Management

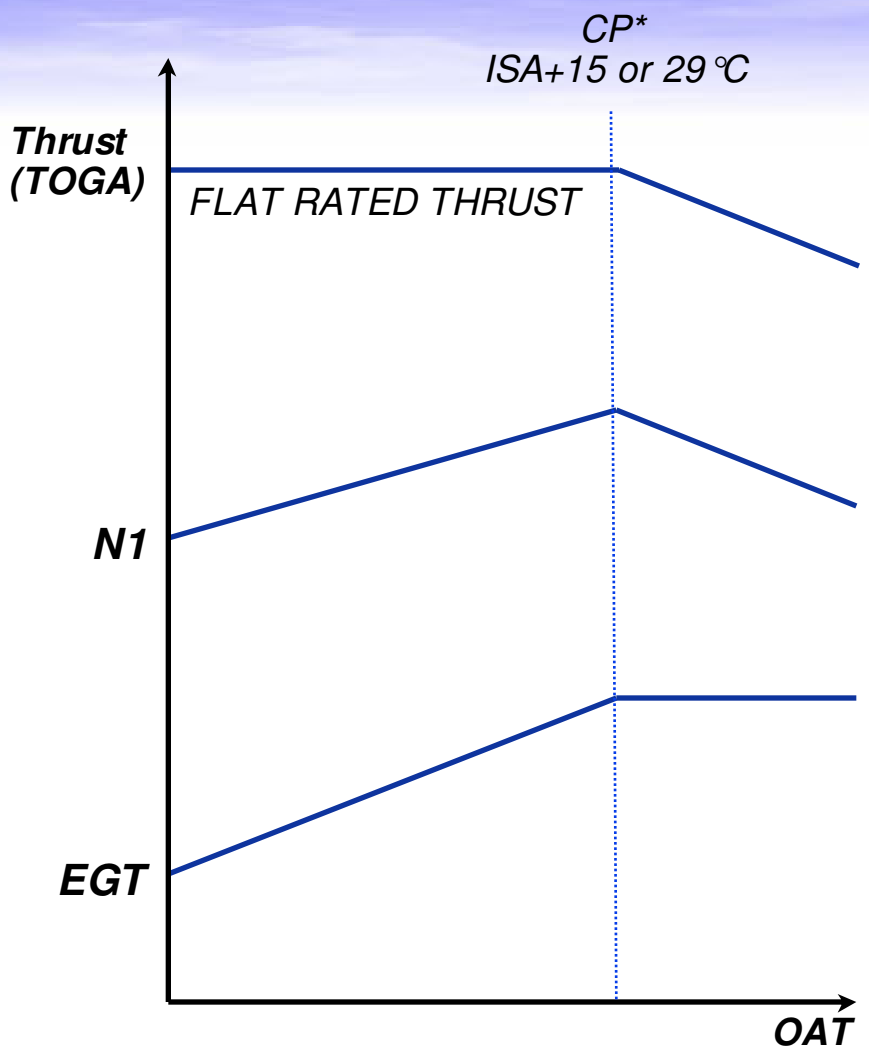
Flat Rate Concept

1. To meet aircraft performance requirements, the engine is designed to provide a given thrust level to some "Flat Rate" Temperature (FRT).

2. N_1 for takeoff power management schedule increases with OAT (up to FRT) to maintain constant thrust. After FRT, power management N_1 (and thrust) decreases.

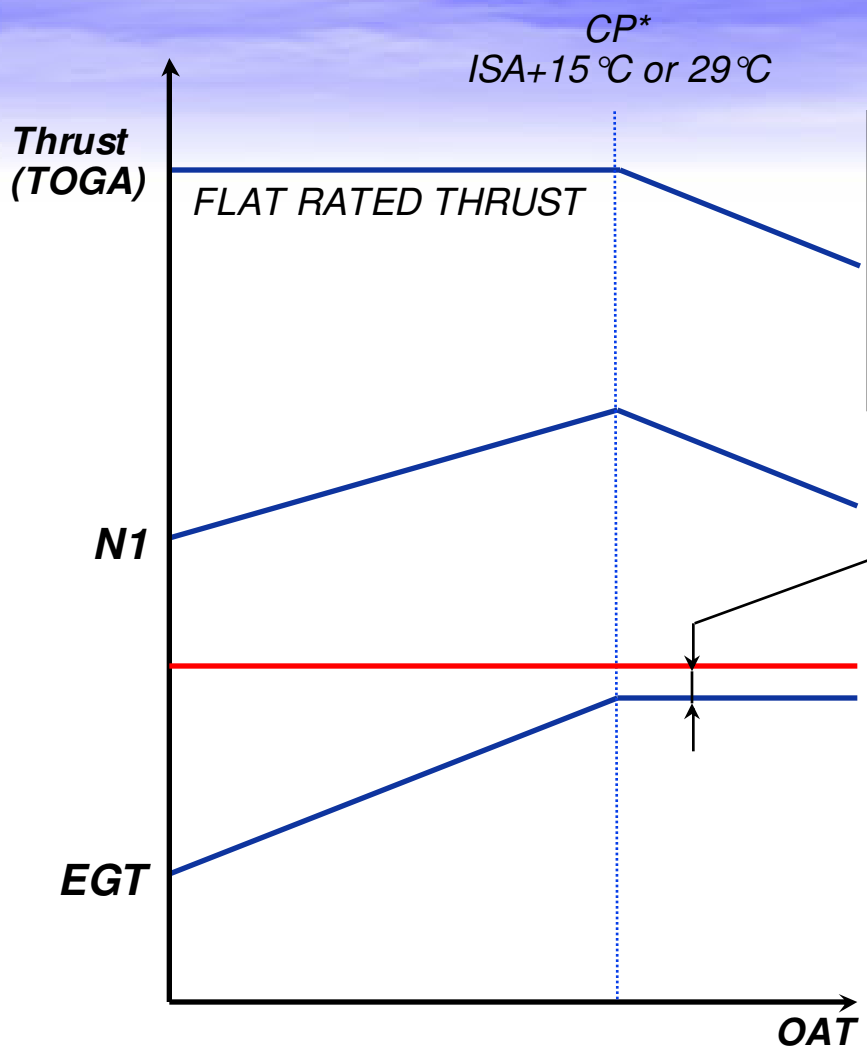
3. EGT increases with OAT to FRT, then remains constant.

At a given OAT, 1%N, is equivalent to approximately 10°C of EGT.



* CP: Corner Point or Flat Rated Temperature

EGTMargin & OATL



EGT MARGIN is the difference between:

- EGT RED LINE

&

- EGT observed on an engine at TOGA with a temperature ≥ CORNER POINT OAT

EGT MARGIN (CP ISA +15°C)

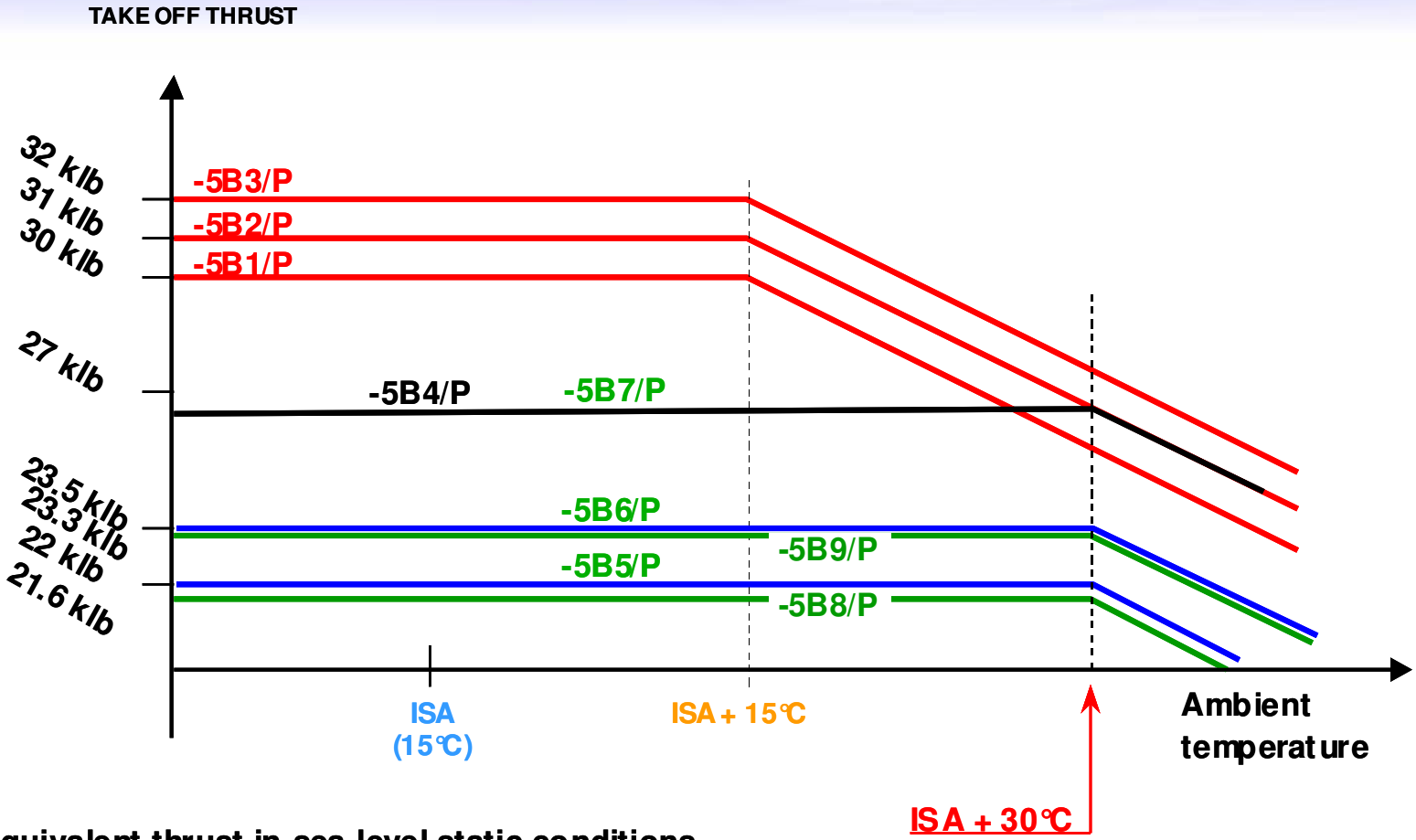
CFM56-5B1/P (30.000 lbs) ⇨ 114°c
CFM56-5B2/P (31.000 lbs) ⇨ 095°c
CFM56-5B3/P (32.000 lbs) ⇨ 068°c

CFM56-5B Fleet average

* CP: Corner Point or Flat Rated Temperature

Power Management

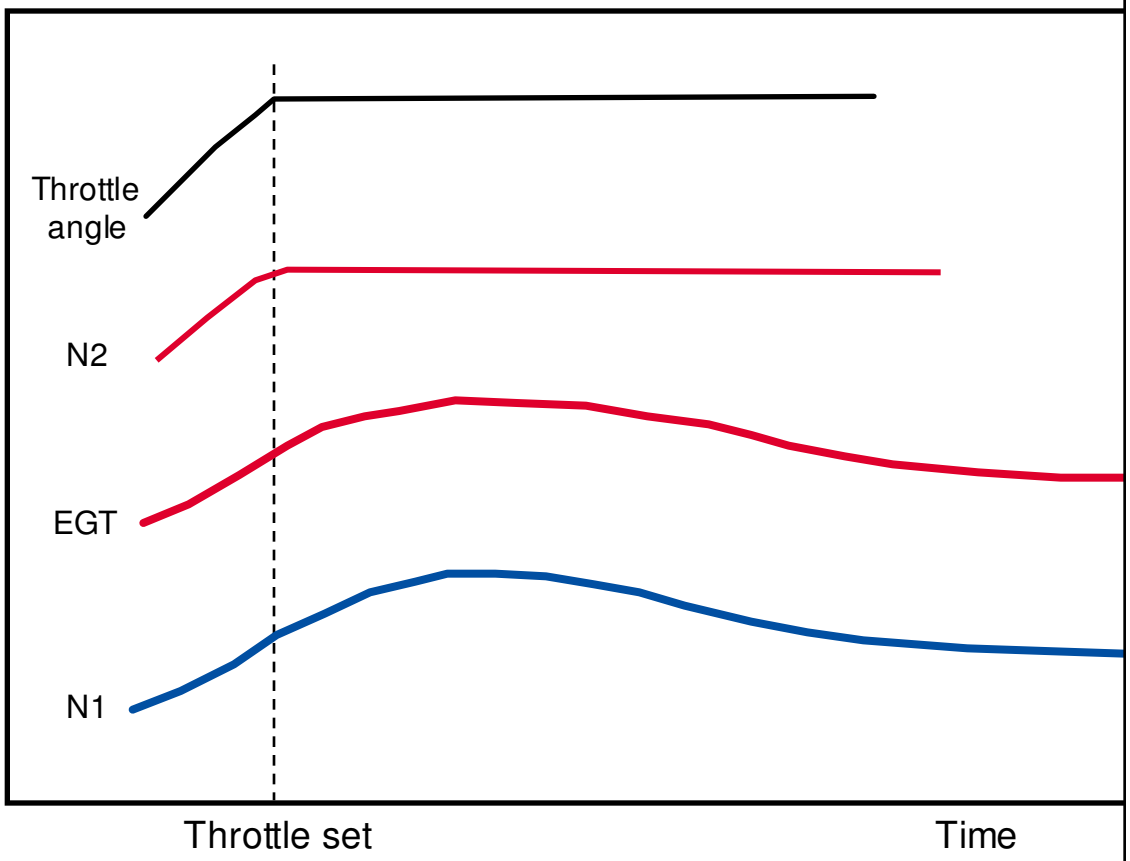
Flat Rate Concept



Equivalent thrust in sea level static conditions
-5B/P version, average engine, worst altitude conditions

Power Management

Transient Characteristics (Hydromechanical Control)

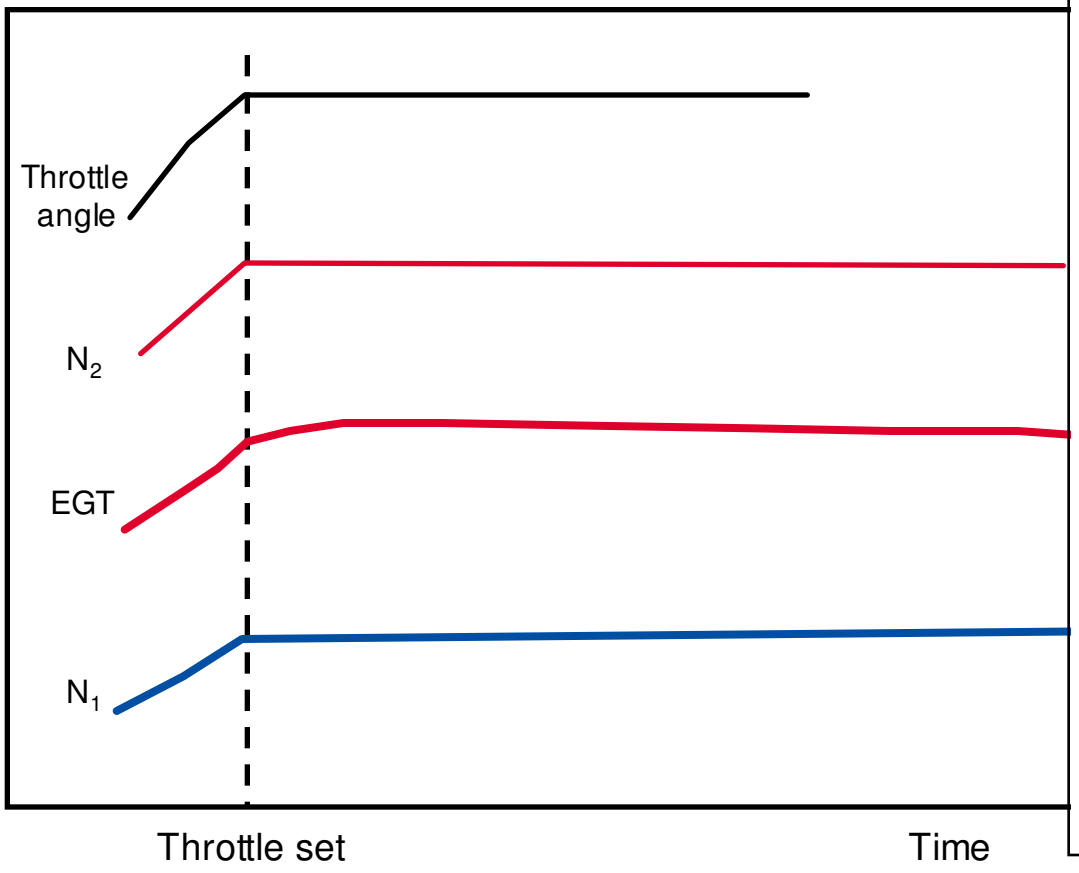


Throttles are advanced until target N1 is achieved. After throttle set, The Main Engine Control maintains the N2 corresponding to that throttle position. Because of different thermal characteristics of the core engine static and rotating components, the core becomes less efficient and a higher fuel flow and EGT is required to maintain N2. The increased energy available at the LPT causes N1 to increase: thus EGT and N1 "bloom". As the thermal growth of core components stabilize, the core becomes more efficient and EGT and N1 will decrease ("droop").

These transient characteristics are taken into account when determining power management N1 required to achieve aircraft performance. They are also taken into account when establishing operating limits for the engine.

Power Management

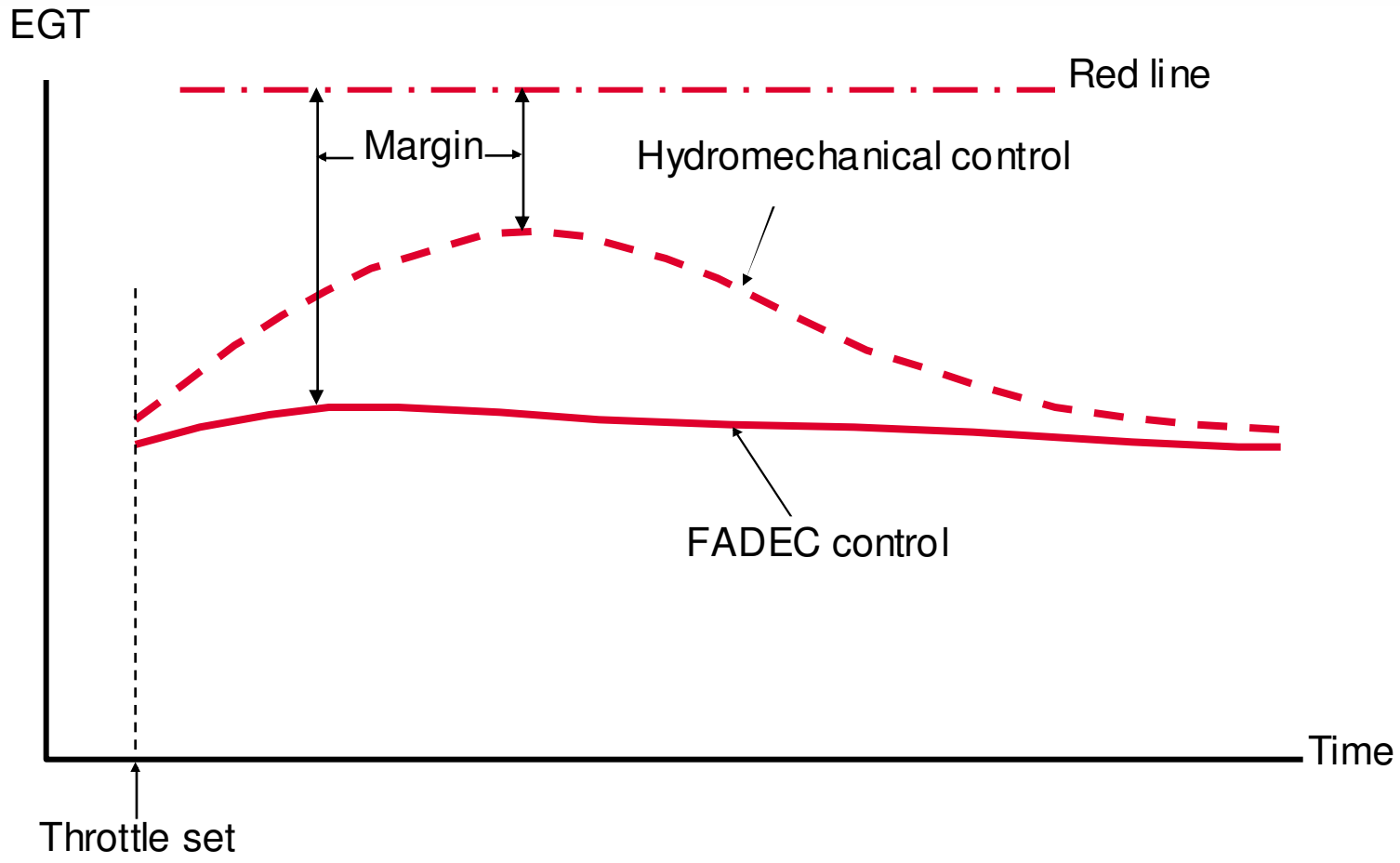
CFM56 PMC or FADEC Transient Characteristics



The power management function on the CFM56 PMC and FADEC engines consists of controlling N_1 (rather than N_2) to produce thrust requested by the throttle position. The PMC and FADEC use the ambient conditions (total air temperature, total pressure and ambient pressure) and engine bleed requirements to calculate N_1 based on a throttle position. Additionally, FADEC modulates the variable bleed valves, variable stator vanes, bore cooling valves and HPT and LPT active clearance control valves to maximize engine efficiency during transient and steady state operations. As a result of this increased efficiency, the EGT bloom and droop are reduced.

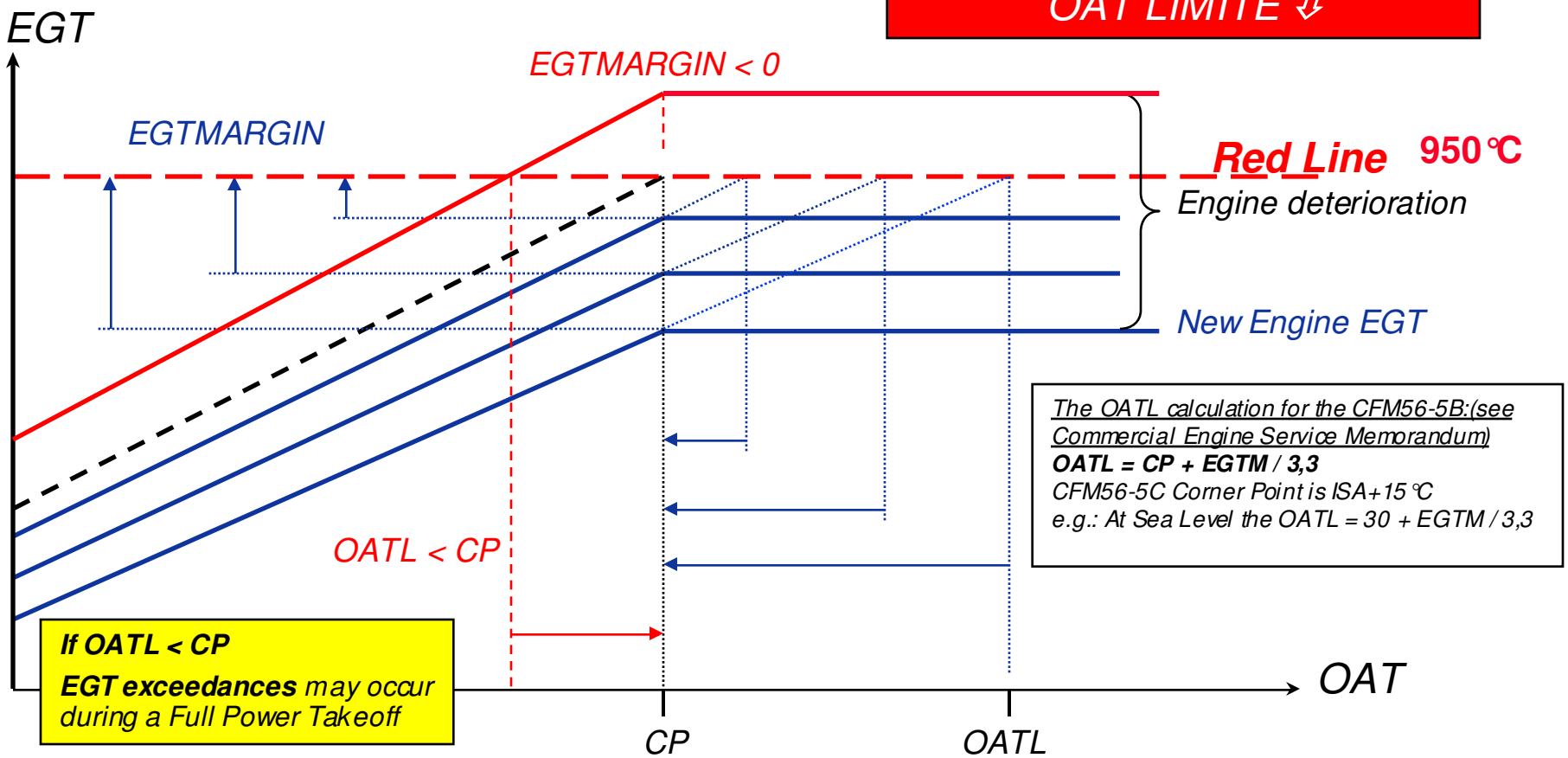
Power Management

EGT Transient



EGTMargin & OATL

ENGINE DETERIORATION ⇧
EGT MARGIN ⇩
OAT LIMITE ⇩

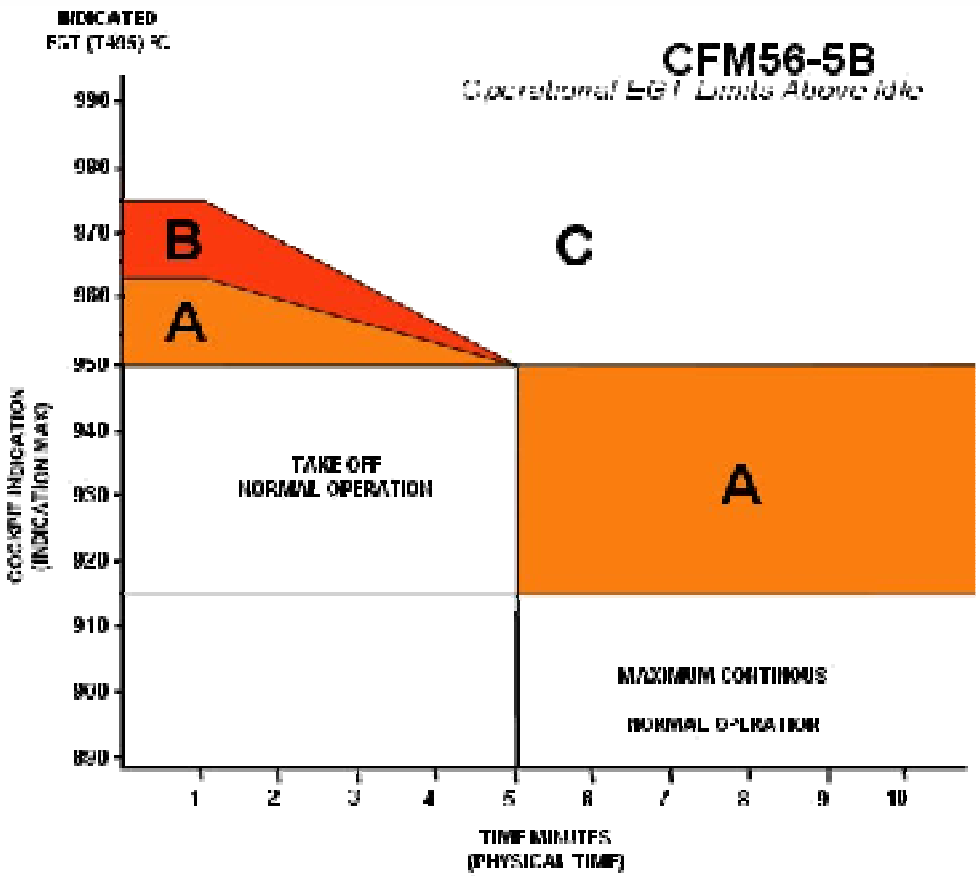


The OATL calculation for the CFM56-5B:(see Commercial Engine Service Memorandum)
OATL = CP + EGTM / 3,3
CFM56-5C Corner Point is ISA+15 °C
e.g.: At Sea Level the OATL = 30 + EGTM / 3,3

If OATL < CP
***EGT exceedances** may occur during a Full Power Takeoff*

1 °C OAT or Flex Temperature = 3,3 °C EGT

EGTMargin & OATL



EGT Transcient
*allowance to **-5B** EGT limits*

Area A
- *If engine warm-up not sufficient*
  No troubleshooting. 20 overtemp permitted.
- *If EGT exceedance condition identified*
  No troubleshooting. 10 overtemp permitted.
- *If EGT exceedance condition can't be identified*
  Troubleshooting. 10 exceedances permetted in area A & B combined before engine removal.

Area B
Troubleshooting. 10 exceedances permetted in area A & B combined before engine removal

Area C
The engine must be removed to examine damage. One nonrevenue flight permitted if damage within boroscope inspection.

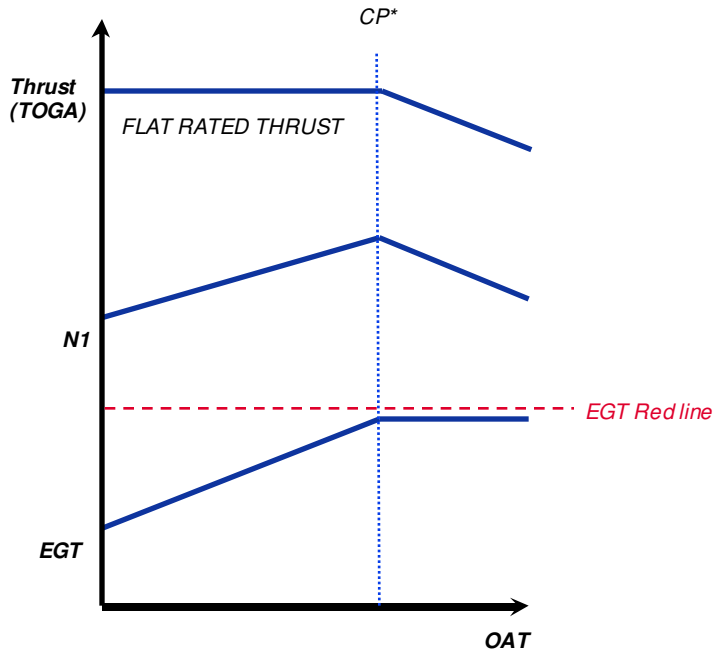
EGTMargin & OATL

Causes of EGT exceedances

- Temperature inversion
- Warm-up time
- Dirty compressor airfoils
- Engine deterioration
- Too much bleed air on the engine
- FOD
- Engine system malfunction

  (e.g. VBV actuation)
- Engine hardware malfunction

Temperature invertion



* CP: Corner Point or Flat Rated Temperature

FADEC will control the engine according to the above charts. Below FRT, thrust would be maintained but N1 and EGT would be higher versus no inversion. Above FRT, some loss of thrust would occur (not deemed significant by the aircraft manufacturers in terms of aircraft performance).

EGTMargin & OATL

KEEP IN MIND

- **Stick to your Flight Manual Procedures**

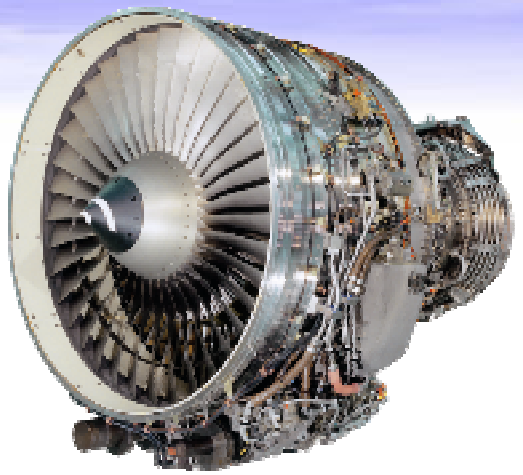
- **Certified thrust will indeed remain available even in case of EGT Exceedance**

- *At TOGA, ENG OVERTEMPERATURE may occur when:*
*OAT ≥ OATL **and** the OATL ≤ CP (ISA+15°C)*

- *No EGT exceedances for performance deterioration as long as the OATL > CP (ISA+15°C)*

- *1°C OAT or Flex Temperature = 3,3°C EGT*
- *OATL data:*
  - *helps the crew to assess potential EGT exceedances*
  - *is the primary basis for the scheduling of engine removal*

Performance Deteriation



ENGINES *contribute...*

... ~ 66 %

... to AIRCRAFT *performance deterioration*

When EGTMargin decrease,
Fuel Burn increase.
+ 10° EGT = + 0.7% SFC

Performance Deteriation

THERMAL Loads

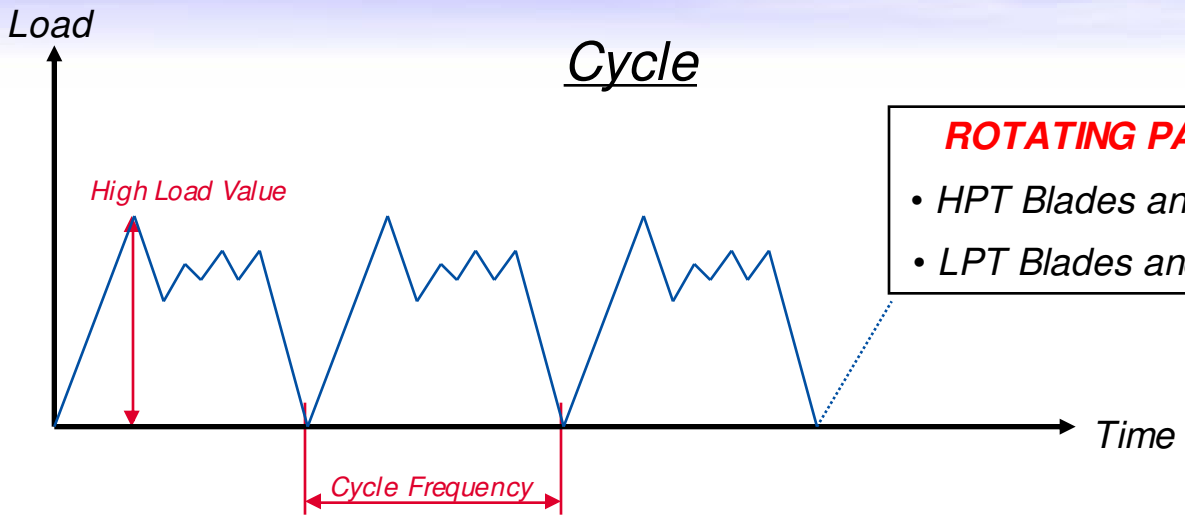
CENTRIFUGAL Loads

ENGINE
performance
deterioration

PRESSURE & AERODYNAMIC Loads

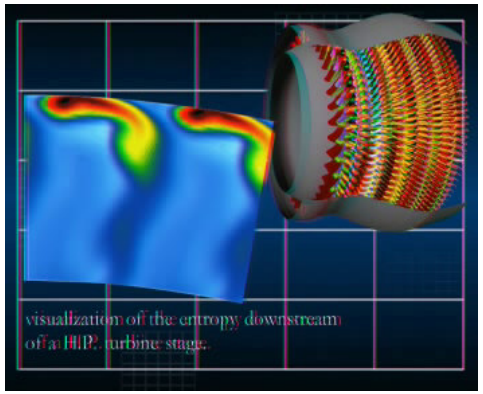
Performance Deteriation

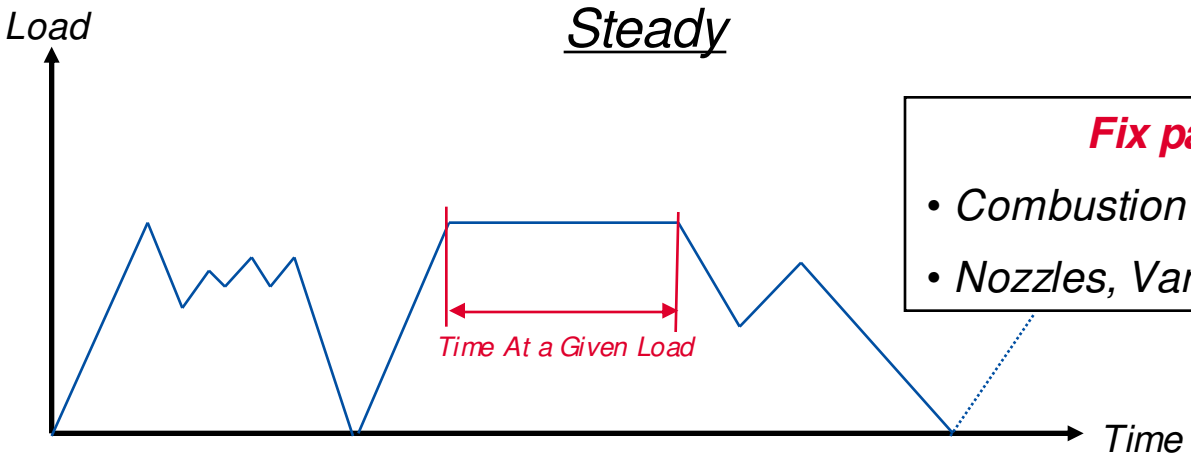
FATIGUES



ROTATING PARTS

- HPT Blades and Disks
- LPT Blades and Disks





Fix parts

- Combustion Chamber
- Nozzles, Vanes, Valves

Performance Deteriation

BLADES / CASING CLEARANCES → **ENGINE WEAR**

LEADS TO A DETERIORATION OF THE ENGINE EFFICIENCY → *Fuel consumption increase*

whith possible EGT overlimit

↓

+ 10° EGT = + 0.7% SFC

ENGINE
performance deterioration

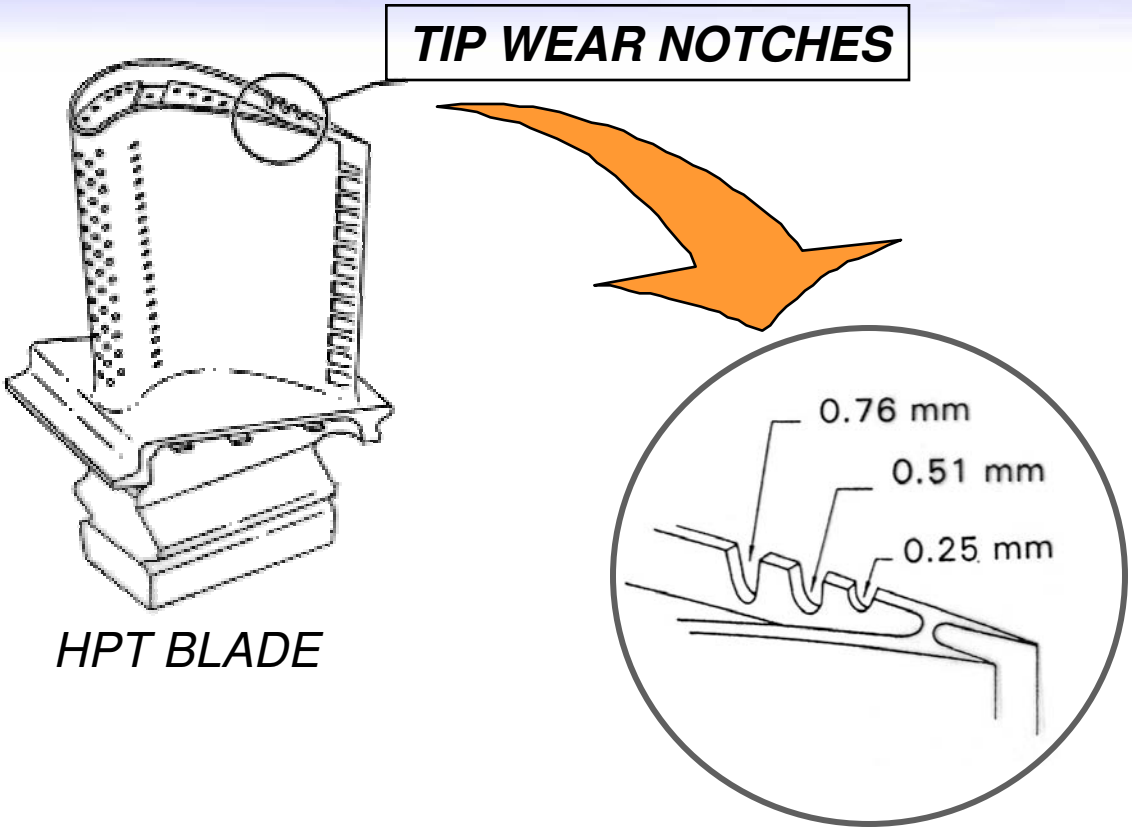
- *1% leakage, 9Th stage* ***HPTCC bleed***
  ➔ ***+ 0.5% SFC***
- *1% leakage, 9Th stage* ***CUSTOMER bleed***
  ➔ ***+ 1.6% SFC***
- ***VBV leakage****, open 10°*
  ➔ ***+ 0.7% SFC***

↑

BLEED AIR → **AIR LEAKAGES** → *Customer Bleeds Valves*

VBV, HPTCC...

Performance Deteriation



1 Notch = 10° EGT margin loss

Performance Deteriation

TAKE CARE OF YOUR ENGINES…

… YOU WILL SAVE MONEY…

… AND KEEP YOUR AIRCRAFT SAFE !!!

Reduced TakeOff Thrust

APPROVED BY INTERNATIONAL AGENCY

Reduced TakeOff Thrust

Technical terms

RATED TAKE OFF THRUST *(FAA AC 25-13)*

The approved Engine Thrust (Name Plate)

TAKE OFF THRUST *(FAA AC 25-13)*

The Engine Rated Take Off Thrust or corrected

Derated Takeoff Thrust

Level less than the max. takeoff thrust. The value is considered a normal take off operating limit.

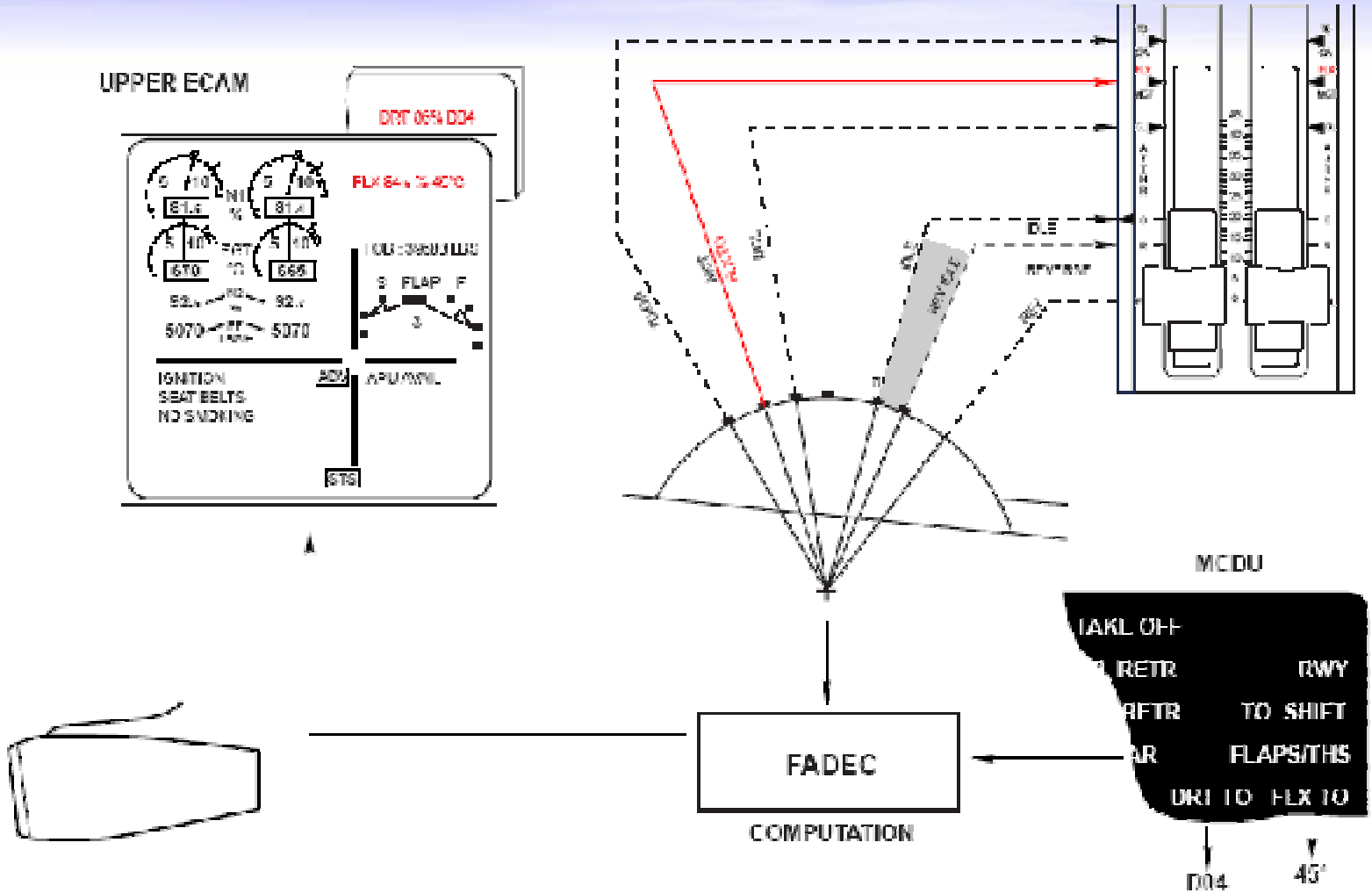
Reduced Takeoff Thrust

Level less than the max. takeoff or Derated Take Off thrust. The thrust setting parameter is not considered a takeoff operating limit.
Is at least 75% of the max. takeoff or Derated Take Off thrust.

RERATING

Is a manufacturer action changing the approved engine thrust (Name Plate)

Reduced TakeOff Thrust



FLEX AND DERATED TAKE-OFF

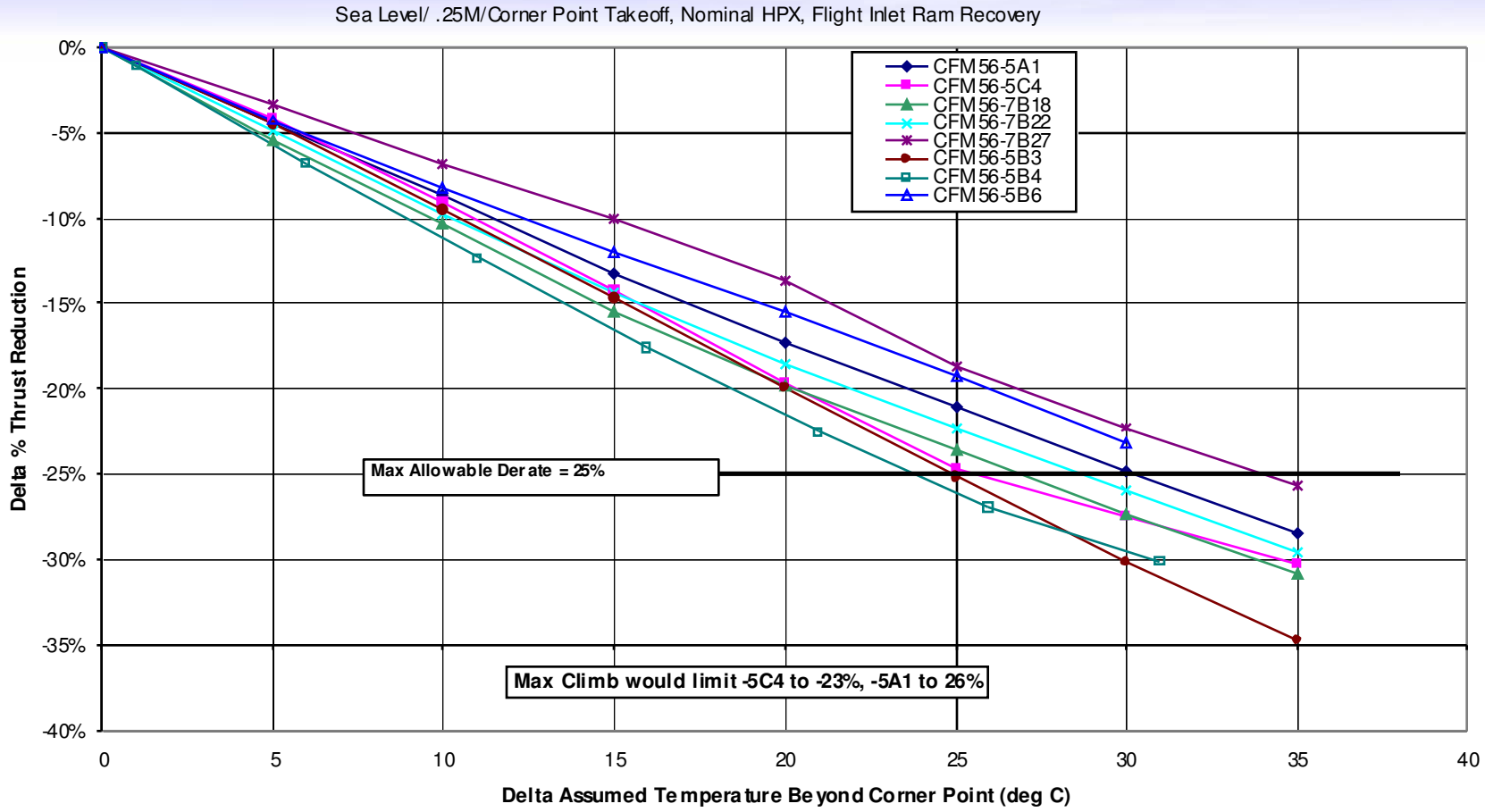
Reduced TakeOff Thrust

Reduced Thrust Versus Derate

- ***Reduced thrust takeoff***
  - *V-speeds used protect minimum control speeds* ***(VMCG, VMCA) for full thrust***
  - *Reduced thrust setting is not a limitation for the takeoff, I.e., full thrust may be selected at any time during the takeoff*
- ***Derated takeoff***
  - *Takeoff at a thrust level less than maximum takeoff for which separate limitations and performance data exist in the AFM. Corresponds to an "alternate" thrust rating*
  - *V-speeds used protect minimum control speeds* ***(VMCG, VMCA) for the derated thrust . . . not original maximum takeoff thrust***
  - *The derated thrust setting becomes an operating limitation for the takeoff*
- *On some installations derated thrust and reduced thrust can be used together, e.g., a derated thrust can be selected and thrust further reduced using the Flex temperature method*

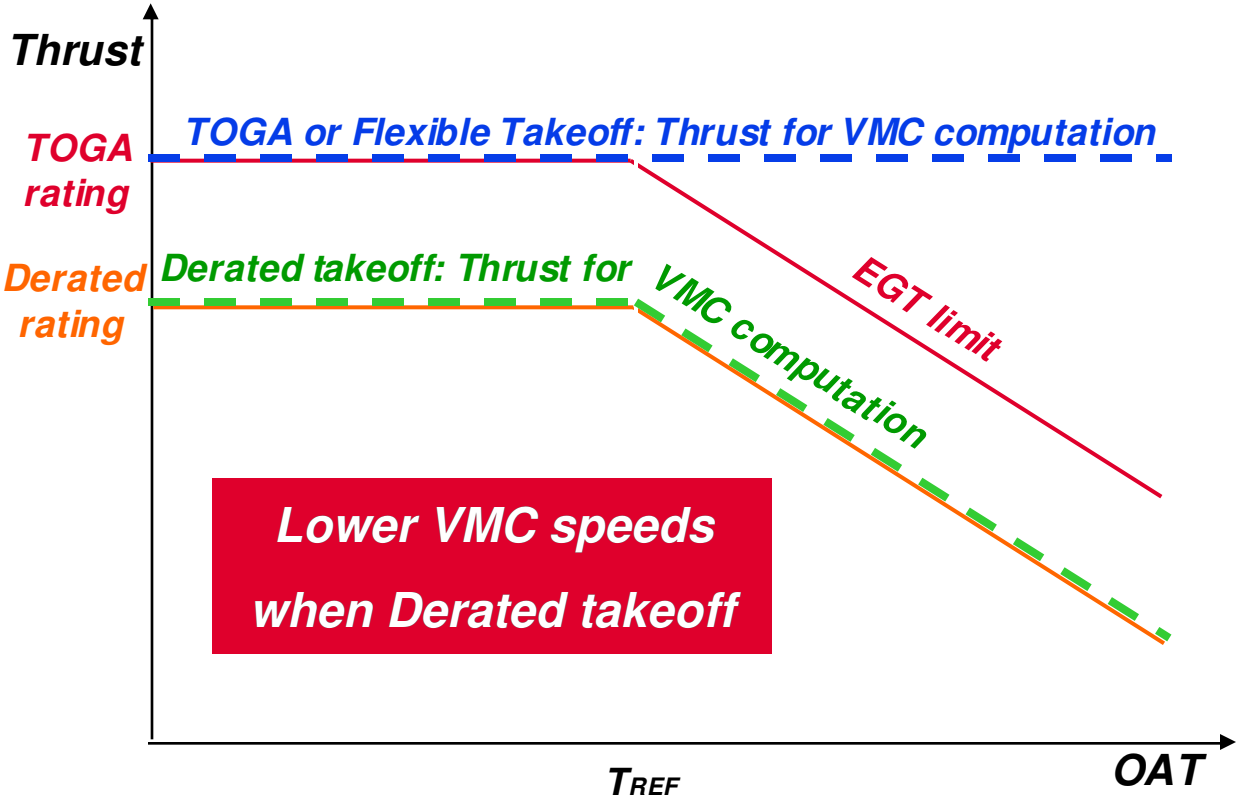
Reduced TakeOff Thrust

Thrust Reduction Vs. Flex/Assumed Temperature



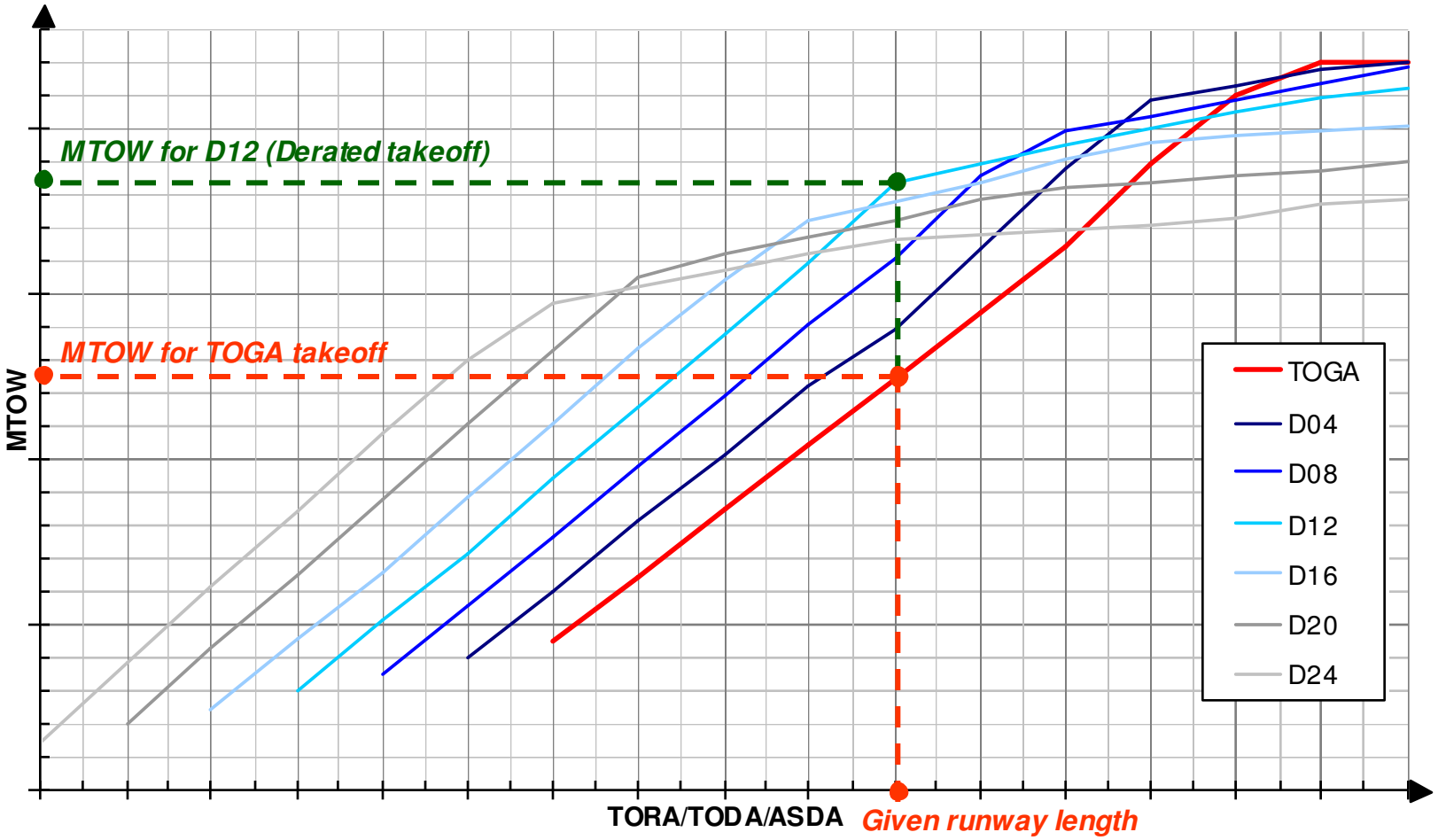
Reduced TakeOff Thrust

Thrust for VMC speeds determination



Reduced TakeOff Thrust

MTOW with Derated takeoff



Reduced TakeOff Thrust

Reduced thrust takeoffs restrictions

- ***On contaminated runways***
  - *"More than 25 % of the required field length, within the width being used, is covered by standing water or slush more than .125 inch deep or has an accumulation of snow or ice."*
- ***If anti-skid system is inoperative***
- ***These restrictions do <u>not</u> apply to "derated" takeoffs***
- *Any other restrictions on reduced thrust or derated thrust are imposed by the aircraft manufacturer or operator; not by AC 25-13*

Reduced TakeOff Thrust

Typical Additional Restriction applied by individual operators on Reduced Thrust Takeoffs

- *Possible windshear*
- *Brakes deactivated*
- *Other MMEL items inoperative*
- *De-icing performed*
- *Anti-ice used for takeoff*
- *Takeoff with tailwind*
- *Wet runway*
- *Performance demo "required"*

AC 25-13 Restrictions

A periodic takeoff demonstration must be conducted using full takeoff thrust. An approved maintenance procedure or engine condition monitoring program may be used to extend the time interval between takeoff demonstrations

Reduced TakeOff Thrust

Periodic Takeoff Demonstrations

- ***Operator methods vary e.g.***
  - *Every tenth takeoff*
  - *Every Friday*
  - ***Never make dedicated full thrust T/O for performance verification***
    - ***Take credit for ECM and full thrust T/O's performed for operational reasons***
- ***Less reduced thrust benefits acrue when unnecessary full thrust takeoffs are performed***
- ***Full thrust takeoffs meaningful only when takeoff is performed at the flat rate temperature****; otherwise the takeoff data must be extrapolated to flat rate temperature*
  - *Reduced thrust takeoffs can be extrapolated as well*
  - *Cruise ECM data can also be used to predict EGT margin*
- ***Negotiate with regulatory agency to extend interval between dedicated performance verification takeoffs***
  - *Take credit for ECM programs (T/O or Cruise)*
  - *Take credit for full thrust takeoffs performed for operational requirements*
  - *Extrapolate data obtained during reduced thrust as well as full thrust takeoffs*

Reduced TakeOff Thrust

TakeOff thrust is reduced when REAL GW < MAX LIMITING GW

- Max Thrust is not any more necessary!

Benefits of Reduced Thrust/Derated

- Lower Takeoff EGT

- Fewer operational events due to high EGT

- Lower fuel burn over on-wing life of engine

- Lower maintenance costs

EGTMargin decrease slowly ⇒ SFC kept at low rate
Better Engine performance retention ⇒ - Longer engine life on wing
- Shop Visit rate decrease

- Improved flight safety

For a given TakeOff, engine stress decreasing,
probability of engine failure decrease on that TakeOff.

Reduced TakeOff Thrust

Three engine ***parameters that determine the degree of engine severity are rotor speeds, internal temperature and internal pressure****. Operating an engine at a lower thrust rating or at reduced thrust reduces the magnitude of these parameters, thus reducing engine severity.*

Less severe operation tends to lower EGT deterioration*. Since lack of EGT margin is one cause of scheduled engine removals, lowering the EGT deterioration rate can increase the time on wing between shop visits.*

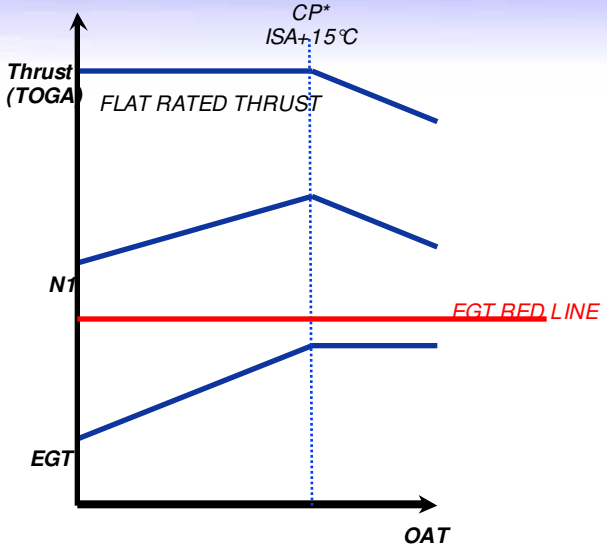
Fuel flow deterioration rate varies directly with EGT deterioration rate*, thus decreasing with the use of reduced thrust.*

Maintenance costs are reduced because of the longer time between shop visits and the lower labor and material costs of the shop visit *to restore the engine to a specified condition.*

Finally, reduced thrust on a given takeoff reduces stress level *and likelihood of an engine failure on that takeoff.*

Reduced TakeOff Thrust

Lower Takeoff EGT



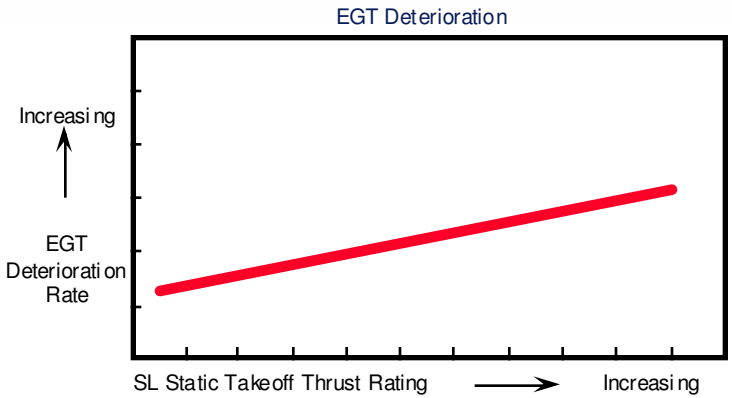
* CP: Corner Point or Flat Rated Temperature

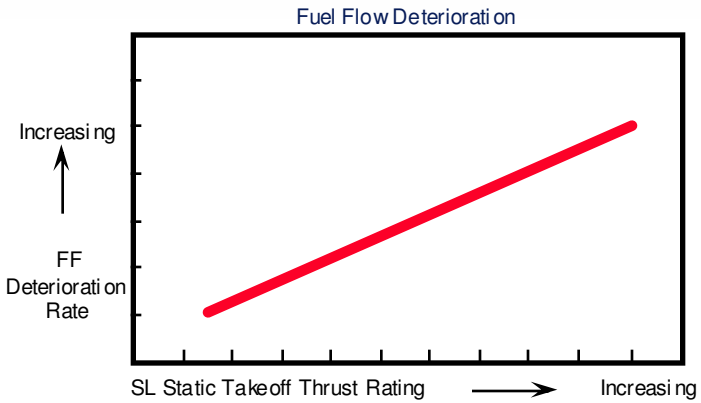
CFM56-5B/P 5B3 Engine Parameters
(Full Versus Reduced Thrust)
At Sea Level, Flat Rate Temperature of 30°C, 0.25 Mach, Typical New Engine

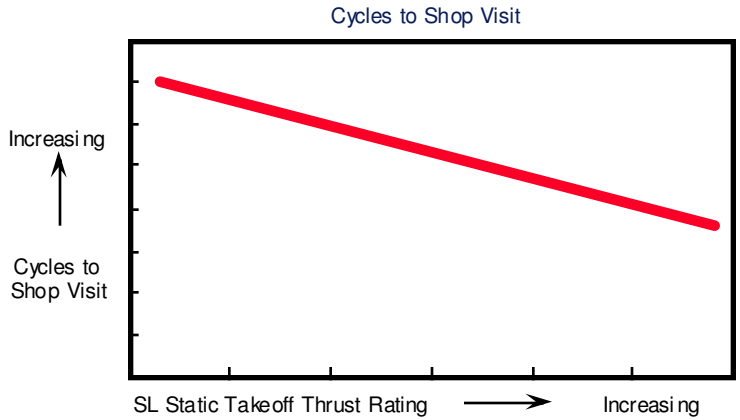
	Full rated thrust	25% reduced thrust	Δ%
Thrust (lbs)	26,218	19,663	-25
N_1 (rpm)	5,061	4,509	-10.9
N_2 (rpm)	14,968	14,490	-3.2
EGT (°C)	**870°**	**752°**	**-13.6**
PS_3 (psia)	482	377	-21.8

Reduced TakeOff Thrust

EGTMargin and SFC deterioration vs Thrust Rating







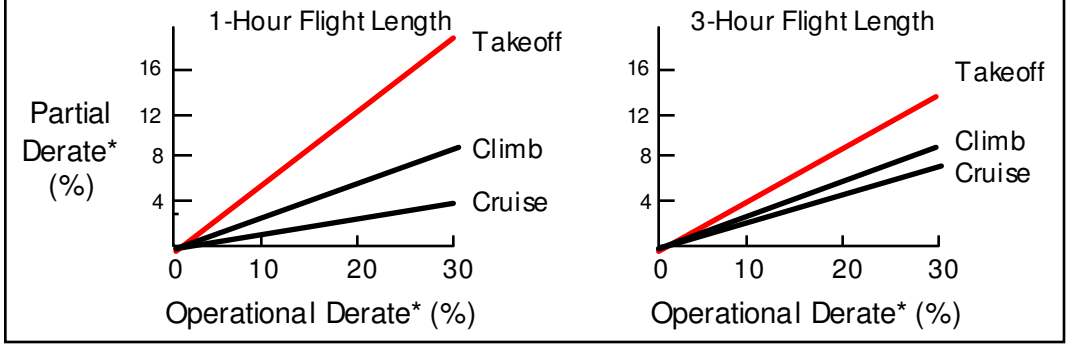
Although we do not have empirical data to allow us to plot EGTM/SFC deterioration or Cycles to Shop Visit versus derate , we do know that for different thrust ratings of the same engine model the deterioration rate tends to be greater on the higher thrust ratings. This concept is shown in the above and across charts.

Reduced TakeOff Thrust

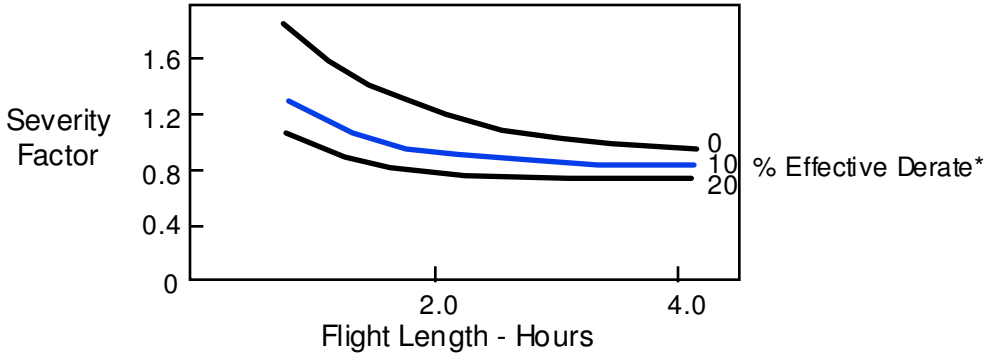
Severity Analysis

A means of quantifying and predicting mission severity based on how the engine is used

- *Severity of operation is a function of flight length and "effective derate*" which is a composite of takeoff, climb and cruise reduced thrust/derate.*
- *T/O is weighted heavier on shorter flights; climb and cruise derate are weighted heavier (relative to takeoff) on long flights.*
- *This visualization is not used in the pricing of maintenance service contracts.*



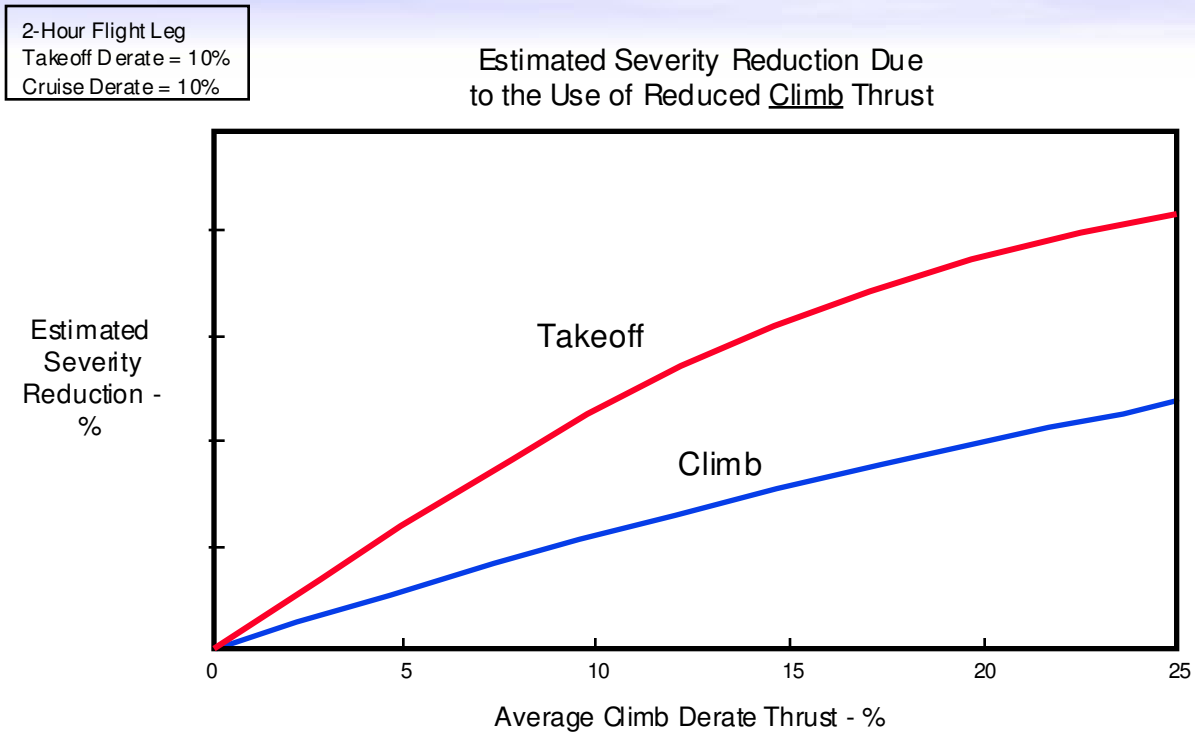
(Effective Derate* = Partial Takeoff % + Partial Climb % + Partial Cruise %)



*Reduced Thrust

Reduced TakeOff Thrust

Severity Analysis



This chart shows that the impact of climb thust reduction on severity, while still positive, is not as great as for takeoff thrust reduction.

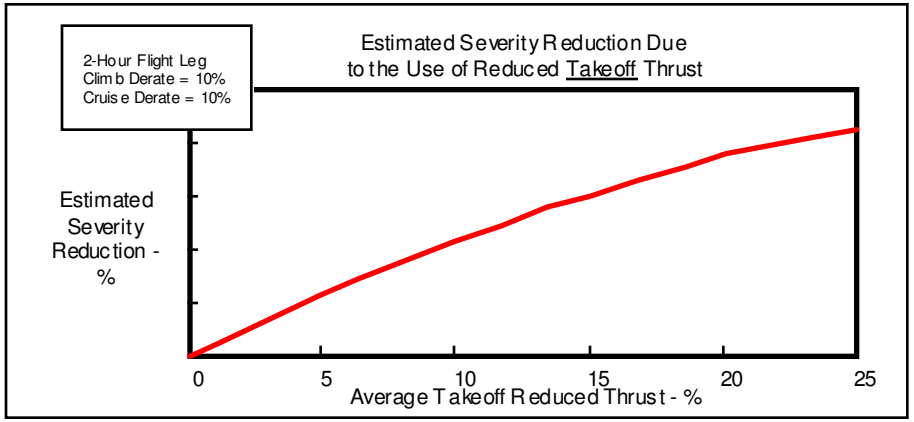
Although climb thrust reduction may reduce engine severity, its use may actually increase fuel burn on a given flight because of the lesser time spent in the highly fuel efficient cruise phase of flight.

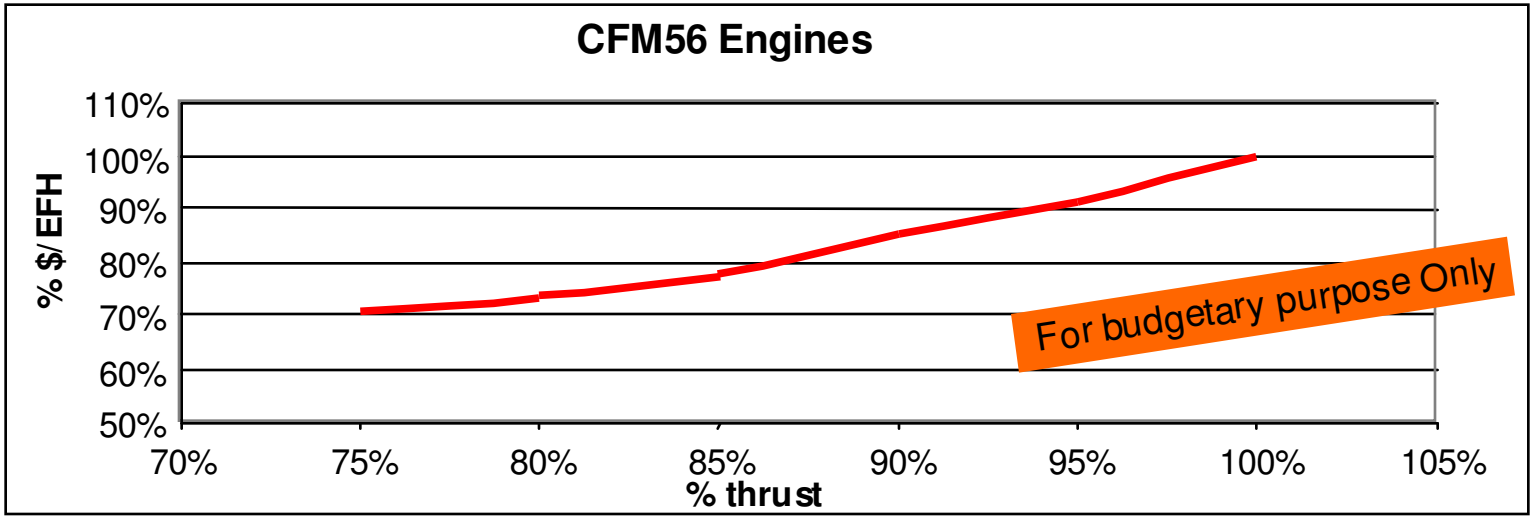
Reduced TakeOff Thrust

Severity Analysis
Reduced Thrust effect on CFM56 Engines

This chart represents the relative impact of reduced thrust increments on severity.

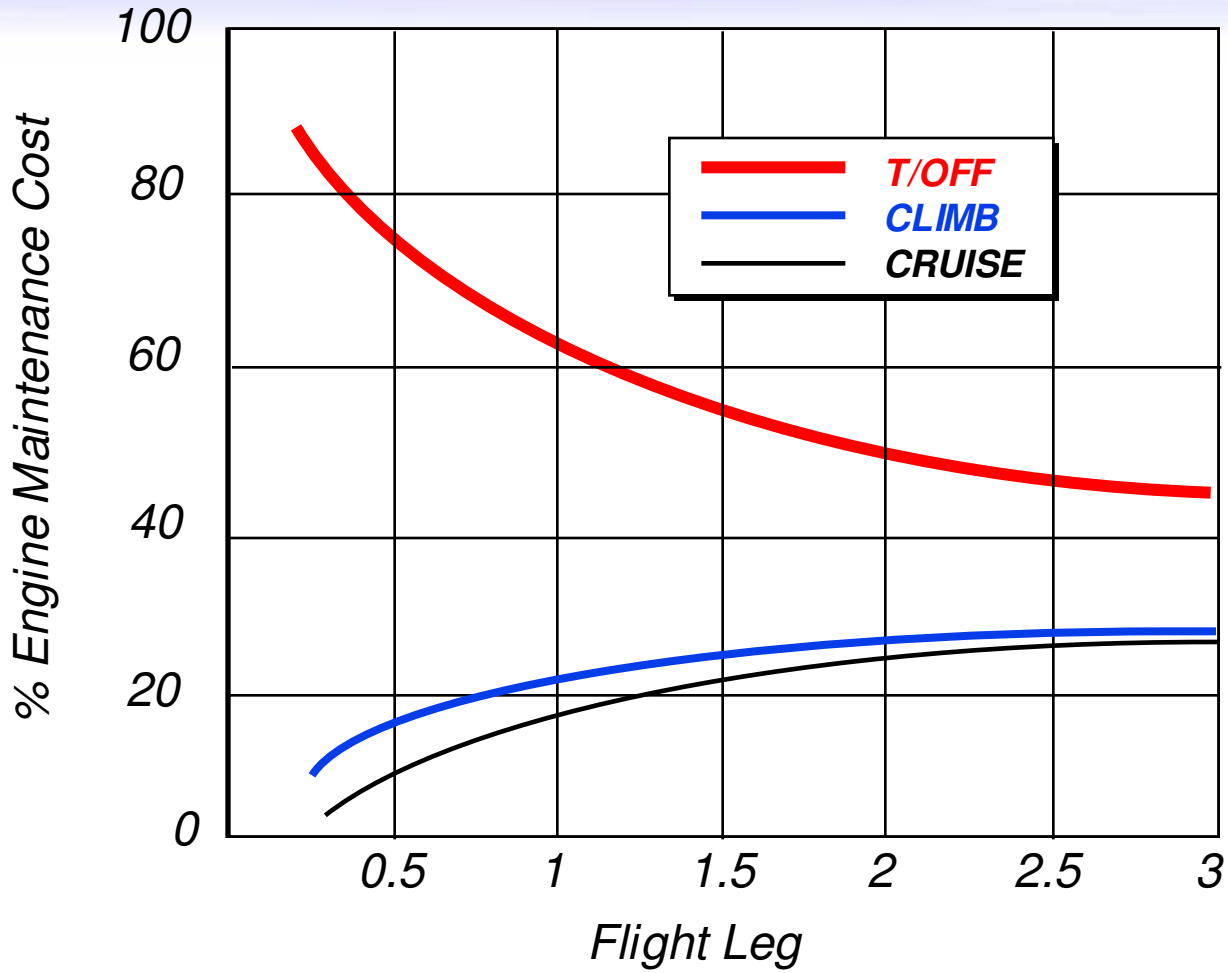
This shows that the first increment of thrust reduction is the most important but that thrust reduction even at the higher increments is important.





Reduced TakeOff Thrust

Lower maintenance costs



1 minute of takeoff has a responsibility of at least 45% at least on the engine maintenance cost

Reduced TakeOff Thrust

Improved flight safety

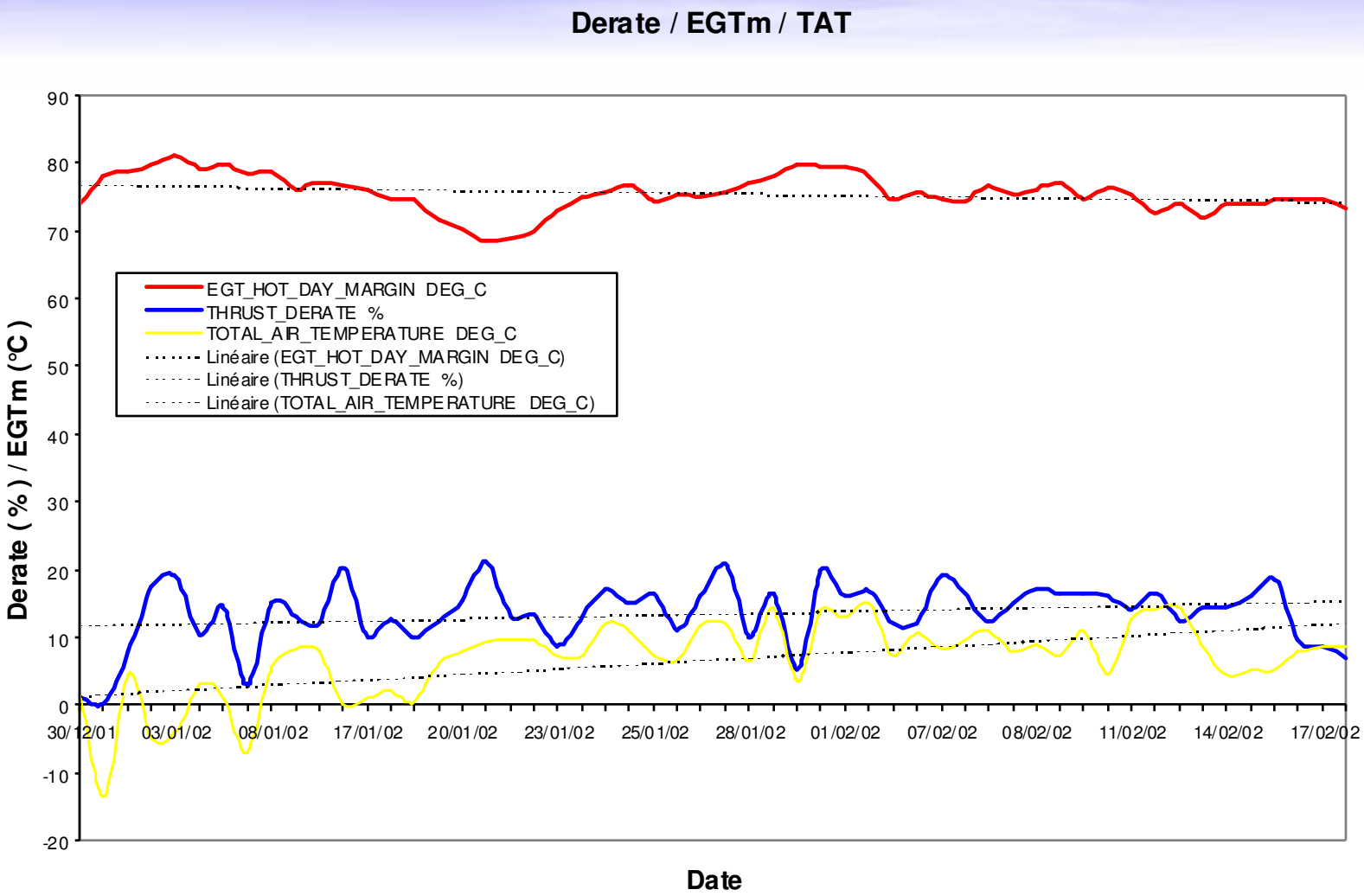
- No data on Thrust Reduction versus engine failures
- Following data is for takeoff phase Vs climb phase, showing significantly higher chance of engine failure at higher thrust settings associated with takeoff

Phase	Exposure Time	% IFSD	IFSD Factor	% Major Failures	Major Factor	% Fires	Fire Factor	% Component Separation	Separation Factor	% All Engine Power Loss	Power Loss Factor
Takeoff	1	4	4	43	43	12	12	23	23	8	8
Climb	14	31	2	30	2	42	3	34	2,5	22	1,6
Takeoff Vs Climb factor			**2**		**21,5**		**4**		**9**		**5**

Note: - Data for entire high-bypass engine-powered commercial transport fleet
- Source: « Propulsion Safety Analysis Methodology for Commercial Transport Aircraft », 1998

Example: For an average high bypass turbofan mission (approximately 2 hours) 43% of the uncontained engine failures occur in the 1% of the time spent in the takeoff phase. This yields an "uncontained factor" of 43÷1 = 43 versus the "uncontained factor" for climb which is 30÷14 ~ 2. Thus, on uncontained failure is 21.5 times more likely to occur in the takeoff (higher thrust) phase than the climb (lower thrust) phase of flight. To make the point that an engine failure is less likely at reduced thrust, one can think of the takeoff phase as a "full thrust" takeoff and the climb phase as "reduced thrust." Thus, the data would show a significantly higher chance of engine failure at full thrust than reduced thrust.

Reduced TakeOff Thrust



Reduced TakeOff Thrust

For

- *RUNWAY (Length, Altitude, slope…)*
- *TEMPERATURE, QNH, wind,…*
- *FLAPS SETTING*
- *OBSTACLES HEIGHT & DISTANCE*
- *AIRPLANE CONDITION*
- *RUNWAY CONDITION*

At

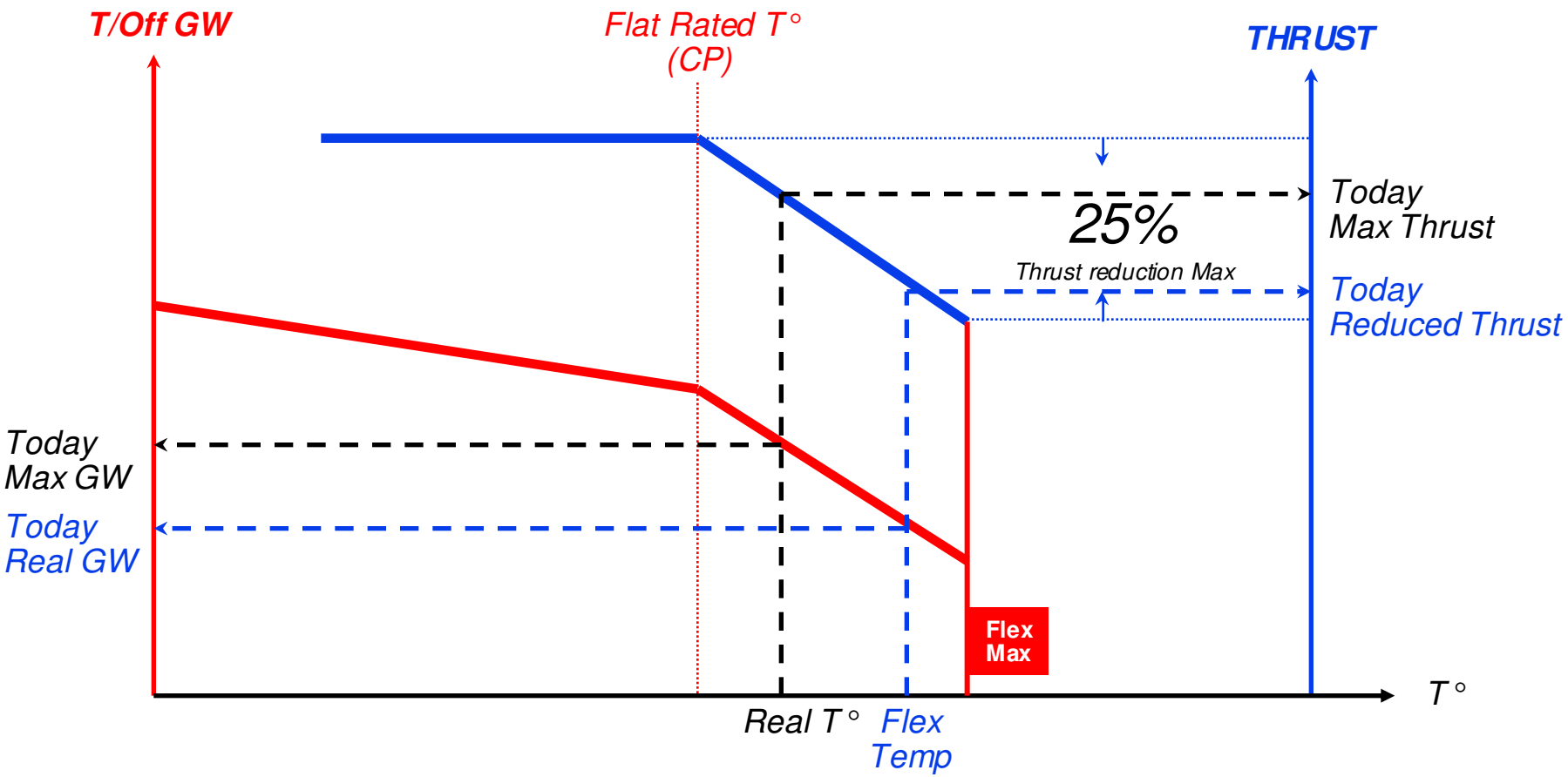
- *MAX TAKEOFF THRUST SETTING*

There is

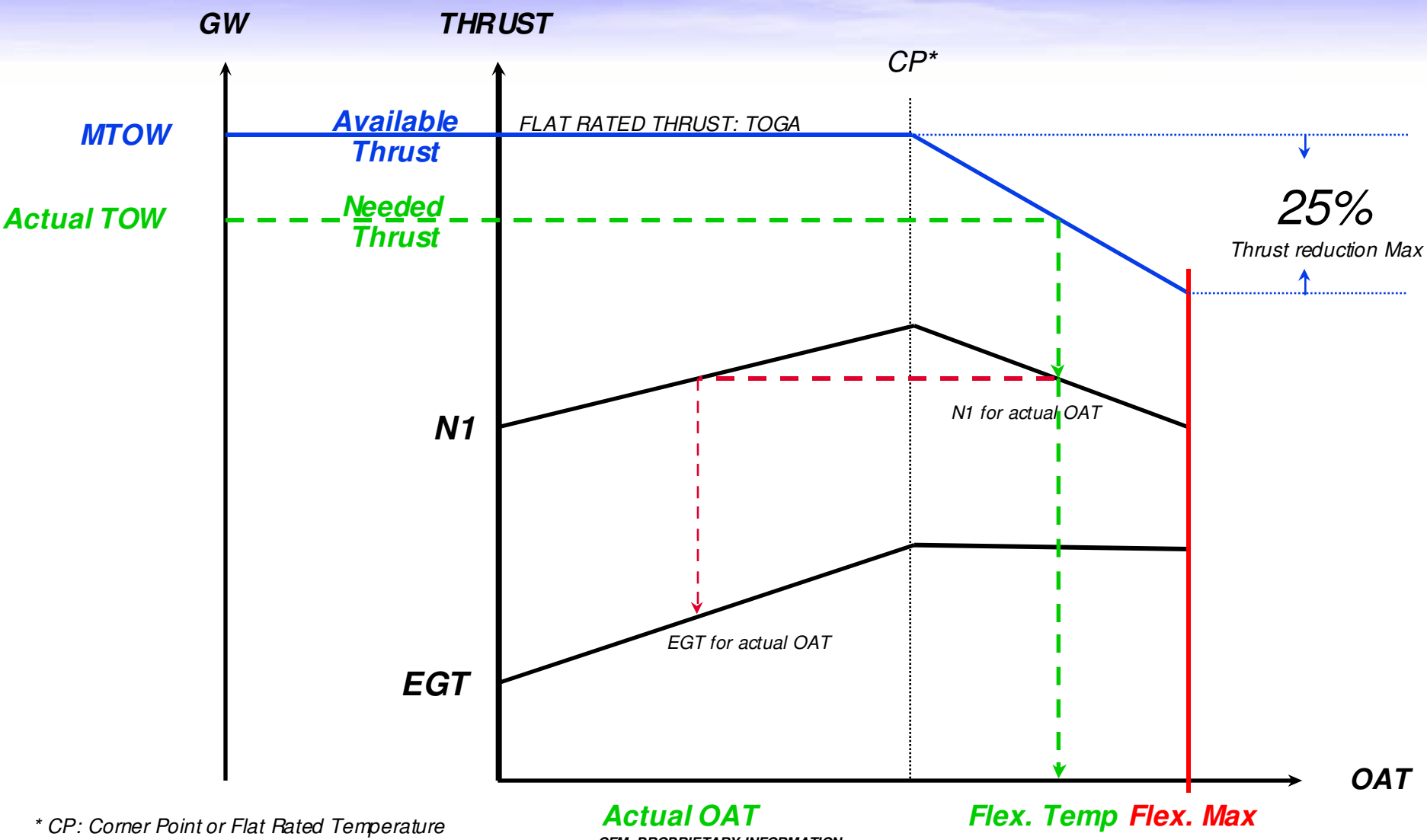
1 LIMITING GW

Reduced TakeOff Thrust

***IF REAL GW < MAX LIMITING GW**, a T° called "**Flex**" can be computed that would limit the airplane performance to the real GW.*



Reduced TakeOff Thrust



* CP: Corner Point or Flat Rated Temperature

Reduced TakeOff Thrust

The Power Of Flight

The accuracy of the OAT is essential to optimize

TAKEOFF GROSS WEIGHT

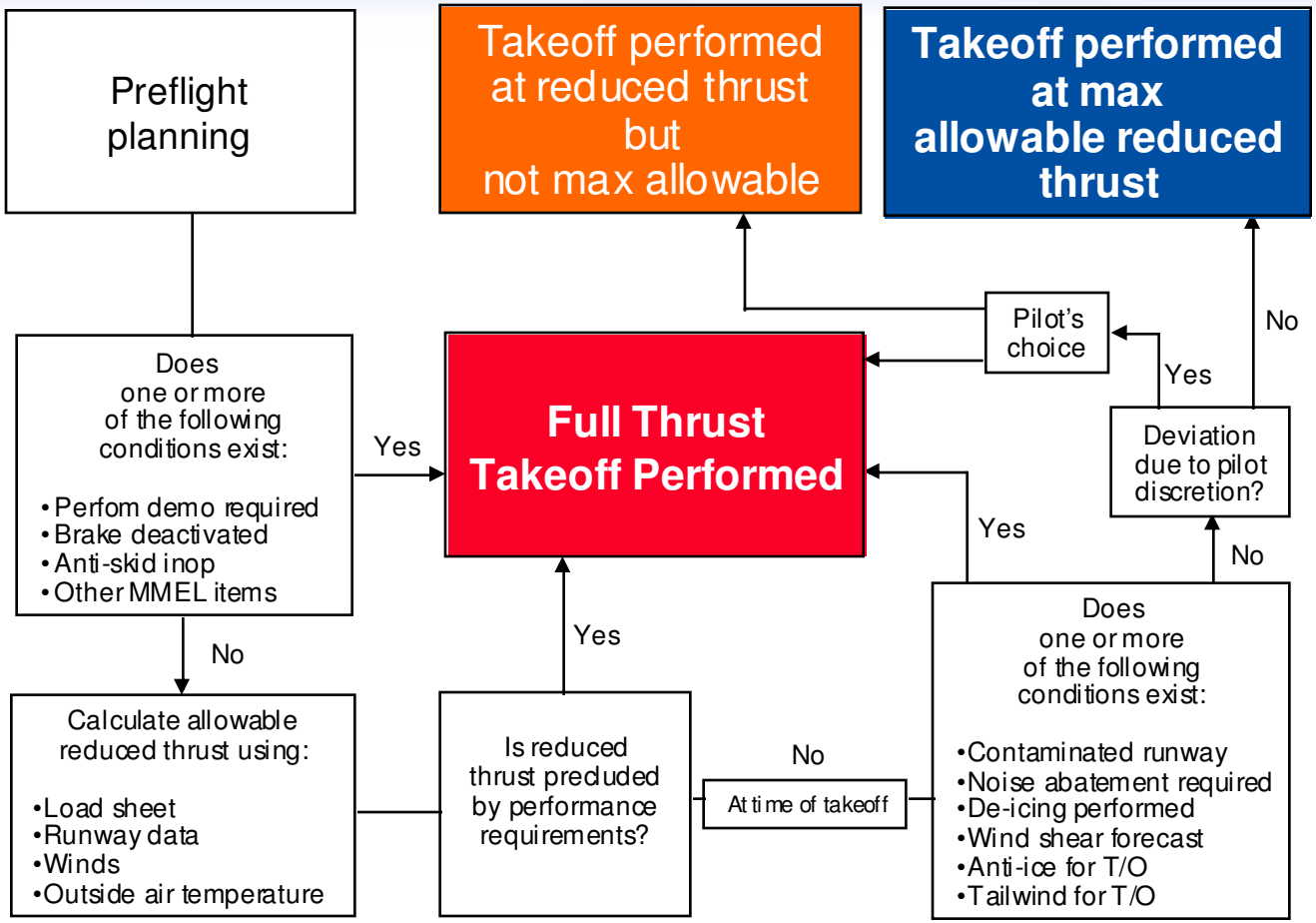
THRUST REDUCTION

ENGINE TYPE	EGTM-SLOATL COEFFICIENT
CFM56-7B27	3,5
CFM56-7B26	3,5
CFM56-7B24	3,5
CFM56-7B22	3,5
CFM56-7B20	3,5
CFM56-7B18	3,5
CFM56-5C4	3,7
CFM56-5C3	3,7
CFM56-5C2	3,7
CFM56-5B6	3,27
CFM56-5B5	3,27
CFM56-5B4	3,28
CFM56-5B3	3,43
CFM56-5B2	3,43
CFM56-5B1	3,43
CFM56-5A5	3
CFM56-5A4	2,9
CFM56-5A3	3,1
CFM56-5-A1	3,1
CFM56-3C-1	3,2
CFM56-3B-2	3,2
CFM56-3-B1	3,2
CFM56-2-C1	3,2

1°C OAT or Flex Temp = 3,3°C EGT

Reduced TakeOff Thrust

Tools to Analyze Reduced Thrust Programs
Process Map (Typical)



This is a process map for a typical operator with the typical company restrictions on reduced thrust discussed earlier in this presentation. Note that there are many hard decision rules and discretionary decisions on the part of the pilot that may result in full thrust takeoffs or takeoffs at less than maximum allowable reduced thrust.

Reduced TakeOff Thrust

Performance Aspects

For a given takeoff, there is obviously more performance margin at full thrust than at reduced thrust, however:

Reduced thrust takeoffs meet or exceed all the performance requirements of the Regulatory Agencies

For a reduced thrust takeoff at a given Flex/Assumed Temperature, the performance margin is greater than for a full thrust takeoff at an ambient temperature equal to the Assumed Temperature

Reduced TakeOff Thrust

THE Flex T° METHOD ALWAYS CONSERVATIVE ON THE AIRCRAFT PERFORMANCES.

Example:

Flex T° = 55°
&
V1 CAS = 140 Kts

⇨ TAS = 151.5 Kts

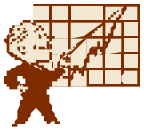
The Speed used to comply with the performance calculations!

Air T° = 10°
&
V1 CAS = 140 Kts

⇨ TAS = 138.5 Kts

The Speed you will have...

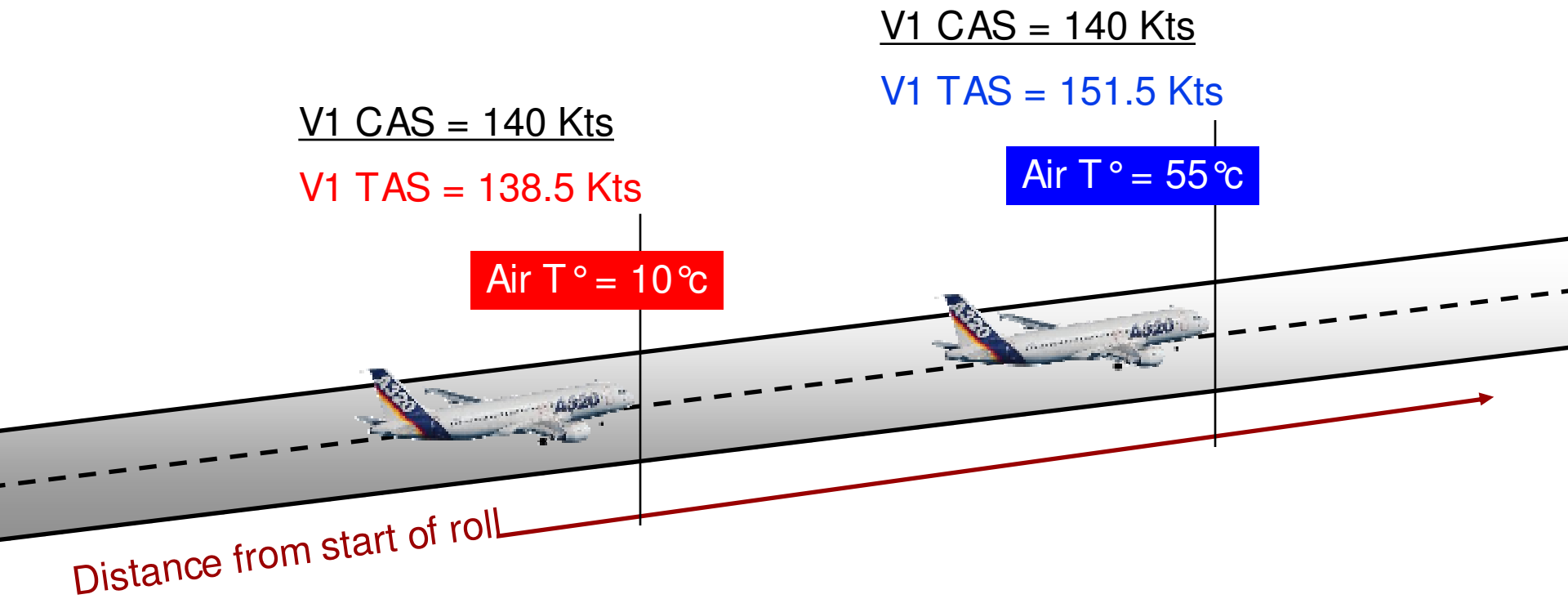
Due to lower ambient temperature and higher air density in the actual takeoff conditions, actual TAS is lower and actual thrust is higher



TAS = CAS +/- 1% ⇨ Δ5 °c / Std (+ if T° > Std, - if T° < Std)

Reduced Take Off Thrust

AIRCRAFT PERFORMANCE MARGIN WITH REDUCED TAKE OFF THRUST IS ALWAYS CONSERVATIVE.



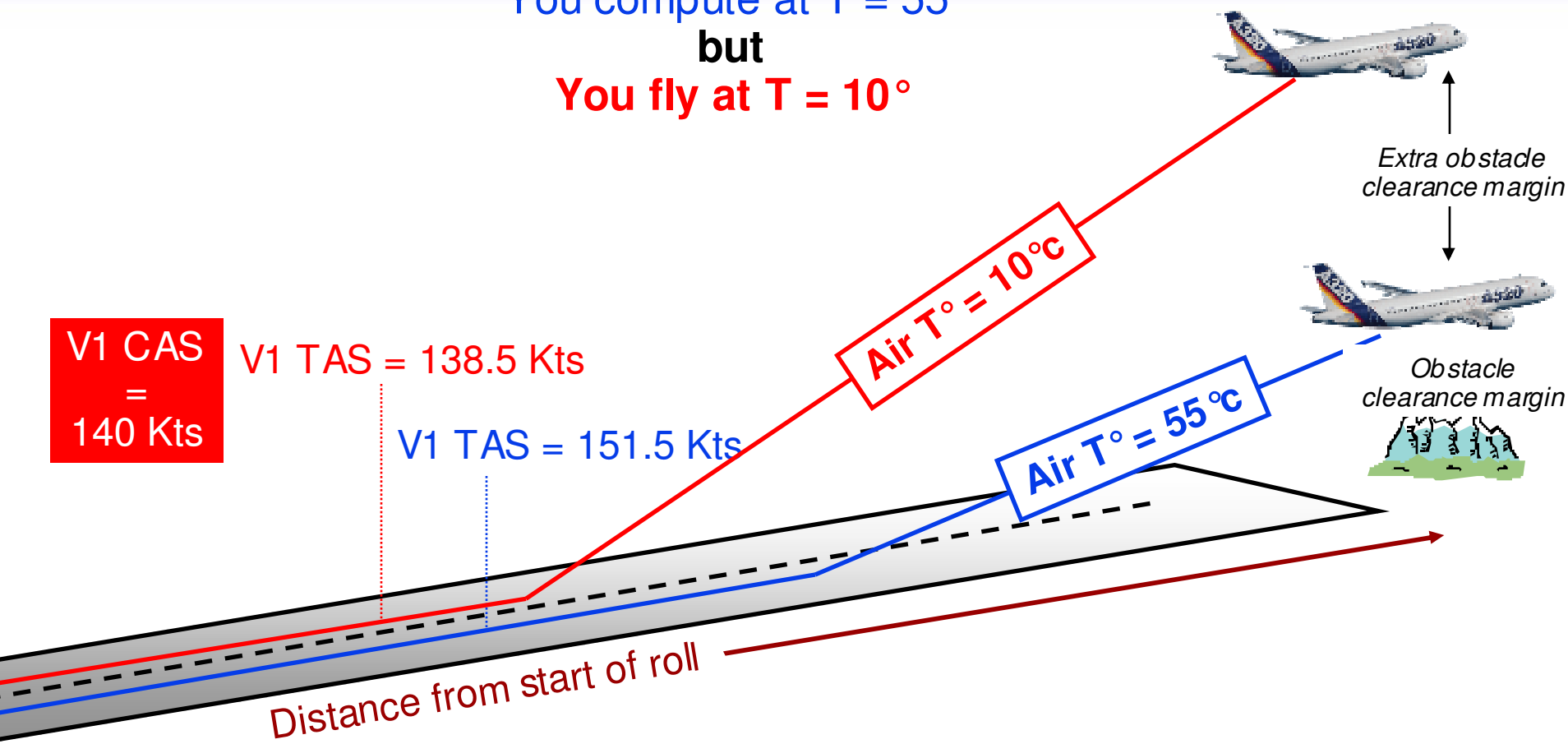
Reduced Take Off Thrust

AIRCRAFT PERFORMANCE MARGIN WITH REDUCED TAKEOFF THRUST IS ALWAYS CONSERVATIVE.

You compute at T = 55°

but

You fly at T = 10°



- *If performance is limited by the one engine inoperative minimum climb gradient requirements, the higher actual thrust will result in a higher climb gradient*
- *If performance is limited by obstacle clearance, the higher climb gradient combined with the shorter takeoff distance will result in extra clearance margin*

Reduced TakeOff Thrust

Reduced Thrust Exemples

A320-200 (CFM56-5A1) at sea level, 15°C. The actual takeoff weight permits an Flex temperature of 40°C

Temperature (°C):	40	15 assuming 40
V_1 (KIAS/TAS)	150/156	150/150
V_R (KIAS/TAS)	151/157	151/151
V_2 (KIAS/TAS)	154/161	154/154
Thrust at V_1 (lb per engine)	17.744	17.744
F.A.R. field length - ft	9,468	9,002
Accelerate-stop distance (engine out) (ft)	9,468	8,760
Accelerate-go distance (engine out) (ft)	9,468	9,002
Accelerate-go distance (all engine) (ft)	7,811	7,236
Second segment gradient %	2.68	2.68
Second segment rate of climb – ft per minute	438	419

Reduced TakeOff Thrust

Reduced Thrust Exemples

A321-112 (CFM56-5B2) at sea level, 15°C. The actual takeoff weight permits an assumed temperature of 40°C

Temperature (°C):	40	15 assuming 40
V_1 (KIAS/TAS)	150/153	150/147
V_R (KIAS/TAS)	158/162	158/155
V_2 (KIAS/TAS)	159/165	159/158
Thrust at V_1 (lb per engine)	23.451	23.451
F.A.R. field length - ft	9,459	8,859
Accelerate-stop distance (engine out) (ft)	9,459	8,547
Accelerate-go distance (engine out) (ft)	9,459	8,859
Accelerate-go distance (all engine) (ft)	7,970	7,393
Second segment gradient %	2.4	2.4
Second segment rate of climb – ft per minute	401	387

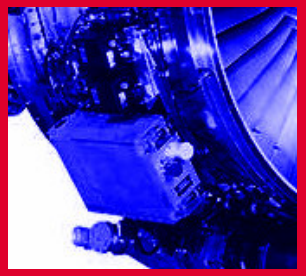
Reduced TakeOff Thrust

More the difference between OAT and Flex Temperature is, More Reduced TakeOff Thrust available…

1 - TakeOff performance margin ⇗⇗

2 - Safety ⇗⇗

3 - Maintenance Cost ⇩⇩



CFM56 General

Technical Features

Engine Certification & Testing

Operat

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Reduc

- Review by flight phase of normal operating considerations
- If there are inconsistencies between this presentation and the Flight Crew Operating (FCOM) or the Aircraft Operating Manual (AOM) the FCOM and/or AOM take precedence

Normal Operating Considerations

Flight phases, ops recommendations

THE POWER OF FLIGHT

Normal Operation

CFM56-5 FADEC Running Mode

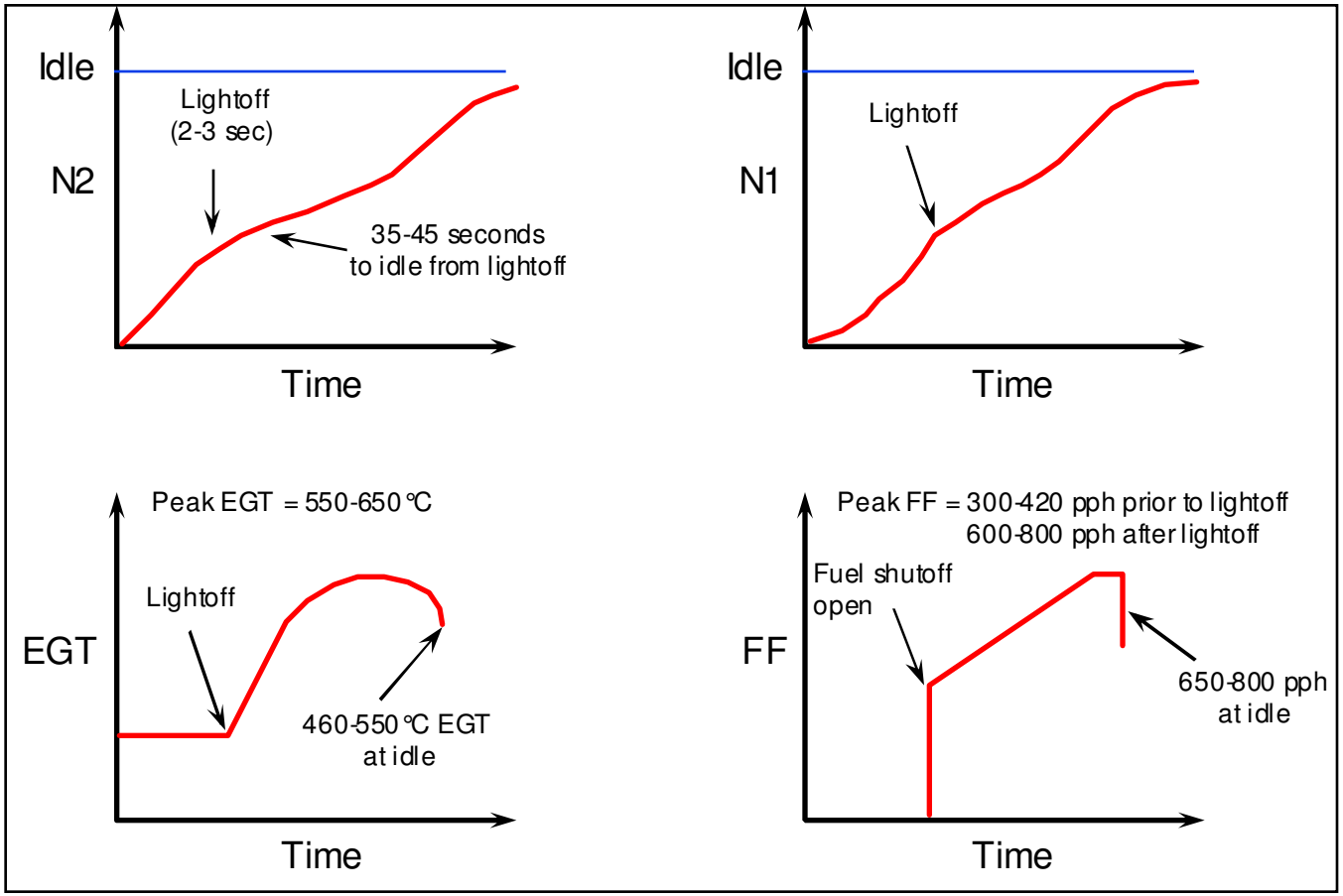
- FADEC exits start mode and enters run mode at 51% N2
- FADEC remains in the running mode until N2 falls to 50% (flameout)
- FADEC does not have the authority to close the fuel metering valve while in the running mode
- Once in the running mode, any modifications made to the fuel schedule during the start cycle are reset
- Ignition can be turned on anytime from the cockpit, and is automatically turned on if a flameout occurs
    - Dual ignition
- Flameout is determined by N2 deceleration higher than the normal deceleration schedule OR N2 dropping below ~55%

Normal Operation

Starting Characteristics

Normal Start (All Numerical Values Are "Typical" Not Limits)

- *Lightoff*
  - *Typically within 2-3 seconds*
- *EGT start limit*
  - ***725°C***
- *Idle*
  - *Indicated by EGT and fuel flow reduction*
  - *Typical start time: 45 to 60 seconds*



Normal Operation

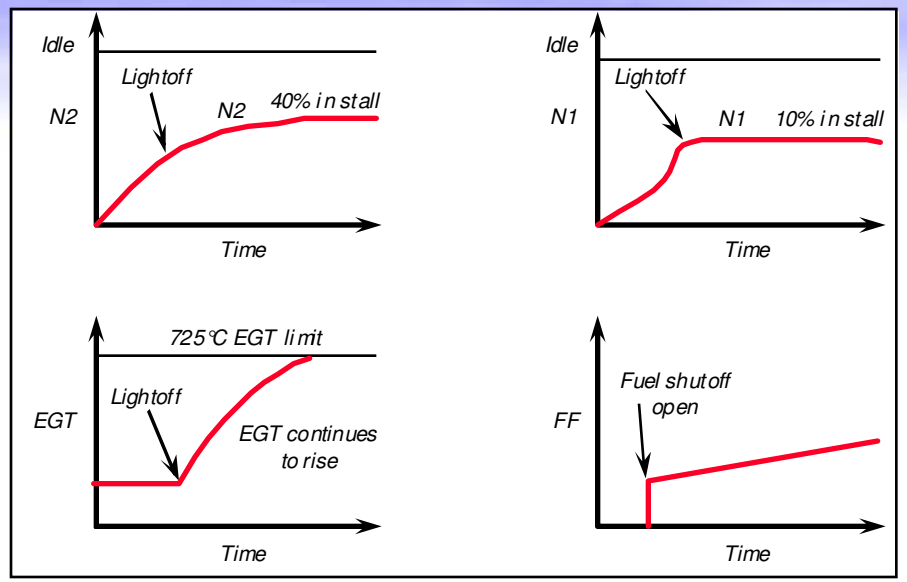
Low Speed Stall Characteristics

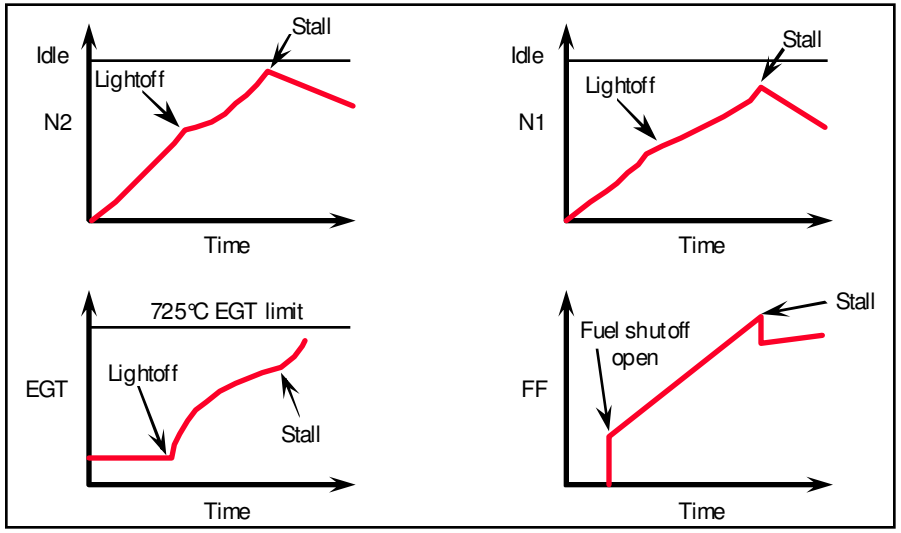
Lightoff Stall

- Engine speed stagnates immediately after lightoff
- EGT rises rapidly
- Not self-recovering
  - Recovery requires FADEC or flight crew intervention

High Sub-idle Stall

- Engine stalls just below idle
- EGT rises rapidly
- Not self-recovering
  - Recovery requires FADEC or flight crew intervention





Selected Abnormal Conditions

Autostart Failure to Lightoff Logic

Ground

- Lightoff **detected when EGT increases 55°C above initial EGT**
- **If no lightoff** within 15 seconds (20 seconds cold engine)
  - **Fuel and ignition turned off**
  - **Dry-motored for 30 seconds**
- Second start attempted with both ignitors for 15 seconds
- **If no lightoff on second attempt**
  - Start is aborted
  - Fuel and ignition turned off
  - Dry-motor for 30 seconds to purge the system of fuel
  - Flight deck advisory

In-flight

- **If no lightoff within 30 seconds**
  - Flight crew must turn fuel off
  - Observe a 30 second windmill/dry motor period between start attempts

Selected Abnormal Conditions

Autostart Hot Starts, Start Stalls, Overtemperature Logic

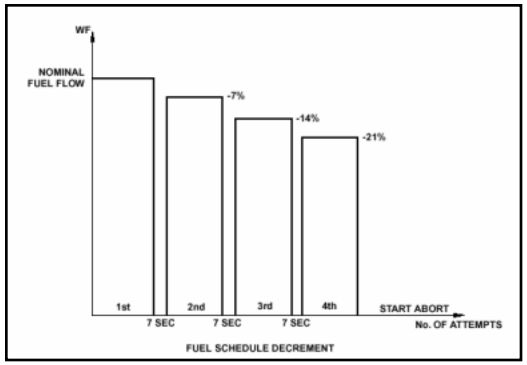
Ground

- *If a **hot start, start stall, or overtemperature** is detected*
  - *Fuel metering valve closes for 6 seconds, then opens with 7% fuel decrement*
  - *Start fuel flow schedule is reduced at a total of 21% in three 7% decerements*

In-flight

- *If a **hot start, start stall, or overtemperature** is encountered*
  - *The flight crew must abort the start*
  - *Observe a 30 second windmill/dry period between start attempts*

- ***If the abnormality occurs after the third increment***
  - *Start is aborted*
  - *Fuel and ignition off*
  - *Flight deck advisory*



Normal Operation

Start

- **Starter air pressure**
  - 25 psi desirable (start valve open)
  - Warmer, slower starts with lower pressure

    Note: the practical minimum starter air pressure is that required to motor the engine to 22% N2 for auto start (programmed fuel on speed) or 20% N2 for manual start (minimum N2 for fuel on)

- **Ignition selection is automatic**
  - Autostart: FADEC alternates A and B igniters on every other start
  - Manual start: both igniters are used

- **Fan rotation**
  - No restriction on opposite fan rotation (tailwind)
    - Initial N1 indication slower with a tailwind
  - If no N1 rotation detected by ~51% N2, an ECAM start fault message ("No N1") is provided to crew
    - Start must be aborted

- **Tailwinds**
  - Starts demonstrated with 53 knot tailwind
  - For CFM56-5A and –5B high tailwinds do not present a problem for start

- Expect **warmer starts** with high residual EGT

- **Crosswinds**
  - No significant impact on start characteristics

Normal Operation

Start SAC/DAC intermix

Start up procedure

◊ Faster/colder ground starts on the SAC Engine

◊ Average start up time	SAC	30	s
	DAC	1	mn

◊ SAC Cross bleed start procedure with the DAC engine
(The operational case is when you start first the DAC engine, then the SAC engine)

Thrust has to be increased at 30% N1 on the DAC engine before lauching the start on the SAC, otherwise you could stay at idle or even have face a roll back on the DAC engine and not be able to start the SAC.

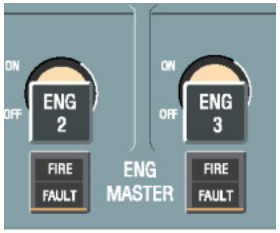
Ground Idle

- Higher EGT & higher fuel flow (25% at idle)can be noticed on the DAC engine.
- Lower N1 and Higher N2 at ground idle and Lower N1 and N2 at min idle in flight on the SAC Engine
- Depending on engine age &/or type &/or bleed supply, the range of EGT difference can reach, basically, from 30°– 40° to 200°-250° C ** on the DAC engine.
- Quicker acceleration in N1 speed range from idle to 50% N1 on the SAC Engine

Normal Operation

Ground Autostart Sequence

- *Pilot positions mode select switch to **IGN/START***
- *Pilot selects **MASTER LEVER ON***
  - *Start valve opens**
  - *APU speed (if used) increases*
  - *Pack valves close*
  - *Ignition comes on at 16% N2**
  - *Fuel comes on at 22% N2**
  - *At 50% N2 starter valve is commanded closed and ignition is turned off**
  - *APU (if used) speed reduces and pack valves open*



FADEC Full authority for Start Protection up to Idle on:
- *EGT & Starter engagement time*
- *Any engine abnormal start*
- *The starter re-engagement*

**The FADEC initiates automatic sequence*

Normal Operation

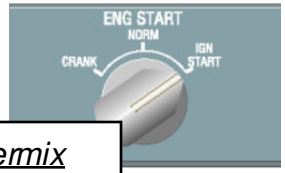
Ground Manual Start Sequence

- Pilot selects mode selector switch to **IGN/START**
- Pilot **depresses MANUAL START PB**
  - Start valve opens (25 psi desirable)
  - APU speed increases
  - Pack valve close
- Pilot selects **MASTER SWITCH ON at 22% N2** or maximum achievable N2 (minimum 20% N2)
  - Dual ignition and fuel flow
  - At 50% N2 starter valve is commanded closed and ignition is turned off

Start protection during Ground Manual Start
FADEC shall provide faults to FWC
LIMITED AUTHORITY TO ABORT THE STARTING SEQUENCE ONLY FOR EGT

Normal Operation

In-flight Autostart Sequence



- ***Same as ground procedure***
- ***FADEC selects starter assisted start*** *if N2 is below windmill start threshold*
  - *12% N2 at or below 20,000 ft*
  - *15% N2 above 20,000 ft*
- ***Starter assisted***
  - *Starter valve opens*
  - *Dual igniters come on immediately*
  - *Fuel comes on at 15%*
  - *At 50% N2, starter valve is commanded closed and ignition is turned off*
- ***Windmill:*** *Dual ignition comes on slightly before fuel flow*

IN-FLIGHT RELIGHT ENVELOPE SAC/DAC Intermix

DAC envelope (More restrictive) must be applied in intermix

•The DAC Relight envelope (20 KFt) is lower than the SAC (27.0 KFt). In intermix configuration, DAC envelope must be applied.

Start protection during Inflight Autostart

FADEC shall provide faults to FWC

NO AUTHORITY TO ABORT THE STARTING SEQUENCE

Start malfunction advisories are operative, but pilot must abort the start if malfunction occurs

Normal Operation

In-flight Manual Start Sequence

- ***In the manual mode a starter assisted start is commanded through FADEC***
- *Pilot positions mode select switch to* ***IGN/START***
- *Pilot* ***depresses MANUAL START PB***
- *Pilot selects* ***MASTER SWITCH ON at 15% N2*** *or maximumachievable N2*
  - *Dual ignition and fuel flow*
  - *At 50% N2 starter valve is commanded closed and ignition is turned off*
  - *APU speed decreases and pack valves open (30 second delay)*

Start protection during Inflight Manual Start
FADEC shall provide faults to FWC
NO AUTHORITY TO ABORT THE STARTING SEQUENCE
Start malfunction advisories are operative, but pilot must abort the start if malfunction occurs

Normal Operation

Taxi

- **One Engines Taxi Out (Not recommended)**
  - *2 minutes minimum recommended before apply TakeOff thrust setting*
  - *Crews have to consider no fire protection available from ground staff when starting the other engine away from the ramp.*
  - *If mechanical problems occur during start up, departure time might be delayed due to a gate return.*
  - *After frequent occurrences, possible increase of deterioration level versus the engine running first.*

- **Warm up 2 min mini prior to takeoff**

*A cold engine is defined by shut-down of more than 6 hours. A 2 minutes minimum warm- up is recommended in the FCOM but CFM experience shows that warm-up times between **10** and **15 minutes** consistently reduces the takeoff EGT.*

Warm up impact on cold engine						
Engines Estimated idle time impact on TakeOff EGTMargin						
Idle time (min)	**2**	**5**	**10**	**15**	**20**	**25**
EGT (°C)	**ref ***	**ref - 4°C**	**ref - 9°C**	**ref - 12°C**	**ref - 14°C**	**ref - 15°C**

*** ref equal to TakeOff EGT with a 2 min warm up**

CFM REP 05/09/00 based on PSE information

Normal Operation

Taxi

Not sensitive to ambient conditions

- *EGT unaffected by crosswinds may be slightly higher with tailwinds*
- *Constant idle thrust: N2 varies with OAT/PA to maintain constant thrust level*

Minimize breakaway thrust

- *Vortices is common cause of FOD ingestion on ground*
- *10 knots headwind/Airspeed will destroy vortices formed up to 40% N1*

10 knots

airspeed/headwind will destroy vortices formed up to ***40% N1***

30 knots

airspeed will destroy vortices formed at typical ***TakeOff thrust settings***

Normal Operation

Taxi

High FOD Potential Areas

- Desert Airports
- Coastal Airports
- Airports with: Construction activit, Deteriorated runways/ramps/taxiways, Narrow runways/taxiways, Ramps/taxiways sanded for winter operation, Plowed snow/sand beside runways/taxiways

Engine Vortices is a common cause of ingestion on ground

Engine Vortices

- Strength increases at high thrust, low airspeed
- High exposure
  - Thrust advance for breakaway from stop
  - Thrust advance for TakeOff
  - Reverse Thrust at low airspeed
  - 180° turn on runway
  - Power assurance runs
- Destroyed by Airspeed and/or Headwind

Normal Operation

Taxi

FOD (Recommendations)

- Avoid engine overhang of unprepared surface
- Minimize
  - breakaway and taxi thrust (Less than 40% N1, if possible)
  - Thrust assist from outboard engine in 180° turn
- Rolling TakeOff, if possible
- Reverse thrust
  - During taxi only on emergency
  - Minimize on contaminated runway

10 knots

airspeed/headwind will destroy vortices formed up to **40% N1**

30 knots

airspeed will destroy vortices formed at typical **TakeOff thrust settings**

Normal Operation

Taxi

- ***Reverse thrust during taxi only in emergency***

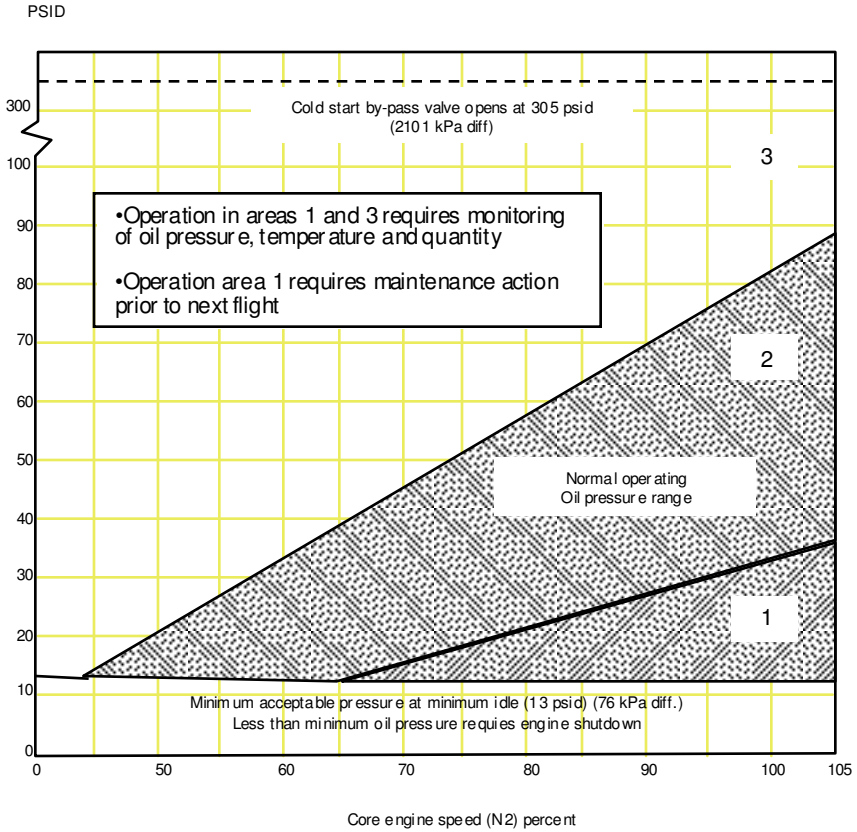
- ***Oil pressure varies with N2***
  - ***Minimum 13 psi*** *(required ENG SHUT DOWN), May be full scale for cold soaked engine. less than 13 PSID is permissible for maximum of 10 seconds during "Negative G" operation*
- ***Oil temperature***
  - *No minimum*
  - *Rise must be noted prior to takeoff*
  - *Maximum 140°C continuous, 155°C for 15 minutes*
- ***Oil quantity:***

Gulping effect

Flight Phase	Deviation From Pre-Start Quantity
Ground idle	4 quarts (20%)
Takeoff	6 quarts (30%)
Climb, cruise, descent	4-5 quarts (20%-25%)
After landing	4 quarts (20%)
Shutdown	0 quarts* (0%)

Note: These values are not limits . . . information only

CFM56-5B Oil Pressure



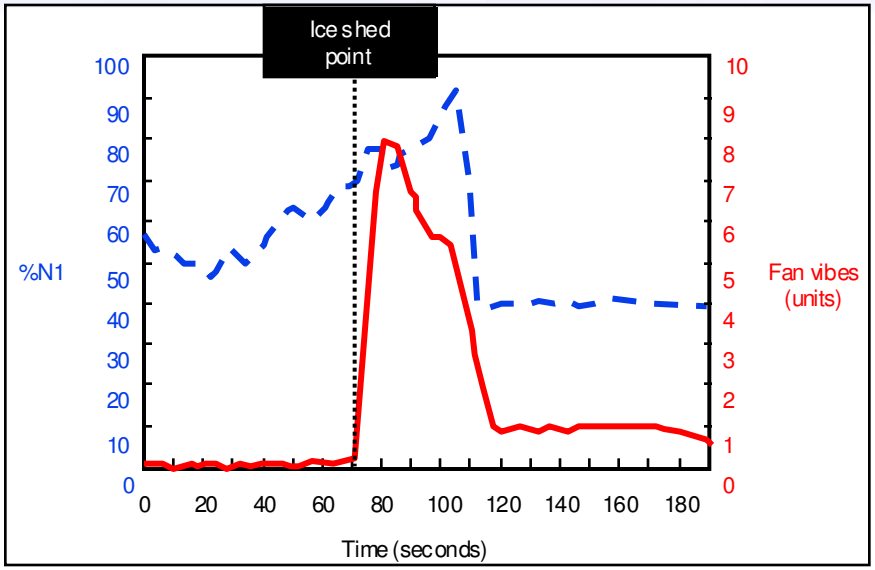
Normal Operation

Ground Operation in Icing Conditions

- ***ANTI-ICE ON***
  - *Anti-ices inlet lip*

- *During extended operation (more than 30 minutes):*
  - ***Accelerates engines to 70% N1 and hold for 30 seconds*** *(or to an N1 and dwell time as high as practical, considering airport surface conditions and congestion)*
    - *Allows immediate shedding of fan blade and spinner ice*
    - *De-ices stationary vanes with combination of shed ice impact, pressure increase and temperature rise*

**** Note: In addition to the above when in freezing rain, drizzle or fog, heavy snow ice shedding may be enhanced by additional runups at intervals not to exceed ten minutes.***



- ***Perform this procedure every 30 minutes and just prior to or in conjunction with the takeoff procedure****, with particular attention to engine parameters prior to final advance to takeoff thrust*

Normal Operation

Takeoff

- ***N1 (fan speed) vs EPR used as power management parameter***
  - *N1 directly related to fan thrust (80% of total) and to core thrust*
  - *N1/thrust relationship insensitive to engine deterioration*
  - *Less complex*
  - *More reliable*

- ***Ignition***
  - *Requirement specified by aircraft manufacturer*
  - *Engine certification tests completed without the use of ignition*
- ***Bleeds***
  - *ON/OFF depending on company policy/performance requirements*
  - *Effect on engine parameters*

Normal Operation

TakeOff SAC/DAC intermix

TAKEOFF PROCEDURE

- In consequence of the DAC spool up time lag (up to 5 seconds), the rolling takeoff procedure is not recommended.
- Apply Static T/O

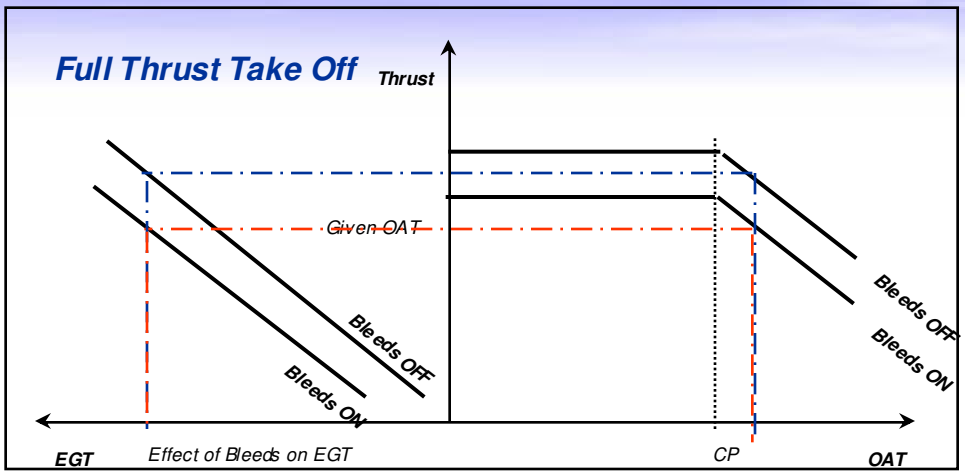
1. Idle to 50% N1 on both engines
2. Release brakes when the 50% N1 is stabilized on both engines.
3. Both engines N1 to takeoff thrust.

Other standard operating procedures for takeoff apply

Flight Crews must be aware of the intermix configuration and its operation

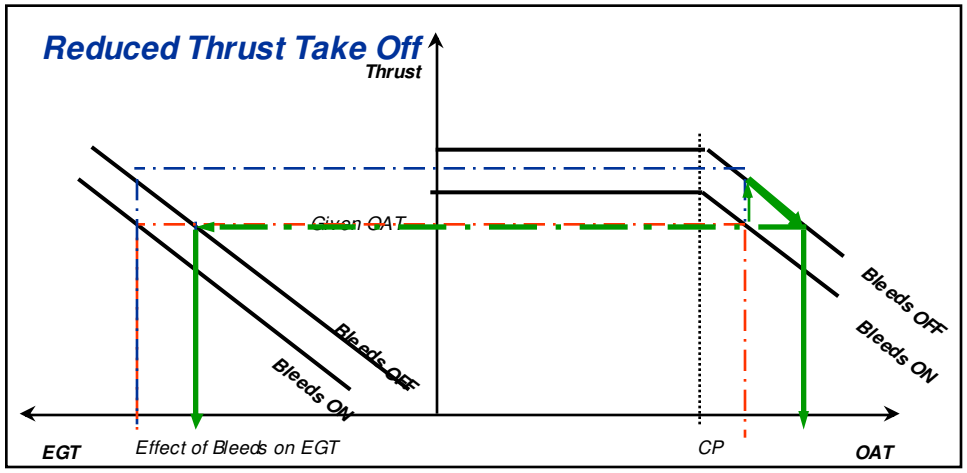
Normal Operation

Eng Bleeds effect at Takeoff



***At full take off power**, there is a thrust decrement when setting Eng Bleeds Off to Bleeds On when EGT remain the same. Only MTOW is impacted, higher with Bleeds Off than Bleeds On.*

***At reduced take off thrust**, this is the same logic that full thrust. But as the TOW (Take Off Weight) is not maximum, in order to recover the same level of thrust Bleeds Off than Bleeds On, reduced thrust need to be increase, so EGT will decrease .*



Redcued thrust Take Off with engine bleeds OFF increase engine live

Normal Operation

Bleeds effect

Takeoff S.O.P.

- *Before Takeoff :*

– **PACK 1 and 2 . . . . . AS RQRD**
Consider selecting packs OFF or APU bleed ON.
This will improve performance when using TOGA thrust.
In the case of a FLEX takeoff, selecting packs OFF or APU bleed ON will reduce takeoff EGT, and thus reduce maintenance costs.

APU BLEED ON or PACKS OFF ?

- *PACKS ON (with APU bleed ON) will increase passenger comfort.*
- *However, this leads to a higher APU use (i.e. increased APU maintenance costs).*

Normal Operation

Bleeds effect

Takeoff S.O.P.

- After takeoff S.O.P.:

PACK 1 + 2 ……ON

- elect PACK 1 ON after CLB thrust reduction
- Select PACK 2 ON after flaps retraction

- EGT would increase if packs are set to ON before CLB thrust is set.
- This 2 steps procedure will maximise passenger comfort when pressurising the aircraft.
- The ECAM caution **AIR PACK 1 (2) OFF** will be triggered if the crew forgets to turn the PACKS ON after 60 sec in Phase 6 (1500 ft after TakeOff till 800ft before Landing).

Normal Operation

Bleed Failure at T/O

- The **thrust decrement is frozen by the FADEC** when:
  - The aircraft is on the ground
  - Thrust **levers at or above MCT/FLX**
  - The configuration is latched in flight **until the thrust levers are set to CL**

- The **thrust decrement is frozen by the FADEC during the takeoff**. This avoids:
  - Thrust fluctuations in case of an intermittent bleed failure.
  - Thrust loss in case of a bleed failure (I.e. APU auto shutdown, with APU BLEED ON).

In case of a failure, the EGT may increase but the takeoff thrust remains.

Normal Operation

Bleeds effect Summary

- ***Bleed selection for takeoff has an impact on the takeoff performance.***
- ***PACKS OFF or APU BLEED ON can be used:***
  - *to improve performance when TOGA is used*
  - ***to reduce EGT when FLEX thrust is used:***
    - *This will increase the engine's life and decrease Maintenance costs*
    - *This will help prevent EGT exceedances on engines with reduced EGT margins.*
- ***Zone Controller and FADEC protection logics ensure a safe takeoff in case of abnormal bleed :***
  - *no engine thrust asymmetry.*
  - *no thrust loss after takeoff power application.*

Normal Operation

Takeoff

- ***From an engine standpoint, rolling takeoff is preferred***
  - *Less FOD potential on contaminated runways*
  - *Inlet vortex likely if takeoff N1 set below 30 KIAS*
  - *Less potential for engine instability or stall during crosswind/tailwind conditions*
- ***N_1 thrust management***
  - *Engine control computes command N_1 for max or reduced thrust*
  - *Throttle "stand up" prior to full thrust (minimizes uneven acceleration)*
  - *Pilot sets throttle for full thrust or reduced thrust*
  - *Aircraft/engine controls maintain N_1 at command value*

Normal Operation

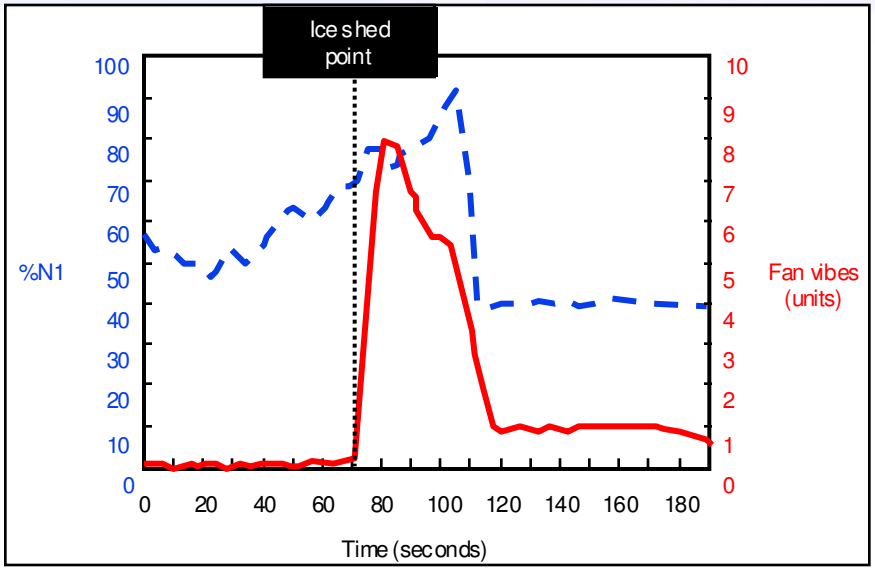
Cruise

- ***Avoid unnecessary use of ignition***
  - *Conserves ignitor plug life*

Cruise Operation in icing conditions

- ***Only inlet cowl is anti-iced:***

*use **ENG ANTI-ICE** per FCOM*



- *Fan/spinner ice manifested as vibration as ice partially sheds*
  - ***If vibration encountered in icing conditions or as a preventive measure when operating at 70% N1 or below in moderate to severe icing conditions, perform the following procedure (1 engine at a time):***
    - ***Reduce N1 to 45%***
    - ***Increase N1 to 80% minimum then reduce as required for flight conditions***
    - ***Repeat the procedure every 15 minutes***
  - *Centrifugal force, temperature rise, and pressure increase will remove ice*

Normal Operation

Descent

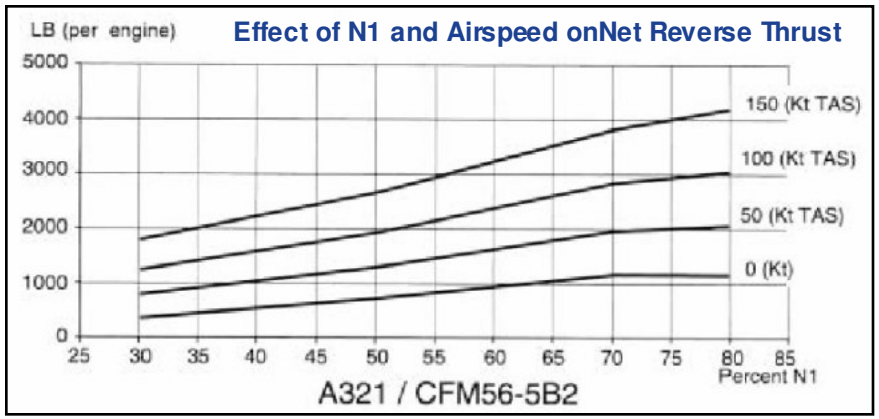
Smooth power reduction

In Approach Idle mode the DAC logic mode switches to the 20/2*5 when the flaps/slats are extended

Idle most economical

Engine control maintains appropriate idle speed

Engine control maintains mini N1 required for operation in icing or rain/hail conditions



Landing/Reversing

- Minimize reverse thrust use on contaminated runways
- Reversers most effective at higher airspeed
- Modulate reverse if full thrust not needed
  - Less thermal stress and mechanical loads
  - Reduced FOD
- Reduce reverse thrust at 70 KIAS
- Reverse thrust is more effective at high speed
  - Use high reverse thrust early, if necessary
- Start reducing reverse thrust per aircraft operations manual
  - For FOD conditions, at 80 kias, if practical
  - Most installations are certified for full thrust use to 60 kias (without engine instability) but re-ingestion of exhaust gases/debris may occur at full reverse thrust below 80 kias
- Select forward thrust at taxi speed and before clearing runway

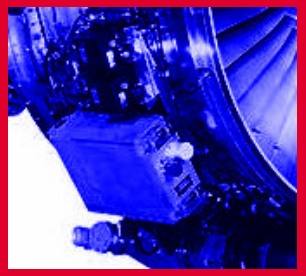
Normal Operation

Shutdown

- ***3 minutes cooldown*** *after coming out of reverse*
  - *Includes taxi*

- ***One Engine Taxi In ?..*** *Operators have to keep in mind some specifics.*
  - *On well known airports to take benefit of this procedure by anticipating maneuvers*
  - *Caution to avoid jet blast and FOD*
  - *More thrust for breakaway and 180° turn*
  - *Turns on the operating engine may not be possible at high GW*
  - *Fuel saving with one-engine taxi: 12 minutes of one-engine taxi on A320 burns 92 kg of fuel versus 138 kg with 2 engines. Saving is 46 kg.*

- ***Cool down not required for emergency shutdown***



CFM56 General

Technical Features

Engine Certification & Testing

Operational Characteristics

EGTMargin, OATL

Reduced TakeOff Thrust

Normal Operating Considerations

Flight phases, ops recommendations

Selected Abnormal Conditions

THE POWER OF FLIGHT

Selected Abnormal Conditions

Evidence of Severe Engine Damage

(Symptoms Observed Following Severe Damage Events)

- Loud bang, spooldown, aircraft yaw
- High indicated vibration (N1 or N2)
- High felt vibration (N1)*
- N1 or N2 rotor seizure*
- Visible damage to cowling or aircraft structure*
- Visual confirmation of metal exiting tailpipe*
- Missing engine parts (e.g. tail cone)*
- Rapid increase in EGT > red line limit
- Fumes or burning smell in the cockpit/cabin
- Gross mismatch of rotor speeds (N1 vs N2)
- Throttle seizure
- Non-response of engine to throttle movement
- High nacelle temperature
- Rapid decrease in oil quantity or pressure
- High oil temperature
- Oil filter clog
- Fuel filter clog

- Observation of one of these symptoms alone may not indicate severe engine damage
- These symptoms occurring in combination or following a suspected bird strike or other FOD ingestion (e.g., ice slab), stall or power loss could indicate severe engine damage
- (*) Asterisked items alone may indicate severe engine damage with or without other indications

Selected Abnormal Conditions

Autostart Failure to Lightoff Logic

Ground

- Lightoff **detected when EGT increases 55°C above initial EGT**
- **If no lightoff** within 15 seconds (20 seconds cold engine)
  - **Fuel and ignition turned off**
  - **Dry-motored for 30 seconds**
- Second start attempted with both ignitors for 15 seconds
- **If no lightoff on second attempt**
  - Start is aborted
  - Fuel and ignition turned off
  - Dry-motor for 30 seconds to purge the system of fuel
  - Flight deck advisory

In-flight

- **If no lightoff within 30 seconds**
  - Flight crew must turn fuel off
  - Observe a 30 second windmill/dry motor period between start attempts

Selected Abnormal Conditions

Autostart Hot Starts, Start Stalls, Overtemperature Logic

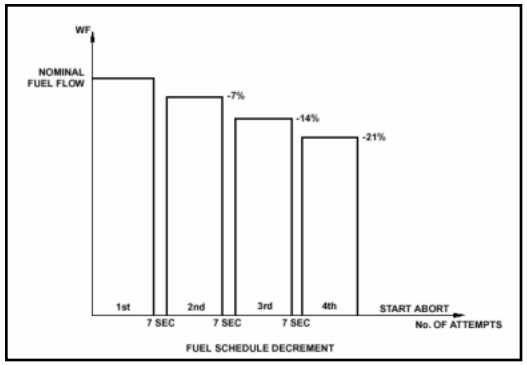
Ground

- *If a **hot start, start stall, or overtemperature** is detected*
  - *Fuel metering valve closes for 6 seconds, then opens with 7% fuel decrement*
  - *Start fuel flow schedule is reduced at a total of 21% in three 7% decerements*

In-flight

- *If a **hot start, start stall, or overtemperature** is encountered*
  - *The flight crew must abort the start*
  - *Observe a 30 second windmill/dry period between start attempts*

- ***If the abnormality occurs after the third increment***
  - *Start is aborted*
  - *Fuel and ignition off*
  - *Flight deck advisory*



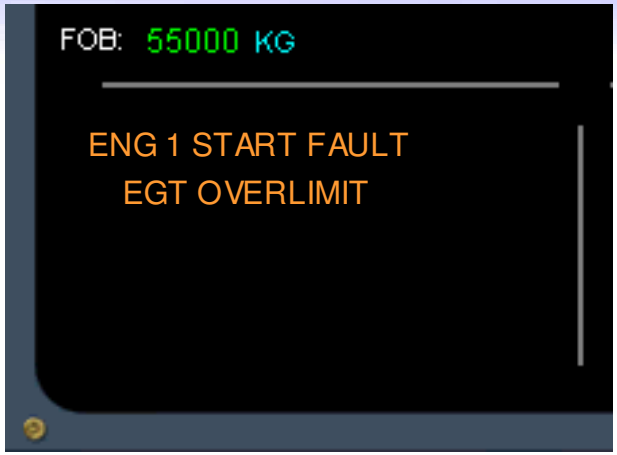
Selected Abnormal Conditions

CFM56-5 Autostart Miscellaneous Adaptive Logic

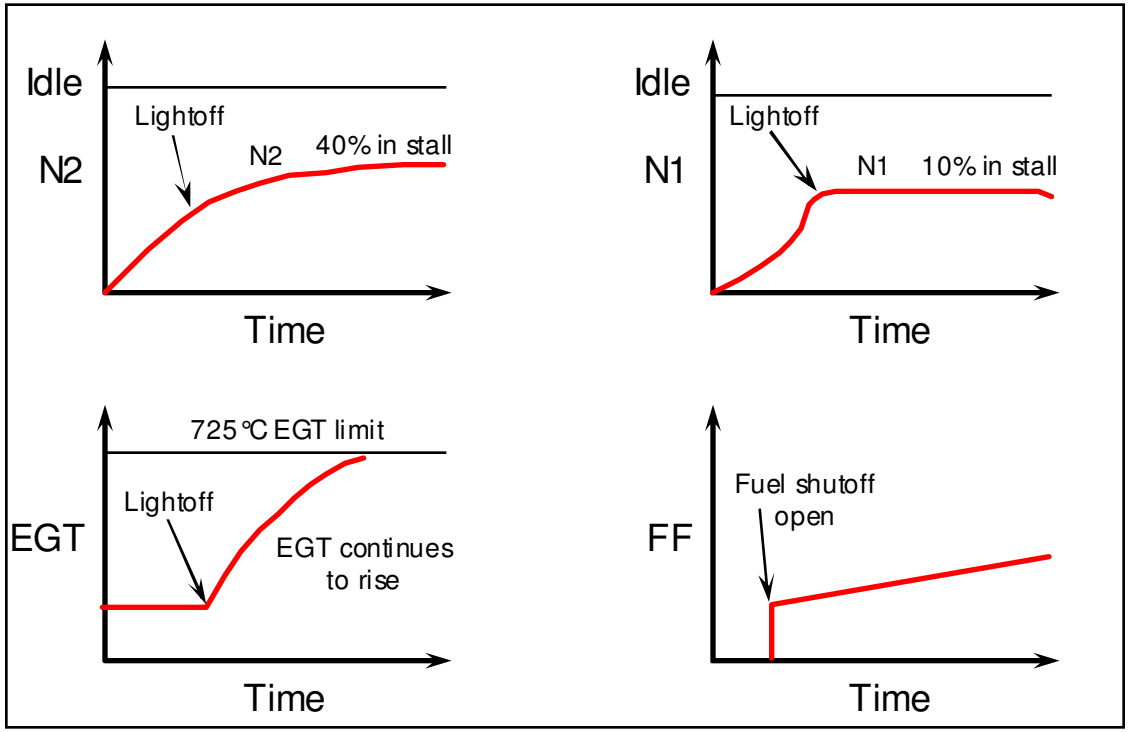
- *Low acceleration*
  - *If the engine is accelerating slowly and the EGT is low, the FADEC will abort the start on the ground. If in flight, the pilot must abort the start*
  - *Observe a 30 second windmill/dry motoring period between start attempts*
- *Low acceleration with reduced fuel flow schedule due to overtemp or start stall*
  - *If the engine is accelerating slowly and the EGT is low, the fuel flow schedule is slowly incremented back up to standard*

Selected Abnormal Conditions

Low Speed Stall Characteristics: Lightoff Stall

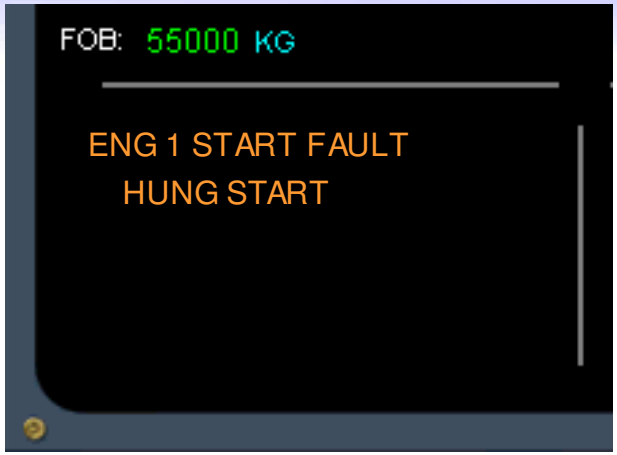


- ***Engine speed stagnates immediately after lightoff***
- ***EGT rises rapidly***
- ***Not self-recovering***
  - *Recovery requires FADEC or flight crew intervention*

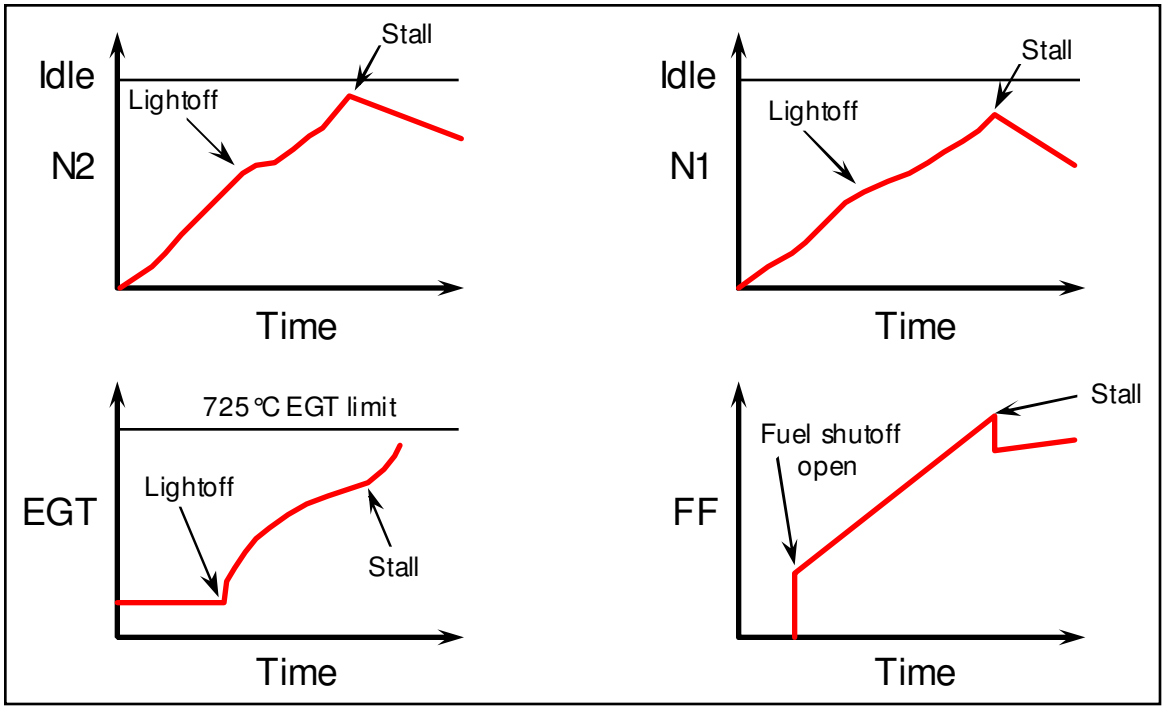


Selected Abnormal Conditions

Low Speed Stall Characteristics: High Sub-idle Stall



- ***Engine stalls just below idle***
- ***EGT rises rapidly***
- ***Not self-recovering***
  - *Recovery requires FADEC or flight crew intervention*



Airlines are fully involved for the engine choice, but crews are the main contributors for saving the engine

- *Pilots are the single most important influence on the engine operation*
- *99% of engine operating time is dedicated to the pilot*
- *Over the last 20 years, engine technology has deeply changed and determines pilots behaviour in terms of aircraft operations.*
- *New generations of engines being not any more handled as in the past, pilot should adapt to new managing.*

Pilots need to be fully informed and confident about either comprehensive overview of optimized engine operation and development of what is qualified as an Economical Reflex to ensure proper and longer Time On Wing.

Airlines are fully involved for the engine choice,...

...But crews are the main contributors for saving the engine...

THE POWER
OF FLIGHT

Thanks for your attention!