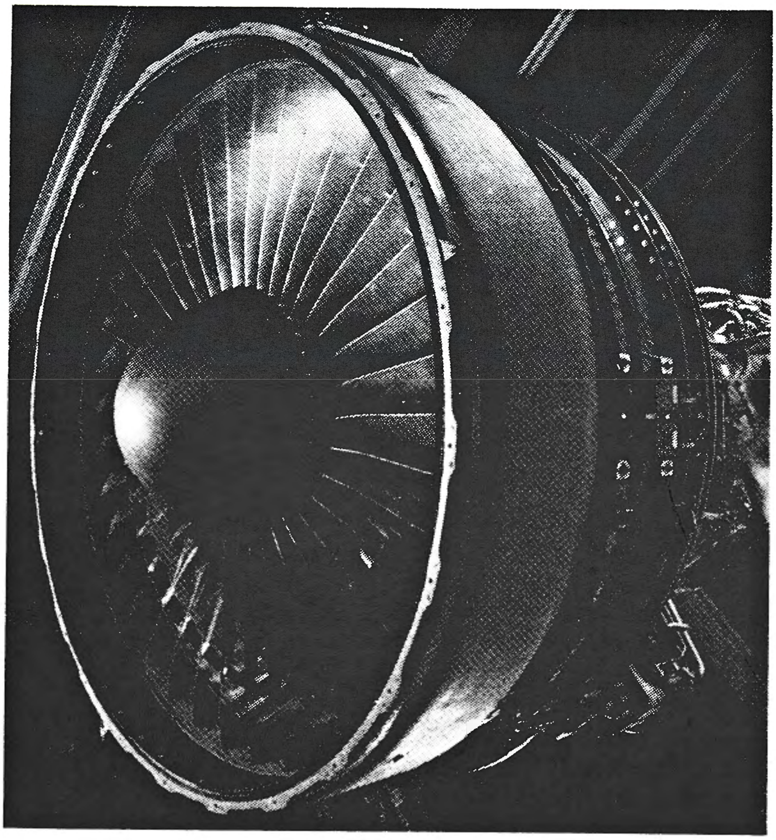

CF6-80C2
Engine Review

Flight Operations
FADEC Version

GE Aircraft Engines

Outline

- Organization and programs
- Technical features
- Testing and operational experience
- Operational characteristics and recommendations
- Trend monitoring
- Erosive FOD prevention

NOTES

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376 Hsin-nan Rd., Sec. 1. Luchu
TAOYUAN HSIEN, Taiwan, R.O.C.
Tel./Fax +886-3-351 69 37

Organization and Programs

T815.02 - 880506

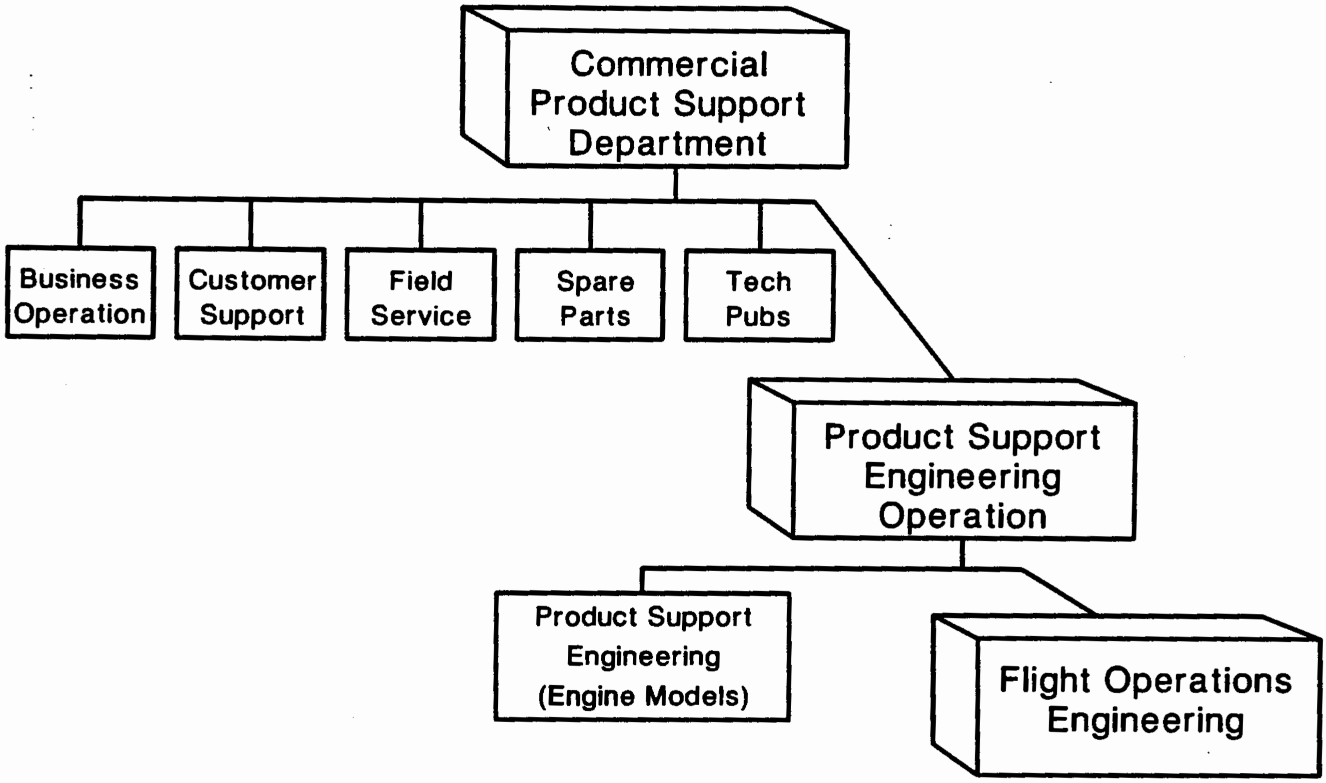
NOTES

GE Aircraft Engines

ST815.03 - 870603

NOTES

Flight Operations Engineering Organization



T1422.22 - 880202

Flight Operations Engineering (FOE) is established within the GE Commercial Product Support Department to:

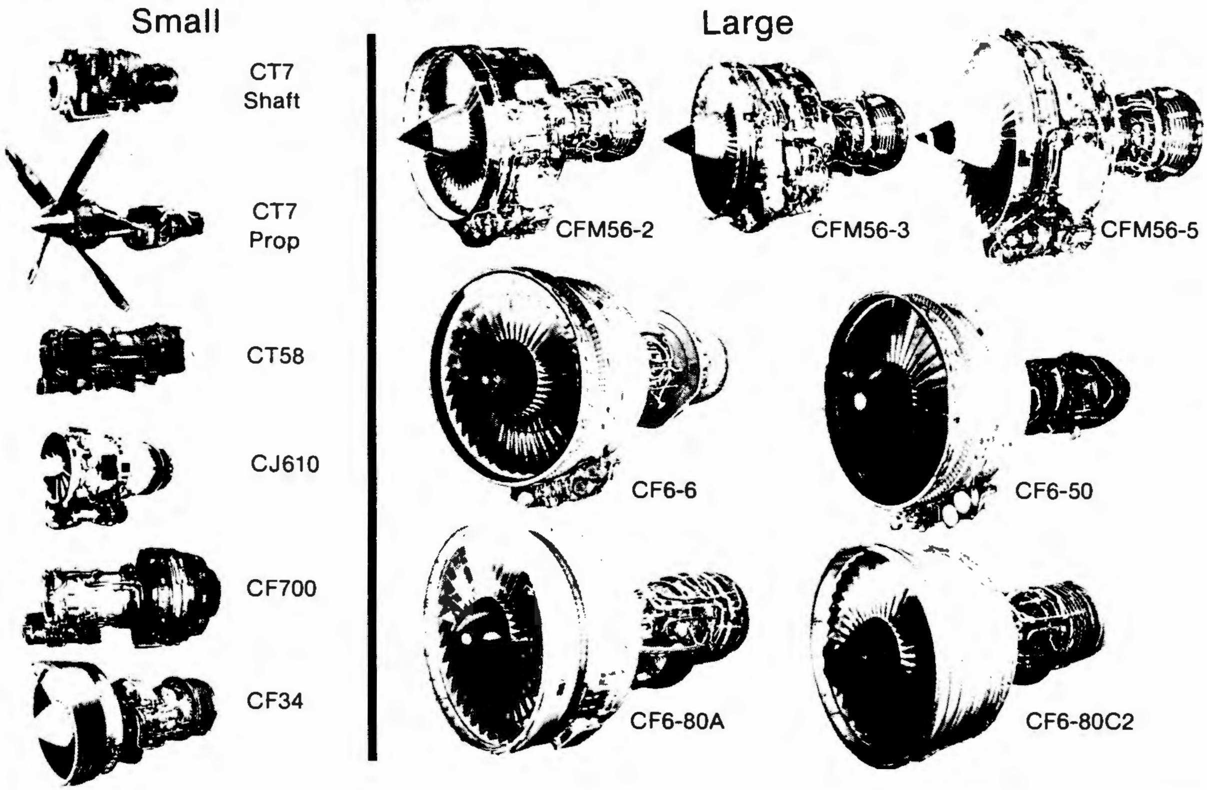
- Interface with customer and airplane manufacturer's flight operations.
- Represent their viewpoint within GE/CFMI.
- Provide flight operations feedback to GE/CFMI.

FOE is currently staffed with pilots with military, flight test, training or engineering experience. A flight operations engineering manager is assigned to each product line (CF6, CFM56).

Some of FOE's specific tasks are:

- Conduct engine systems/operations briefings and seminars.
- Perform routine and special purpose operations surveys.
- Research engine operations questions from customers and manufacturers.
- Issue and maintain engine operations documents.
  - Specific operating instructions.
  - Operations engineering bulletin.
- Maintain selected airplane flight/ operations manual.
- Participate in flight test programs.

Commercial Engines

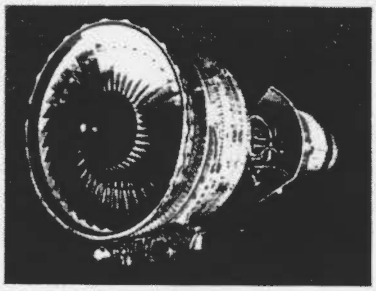


7S-1049-081285

GE's small commercial engines (turboprop and turboshaft) are built at our plant in Lynn, Massachusetts. Our large commercial engines (greater than 20,000 pounds of thrust) are built in Evendale, Ohio. CFM (Commercial Fan Moteur) engines are designed, marketed, manufactured and supported by CFM International, a joint company formed by GE and SNECMA of France. Some of these engines are assembled in France.

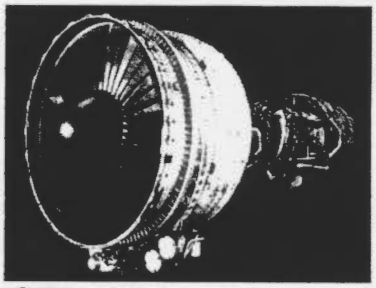
NOTES

CF6 Commercial Engines



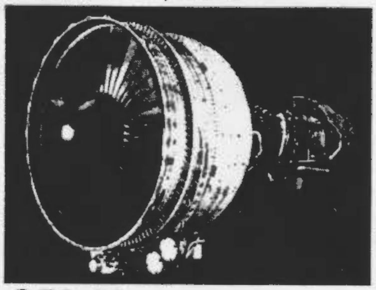
CF6-6

40,000 to 41,500 lb



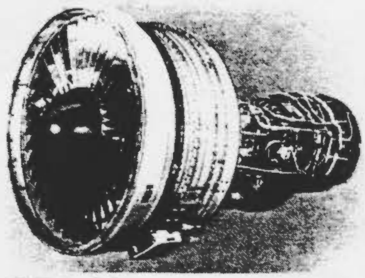
CF6-45A2

46,500 lb



CF6-50

46,500 to 54,000 lb



CF6-80

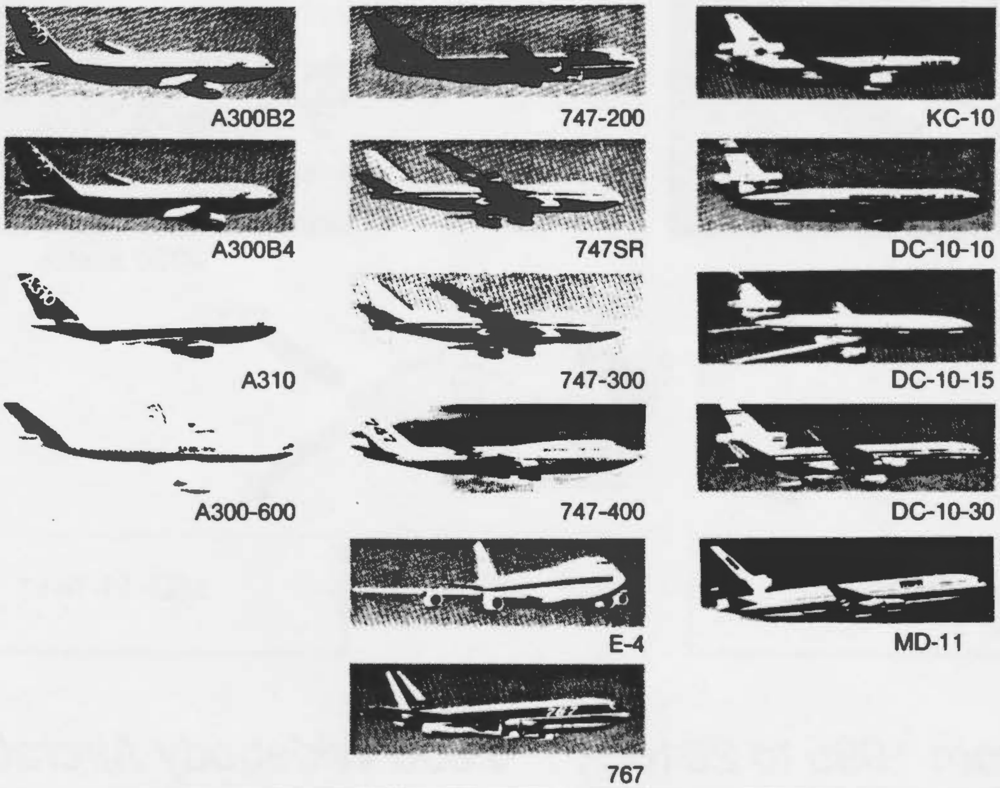
48,000 to 60,200 lb

5S-733-072385

The CF6 product line encompasses the thrust range from 40,000 to over 60,000 pounds of thrust.

NOTES

CF6 Powers Fifteen Aircraft Types



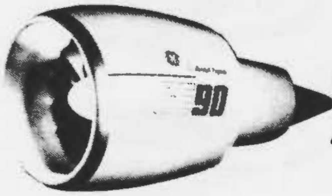
5S-694-052389

NOTES

GE90 Engine

767-X

A330 stretch



Advanced 747

MD-11 twin

From 1995 to 2010 . . . ~2500 Widebody Aircraft

MAC5-50013-121489

NOTES

GE90 Comparisons

	GE90	CF6-80C2	CF6-50C
Thrust (lb)	75,000-95,000	60,800	50,400
Fan diameter (in)	120	93	86.4
Fan blades	Composite or Titanium	Titanium	Titanium
Bypass ratio	10	5.3	4.4
Overall compressor ratio	40	30	30
Certification date	May 1994	Sept 1987	Nov 1973

MAC2-52088-032090

NOTES

CF6 Today

- 1129 Commercial aircraft in service
- 3818 Commercial engines in service
- 83.4M flight hours
- One departure every 28 seconds

99.90% ________ Dispatch Reliability

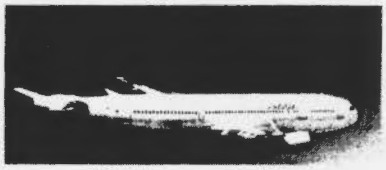
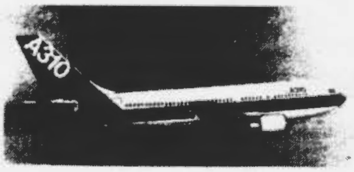
0.011/1000 hours ________ Basic In-Flight Shutdown Rate

0.202/1000 hours ________ Basic Shop Visit Rate

MAC5-21906-102290

NOTES

CF6-80C2/E1 Airbus Customers

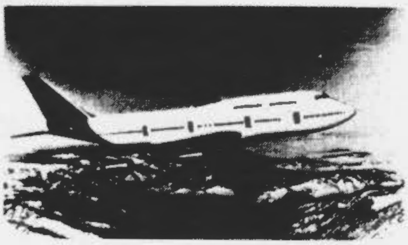
Aircraft	Customers	A/C Firm/ Option	Installed Engines
 A300-600/600R	*American Airlines, China Eastern, Compass, *Emirates, ILFC, *Lufthansa, Monarch, Olympic, *Thai Airways Int'l	73/9	146/18
 A310-300/-200 Advanced	Aeroflot, Air Afrique, Air France, Air-India, *China Eastern, *Condor, CSA, *Cyprus, *Emirates, Europe Aero Service, *Hapag-Lloyd, ILFC, *Interflug, *Kenya, *Lufthansa, Pakistan Int'l. Airways, *Royal Jordanian, *Somali, *TAP, TEA Int'l., *Thai Airways, *THY, *Wardair, *VIP	112/17	224/34
 A330 (CF6-80E1)	Air Inter, Continental, ILFC, Thai Airways Int'l.	36/25	72/50
		Total Orders 221/51	Total Engines 442/102

* In service

MAC5-20881-081590

NOTES

CF6-80C2 Boeing Customers

Aircraft	Customers	A/C Firm/ Option	Installed Engines
 747-200/-300/-400	Air France, *Air-India, All Nippon Airways, Asiana, Canadian Airlines Int'l., EVA Airways, ILFC, JAL, KLM, Lufthansa, Malaysia, *Thai Airways Int'l., U.S. Air Force, UTA, *VARIG, VIP	161/109	640/436
 767-200ER/-300/-300ER	*Air Algerie, *Air Mauritius, Air New Zealand, Air Seychelles, *All Nippon Airways, *American Airlines, Asiana, Britannia, *Canadian Airlines Int'l., EVA Airways, *Gulf, ILFC Air, LOT-Polish Airlines, Monarch, *QANTAS, TACA, *USAir, *VARIG, VIP	166/75	332/150
		Total Orders 327/184	Total Engines 972/586

* In service

MAC5-20882-081590

NOTES

CF6-80C2 Douglas Customers

MD-11

Alitalia, American Airlines, EVA Airways, Federal Express, Finnair, Garuda, GPA, Mitsui, Nigeria, Thai Airways Int'l., VARIG, VIASA, Zambia

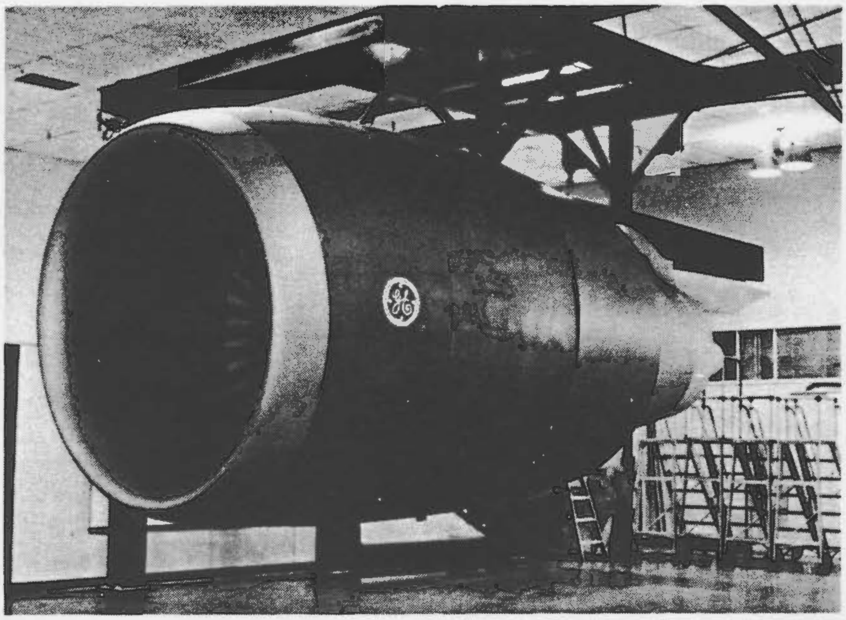
A/C Firm/ Option	Installed Engines
73/72	219/216

NOTES

Technical Features

T815.09 - 860506

NOTES



The CF6-80C2 advanced propulsion system

27S-746-012286

The CF6-80C2 is a dual-rotor, variable stator, high bypass ratio turbofan engine designed for subsonic commercial airline service.

Design features:

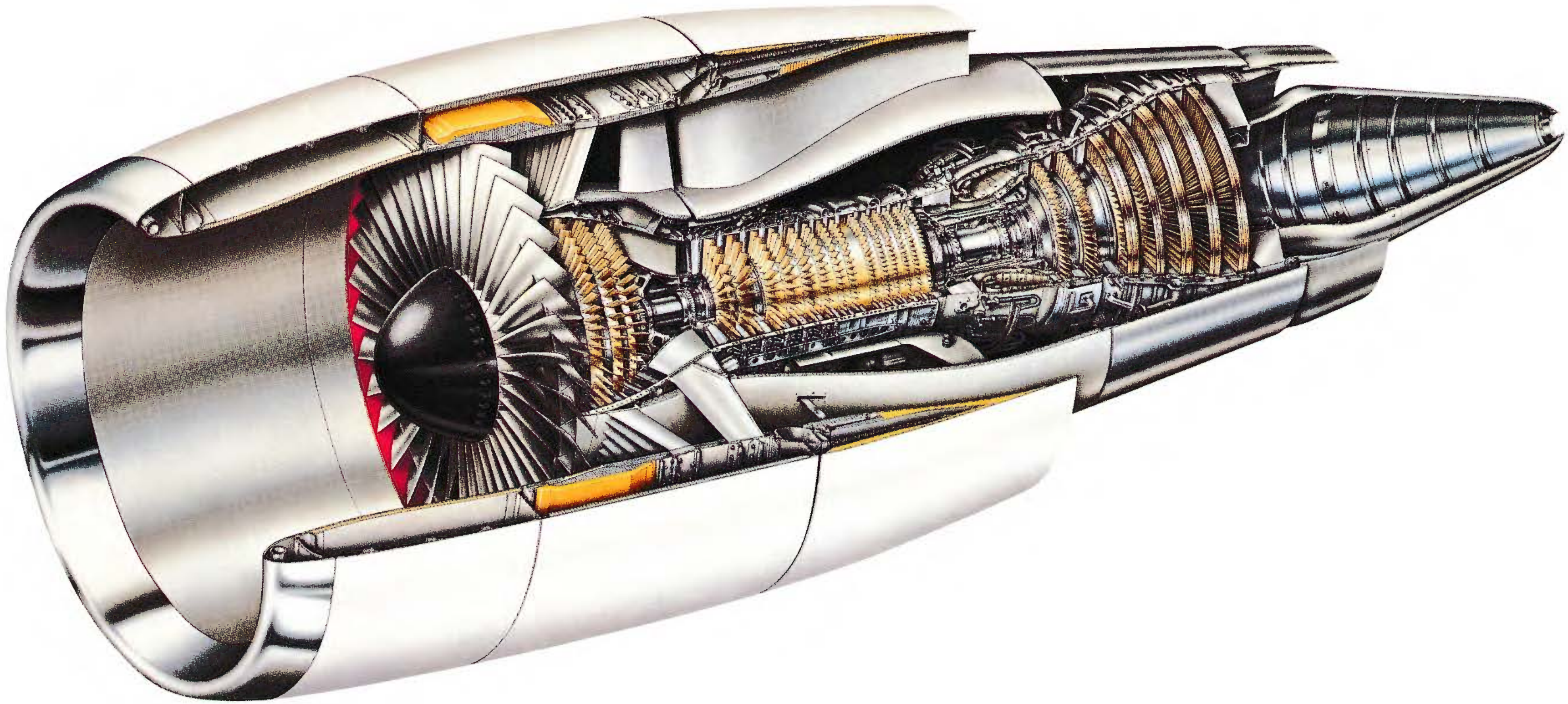
- High thrust to weight ratio
- Long life
- High reliability
- Easy access for line maintenance
- Modular disassembly
- Low noise and smokeless operation
- Built in growth potential

Engine weight and dimensions (with nacelle)

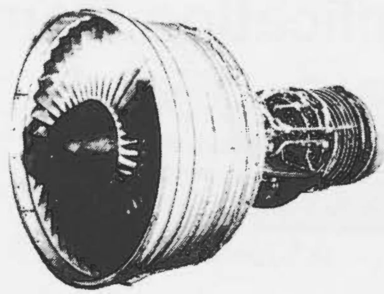
- Weight – 12,860 pounds
- Length – 283 inches
- Diameter – 133 inches

NOTES

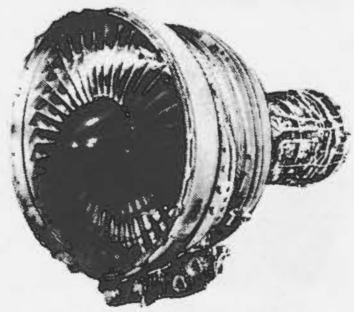
GE CF6-80C2 Propulsion System



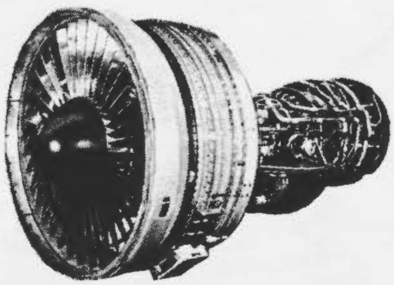
The CF6-80 Family



-80C2 *
Thrust: 50-61,500 lb **



-80A1/A3
Thrust: 48-50,000 lb *



CF6-80A/A2
Thrust: 48-50,000 lb *

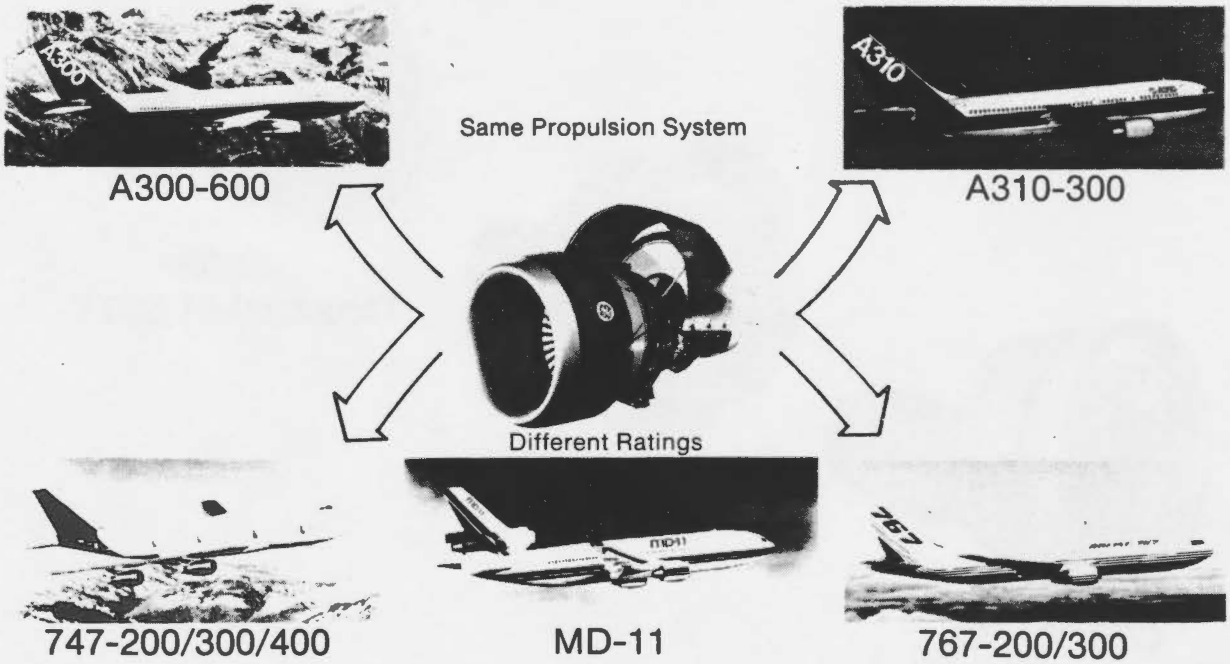
* Ideal thrust ratings
** Growth to 67,500 lb

10S-1582-090385

Model	Application
CF6-80A	767-200 A310-200
CF6-80C2	A300-600 A310-200 Adv/-300 747-300/-400 767-200ER/-300 MD-11

NOTES

Application Commonality



5S-727-012986

The CF6-80C2 is offered on virtually all the advanced wide body aircraft: A300-600, A310-200/300; B747-200/300/400; B767-200/300 and MD-11.

NOTES

CF6-80C2 Specifications

Ideal Thrust Ratings

Model	-A2	-A3	-A5	A7	-B1	-B1F	-B2	-B4	-B6	D1F
Application	A310-200 Adv. A310-300	A300-600	A300-600R	A310-300	747-200/ -300	747-400	767-300/ -200	767-200ER 767-300ER (380K TOGW)	767-300ER (400K TOGW)	MD-11
Takeoff	53,500	60,200	61,300	56,200	56,700	57,900	52,500	57,900	60,800	61,500
Flat rate										
Temp. – °F	111	86	86	111	86	90	90	90	86	86
– °C	44	30	30	44	30	32	32	32	30	30
BPR	5.3	5.1	5.0	5.1	5.2	5.1	5.3	5.1	5.1	5.0
OPR	27.8	31.1	31.5	31.3	29.3	29.9	27.4	29.9	31.1	31.9
35,000ft/0.8M/ ISA + 18°F										
Max Climb	12,790	13,250	13,250	12,790	13,180	13,550	12,880	13,180	13,500	13,150
Max Cruise	11,810	11,800	11,800	11,810	12,820	13,200	12,010	12,330	12,700	11,750

MAC7-18681-081189

The CF6-80C2 engine is sold in a variety of thrust ratings and flat rate temperatures. All hardware is essentially the same. Models with "F" suffix are equipped with Full Authority Digital Electronic Control (FADEC).

NOTES

CF6-80C2 Specifications

Ideal Thrust Ratings

Model	-A2	-A3	-A5	A7	-B1	-B1F	-B2	-B4	-B6	D1F
Application	A310-200 Adv. A310-300	A300-600	A300-600R	A310-300	747-200/ -300	747-400	767-300/ -200	767-200ER 767-300ER (380K TOGW)	767-300ER (400K TOGW)	MD-11
Takeoff	53,500	60,200	61,300	56,200	56,700	57,900	52,500	57,900	60,800	61,500
Flat rate										
Temp. – °F	111	86	86	111	86	90	90	90	86	86
– °C	44	30	30	44	30	32	32	32	30	30
BPR	5.3	5.1	5.0	5.1	5.2	5.1	5.3	5.1	5.1	5.0
OPR	27.8	31.1	31.5	31.3	29.3	29.9	27.4	29.9	31.1	31.9
35,000ft/0.8M/ ISA + 18°F										
Max Climb	12,790	13,250	13,250	12,790	13,180	13,550	12,880	13,180	13,500	13,150
Max Cruise	11,810	11,800	11,800	11,810	12,820	13,200	12,010	12,330	12,700	11,750

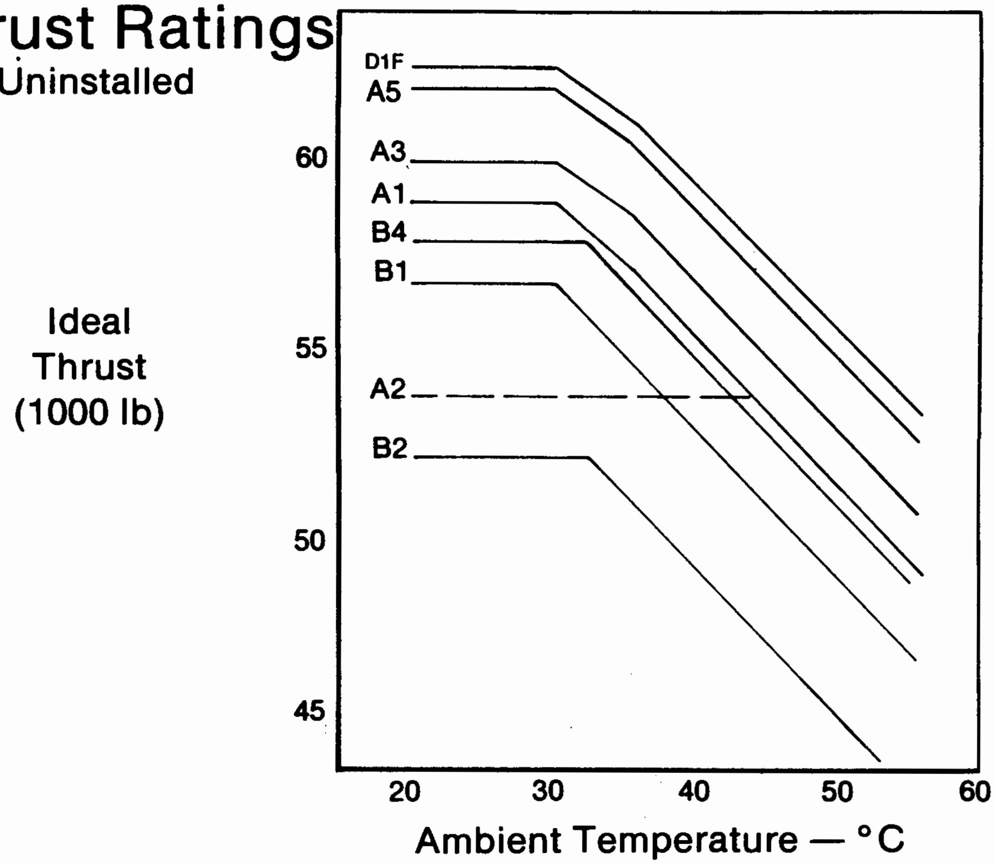
MAC7-18681-081189

The CF6-80C2 engine is sold in a variety of thrust ratings and flat rate temperatures. All hardware is essentially the same. Models with "F" suffix are equipped with Full Authority Digital Electronic Control (FADEC).

NOTES

Thrust Ratings

SLS, Uninstalled



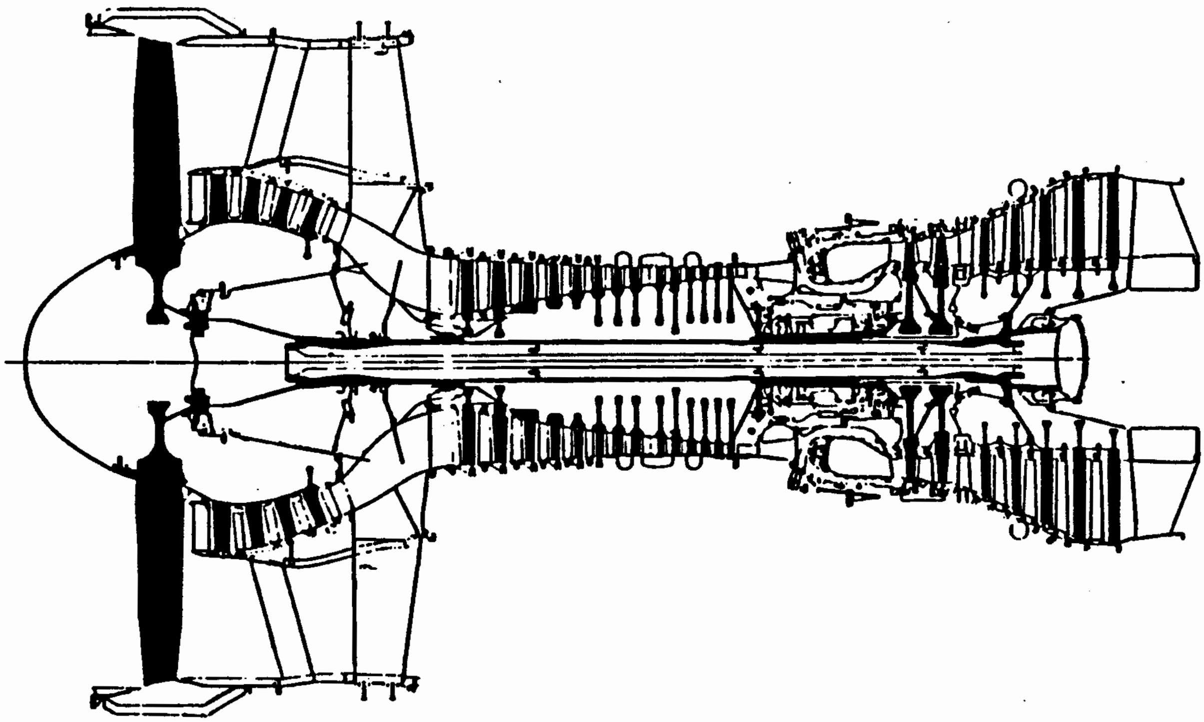
12S-193-101985

The engine is defined as flat rated because it is run to a specific thrust output up to the flat rating temperature specified by model type. At temperatures above the flat rated temperature the maximum thrust is limited so as to maintain a constant EGT value.

This chart, while it does not include all available thrust ratings for the CF6-80C2, does illustrate the concept of different ratings and flat rate temperatures.

NOTES

Cross Section

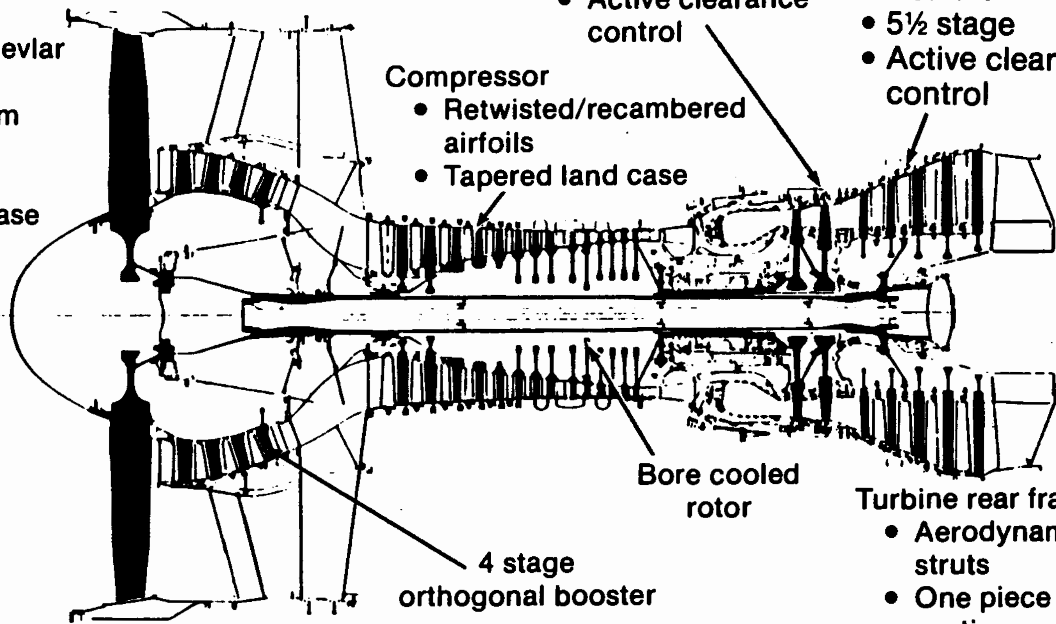


28S-4957-102687

The CF6-80C2 is a high bypass, dual spool engine; "high bypass" because 80% of the airflow entering the engine bypasses the "core engine" and exits the fan duct as fan thrust. The dual spools are the low pressure (LP) spool and the high pressure (HP) spool which rotate concentrically and independently of each other. The LP spool consists of the 5-stage LP compressor (fan and 4-stage booster), LP shaft and 5-1/2-stage LP turbine (the last 1/2 stage is stator). The HP spool consists of the 14-stage HP compressor, HP shaft and 2-stage HP turbine.

Looking at the components' functions from front to rear: the fan provides about 80% of the engine thrust from the air bypassing the rest of the engine and exiting the fan duct (thus the term "high bypass"). About 20% of the air enters the booster where it is super charged prior to entering the HP compressor. In the HP compressor the pressure of the air is increased by a factor of 30, mixed with fuel and burned in the combustor. The resultant hot gases pass across the HP turbine which transmits torque via the HP shaft to the HP compressor, and the LP turbine which transmits torque via the LP shaft to the fan and booster.

Major Design Features



Significant component efficiency and weight improvements

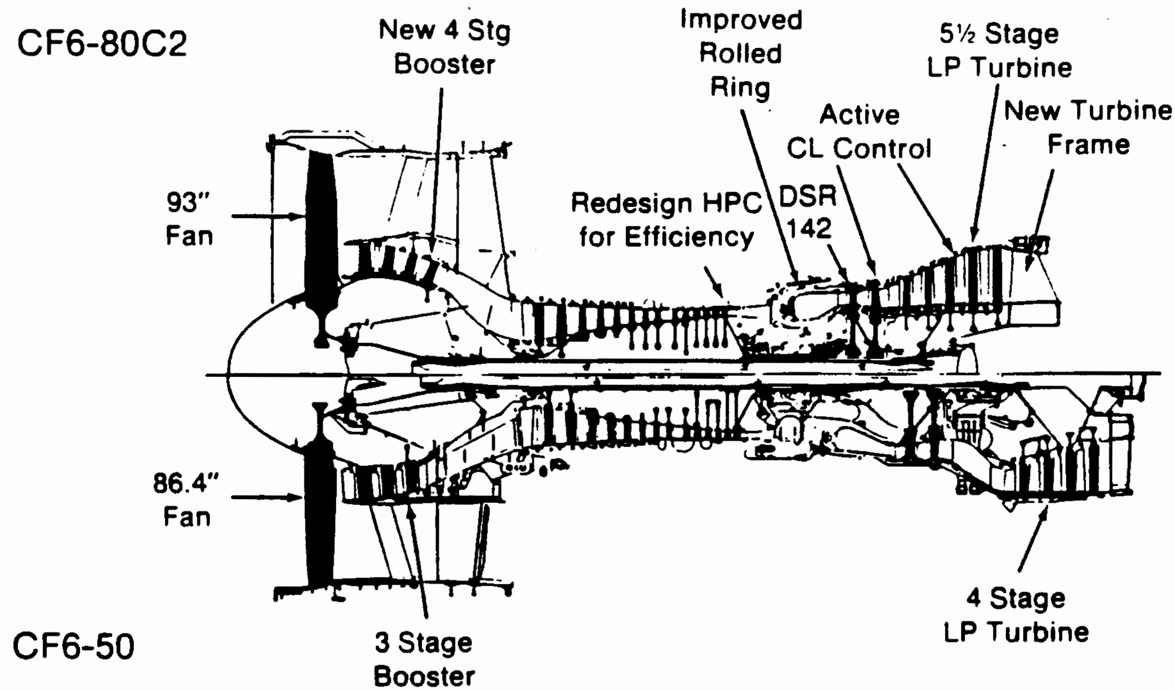
305-8110(AMD1)-042486

Major features of the CF6-80C2 provide increased thrust, reduced weight, and reduced SFC. SFC reduction is accomplished by recambering the fan blades, reducing pressure losses and leakages, and retwisting/recambering the compressor airfoils. A large portion of the SFC improvement is a result of redesigning the turbines to incorporate General Electric's latest aerodynamic technology with active clearance control on all stages.

Weight optimization features include aluminum composite structures, a titanium fan frame, composite sectored OGV's (outlet guide vanes), one piece cast turbine rear frame, lightweight sumps, and a space frame type gearbox mount.

NOTES

CF6-80C2 vs -50



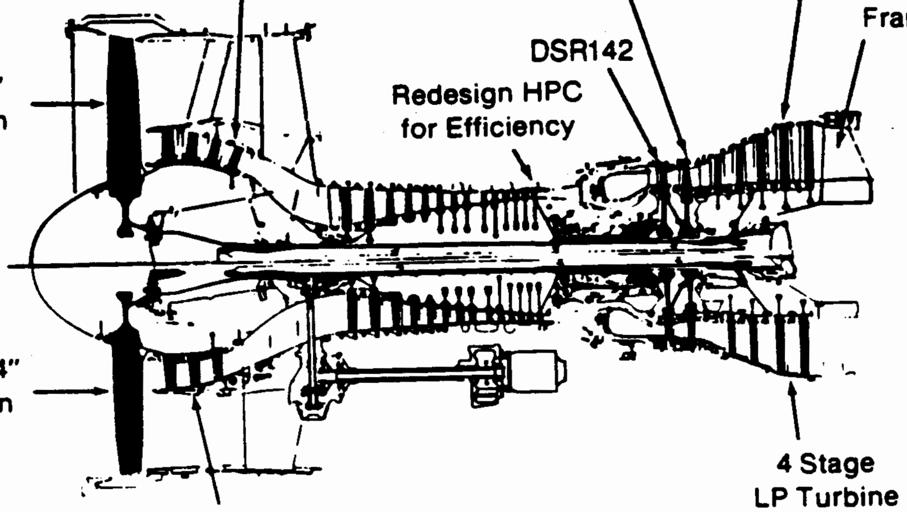
6S-841A-063086

CF6-80C2 design improvements over CF6-50

- Larger fan diameter (86.4 in. vs. 93.0 in.)
- Additional booster stage
- Shortened fan frame
- Eliminated turbine mid frame
- Reduced HPT cooling requirements
- Redesigned HP compressor for efficiency
- Shortened combustor by 3 inches
- HP and LP active clearance control
- Additional 1 1/2 LPT stage
- FADEC or PMC/MEC control

NOTES

CF6-80C2 vs -80A



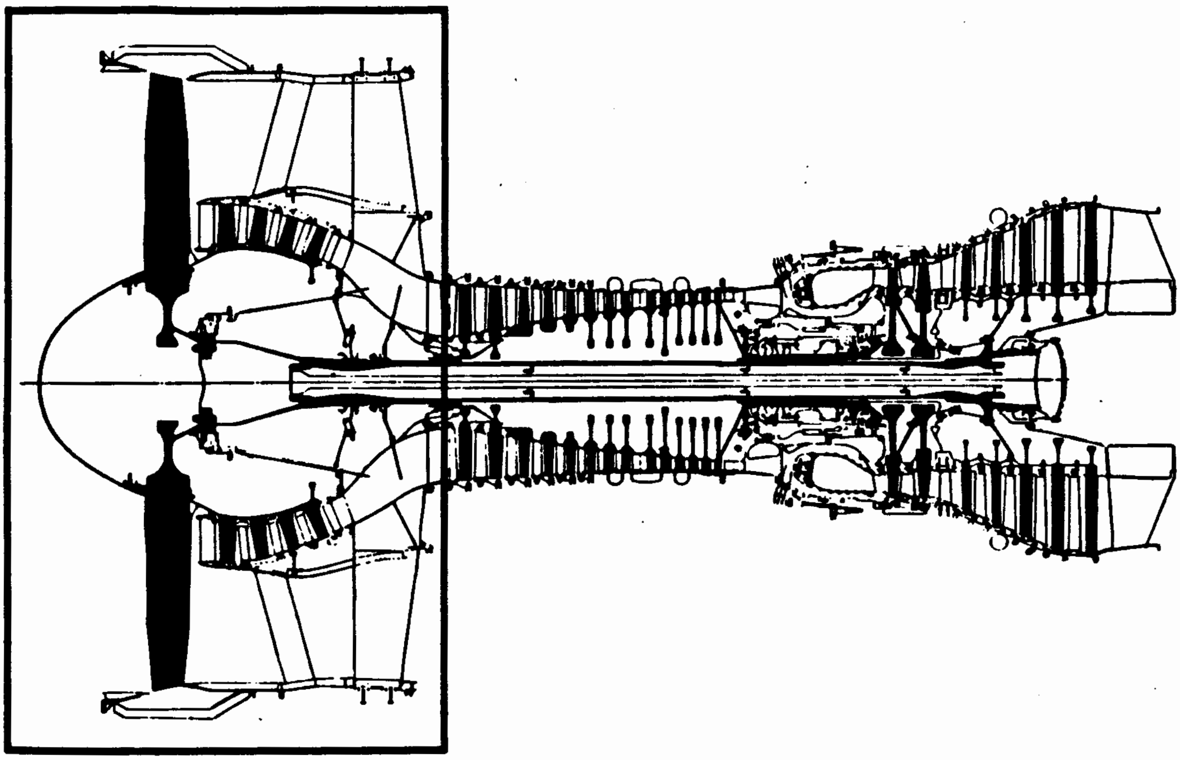
6S-841-061289

CF6-80C2 design improvements over CF6-80A

- Larger fan diameter (93.0 inches vs 86.4 inches)
- Additional booster stage
- Additional LPT stage
- HPT Active Clearance Control
- Governed N_1 vs N_2 speed control
- FADEC control option

NOTES

Fan and Booster



24S-4087-120285

Function

Fan

- Provides thrust
  - 80% of airflow exits through the fan duct
- First stage of low pressure compressor
  - 20% of Air directed to booster

Booster

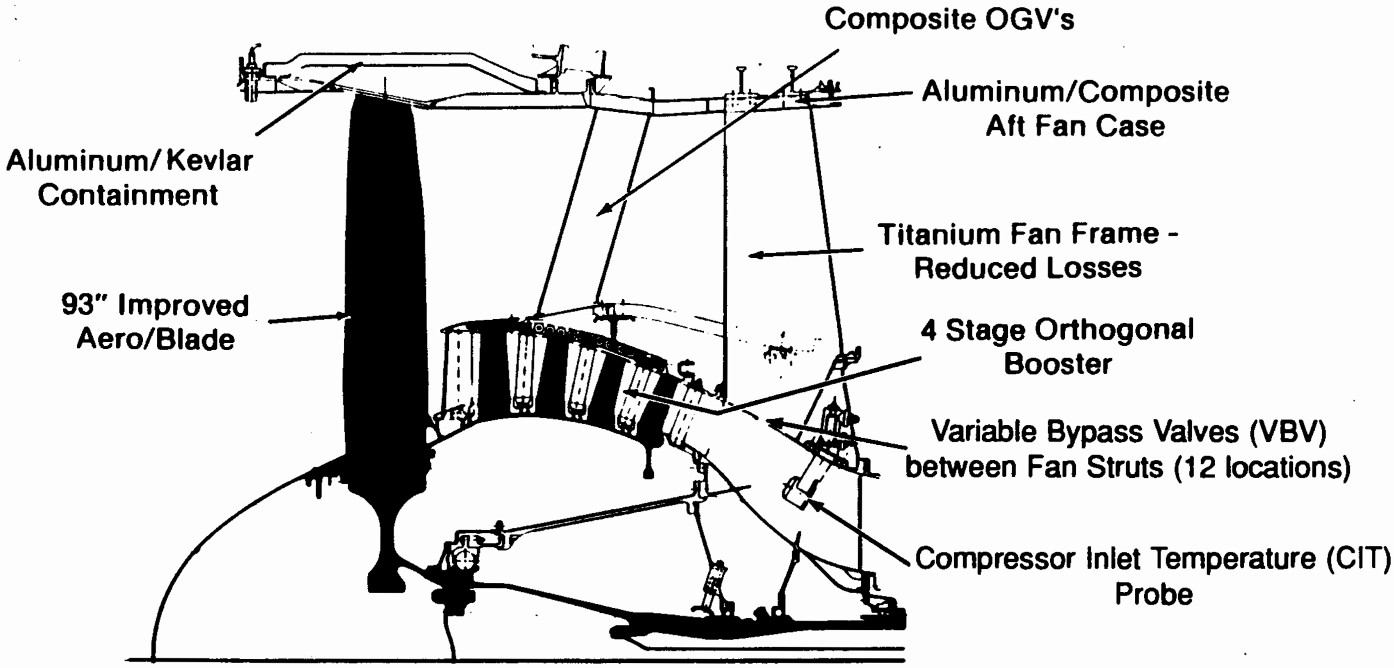
- Four stages accept 20% of fan air
- Supercharges air for high pressure compressor

Variable Bleed Valves

- Located just aft of booster
- At low engine speeds, excess booster airflow bypasses the HPC
- VBV's provide optimum matching of booster and core airflow
- Position is a function of N_2, N_1 and compressor inlet temperature.
  - No VBV control in cockpit
  - Positioning is all automatic

NOTES

Fan Module



17S-1340-101585

The fan module has been redesigned to reduce weight and improve performance. Strut thickness of the fan frame has been reduced 30% to lower pressure losses. The frame itself is cast titanium accounting for a major part of the weight savings. This is the most modern structural casting technology available today.

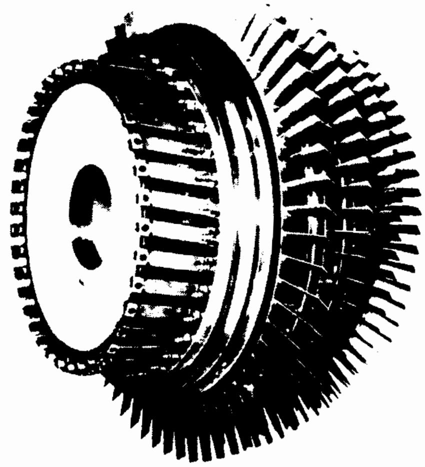
The use of aluminum composite structures are responsible for additional weight savings.

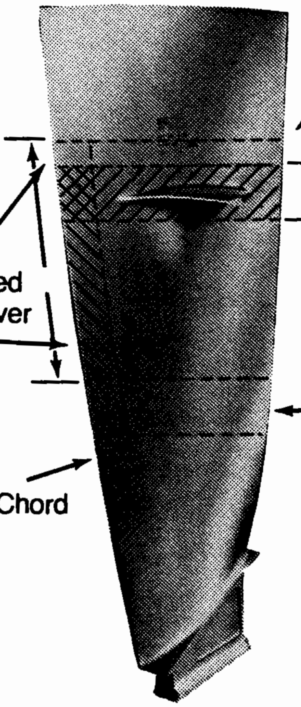
Fan blades have been recambered, for improved performance, based on research program results.

The four-stage booster with orthogonal airfoils is based on demonstrated modern technology.

NOTES

Fan Blade Ruggedization





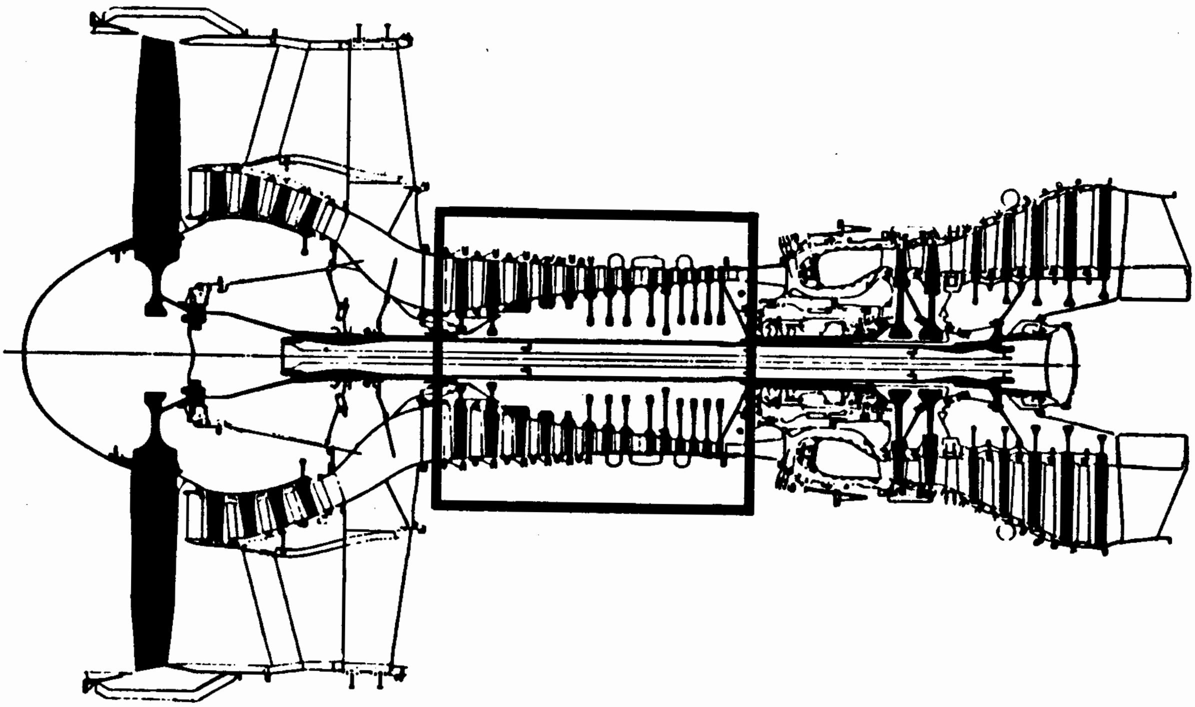
90S-18109-060487

Thirty-eight fan blades are assembled in dovetail slots of the fan disc to produce a 93 inch diameter fan. A mid span shroud stiffens the blades. The blades are longer, have a deeper chord width, and greater twist angle than previous engines. They have an improved aerodynamic shape and are strengthened to better resist bird strikes.

NOTES

CF6-80C2

High Pressure Compressor



24S-4093-120285

High Pressure Compressor

Function

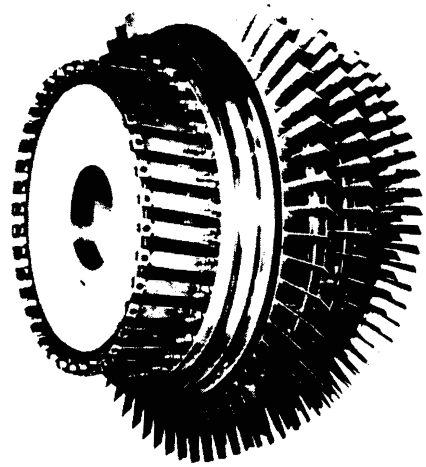
- Increase pressure of air for combustion
- Bleed air source for engine and aircraft systems
- Drives accessory drive gearbox

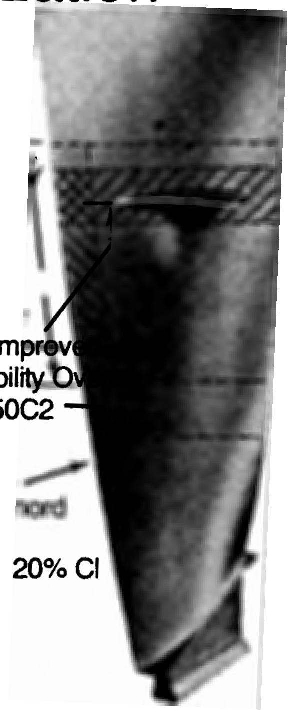
Design

- Fourteen stages of rotating blades
- Variable inlet guide vanes
- Five stages of variable geometry stator vanes
- Eight stages of fixed stator vanes

NOTES

Fan Blade Ruggedization



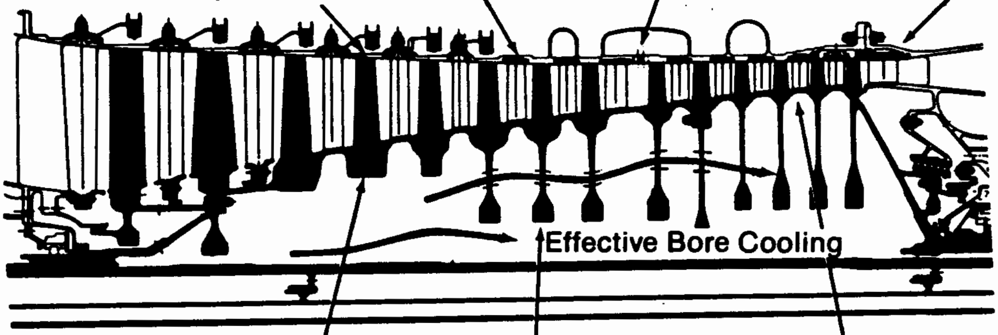


90S-18109-060487

Thirty-eight fan blades are assembled in dovetail slots of the fan disc to produce a 93 inch diameter fan. A mid span shroud stiffens the blades. The blades are longer, have a deeper chord width, and greater twist angle than previous engines. They have an improved aerodynamic shape and are strengthened to better resist bird strikes.

NOTES

High Pressure Compressor



S-1343-050786

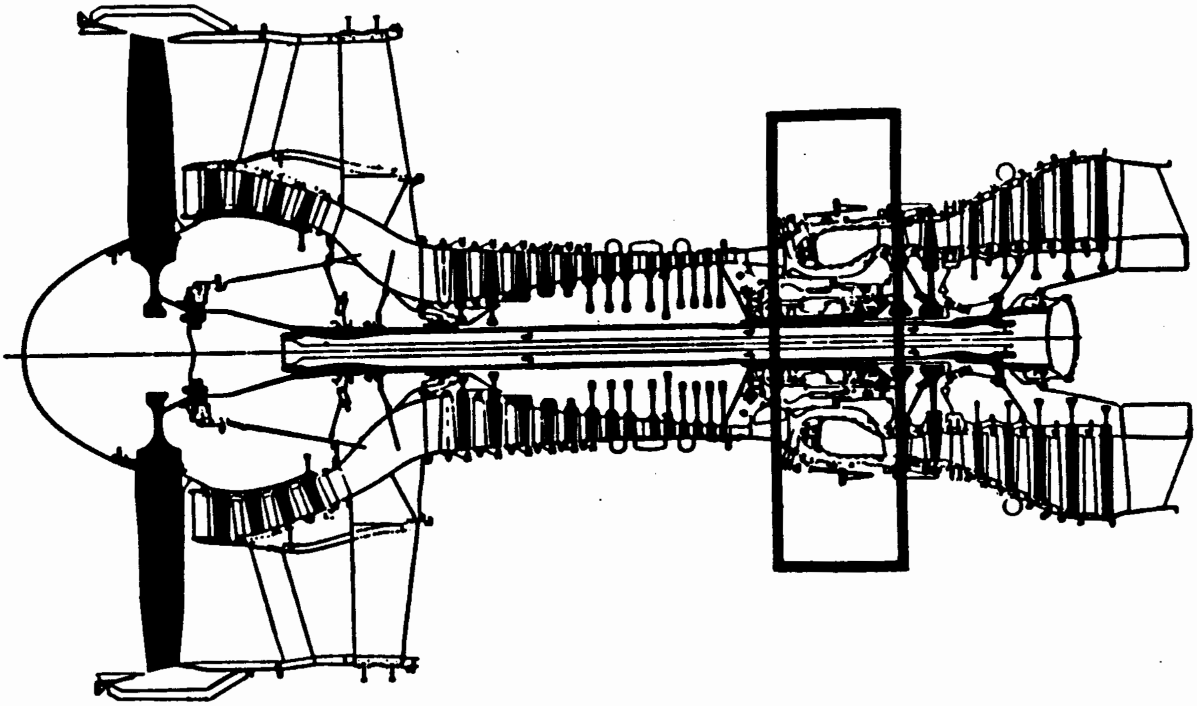
Improvements in the high pressure compressor are for weight reduction and improved efficiency. The airfoils have a revised camber/twisting to improve the radial pressure profile based on demonstrated E^3 (energy dfficient engine) technology. High Pressure compressor efficiency is improved by utilizing blade dovetail and vane platform sealing. Contoured holes in the compressor case provide a low loss bleed system.

Clearances are maintained by FADEC controlled cooling of the bore.

The bore cooling valves are opened and closed by FADEC ECU commands to modulate booster discharge air into the compressor bore. These valves are closed during steady state operating conditions so that the compressor rotor growth, and therefore decreasing blade clearances.

NOTES

Combustor



24S-4099-120285

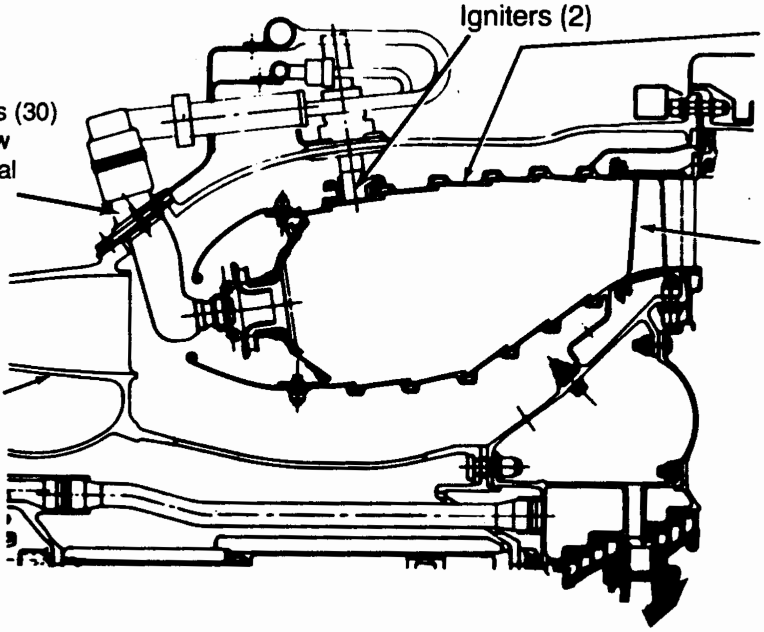
Combustion Section

Function
- Mix/burn fuel and air

Design
- Annular
- 30 fuel nozzle ports
- 2 igniter pads

NOTES

Rolled Ring Combustor



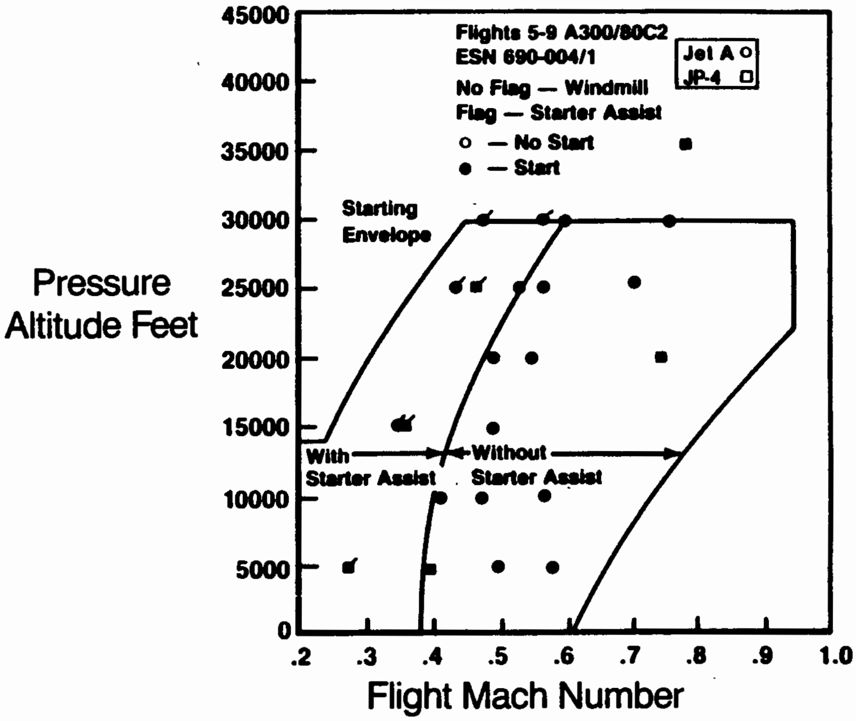
1347-082185

The CF6-80C2 combustor retains the space saving features of the CF6-80A rolled ring design.

Large secondary flow paths reduce velocity and gives better pressure recovery. Pattern factor is improved to achieve long HPT nozzle life. High pressure fuel nozzles with counter-rotating swirlers atomize the mixture for no visible smoke. The combustion system utilizes 30 fuel nozzles, 28 of which are identical, and 2 are high flow narrow angle spray for decel blow out improvement. The film effectiveness of the liner cooling slot construction combined with a new thermal barrier coating will double the life expectancy relative to current design.

NOTES

Combustor Altitude Light Off



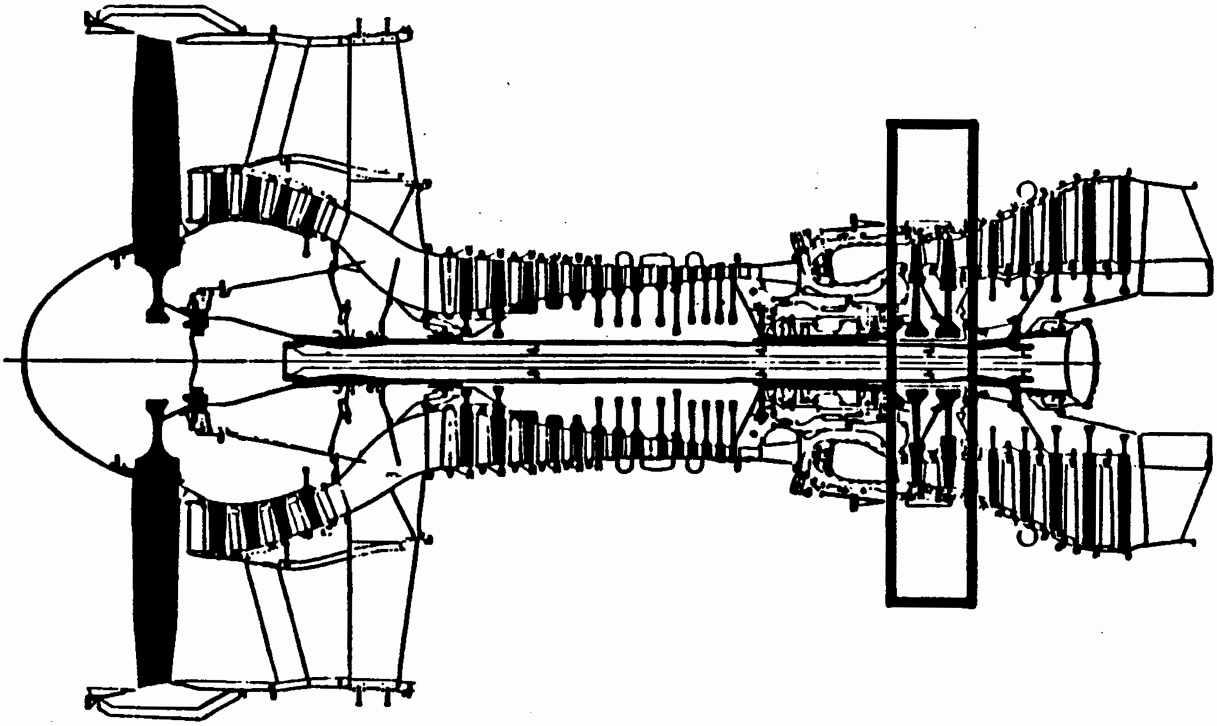
1349-062185

Shown here is flight test data from the GE A-300B flight test program. The envelope successfully tested, was nearly identical to the envelope ultimately certified on the Airbus and Boeing aircraft.

Note that successful airstarts were completed outside the certified envelope. While the certified envelope defines the region where airstarts are guaranteed, nothing precludes the crew from attempting an airstart outside this envelope; if the airstart is unsuccessful establish conditions within the envelope and attempt another airstart.

NOTES

High Pressure Turbine



S-1525-103085

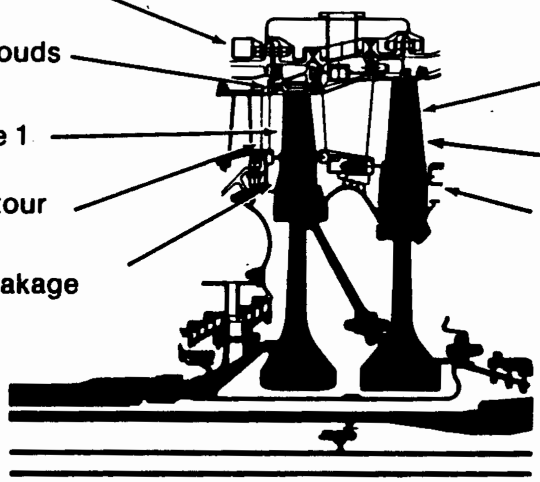
HP Turbine

Function
- Extracts energy to drive the HPC

Design
- Two stage
- Stators contain nozzle segments to direct gases from combustor
- Active Clearance Control
- Blade Cooling

NOTES

High Pressure Turbine



1350-061289

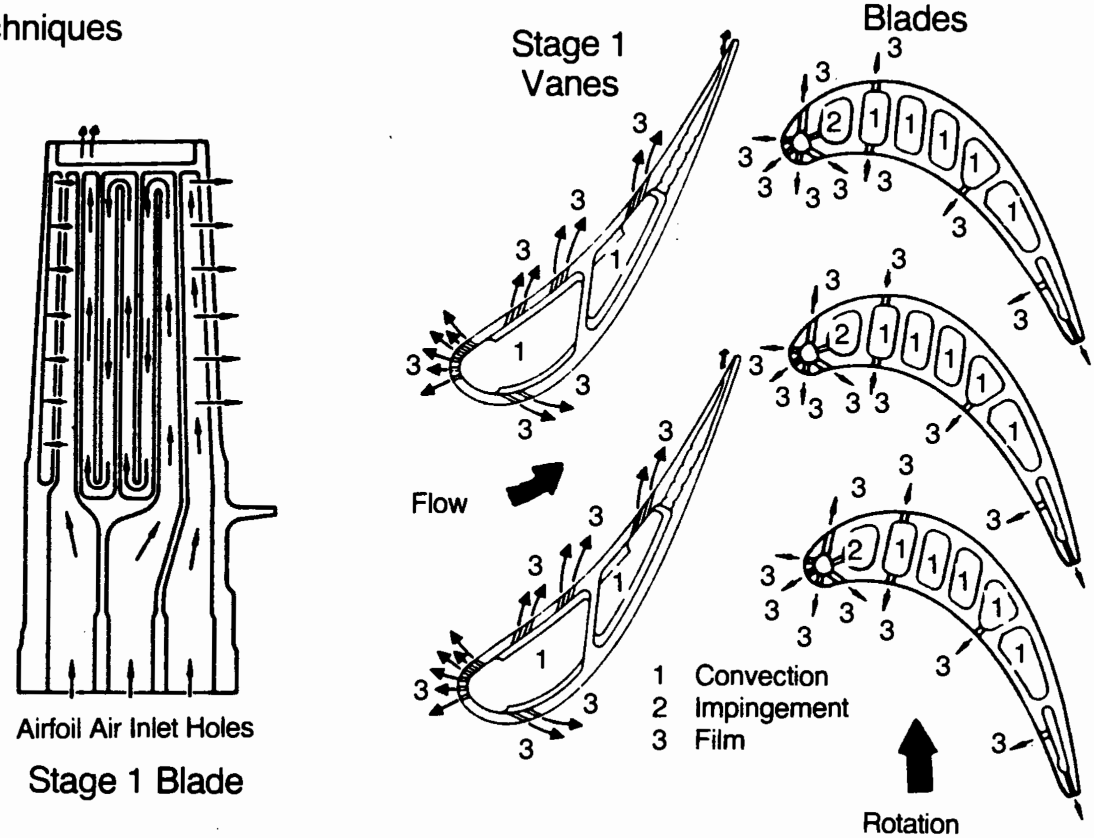
The high pressure turbine (HPT) has the most modern aerodynamic technology derived from GE research and development programs. Recent air turbine tests have demonstrated improved turbine efficiencies with a shaped flow path and airflow contour which have been incorporated in the -80C2 HPT.

The entire high and low pressure turbine flow path has been redesigned for improved performance while maintaining clearances and reducing cooling requirements. The active clearance control, on both stages 1 and 2, reduces clearances at cruise by porting fan air to cool the HPT case. Improved material properties of DSR142 for the HPT Stage 1 blade and ceramic coated shrouds permit higher operating temperatures with reduced cooling air requirements.

NOTES

CF6-80C2 Turbine Blade and Vane

Cooling Techniques



90S-18107-060487

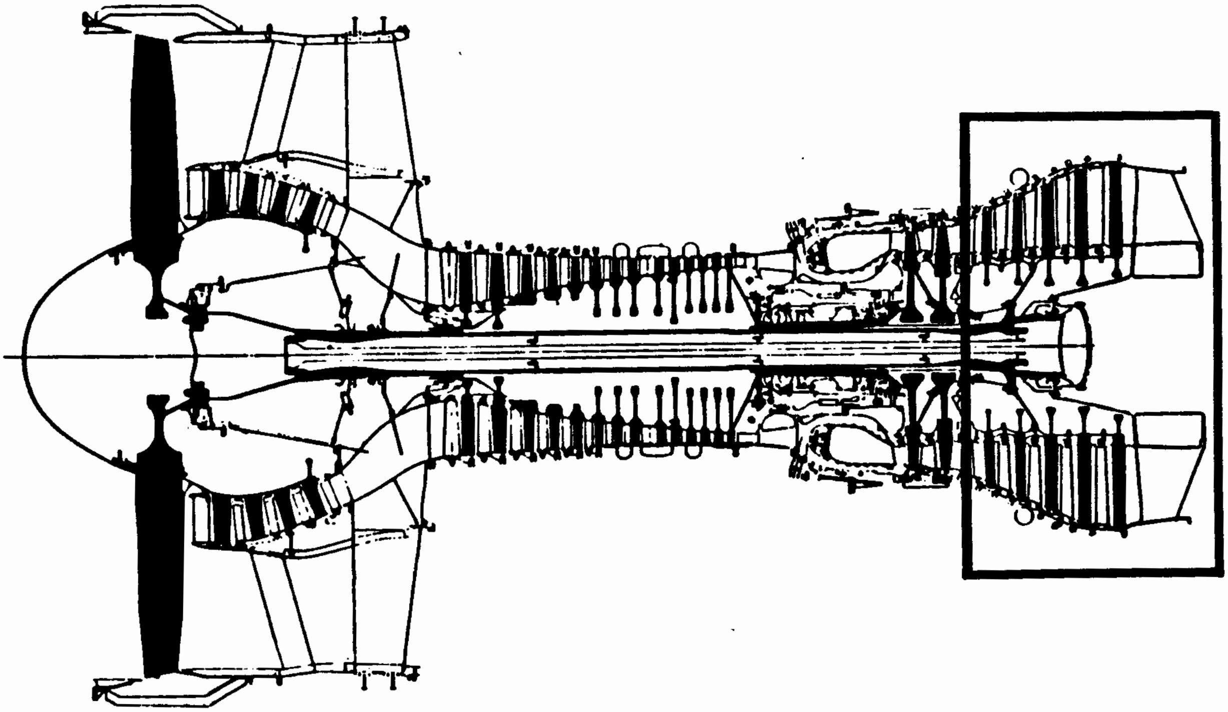
The Stage 1 HPT nozzle vanes and both Stage 1 and 2 turbine blades are internally cooled by compressor discharge air. Stage 2 nozzle vanes are cooled using HPC stage 11 bleed air. Blade cooling is accomplished through a combination of internal convection, leading edge internal impingement, and external film methods.

The stage 11 bleed air is modulated by the FADEC ECU to reduce the cooling airflow at cruise thrust and below.

Control valves are opened and closed based upon EGT levels. This improves SFC by conserving bleed off take when not needed.

NOTES

Low Pressure Turbine



24S-4110-120385

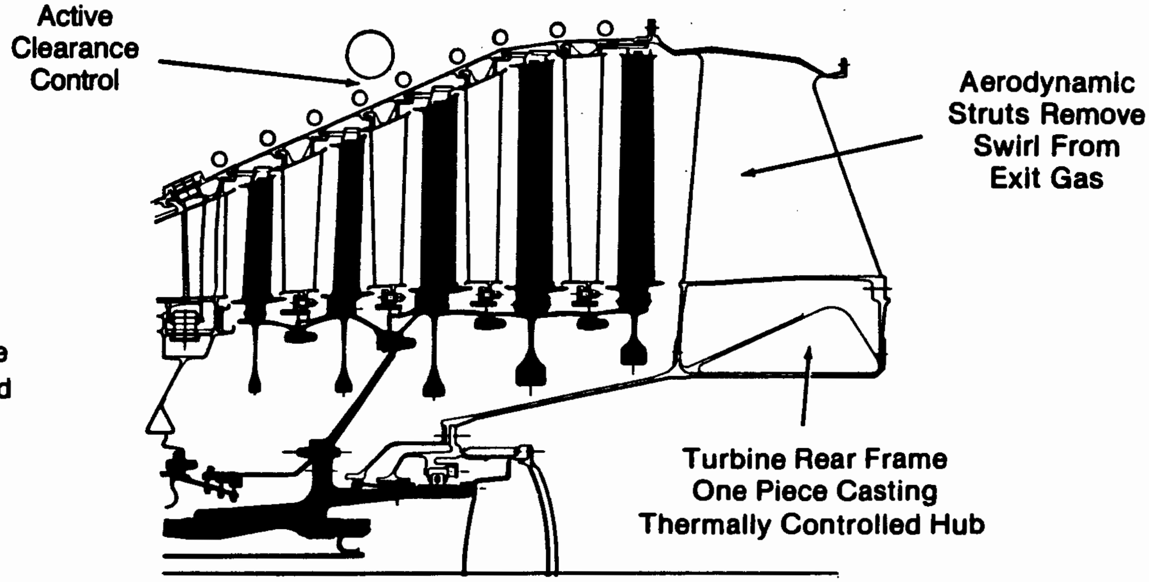
LPT

Function
- Extracts energy to drive fan and booster

Design
- 5-1/2 stages
- Active Clearance Control

NOTES

Low Pressure Turbine



- 5½ Stage
- Improved Aero

Efficient 5½ Stage Design Reduces Weight and Improves Fuel Burn

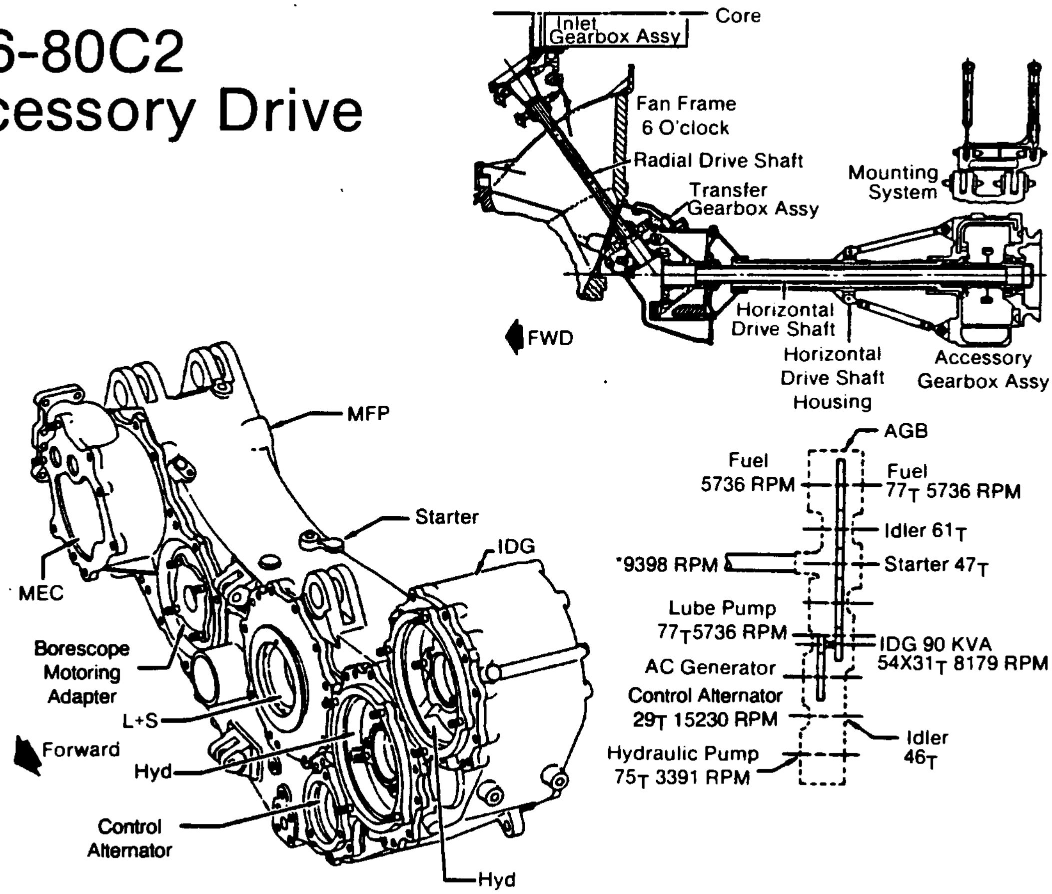
The -80C2 low pressure turbine is a 5-1/2 stage design (the rear turbine frame acting as the additional half stage). The flow path embodies all the high efficiency features of the design used in the joint GE/NASA energy efficient engine (E^3) to reduce aerodynamic losses to a minimum. In cruise, cooling air from the fan is provided to the LPT outer case to obtain minimum clearances thus improving SFC.

EGT is measured by 16 chromel-alumel thermocouple probes, installed immediately ahead of the first stage LPT nozzle vane. These 16 probes are averaged to provide the indicated EGT.

The one piece cast turbine rear frame eliminates weld joints to improve gas path pressure losses.

NOTES

CF6-80C2 Accessory Drive



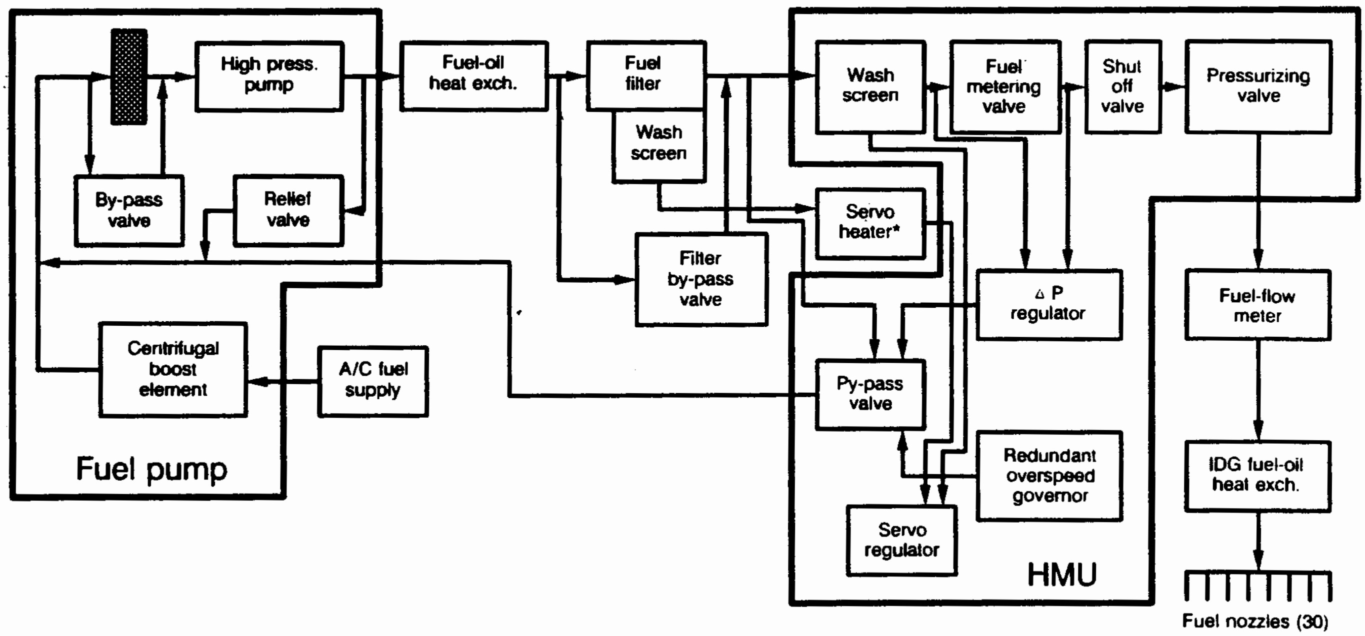
28S-4956-012486

Accessory Drive Section

- Inlet gearbox driven by front end of HP shaft (N_2)
- Radial drive shaft
- Transfer gearbox
- Accessory gearbox
  - Mounted to core structure
- Provides drivepads for:
  - Hydraulic pump(s)
  - Integrated drive generator
  - Starter
  - Main fuel pump
  - Main engine control (hydromechanical unit on FADEC)
  - Lube and scavenge pump
  - Control alternator

NOTES

CF6-80C2 FADEC Fuel System



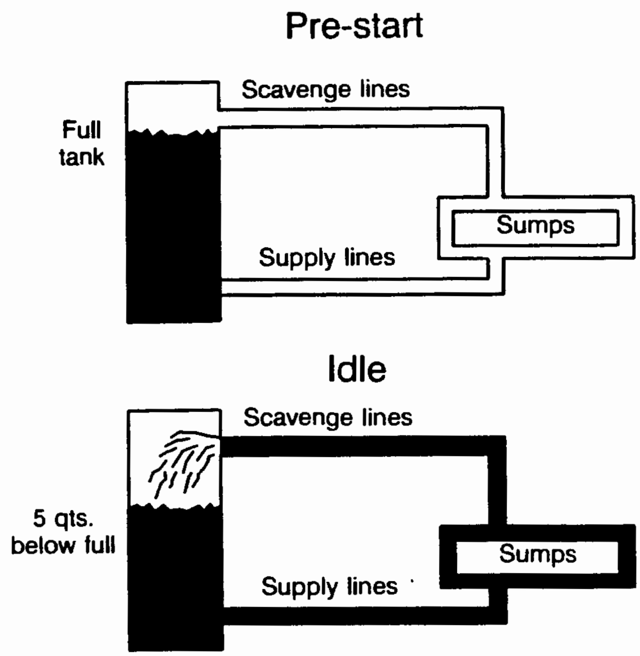
* Boeing installations only

T1671.37 - 900518

NOTES

CF6-80 Oil "Gulping"

Operational mode	Change from pre-start quantity CF6-80 ± 2 qt.
Ground idle	-5
Takeoff	-10
Climb	-8
Cruise	-6 to -8
Descent	-5
Shutdown	0



NOTES

Fuel/Oil Heat Exchanger Leakage

- Leak in fuel/oil heat exchanger results in fuel entering oil supply
- Cockpit indications of fuel/oil heat exchanger leakage:
  - Increasing or overfilling oil tank quantity
  - Lack of oil "gulping"
- Extreme overfilling indication may be accompanied by:
  - Increasing oil temperature
  - Fluctuating or decreasing oil pressure
  - Fuel/oil fumes in cabin
- Suspicion of fuel leaking into oil should be investigated prior to next flight

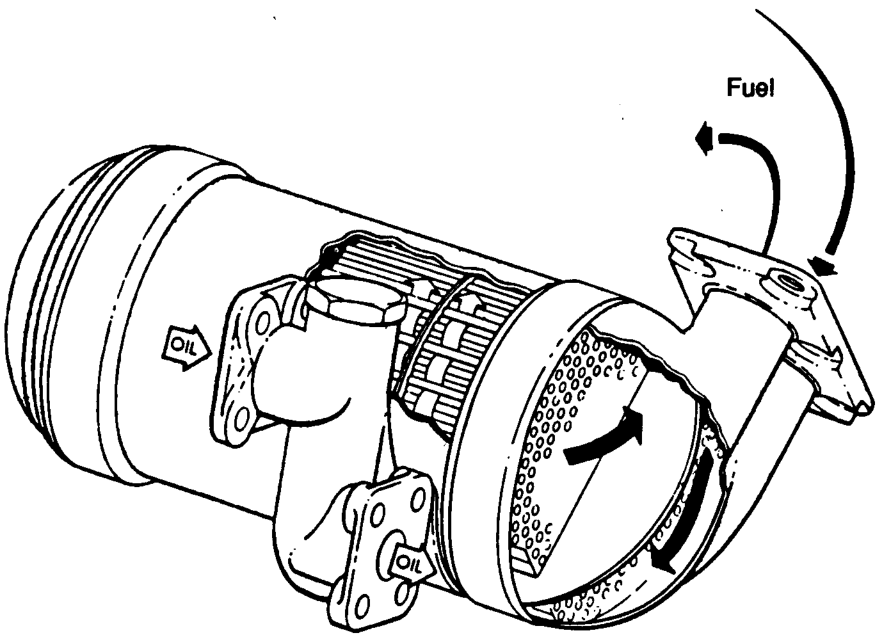
MAC5-50060-010490

Fuel/Oil Heat Exchanger Leakage

- The heat exchanger is a shell and tube design, such that internal tubes containing fuel pass through warm oil circulated over the outer surfaces of the fuel tubes.
- If a tube leak develops, fuel enters the oil system because the fuel pressure is always higher than the oil pressure
- Cockpit indications of increasing oil quantity or lack of oil gulping can be first sign of fuel/oil heat exchanger leakage
- If oil tank is filled before engine start, then the maximum indicated oil quantity observed during normal operation should be approximately 19 quarts
- Any indication of "making oil" should be entered in the aircraft log for maintenance action before the next flight.

NOTES

Fuel/Oil Heat Exchanger



S-46993-083089

NOTES

CF6-80C2
FADEC*
Engine Control System

*Full Authority Digital Electronic Control

NOTES

What Is FADEC?

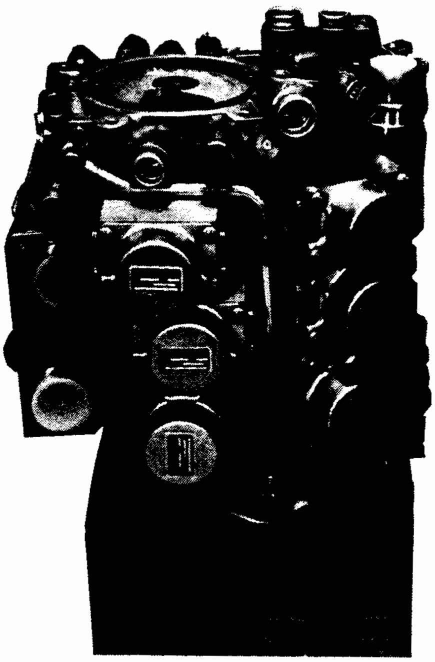
- Full Authority Digital Electronic Control
  - Not just supervisory
  - No mechanical connection cockpit to engine
  - Analogous to "fly by wire" aircraft control system
- Consists of
  - Dedicated alternator and power supplies
  - Electronic control unit (ECU) - "brains"
  - Hydromechanical unit (HMU) - "muscle"
  - Sensors for control, monitoring and feedback
  - Cables and connectors
- More than just fuel control functions
  - Start (N/A MD-11)
  - Ignition (N/A MD-11)
  - Variable geometry (VSV's and VBV's)
  - Clearance/cooling control
  - Reverse thrust

T1671.04 - 881006

FADEC is Full Authority Digital Electronic 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 twin, it is simpler to operate, and easier to maintain.

NOTES

HMU — Hydromechanical Unit



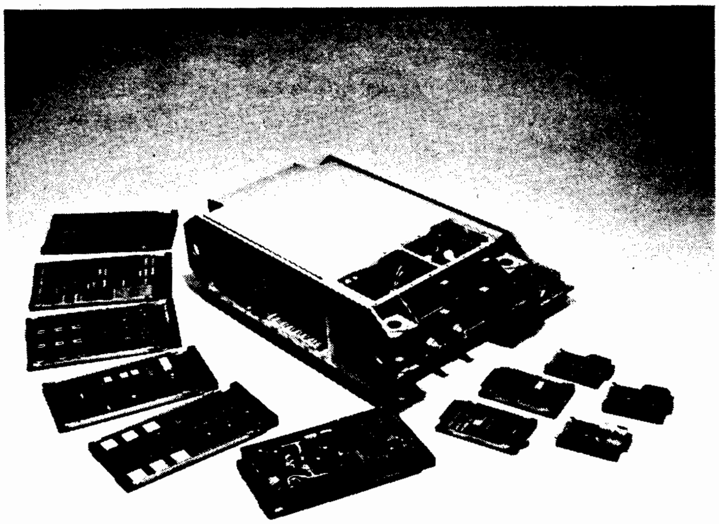
- Servo valves for metering: FMV, VSV, VBV, HPTACC, LPTACC
- Mechanical N2 overspeed governor
- Stopcock
- Conventional technology
- Non-redundant design

MAC5-36890-i00688

The purpose of the HMU is to provide metered fuel to the fuel nozzles in the engine combustor and provide fuel pressure to operate the variable stator vanes (VSV), variable bleed valves (VBV), LPT and HPT active clearance control (LPTACC, HPTACC). The HMU is comprised of three hydraulic circuits: fuel metering, servo control and bypass. The fuel metering subsystem consists of a fuel metering valve (FMV) and high pressure shutoff valve (HPSOV). The FMV receives an electrical demand signal from the electronic control unit (ECU) and the HPSOV receives electrical inputs from the fuel condition lever located in the cockpit. The servo control circuit has five electro-hydraulic servo valves which receive electrical signals from the ECU to provide modulated fuel pressure to operate the VSV, VBV, FMV, HPTACC and LPTACC systems. The bypass circuit regulates the fuel that exceeds the metered fuel supply requirements, regulates the fuel pressure to the FMV, and has a hydro-mechanical speed governor that limits core engine overspeeds to 113.4 percent N_2.

NOTES

Electronic Control Unit (ECU)



- Dual channel
- Fan case mounted
- Air cooled
- Plug in cards
- Contains
  - Engine ratings
  - Thrust management schedules
  - Fault detection/ accomodation logic
  - Limit protection logic
  - Start ignition, reverse logic (N/A MD-11)
  - Variable geometry, clearance control logic
- Either channel has full capability for non-degraded engine operation

LM-25221-050688

The Electronic Control Unit (ECU) is the functional heart of the entire FADEC system. It is mounted to the aft fan case at the 8:30 position. Fourteen electrical connectors and four pneumatic connectors interface the ECU with the aircraft and every FADEC subsystem.

The ECU is a dual channel digital electronic engine control containing two special purpose computers with a host of associated circuitry. One computer together with its associated circuits is identified as Processor A, and the other with its circuits as Processor B. All critical input and output interfaces to each processor are electrically isolated and fully redundant.

Both processors are always receiving inputs, processing them, and producing outputs. Outputs controlling valves and actuators in the engine control subsystems, and relays in the aircraft, are supplied by only one processor at a time.

To enhance system reliability, all inputs to one channel processor are made available to the other through a Cross Channel Data Link (CCDL). This allows both channels to remain fully functional even if important inputs to one of them fail. The CCDL also allows the processors to compare inputs, and average out errors that would otherwise be introduced into the system uncorrected.

FADEC Control System

- Improved performance (reduced fuel burn)
  - Modulated clearances
  - Modulated parasitic airflows

- Improved operational characteristics
  - Reduced EGT thermal overshoot
  - Full flight regime thrust management
  - Better stall margin
  - Uniform engine response times
  - Automated, adaptive starting
  - Fault tolerant design - fail operational
  - Built-in thrust ratings
  - Idle speed control for aircraft bleed requirements
  - More flameout margin

T1671.02 - 880630

NOTES

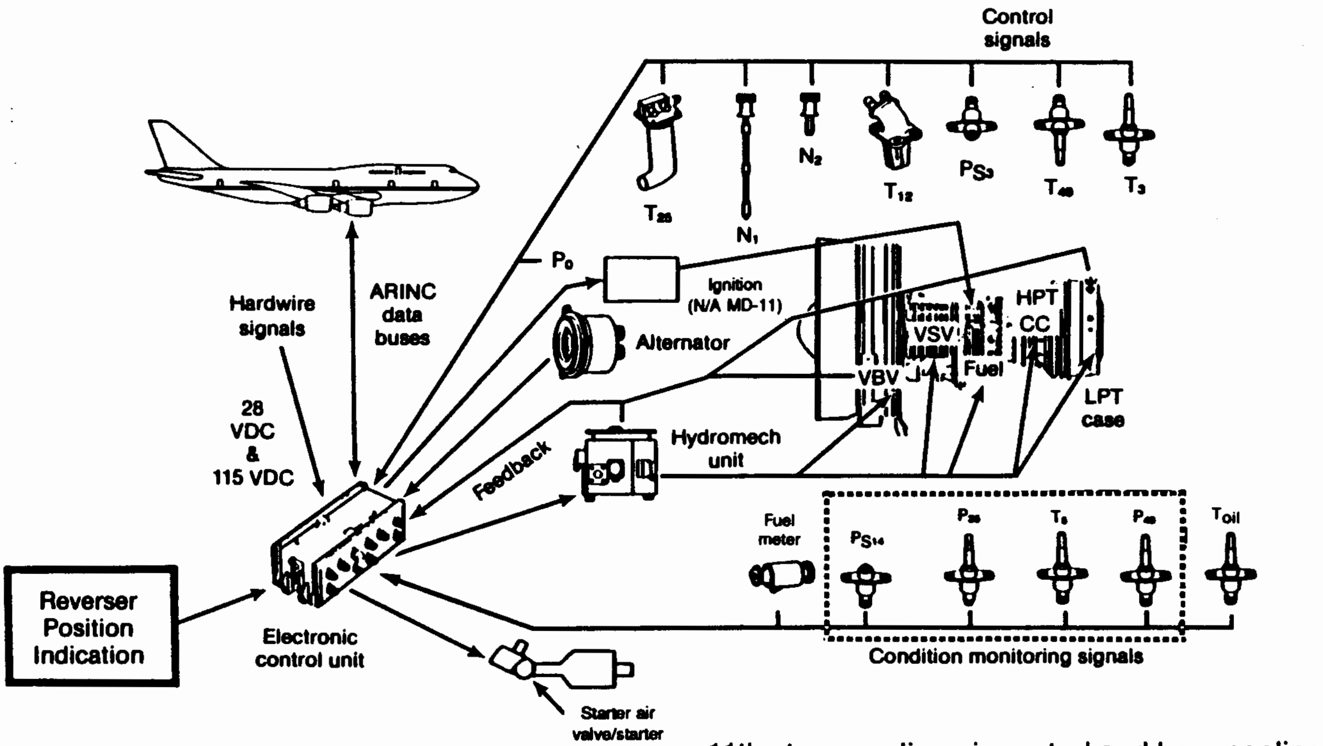
FADEC Control System (Continued)

- Improved aircraft - engine integration
  - Auto-throttle system features and compatibility
  - Less hysteresis
  - Digital aircraft interface
  - Better informed cockpit
- Reduced pilot workload
  - Single position throttle for thrust rating (takeoff, climb, etc.)
  - Throttle stagger compensation (to 2.5% N_1)
  - Uniform transients
  - Automatic start/restart (not on MD-11)
- Improved system maintenance
  - Built-in diagnostics
  - Non-volatile memory

T1671.03 - 881006

NOTES

Full Authority Digital Electronic Control



11th stage cooling air control and bore cooling valves not shown

60S-11393-073087

FADEC is a computer based electronic engine control system which provides information processing and engine control.

Information Processing refers to the FADEC's ability to input, manipulate, and output large amounts of electronic data. Using these functions, the FADEC computer gathers information about the environment and operating conditions within the engine. With the information, the computer calculates fuel and air flows required to maintain engine operation at the rated performance levels with peak efficiency. Information processing also allows the FADEC computer to communicate directly with other computerized aircraft systems including the: Engine Indicating and Crew Alerting System (EICAS), Central Maintenance Computer (CMC), Air Data Computers (ADC) and Auto-Throttle System (ATS). It is extensive information processing capabilities, more than any other, that distinguish the FADEC from mechanical engine control systems.

Engine Control refers to the FADEC's avility to physically control the operating, performance, and efficiency characteristics of the engine. Capabilities in this area include precise control over fuel flow, primary and parasitic airflows, internal rotor to stator clearances (Active Clearance Control), engine start sequencing, and igniter operation.

Sensors/Signals

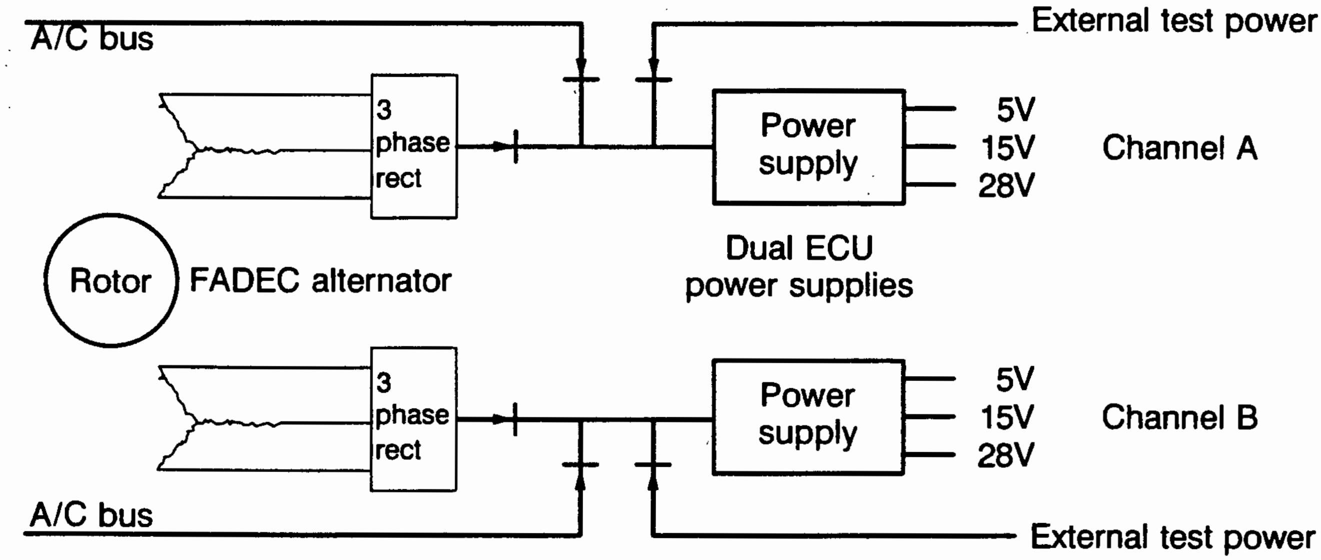
Control		Feedback	Monitoring	
P_0	: Ambient pressure	Fuel metering valve	T_{Fuel}	: Fuel temperature
T_{25}	: Compressor inlet temperature	VSV position	W_F	: Fuel flow
N_1	: Low pressure rotor speed	VBV position	PS_{14}	: Fan bypass static pressure
N_2	: High pressure rotor speed	HPTACC position	P_{25}	: Compressor inlet pressure
T_{12}	: Fan inlet temperature	LPTACC position	T_5	: Low pressure turbine discharge temperature
PS_3	: Compressor discharge static pressure	Reverser position		
T_{49}	: EGT	Start valve position	P_{49}	: Low pressure turbine inlet pressure
T_3	: Compressor discharge temperature	11th stage cooling valve position		
			T_{Oil}	: Oil temperature
		HPSOV position		

- Control and feedback signals are at least dual
- Monitoring signals are single

The sensors for engine temperature, speed, fuel flow and thrust reverser position provide electrical inputs to the ECU. The pressure probes provide pneumatic inputs to the ECU which are converted to electrical signals within the ECU. The feedback signals from the fuel metering valves, VSV, VBV, HPTACC, and LPTACC are electrical signals proportional to the position of the valves. The position of the reverser, starter valve, 11th stage cooling valve and HPSOV is a discrete electrical signal to the ECU. The monitoring signals are used for engine health diagnosis and maintenance, and are not required for engine performance.

NOTES

CF6-80C2 Power Supply



- Features
  - Each channel is independent
  - Dual 3 phase power provides engine needs above 11% N2
  - Airframe DC for zero RPM test, starting & backup
  - External power is for test w/o A/C power

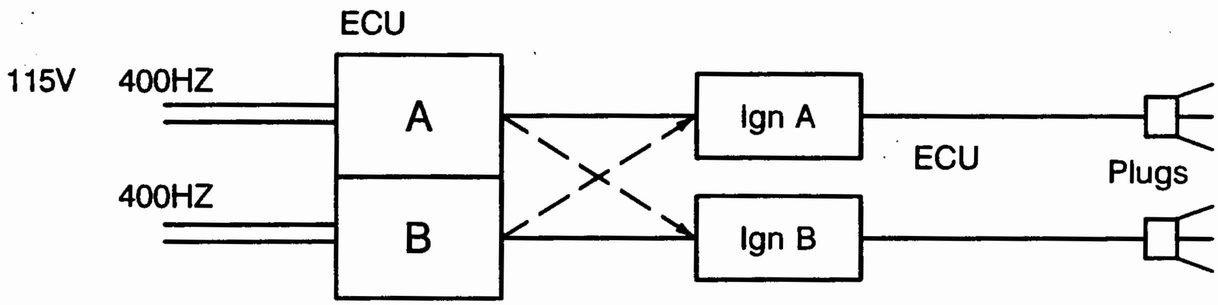
T1671.06 - 880630

The permanent magnet alternator is composed of a rotor and two independent sets of windings. Each set of windings supplies 3 phase power to its respective FADEC channel. The alternator will meet all power requirements at N_2 speeds of 45% or higher even if one phase of either set, or one phase in both sets of windings fail.

In the case of an alternator failure, FADEC power supply requirements are met with aircraft supplied A/C power (except MD - 11).

NOTES

Ignition System



- Features
  - Automatically alternated every two starts
  - Ignition on - slightly before fuel
  - Delayed ignition logic
  - Either channel can control both ignition boxes
  - Ignition off when $N_2 > 50\%$
  - Auto message if either ignition delayed/failed
  - Auto relight if "flame-out" sensed
  - Pilot can select continuous ignition
  - Both ignitors on for air starts
  - Ignition is not controlled on MD-11 by FADEC

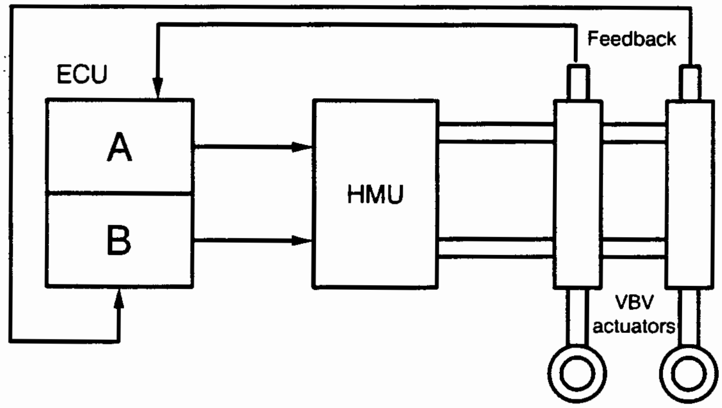
T1671.07 - 890315

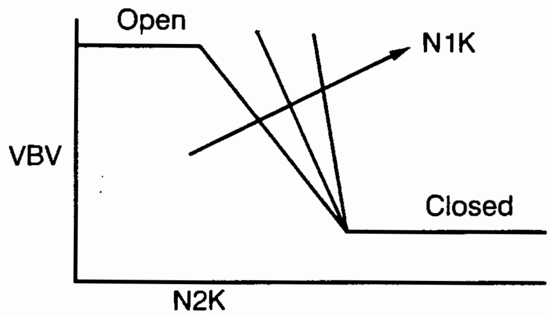
The ignition system provides a low energy capacitor discharge spark within the combustor to ignite the fuel discharge at selected positions within the combustor. It is a dual system composed of two ignition exciters, ignition leads, and the ignitor plugs.

The two Ignition Exciters are mounted, one above the other, to the aft fan case below the ECU. Each receives a 115 volt, 400 Hz input from the ECU, and provides a 14,000 to 18,000 volt pulsed output at the rate of approximately one pulse per second. They are rated for continuous operation.

NOTES

VBV Control



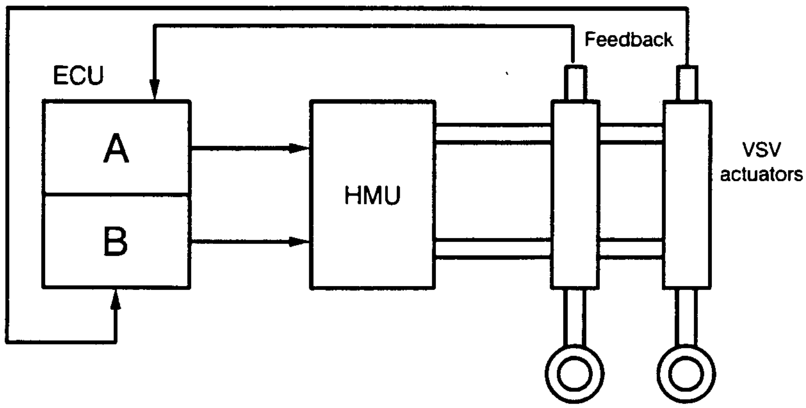


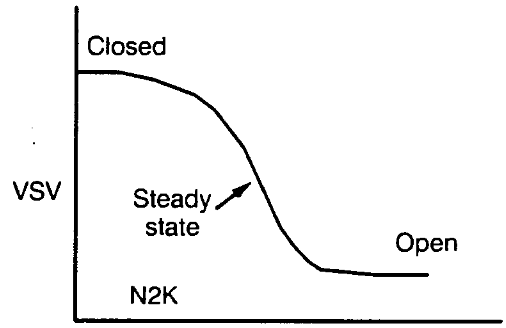
- Match booster/compressor airflow
- Scheduled as function of N_1/N_2
- Electrical vs mechanical schedule
- VBV actuators controlled by ECU logic
- Position feedback is electronic (through LVDT's) rather than mechanical
- Capability to advise crew of problem due to off-schedule VBV's

The primary airflow through the low pressure compressor at low engine speeds is more than the high pressure compressor requires at those speeds. Therefore, the variable bleed valves (VBV) are used to bleed excess booster air into the fan duct in order that only the desired amount of air is available to the high pressure compressor inlet. The position of the VBVs required to relieve the excess air is controlled by the ECU as a function of N_1 and N_2 speed. An electrical feedback signal is provided from a Linear Variable Differential Transformer (LVDT) located within the two actuators. The position of the VBVs will range from fully closed at high engine speeds to fully opened at idle.

NOTES

VSV Control





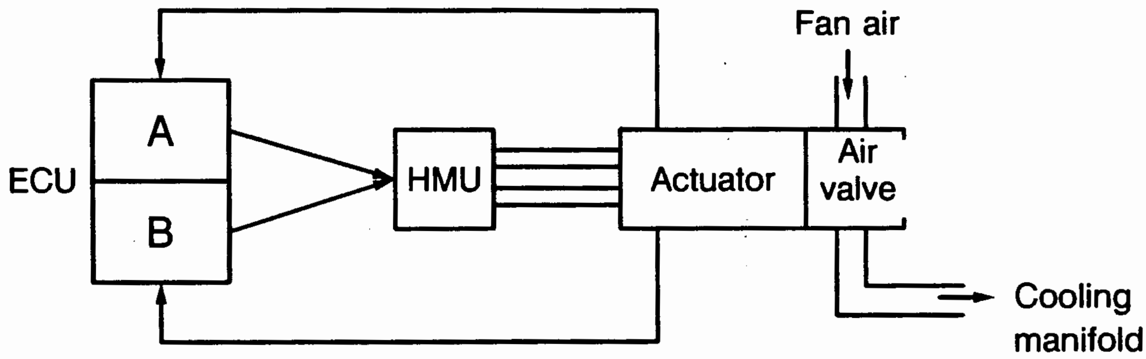
- Match airflow of Fwd/Aft compressor stages
- Electrical vs mechanical schedule
- Steady state and transient schedules the same
- Controlled by ECU through HM servo valves
- Position feedback is electronic (through LVDT's) rather than mechanical
- Capability to advise crew of problem due to off-schedule VSV's

T1671.09 - 890315

At low engine speeds the forward stages of the high pressure compressor (HPC) are not matched to the aft stages abilities. To achieve this matching, the VSV system varies the angle of attack of the first six stages of the HPC stator vanes to maintain a smooth, turbulent free airflow through the compressor at all engine operating speeds, temperatures and altitudes. Position feedback to the ECU is via an electrical signal from a connector on each actuator.

NOTES

Active Clearance Control (HPT and LPT)



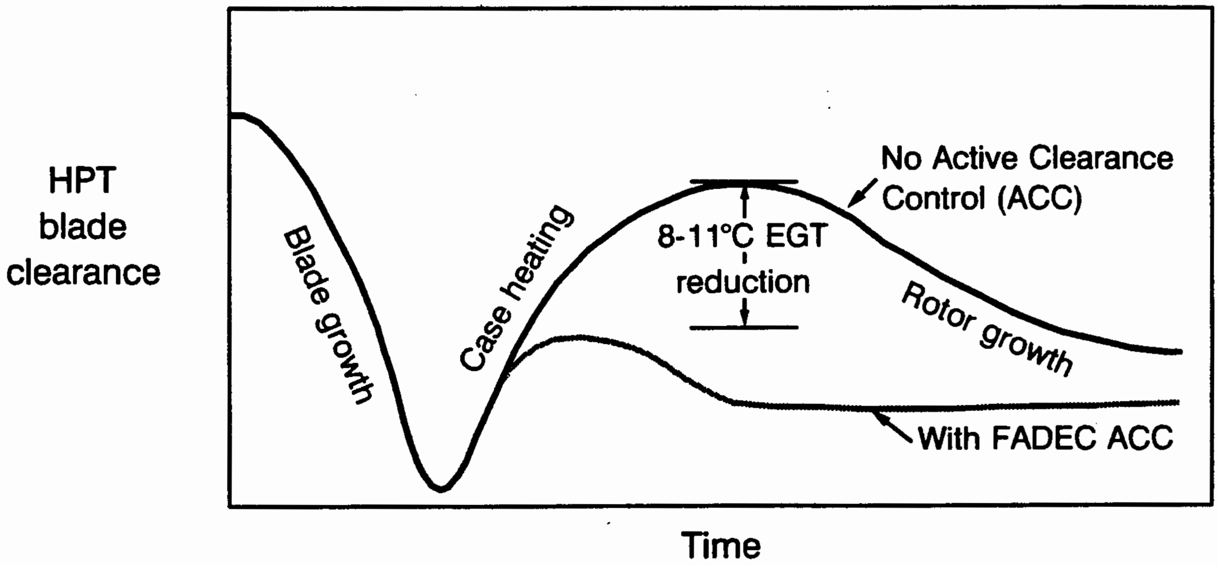
- Separate systems for HPT and LPT cooling
- Both systems continuously modulate cooling air as a function of temperature, pressure, and cycle speeds
- Valve failure mode is closed (no cooling airflow) to protect against rubs

T1671.10 - 881006

To provide high efficiency and long life it is necessary to have close clearances without rubs between the turbine blades and the shrouds. However, the clearances will vary as the engine temperature changes. Generally, since the cases are less massive, they expand and contract with pressure and temperature changes more rapidly than the rotors. Therefore, to precisely control the clearances throughout the operating range of the engine, a HPT and LPT clearance control system provides cooling air to the turbine case via a manifold containing hundreds of small holes. The source of the cooling air is fan discharge air from the fan duct. The flow of air is controlled by the electronic control unit via the hydromechanical unit which in turn provides hydraulic signals to operate the HPT and LPT Active Clearance Control Valves.

NOTES

Active Clearance Control Protection During T/O Power Set



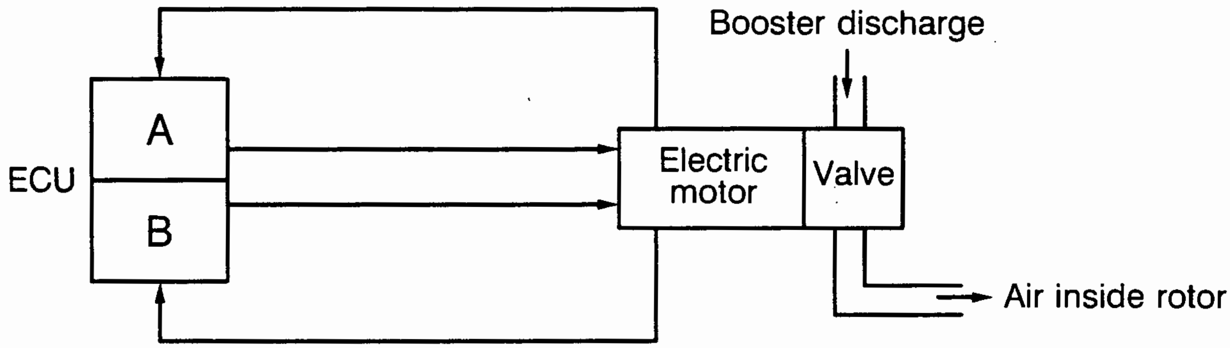
- FADEC controls clearances during transients
- Clearance control provides extra EGT margin

T1671.11 - 880705

This graph shows how active clearance control increases engine efficiency and provides extra EGT margin during takeoff. Initially as the engine temperature increases the blades expand before the case thus reducing the clearance. However, as the case expands, the blade clearance increases resulting in lower efficiency (higher EGT). By using active clearance control, the blade to case clearance can be minimized throughout engine transients. The result is a reduction in the EGT "bloom" which provides extra EGT margin.

NOTES

Bore Cooling



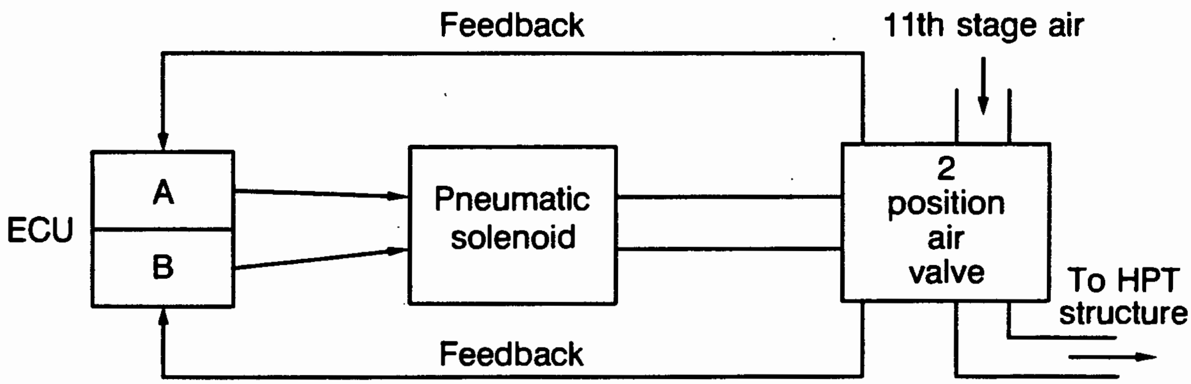
- 3 Bore Cooling Valves (BCV) on fan case
- BCV's are all open below 15,000 ft and/or N_1K below 85%
- 1, 2, or 3 valves can be closed to control rotor temperature and minimize parasitic airflow losses
- Valve failure mode is open (max cooling)

T1671.12 - 890315

Bore cooling directs fan discharge air to the center bore of the engine for cooling of the turbine rotors. This cooling shrinks the rotors, thus increasing the clearance between the blades and turbine case. During low altitude operations and/or low N_1 speeds the bore cooling operates to provide maximum cooling to prevent blade rubbing. At high altitude cruise conditions, the bore cooling is reduced to allow the rotors to expand, decreasing blade clearance and conserving primary air flow, thus increasing engine efficiency and improving specific fuel consumption. The fan cooling air is regulated by three bore cooling valves mounted to the aft fan case. They are operated by an electrical signal from the ECU. In the event of a valve failure, the valves fail in the open position to ensure positive cooling and open clearances under all conditions.

NOTES

11th Stage Bleed Air Control



- 11th stage cooling flow to HPT structures controlled by ECU (SFC)
  - Reduction in flow at cruise power and below to minimize parasitic bleed loss
  - Maximum flow at high power to ensure structure integrity
- Signal pressure to air valves supplied by independent solenoid valve
- Position feedback obtained from electrical switches mounted on valves
- Valve failure mode is open (max cooling)

T1671.13 - 880630

In order for the HPT stage 2 nozzle to withstand the high gas temperatures generated by the combustor, air from the 11th stage compressor is used to pass through the internal passageways and surface holes of the nozzles for cooling. The 11th stage air is controlled through two valves which are solenoid activated by electrical signals from the ECU. During high power operation, the valves are open to provide maximum HPT cooling. During cruise, less cooling is required so the 11th stage air to the HPT is decreased thus reducing the bleed air load on the compressor and improving specific fuel consumption. In case of control failure the valves fail open to provide continuous cooling air to the HPT components.

NOTES

Thrust Reverser

- FADEC does not control reverser position
- FADEC measures reverser position and transmits to aircraft
- FADEC physically locks throttle at idle until reverser is deployed
- FADEC controls N_1 speed while in reverse (reverse N_1 limit protection)
- If reverser is in uncommanded position, FADEC retards engine to idle

T1671.14 - 880630

Reverse thrust is obtained by actuating blocker doors in the fan duct and re-directing the fan air through deflector vanes. The core engine exhaust is through a fixed nozzle and does not provide reverse thrust. Since increased fan speed to increase reverse thrust requires a commensurate increase in core speed, and since core thrust is not reversed, there is an optimum reverse fan/core speed. Flight test indicates net reverse thrust is obtained at approximately 95% N_1. On FADEC controlled engines the thrust reversers are operated through the throttle resolver which produces an electrical output which is used by the ECU to control the reverse N_1.

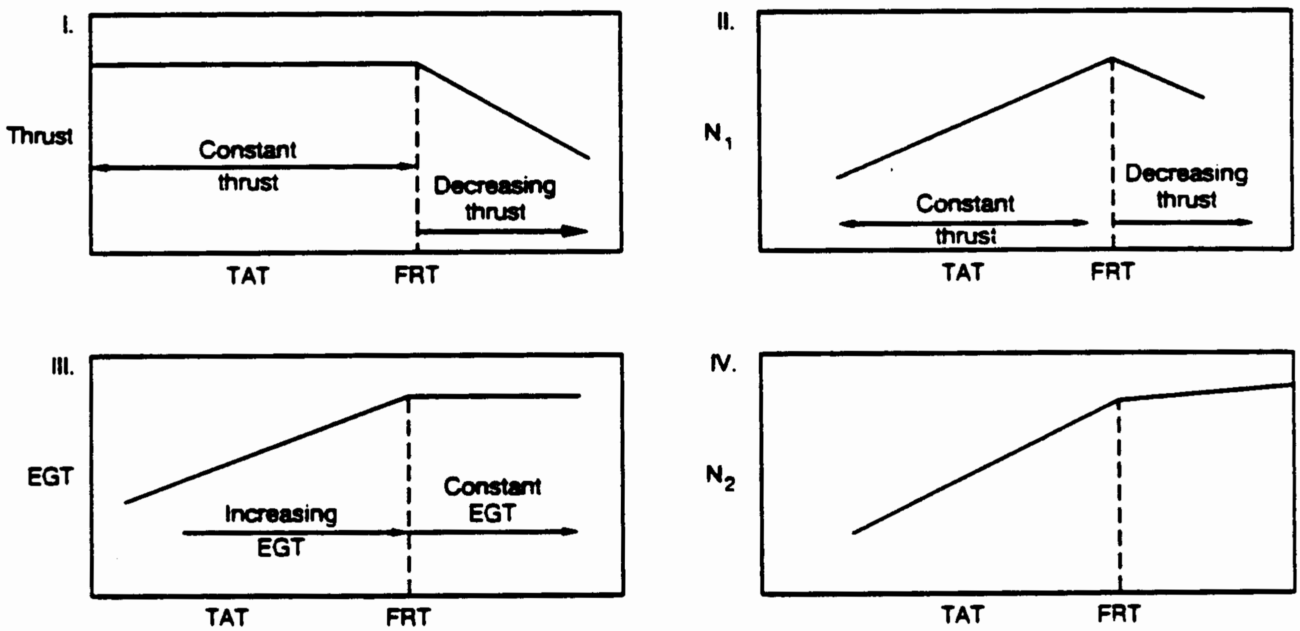
NOTES

FADEC Failure Modes

- Loss of both N_1 signals
  - N_1 signal is provided by a mathematical model built into FADEC, based upon N_2
- Loss of throttle lever position
  - If both signals are lost, the engine goes to idle. If both signals are out of range, then FADEC sets power to the last valid position
- Failure of both FADEC channels
  - Controlled rate engine shutdown
- FADEC total alternator failure
  - Boeing 747-400 reverts automatically to aircraft power
  - MD-11 requires pilot manual switching to supply aircraft power
- Disagreement between reverser actual and command position
  - Engine goes to idle

NOTES

Engine Parameters at Takeoff Thrust
(Flat Rated Engine)



T1422.20 · 880201

I. To meet aircraft performance requirements, the engine is designed to provide a given thrust level to some "Flat Rate" Temperature (FRT). At temperature above FRT, thrust decreases and aircraft performance is adjusted accordingly.

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

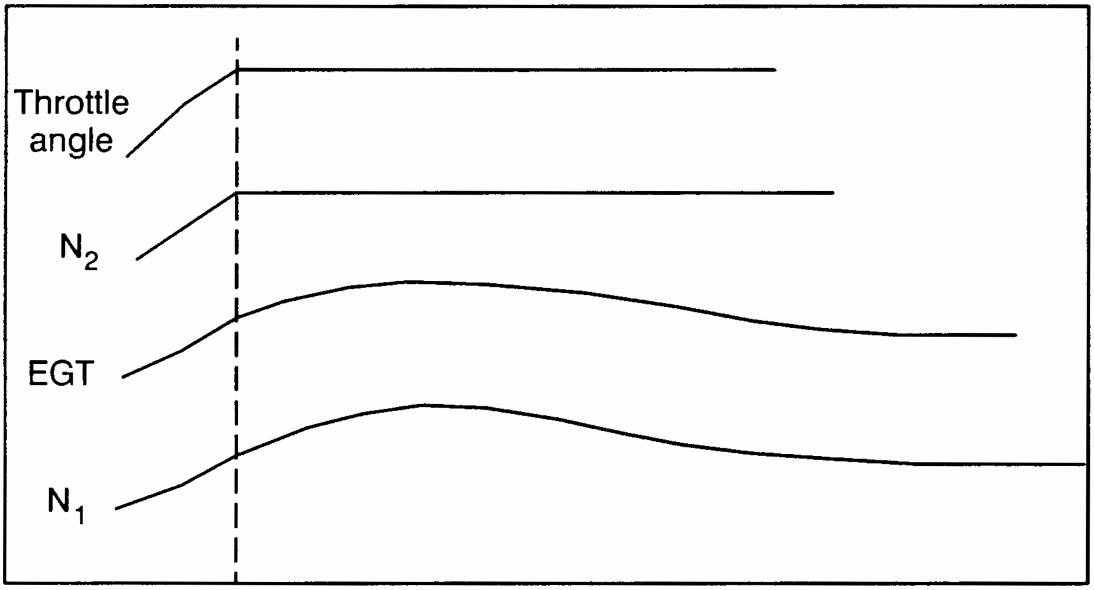
III. EGT increases with TAT to FRT, then remains constant.

IV. N_2 increases with TAT to FRT then is essentially constant.

Any deviation from N_1 power management will result in corresponding deviations in N_2 and EGT. This applies to positive deviations of N_1 (overboost) as well as to reduce thrust operation.

NOTES

CF6-50 Transient Characteristics
(N_2 Governor)



T1422.17 - 880201

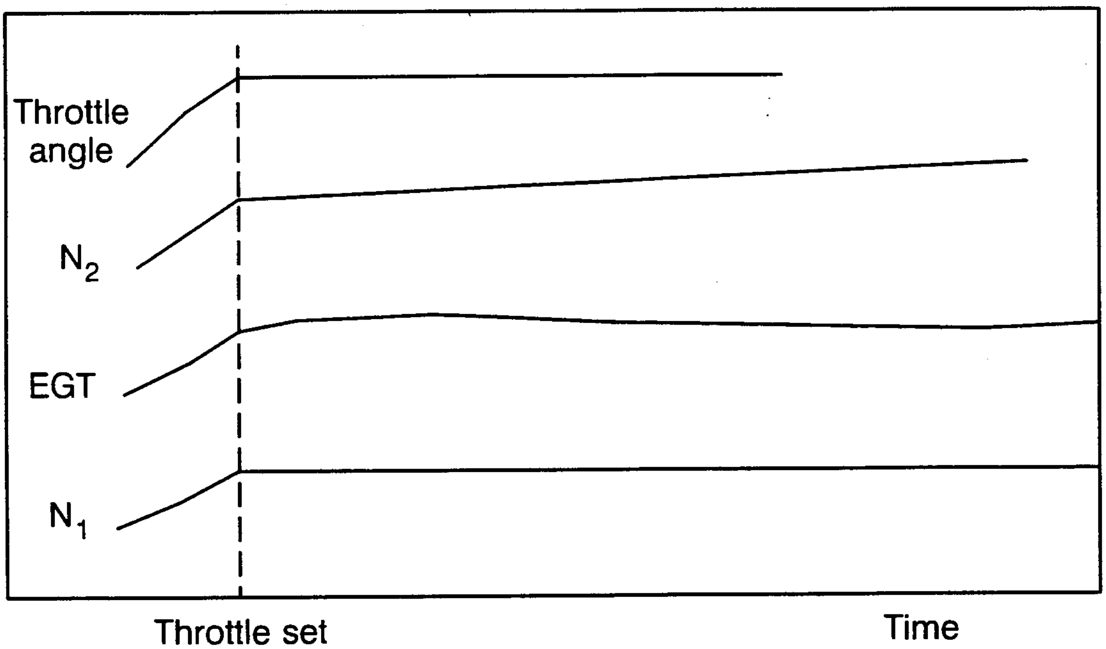
Throttles are advanced until target N_1 is achieved. After throttle set, the Main Engine Control maintains the N_2 corresponding to that throttle position. Because of different thermal characteristics of the core engine static and rotating components, the core becomes less efficient and a higher fuel flow and EGT is required to maintain N_2. The increased energy available at the LPT causes N_1 to increase; thus EGT and N_1 "bloom". As the thermal growth of core components stabilize, the core becomes more efficient and EGT and N_1 will decrease ("droop").

These transient characteristics are taken into account when determining power management N_1 required to achieve aircraft performance. They are also taken into account when establishing operating limits for the engine.

To minimize these transients, the CF6-50 is equipped with a Variable Stator Vane (VSV) reset actuator which senses thermal transients and closes the VSV's from their normal schedule, then allows them to go back on the normal schedule as temperatures stabilize. With the VSV's more closed, less airflow passes through the core engine, less fuel is required to maintain N_2 (resulting in less EGT "bloom") and less energy is available to the LP turbine, resulting in less N_1 "bloom". With VSV's more closed, less fuel is required to maintain N_2 and airflow across the LPT decreases, resulting in less EGT and N_1 bloom.

NOTES

CF6-80C2/FADEC Transient Characteristics



T1671.16 - 890315

The power management function on the CF6-80C2/FADEC engine consists of controlling N_1 (rather than N_2) to produce thrust requested by the throttle position. FADEC uses 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 significantly reduced.

NOTES

Testing and Operational Experience

T815.18 - 860506

NOTES

Development Tests

- Ice ingestion
  - Accumulation
  - Ice slab
- Medium bird
  - Eight 1½ pound birds
  - Takeoff power (60.2K thrust rating)
  - Throttle setting maintained 5 minutes
  - Engine retained 95% thrust
- Large bird
  - Four pound bird
  - Takeoff power (60.2K thrust rating)
  - Engine operated satisfactorily for required time
  - Normal shutdown
- Water ingestion
- Fan blade out

26S-1319-072486

NOTES

CF6-80C2

Overlimit Testing

T815.21 - 860506

NOTES

EGT/Rotor Speed Limits

EGT°C

960 takeoff	5 min
925 maximum continuous	Unlimited

Rotor speed %

117.5	N_1
112.5	N_2

NOTES

Over-limit Demonstrations Prior to Certification

960°C EGT or above	107 cycles
965°C EGT or above	9 cycles
1009°C EGT or above	5.1 minutes
1002°C EGT or above	11 minutes

T815.23 - 860506

NOTES

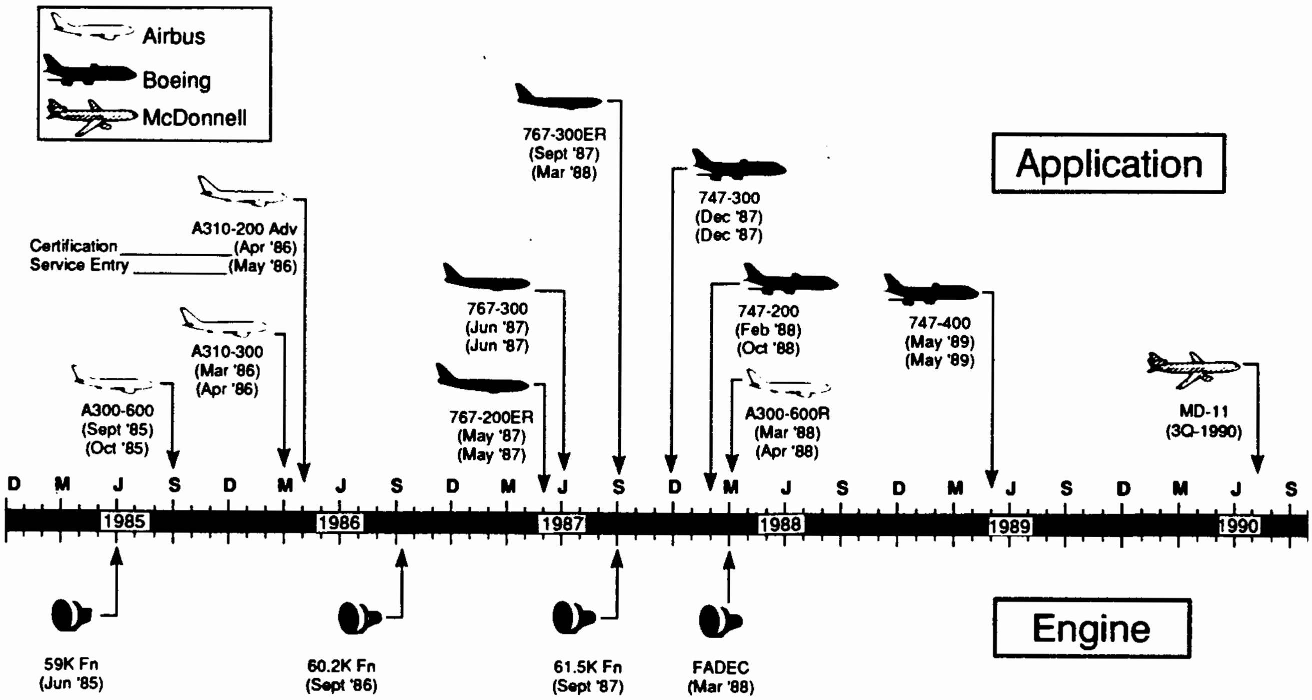
Over-limit Qualification

Fan module	160.3% N_1
LPT module	162.8% N_1
HPC module	141.6% N_2
HPT module	138.5% N_2

T815.24 - 860506

NOTES

CF6-80C2/Applications Programs



MAC2-8402.1-090589

NOTES

CF6-80C2 Revenue Service

- A300-600/-80C2 entered service
  5 October 1985

- 236 aircraft in service (49 A300-600s/
  68 A310s/81 767s/38 747s)
  - 22 engine caused IFSD. . . .0.007/1000 hours
  - 20 engine caused rejected takeoffs to date

- Experience to date (through September 1990)
  - 3,324,180 engine hours; 1,176,209 cycles
  - High time engine: 14,496 hours; 7,650 cycles
  - Engine operation excellent

NOTES

EROPS Status for GE CF6-80 Engine Family

- FAA approval granted for CF6-80A/A2 EROPS operation on Boeing 767
- DGAC approval granted for CF6-80A3 EROPS operation on A310-200
- DGAC approval granted (120 minutes at single engine speed) for CF6-80C2 EROPS operation on Airbus A310-300 and A300-600
  - DGAC agreed to consider requests for 138 minutes from individual operators
- FAA approval for 120 minutes at single engine speed received for CF6-80C2 powered A300-600 (Spring, 1988)
- FAA approval granted for 180 minutes EROPS operation on CF6-80A/A2 and CF6-80C2 powered B767 (January 1989)

T1671 18 - 890210

NOTES

FADEC Status

- CF6-80C2 FADEC flown on A300 test bed by GE pilots
- FADEC engine certified 3/88
- Currently flying on B747-400
  - First flight was June 27, 1988
  - Aircraft certified 1st quarter 1989
- First FADEC on Airbus will be A330 to be certified in 1993
- First FADEC on MD-11 (4th qtr 1990 certification)

NOTES

CF6-80C2

Operational Characteristics and Recommendations

T815.27 - 860508

NOTES

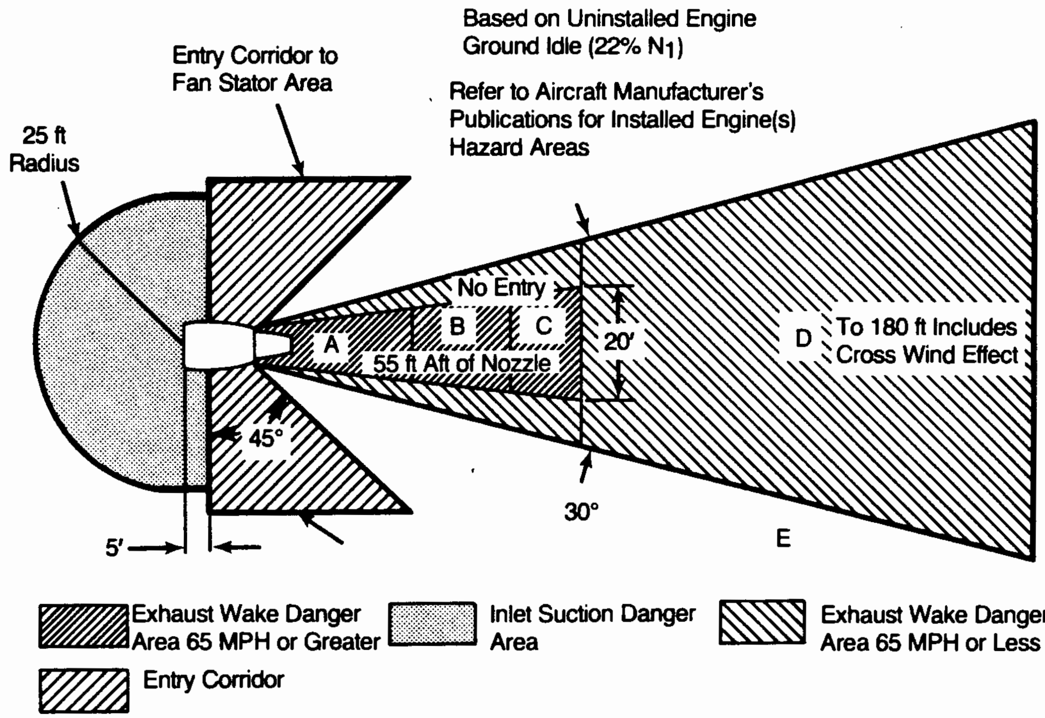
CF6-80C2 Preflight

- Inlet and exhaust
  - Clear of foreign objects
  - Condition of fan inlet, spinner and blades
  - Fan rotational freedom
- Cowlings latched
- Reversers stowed
- External evidence of fuel, oil or hydraulic leaks
- Condition of LPT blades (Shingling, unlatching)

90S-18108-060487

NOTES

Physical Hazard Areas (Ground Idle)



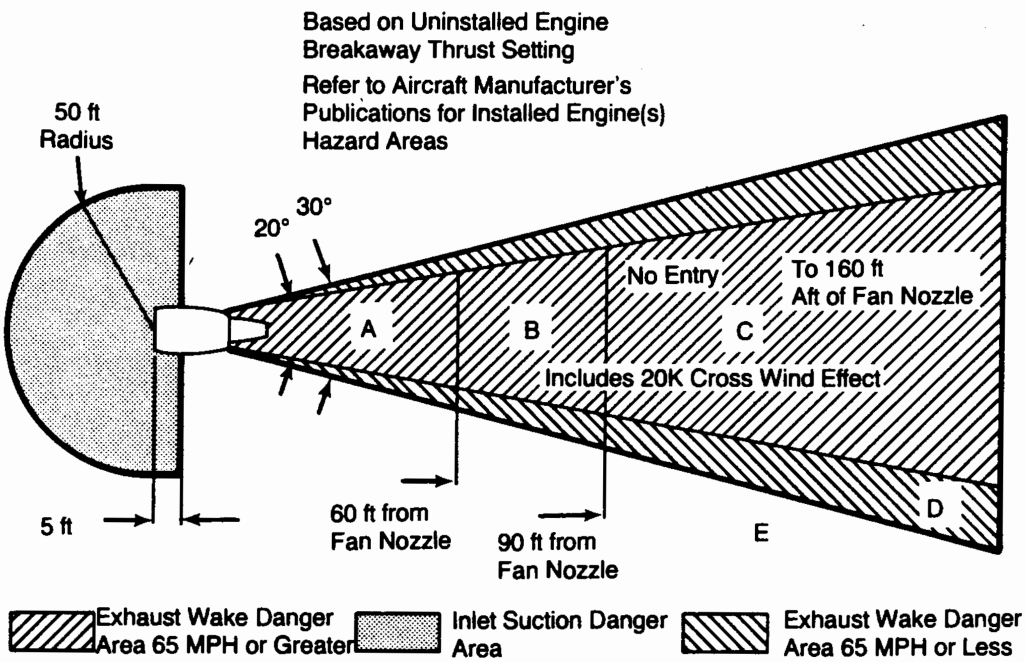
90S-18096-060487

Engine Physical Hazard Areas - Ground Idle (Uninstalled)

Area	Approx. Wind Velocity (MPH)	Possible Effects within Danger Zone Based on "Radiological Defense" Vol II Armed Forces Special Weapons Project, Nov. 1951
A	210 to 145	A man standing face-on will be picked up and thrown: Aircraft will be completely destroyed or damaged beyond economical repair: Complete destruction of frame or brick homes.
B	145 to 105	A man standing face-on will be picked up and thrown: Damage nearing total destruction to light industrial buildings or rigid steel framing: Corrugated steel structures less severely damaged.
C	105 to 65	Moderate damage to light industrial buildings and transport type aircraft.
D	65 to 20	Light to moderate damage to transport type aircraft.
E	20	Beyond danger area.

NOTES

Physical Hazard Areas (Breakaway Thrust)



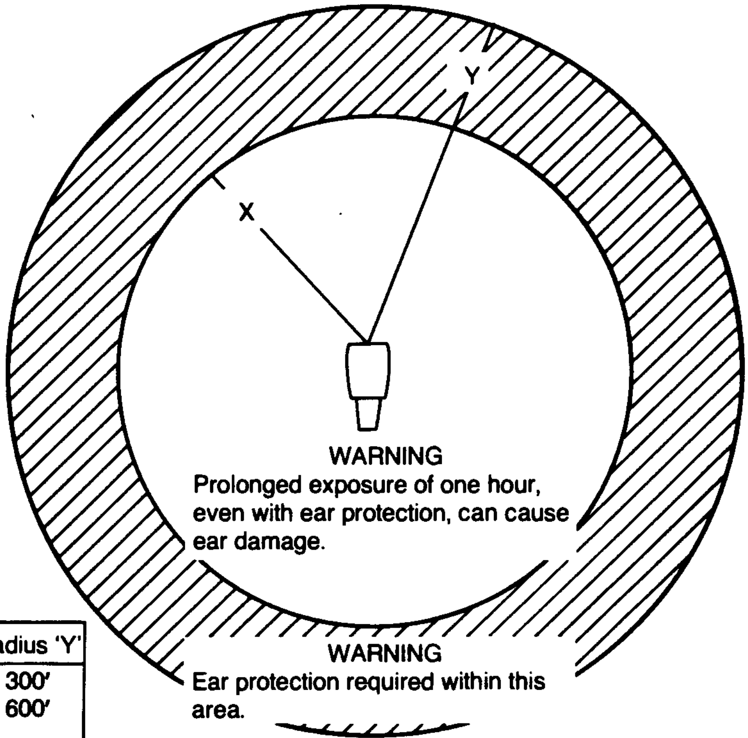
90S-18097-060487

Engine Physical Hazard Areas - Breakaway Thrust (Uninstalled)

Area	Approx. Wind Velocity (MPH)	Possible Effects Within Danger Zone Based on "Radiological Defense" Vol II Armed Forces Special Weapons Project, No. 1951
A	210 to 145	A man standing will be picked up and thrown: Aircraft will be completely destroyed or damaged beyond economical repair: Complete destruction of frame or brick homes.
B	145 to 105	A man standing face-on will be picked up and thrown: Damage nearing total destruction to light industrial buildings or rigid steel framing: Corrugated steel structures less severely.
C	105 to 65	Moderate damage to light industrial buildings and transport type aircraft.
D	65 to 20	Light to moderate damage to transport type aircraft.
E	20	Beyond danger area.

NOTES

Acoustical Hazard Areas



NOTE:
Based on uninstalled engine, refer to aircraft manufacturer's publications for installed engine(s) Hazard Area.

*Current USA OSHA act requirement for continuous (8 hrs max.) noise exposure (90dBA)

Engine Acoustical Hazard Areas (Uninstalled)

Power Setting	Radius 'X'	Radius 'Y'
Ground Idle	75'	300'
Breakaway Thrust (N_1 - 1800 RPM)	100'	600'
Takeoff thrust	100'	2400'

90S-18098-060487

NOTES

CF6-80C2 FADEC Starting

- Autostart not available on MD-11
- Automatic or manual
- Not sensitive to crosswinds/tailwinds
- No restriction on reverse fan rotation
- Starter air pressure
  - 25 to 55 psi (valve open)
  - Warmer, slower starts with lower pressure
  - FADEC detects low starter air pressure (low N_2 acceleration) in the automatic start mode
- Ignition
  - FADEC in auto mode turns on ignition at 10% N_2
  - Ignition during manual starts comes on with fuel lever activation
  - FADEC always alternates A and B igniters for every two ground starts (auto or manual)
- Fuel
  - On at 15% N_2 minimum if done manually
  - Normal fuel flow $\leq$700 pph (320 Kgh)

T1671.20 - 900518

NOTES

Start (Continued)

- Light off
  - Almost instantaneous
  - If no light off in 25 seconds fuel off and motor for 30 seconds prior to next start attempt

- Oil pressure
  - Must be indication by ground idle
  - May be full scale for cold soaked engine

- N_1
  - Typical 6% at 30% N_2
  - If no N_1, within 30 seconds after idle N_2, shut engine down
  - Attempt restart . . . if no N_1 on this start, maintenance action required

NOTES

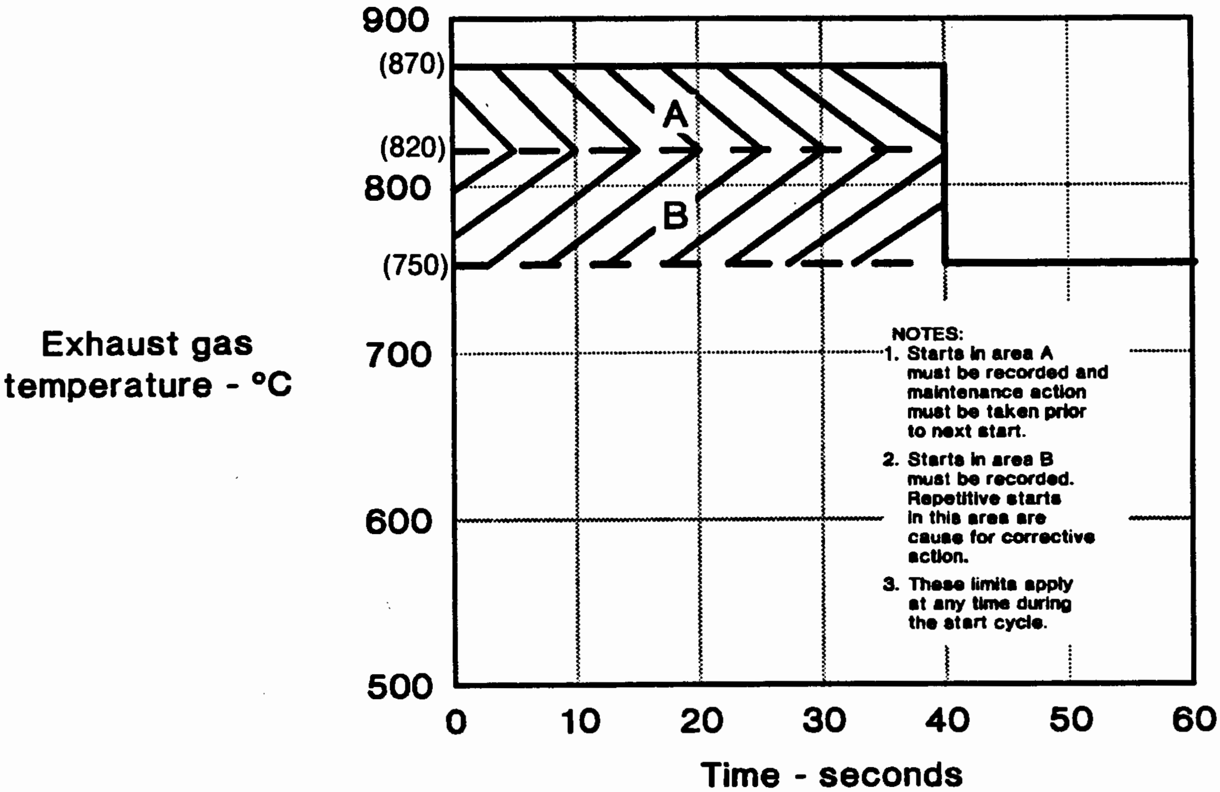
Start (Continued)

- EGT
  - Typical values : 550°C - 650°C
  - See chart for limits

- Ground idle
  - Slower to ground idle than CF6-50 or CF60-80A
  - Typical start time: 35 to 50 seconds

NOTES

EGT Start Temperature Limits



T815.55 - 860506

NOTES

Starter Limits

- Duty cycle
  - Maximum continuous operation - 5 minutes
  - Cool 30 seconds per minute of operation
  - After two consecutive 5 minute cycles, cool for 10 minutes prior to further use
- Re-Engagement
  - Maximum N_2: 30%
  - Recommended N_2: 0%

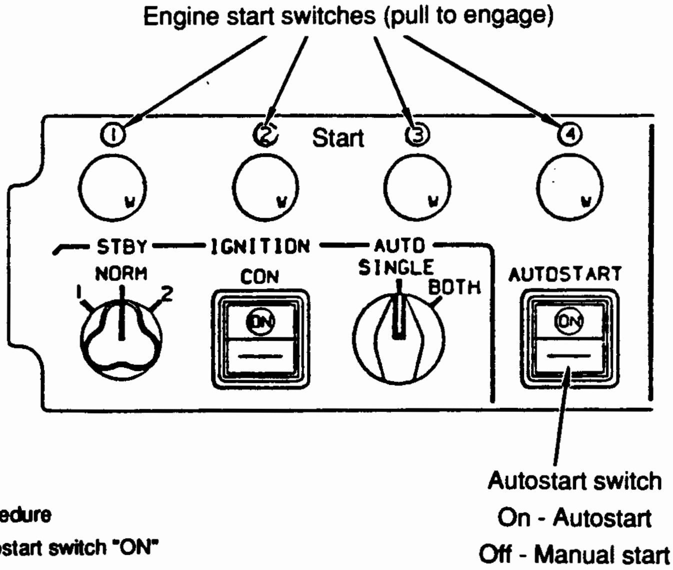
NOTES

FADEC Auto-start (N/A MD-11)

- Pilot initiates starting sequence
- ECU controls starter, ignitors, fuel
- Ignitors alternated on every two ground starts; dual ignition available on ground if selected and for all air starts
- Start problem detection and correction
- Pilot can abort start at any time

NOTES

B747-400 Overhead Engine Start Panel



Autostart procedure

1) Select autostart switch "ON"
2) Pull engine start switch "ON" (white)
3) Select fuel lever "ON" (isle stand)

MAC5-36891-070188

When ready to start an engine, the Autostart Switch should be "on" to use the FADEC automatic start capability. In the Autostart Mode, pulling the Engine Start Switch arms the starter air valve, but no immediate action takes place. Starter Air Value opening and engine rotation begins when the Fuel Lever is selected on. Ignition and fuel flow are sequenced on automatically.

NOTES

FADEC Ground Auto-start Sequence

- Pilot selects automatic start mode
- Pilot selects engine start switch on
  - Starter does not come on until fuel condition lever selected on
- Pilot selects fuel condition lever on
  - Starter comes on
  - Ignition comes on at 10% N_2
  - Fuel comes on at 15% N_2
  - At 50% N_2, starter and ignition is turned off
- Start protection
  - Low starter air pressure
  - Failure to light off
  - Stall/overtemperature
  - Low acceleration

T1671.24 - 890926

NOTES

FADEC In-flight Auto-start Sequence

- Starter assisted
  - Dual ignition automatically used for all auto airstarts
  - Pilot selects start switch on
    - Starter does not come on until fuel condition lever selected on
  - Pilot selects fuel condition lever on
    - Starter comes on
    - Dual ignitors come on immediately
    - Fuel comes on at 15% N_2
    - At 50% N_2, starter and ignition is turned off
  - The use of continuous ignition is optional
- Windmill
  - Pilot selects fuel condition lever on
    - Dual ignition comes on slightly before fuel flow
- All adoptive start protection features are operative

NOTES

Auto-start Low Starter Air Pressure Logic

- If N_2 acceleration is low at 14% N_2, FADEC notes low starter air pressure
- If stall/overtemperature occurs, the stall recovery sequence is performed
- Informs maintenance of low starter air pressure

NOTES

Auto-start Failure to Light Off Logic

- Light off detected when EGT increases 55°
- If no light off within 20 seconds
  - Fuel and ignition off
  - Dry-motor for 30 seconds
- Second start attempted with both ignitors for 15 seconds
- If no light off on second attempt
  - Fuel and ignition off
  - Dry-motor for 30 seconds
- Third start attempted with both ignitors for 15 seconds
- If no light off on third attempt
  - Start is aborted
  - Fuel and ignition off
  - Dry-motor for 2 minutes to purge the system of fuel

NOTES

Auto-start Stall/Overtemperature Logic

- Ground start
  - Stall detected by low N_2 acceleration and/or high EGT, with consideration of the pre-start residual EGT
  - EGT overtemperature limit is 750°C
- In-flight start
  - Stall detected by low N_2 acceleration and/or EGT greater than 750°C
  - In-flight EGT overtemperature limit is 960°C

NOTES

Auto-start Stall/Overtemperature Logic (Continued)

Stall/Overtemperature Corrective Action

- Ground start
  - Fuel metering valve closes for 6 seconds (fuel off)
  - Fuel is turned back on with a 7% reduction in F.F. schedule
  - If a stall reoccurs, the recovery process repeats with an additional 7% F.F. reduction (total of 14%)
  - If another stall/overtemperature occurs, start is aborted, engine is dry motored for two minutes and shutdown
- In-flight start
  - Same as ground starts, except:
    1. Start is never aborted without pilot action
    2. If more than 2 stall/overtemperature events occur, start attempts continue with constant 14% F.F. reduction
    3. If stall occurs after starter cutout, stall recovery process continues

NOTES

Auto-start Miscellaneous Adaptive Logic

- Low acceleration with reduced fuel flow schedule
  - If the engine is accelerating slowly and the EGT is low, the fuel flow schedule is slowly incremented back up to standard
- Starter system failure (in-flight)
  - If N_2 is not accelerating 5 seconds after the start valve open command, fuel is turned on regardless of N_2
  - If N_2 does not reach 15% within 10 seconds of the starter air valve open command, fuel is turned on regardless of N_2

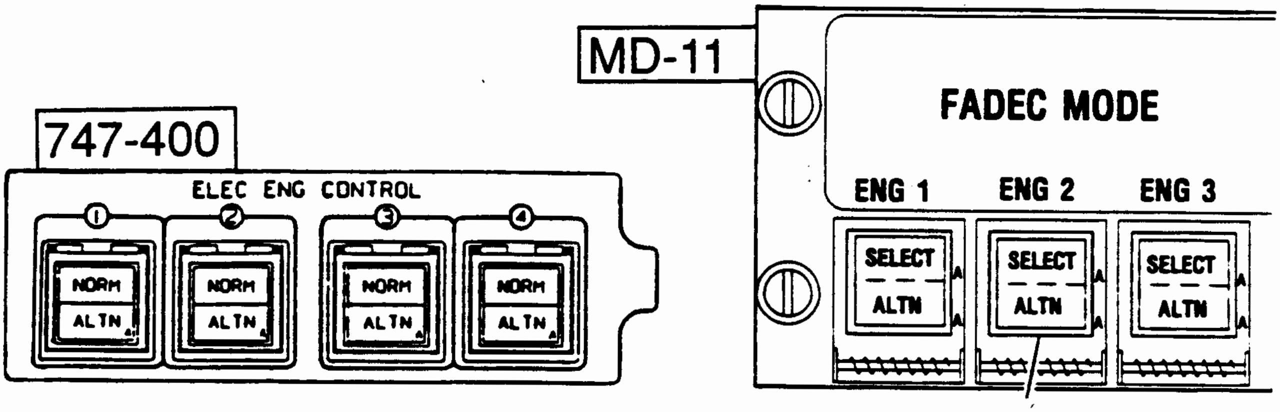
NOTES

CF6-80C2 FADEC Running Mode (N/A MD-11)

- FADEC exits start mode and enters run mode within 1% N_2 of the minimum idle schedule (approx 64% N_2)
- FADEC remains in the running mode until N_2 falls to 50% (flameout)
- FADEC does not have the authority to close the 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
- Flameout is determined by N_2 deceleration higher than the normal deceleration schedule OR N_2 dropping below approx. idle (64%)

NOTES

747-400 Overhead Electronic Engine Control



- Normal Position
  - Normal FADEC operation
  - Automatic reversion to the soft reversionary mode
- Altn position
  - FADEC enters hard reversionary mode
  - Engine overboost is possible

MAC12-36892-051890

NOTES

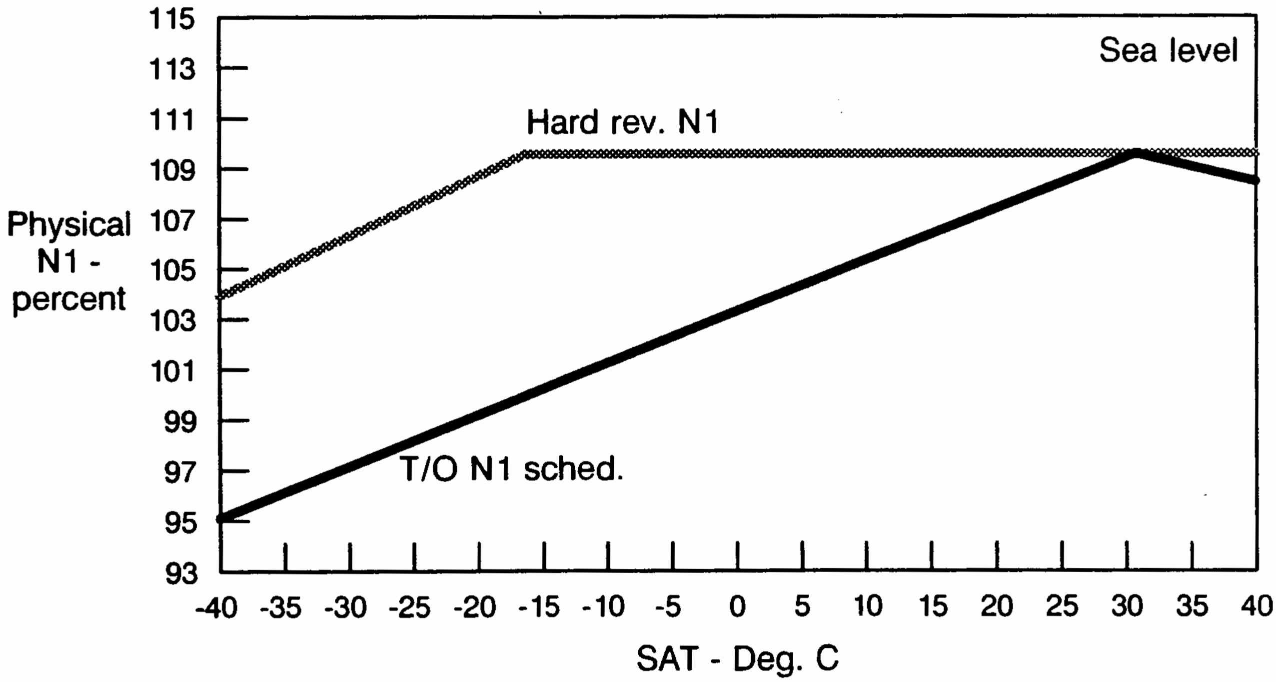
FADEC Reversionary Modes

- Normal mode
  - FADEC power management based upon ambient temperature, pressure, Mach, and bleed status. Mach is based upon total pressure data from the aircraft Air Data Computer System
- Soft reversionary mode
  - FADEC automatically reverts to soft reversionary when aircraft total pressure data is lost. The loss of total pressure results in the loss of Mach number and ambient temperature. FADEC assumes the last valid ambient temperature signal and adjusts for changes in altitude. There are no unexpected changes in N1 when FADEC goes into the soft reversionary mode
- Hard reversionary mode
  - Hard reversionary is entered by pilot selection (overhead switches or throttles through frangible stop). In hard reversionary, the worst case temperature is assumed for power management. The engine may be overboosted in hard reversionary

T2351.08 - 900613

NOTES

CF6-80C2B1F Normal/Hard Reversionary Control Comparison - Takeoff Rating



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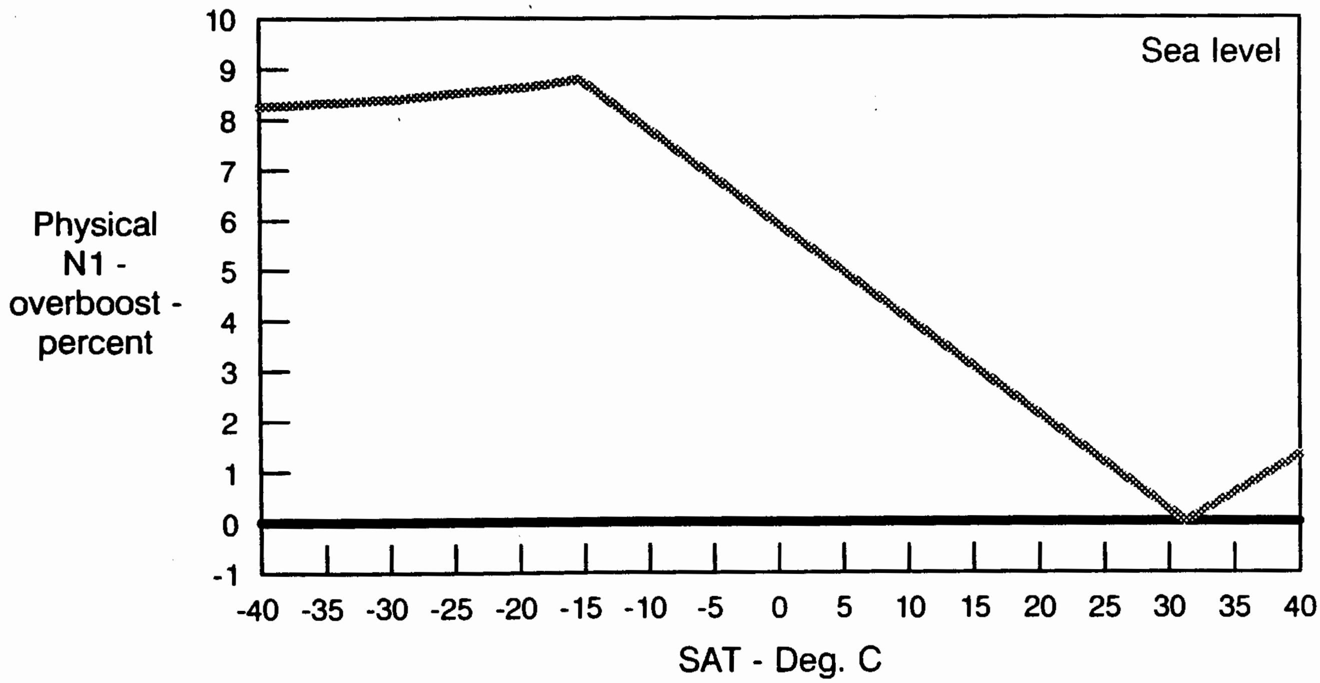
NOTES

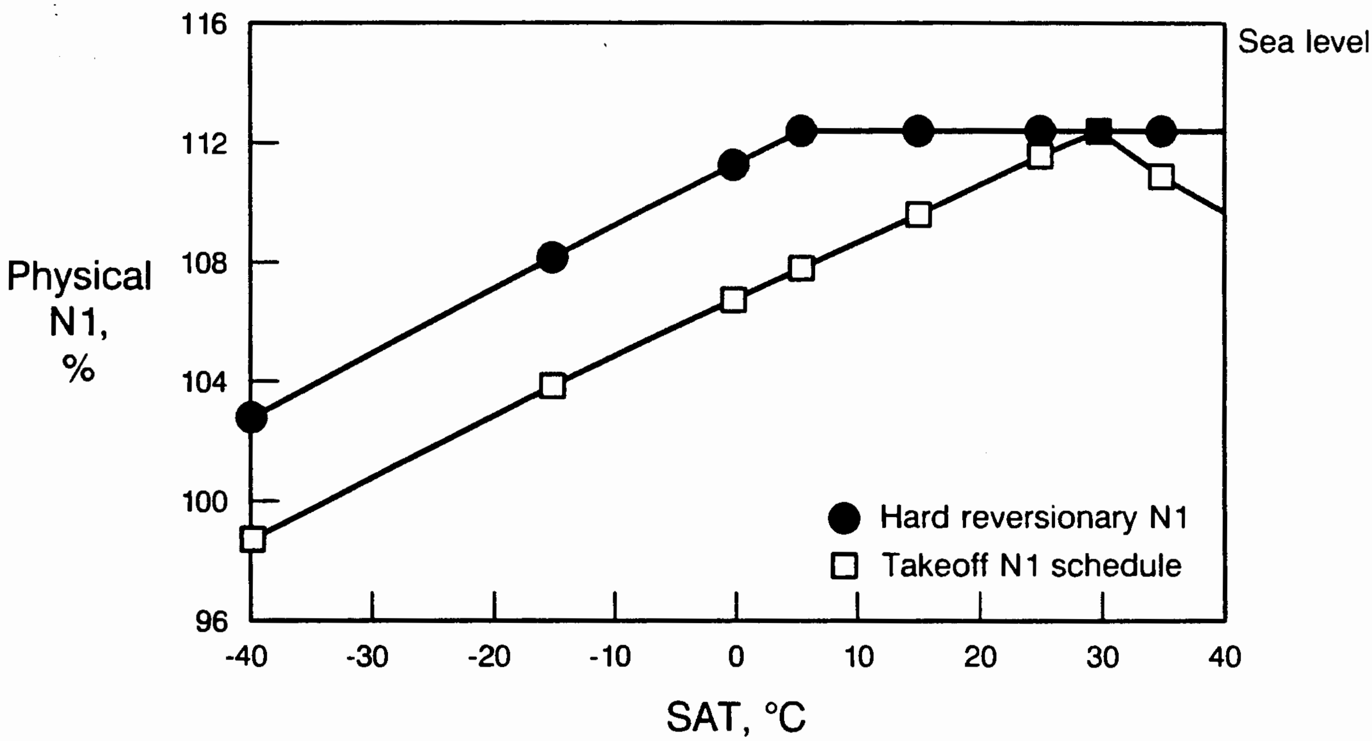
CF6-80C2B1F N1 Overboost Capability in Hard Reversionary Mode - Takeoff Rating



T1671.40 - 900518

NOTES

CF6-80C2D1F Normal/Hard Reversionary Control Comparison -- Takeoff Rating



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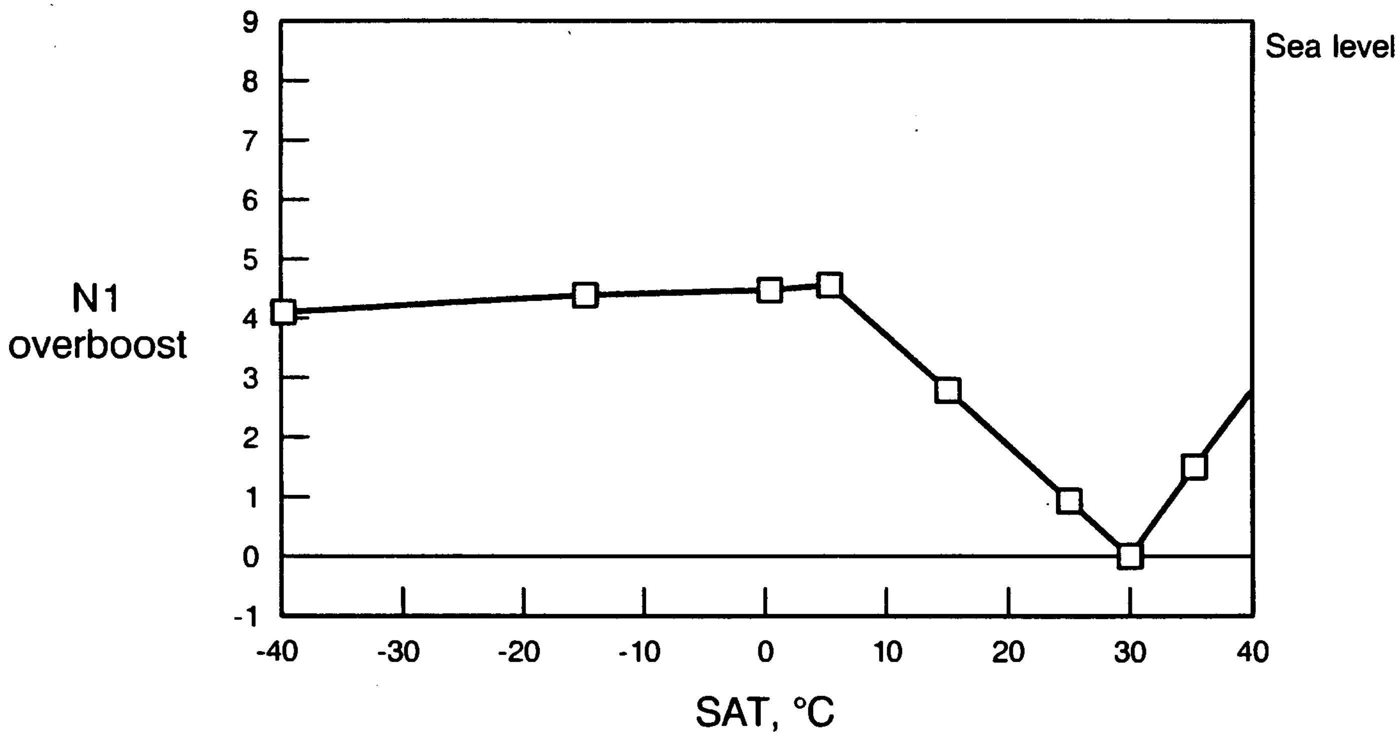
NOTES

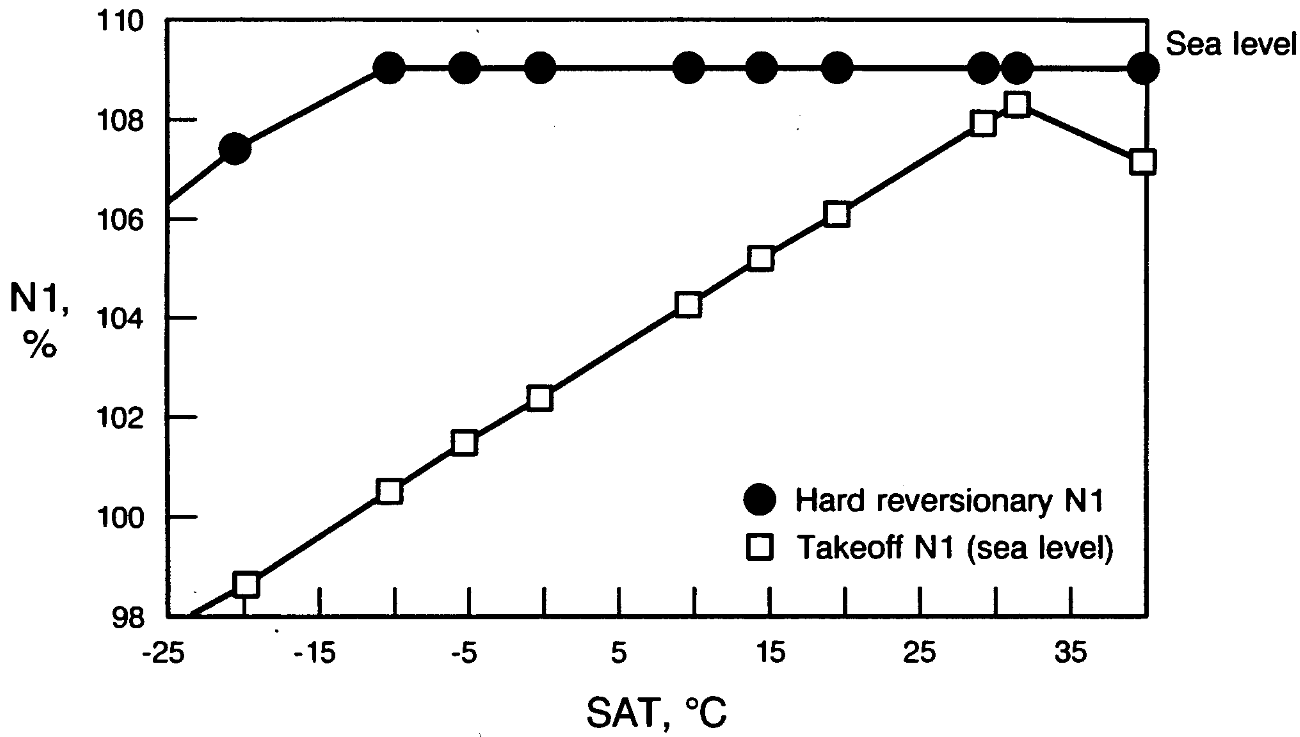
CF6-80C2D1F N1 Overboost Capability in Hard Reversionary Mode -- Takeoff Rating



T2351.10 - 900613

NOTES

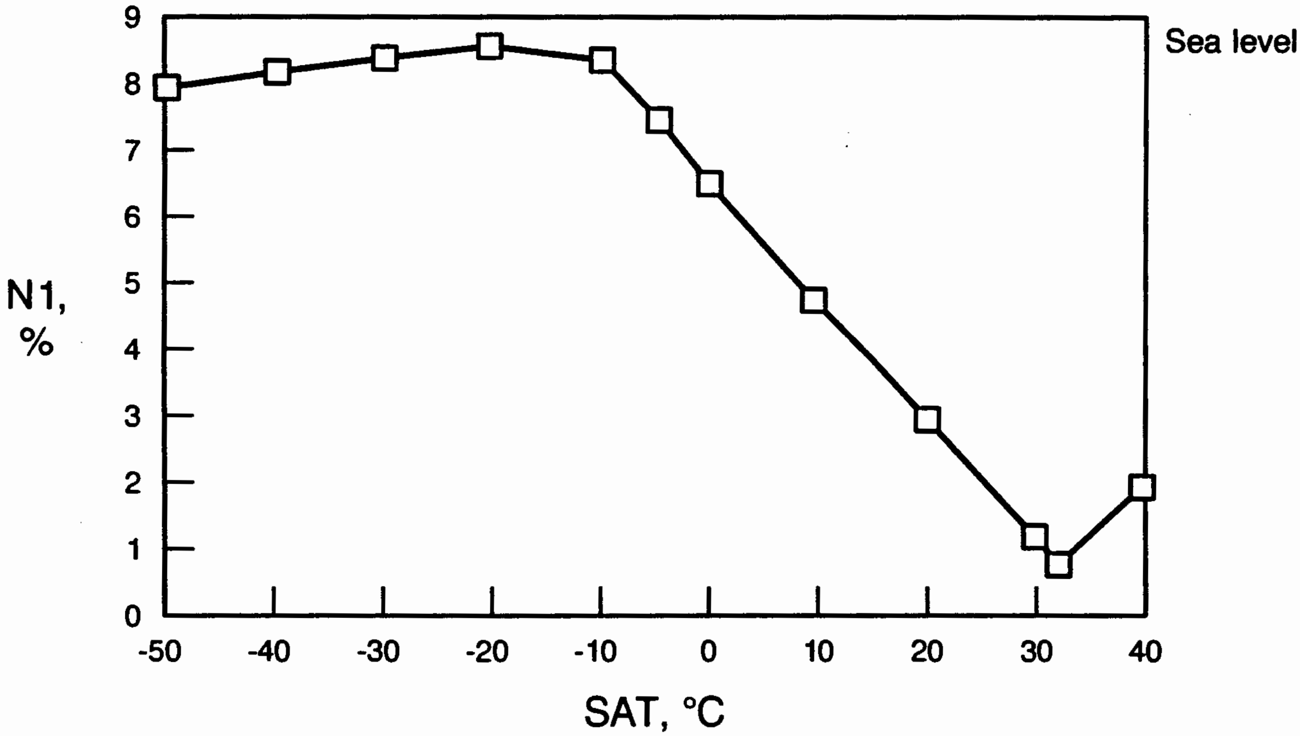
CF6-80C2B4F Normal/Hard Reversionary Control Comparison -- Takeoff Rating



T2351.12 - 901029

NOTES

CF6-80C2B4F N1 Overboost Capability in Hard Reversionary Mode -- Takeoff Rating



T2351.13 - 901025

NOTES

Taxi

- Not sensitive to ambient conditions
  - EGT unaffected by crosswinds or tailwinds
  - Constant idle thrust
    - N_2 varies with OAT/PA to maintain constant thrust level

- Typical idle indications
  - N_1 20-25%
  - EGT 390-425°C
  - N_2 60 - 65 %
  - Fuel flow 600-700 kg (1300-1500 lb/hr)

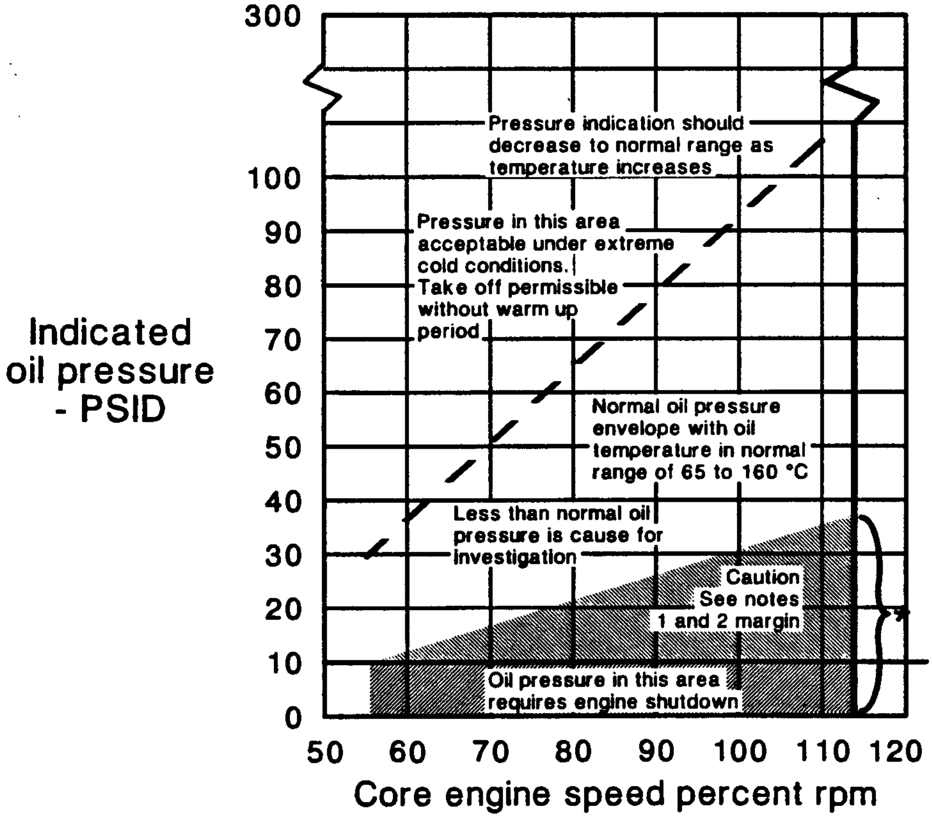
NOTES

Taxi (Continued)

- **Oil pressure**
  - Varies with N_2 (see chart)
  - Minimum 10 psi
  - May be full scale for cold soaked engine
- **Oil temperature**
  - No minimum
  - Rise must be noted prior to takeoff
  - Maximum 160°C continuous, 175°C for 15 minutes
- **Minimize breakaway thrust**
- **Minimize reverse thrust**
- **Three minute warm-up prior to takeoff**

NOTES

Oil Pressure Versus N_2



*Caution

1) Ground -
   Oil pressure in this area requires correction before flight.

2) Flight
   Oil pressure in this area requires monitoring of temperature and pressure. Shutdown engine if oil temperature limit is exceeded or oil pressure drops below 10 PSID.

3) During "negative-G" operating conditions, oil pressure less than 10 PSID is permissible for a maximum time limit of 30 seconds

NOTES

Taxi (Continued)

- Ground operation in icing conditions
  - No special procedure required for up to 30 minutes
  - After 30 minutes of idle operation in icing conditions, accelerate to 60% N_1 for 30 seconds
    - Allows immediate shedding of fan blade root and spinner ice
    - De-ices stationary vanes (OGV's) with combination of shed ice impact and adiabatic temperature rise (typical rise across fan is about 20°F)

NOTES

Takeoff N_1 (Fan Speed) vs EPR as Power Management Parameter

- High Bypass Fan Engine at Takeoff Power
  - 80% of Thrust From Fan
  - 20% of Thrust From Core
- Standard EPR System Measures Delta Pressure Fan Inlet to Core Exhaust
- Practical Use of EPR Requires Integration of Pressure and Areas of Both Fan Discharge and Core Jet Nozzles
- N_1 Directly Related to Fan Thrust (80% of Total) and to Core Thrust
- N_1/Thrust Relationship Relatively Insensistive to Engine Deterioration
- N_1 Measurement Accuracy $\pm .2\%$ rpm
  - At T/O Power 1% N_1 Δ is approximately 2.46% Thrust Δ

28S-4860-012486

NOTES

Takeoff

- Ignition
  - Requirement specified by aircraft manufacturer
  - GE requires for start only

- N_1 thrust management
  - FADEC computes command N_1 for max or reduced thrust
  - Pilot (or autothrottle) sets command indication to target N_1
  - Throttle position (through FADEC) drives command arc (Boeing) or throttle position T (McDonnell Douglas)
  - Maintains N_1 at command value

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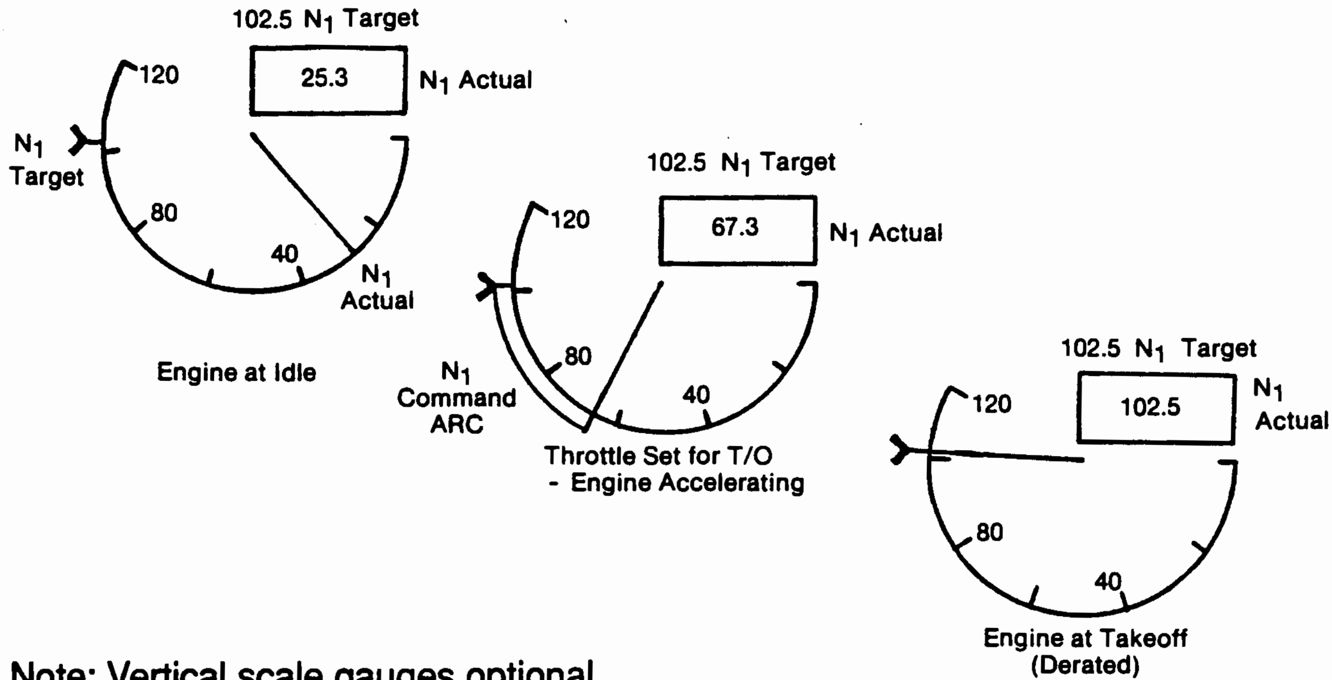
NOTES

Power Setting Sequence

(Boeing Installation)



Note: Vertical scale gauges optional

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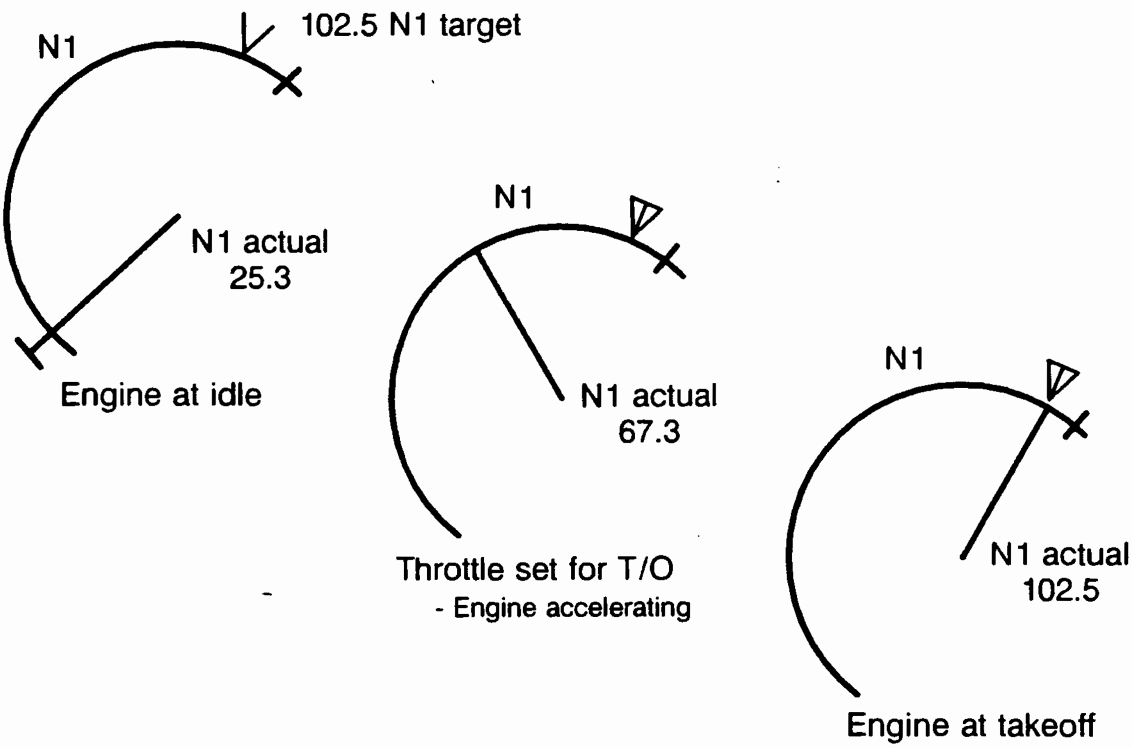
In setting take-off power, the target N_1 is determined (normally by the Thrust Management Computer) and the N_1 Command Arc (from the ECU) is set to this targer value. Actual N_1 will increase until it equals N_1 target. The pilot always sets the same throttle position for full take-off power.

NOTES

Power Setting Sequence -- MD-11 Installation



T1671.38 - 900518

NOTES

CF6-80C2 FADEC Acceleration Rate

- FADEC accelerates all engines at a uniform N2 rate

- N2 acceleration rate based upon a "worst case" engine, so even a deteriorated engine will match new engine acceleration capability

NOTES

Takeoff Thrust Lapse Recovery

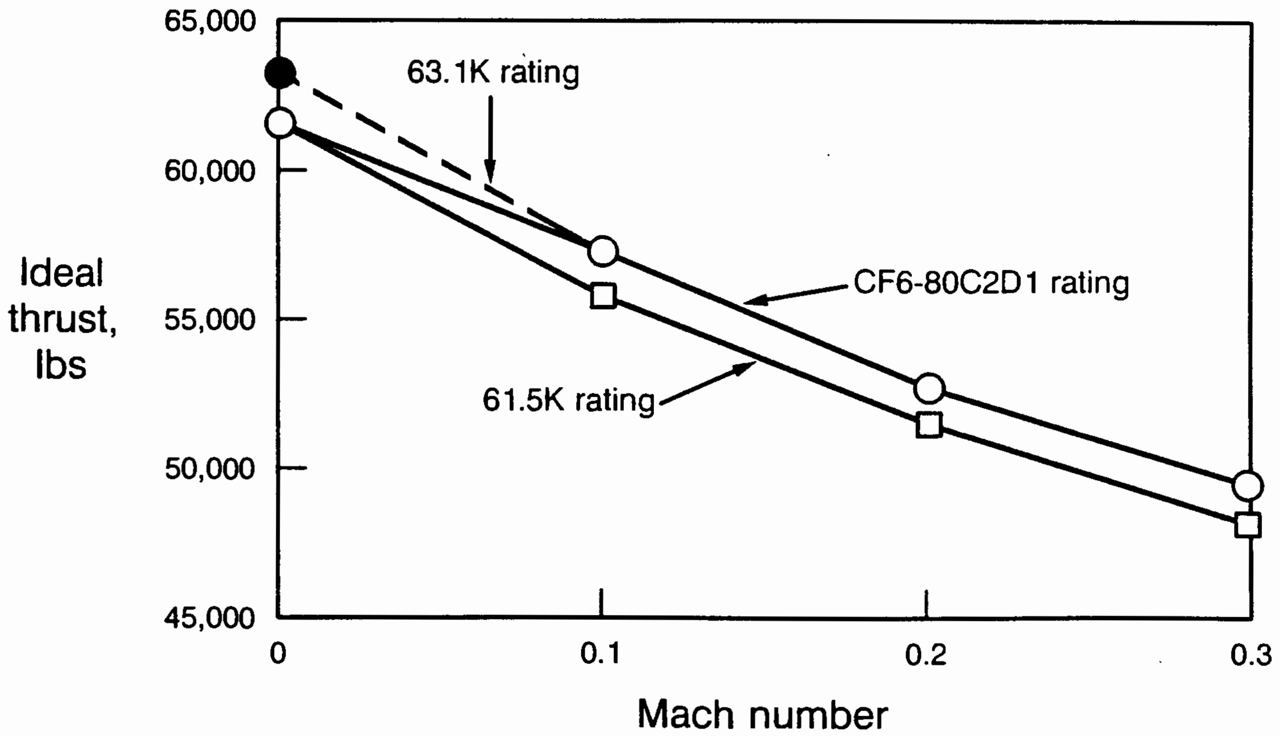
- FADEC has the ability to increase N1 during the takeoff roll to counteract normal thrust lapse caused by increasing aircraft speed

- On the MD-11, this allows a 61,500 lb static thrust engine to provide the equivalence of a 63,100 lb static thrust engine during the later stage of the takeoff roll

T2351.05 - 900613

NOTES

Thrust Lapse Recovery -- CF6-80C2D1F



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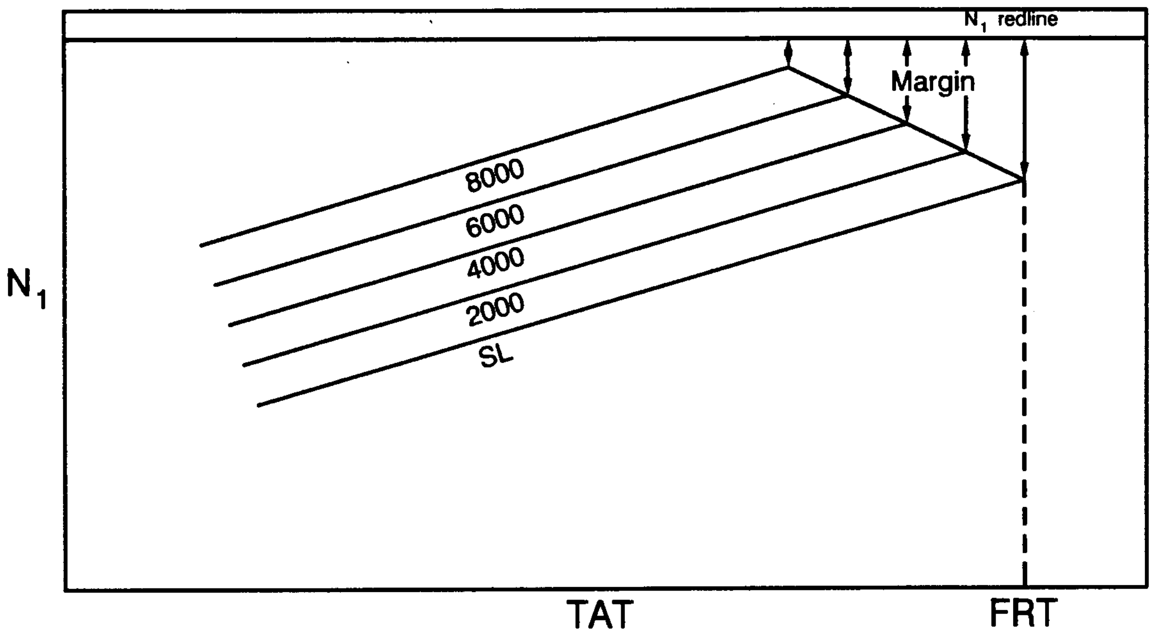
NOTES

N_1 Margin

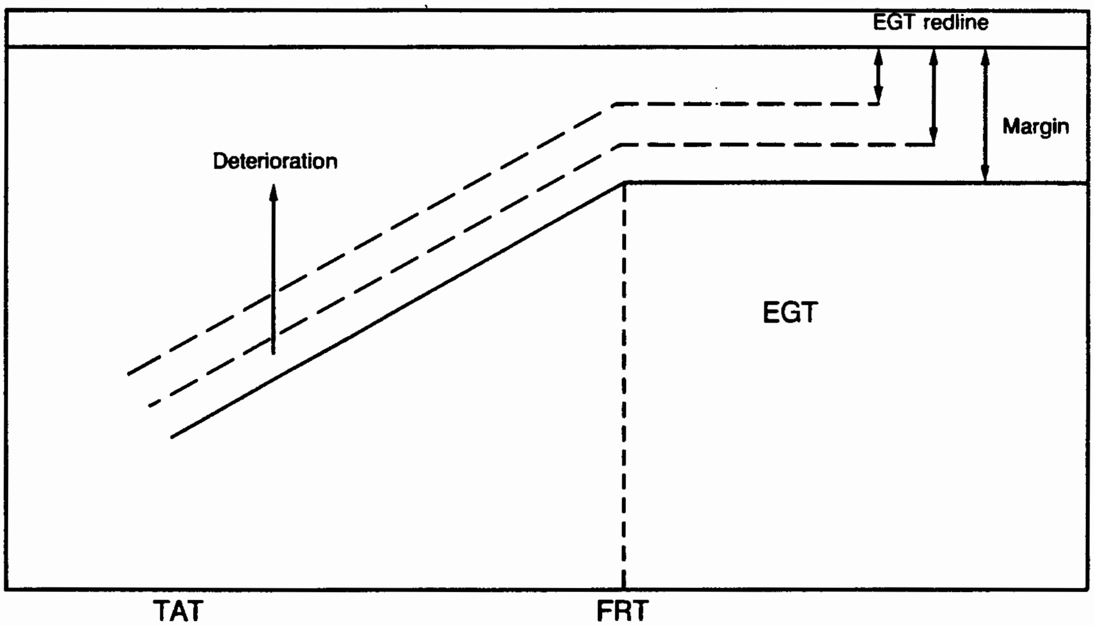


T1422.10 - 880201

Power management at higher altitude is such that N_1 for rated thrust is higher. The point of least margin occurs at high altitude and at FRT for that altitude.

NOTES

EGT Margin



T1422.09 - 880201

EGT Margin is the difference between the EGT redline and the EGT observed on a full thrust takeoff at or above flat range temperature (FRT). The EGT margin decreases as engine components deteriorate.

NOTES

CF6-80C2 Limits

- EGT 960° C
- N_1 117.5%
- N_2 112.5%

NOTES

CF6-80C2 EGT Overlimit Actions

Temperature	Recommended procedure
961° - 970°C	Reset thrust, continue normal operation to landing
971° - 979°C	Reduce to idle. Use higher thrust only at pilot's discretion
980°C and above	Precautionary shutdown

Caution: Any temperature or time limit exceedance must be reported to maintenance for review and/or corrective action

T815.31 - 890214

NOTES

CF6-80C2 N_1 Overlimit Actions

N_1 RPM	Recommended procedure
117.6 to 123.5%	Reset thrust, continue normal operation to landing
123.6 to 125.5%	Reduce to idle. Use higher thrust only at pilot's discretion
Above 125.5%	Precautionary shutdown

Caution: Any N_1 limit exceedance must be reported to maintenance for review and/or corrective action

NOTES

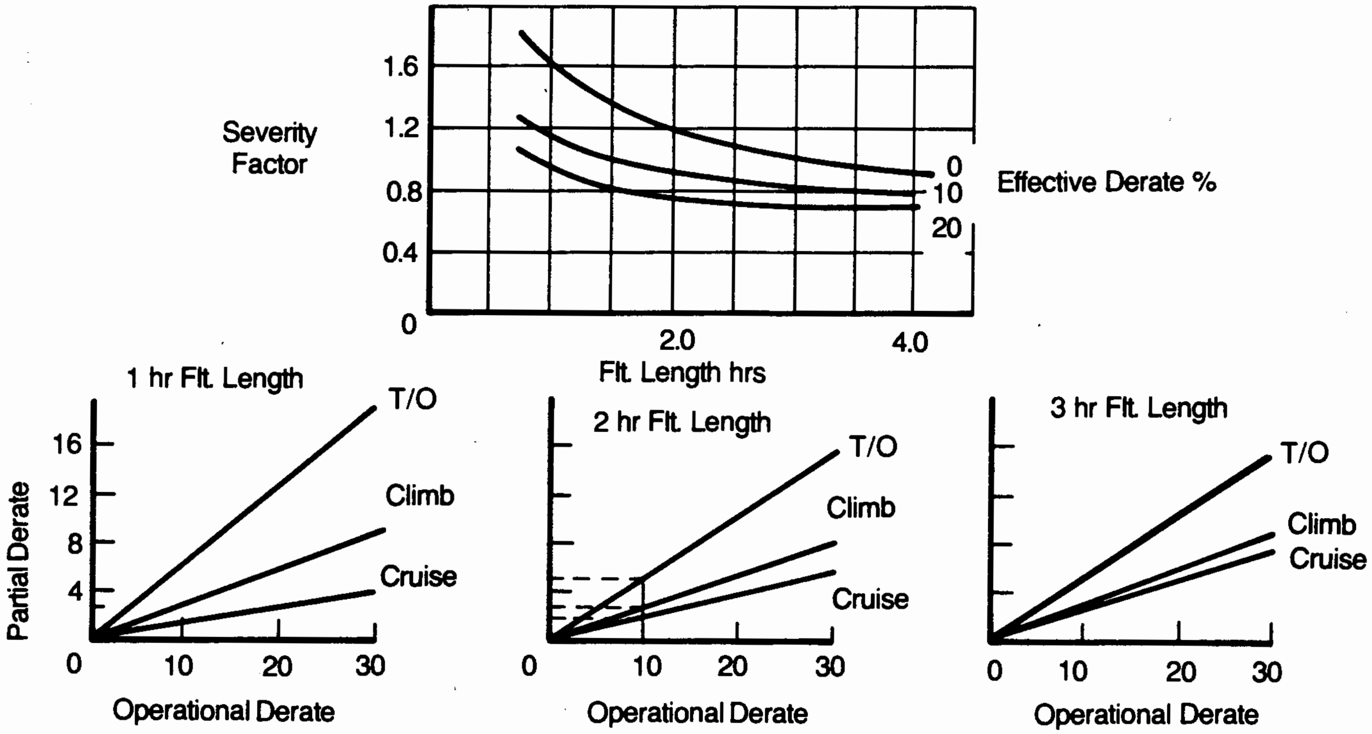
CF6-80C2 N_2 Overlimit Actions

N_2 rotor speed	Recommended procedure
112.6 to 113.0%	Reset thrust, continue normal operation to landing
113.1 to 113.5%	Reduce to idle. Use higher thrust only at pilot's discretion
Above 113.5%	Precautionary shutdown

Caution: Any N_2 limit exceedance must be reported to maintenance for review and/or corrective action

NOTES

Effects of Derate



(Effective Derate = % T/O + % Climb + % Cruise)

90S-18101-060487

The severity factor is dependent upon the operational derate used for each flight phase and the flight length of time. Using the smaller graphs at the bottom of the page for the average flight length, determine the partial derate from the operational derate and each flight phase (T/O, climb, and cruise). Add the 3 individual partial derates to obtain the effective derate. Then, using the effective derate and the flight length, the severity factor can be determined from the graph at the top of the page.

NOTES

Effects of Derate on Maintenance Costs
(Typical)

- Takeoff
  - First 5% decreases maintenance costs 6 - 8% (depending on flight length)
  - Last 5% (from 20% to 25%) decreases maintenance costs 3.5 - 4.0% (depending on flight length)
- Climb
  - Maintenance costs are decreased about 2% for each 5% of climb derate

NOTES

Climb

- Fixed throttle position with FADEC
- Throttle adjustments required in reversionary mode
- Reduced thrust climb per company instructions/aircraft manufacturer instructions

NOTES

Cruise

- Use auto-throttle during cruise
  - Insures optimum fuel economy by maintaining optimum Mach number
- Avoid unnecessary use of engine anti-icing and ignition
  - Conserves fuel and ignitor plug life
- Trend monitoring
  - Try to record the data on each flight

NOTES

N1 Trim Systems

- Provides equal N1 speeds from all engines
- Accounts for throttle stagger
- Eliminates excess thrust requirements due to trim drag
- Works in conjunction with FMC/auto throttles
  - 747-400
    - Trim system equalizes the N1 on all four engines
    - Auto throttle sets target N1
  - MD-11
    - Trim system slaves all three engines to the mid-range N1
    - If the target N1 is provided by the FMC, the trim system will set all engines to the target

NOTES

High Vibrations

- Symptomatic of deterioration in rotating machinery
- Separate vibration indicators for N1 and N2
- High N1 vibration may be felt in aircraft structure
- N2 vibration cannot usually be felt or heard
- High N2 vibration may be accomplished by changes in other engine parameters
- Sudden shifts in vibration are more significant than absolute vibration levels

MAC5-50064-042690

High Vibrations

- Actual or impending engine problems may be detected by vibration monitoring. Consider high vibration levels valid unless there is a known vibration system failure.

- Higher N1 vibration levels with takeoff or climb thrust settings may be experienced since N1 rotor imbalance will increase as engine speed increases. High N2 vibration indications are usually more apparent during low engine speed operation (ground/flight idle).

- Vibration transients can be considered normal during high thrust operations prior to thermal stabilization (4 minutes) and during power changes.

- Sudden shifts in vibration levels should be investigated carefully. Check vibration indication with other engine parameters. If vibration increase is accompanied by changing engine parameters, noise, and/or airframe vibration, consider engine shutdown, flight conditions permitting.

NOTES

Descent

- Smooth power reduction
- Idle most economical
- Hi-stage bleed, air provides manifold pressure for pressurization, anti-icing
- With anti-ice on, idle speed increases to approach idle
- No minimum N_1 prescribed for operation in icing conditions. Fuel control will maintain minimum N_2 of about 62% to insure accel from idle after ice build up

NOTES

Hot Rotor Reburst

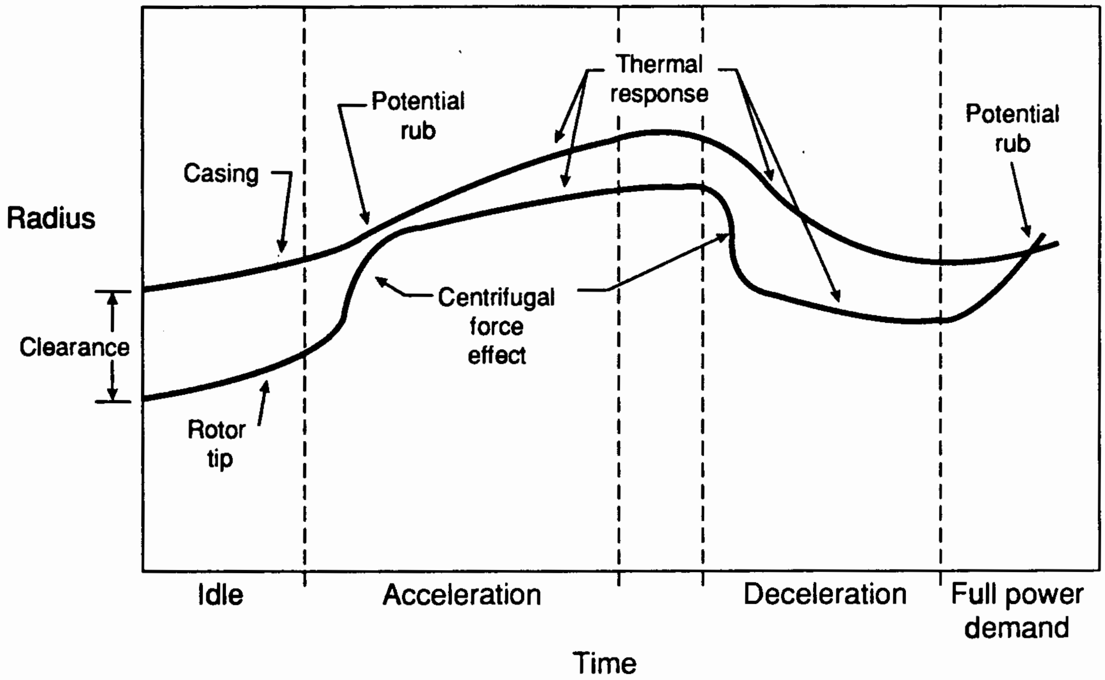
- Causes blade tip rubs
- Contributes significantly to turbine deterioration
- Hot rotor reburst scenario
  - Deceleration from high power to idle
  - Acceleration to high power before thermal stabilization
- If possible, avoid reburst acceleration one to eight minutes after deceleration to idle

MAC5-50062-010490

Tight clearance bewteen the blade tips and case is necessary to achieve high aerodynamic efficiency of the turbine. However, during engine transients the clearances vary because the thermal response of the casing and rotor are not the same because of differences in mass, cooling-air circulation, heat transfer, and material. The case tends to have a much faster thermal response to the gas stream temperature than the rotor. Also the rotor growth due to acceleration affects clearances. Under certain combinations of engine transients (deceleration and acceleration) the blade tips can rub the case causing turbine efficiency to deteriorate.

NOTES

Hot Rotor Reburst



MAC5-50063-010490

During an acceleration the rotor growth is initially due to the centrifugal force. If assembly clearances are small, a rub could occur. However, the most likely cause of rubs occurs from a deceleration followed by an acceleration (hot rotor reburst). On a deceleration from high power to idle, the case cools faster than the rotor structure thus reducing the clearance. If an acceleration to high power takes place before the temperatures are stabilized, the growth of the rotor due to centrifugal force will reduce the clearance more than if the acceleration was from a stabilized idle condition. To reduce the potential for rubs it is recommended that reburst accelerations be avoided one to eight minutes after a deceleration to idle from a high power. If this hold time cannot be achieved, it is recommended to advance the throttle slowly from idle to climb or takeoff power.

NOTES

Landing/Reversing

- Modulate reverse if full thrust not needed
- Reduce reverse thrust at 80 KIAS - idle by 60 KIAS
- Can go to stop (FADEC schedules)

T1671.36 - 880630

NOTES

Shutdown

- One minute cooldown (after coming out of reverse)
- Three minute cooldown if following was exceeded:
    - 650°C EGT on approach
    - 750°C EGT during reverse

NOTES

Trend Monitoring

T815.35 - 860506

NOTES

On condition maintenance

- Condition vs fixed-interval maintenance
  - Optimized shop visit intervals
  - Demonstrated quantum improvement in engine reliability
  - Significant reduction in cost of operation

Requires accurate engine performance monitoring

T815.36 - 880508

A big driver for engine condition monitoring is the concept of on condition maintenance. Today very few engine parts have hard time maintenance or replacement intervals. The rest of engine maintenance is on condition - only when it is evident that the engine has a mechanical problem or deterioration to the point where rated thrust cannot be achieved within normal operating limits or where the probability is high that continued operation will result in a major engine failure.

On condition maintenance optimizes shop visit intervals. Instead of a 4000 hour hard time shop visit, for example, we now may have a 2000 hour shop visit on a particularly "sick" engine but may go 8000 hours between shop visits on an engine that has for some reason not deteriorated as rapidly.

In addition to reducing the costs of operation, on condition maintenance has demonstrated a quantum improvement in reliability, which translates to safety. The reason for this is that to meet the requirements of on condition maintenance, the engines are watched more closely.

The key to a successful On Condition Maintenance is engine condition monitoring.

Objectives

- Monitor engine health
  - Minimize operational events
- Assist in line maintenance and troubleshooting
- Assist in workscope planning
- Manage total costs
  - Operating vs. maintenance
  - Monitor guarantees

T815.37 - 860506

Operational events are IFSD's, T/O Aborts, Air Returns and Unscheduled Engine Removals. These are minimized by Engine Condition Monitoring.

Maintenance can often correlate crew reported symptoms with condition monitoring data to effectively trouble shoot a reported problem.

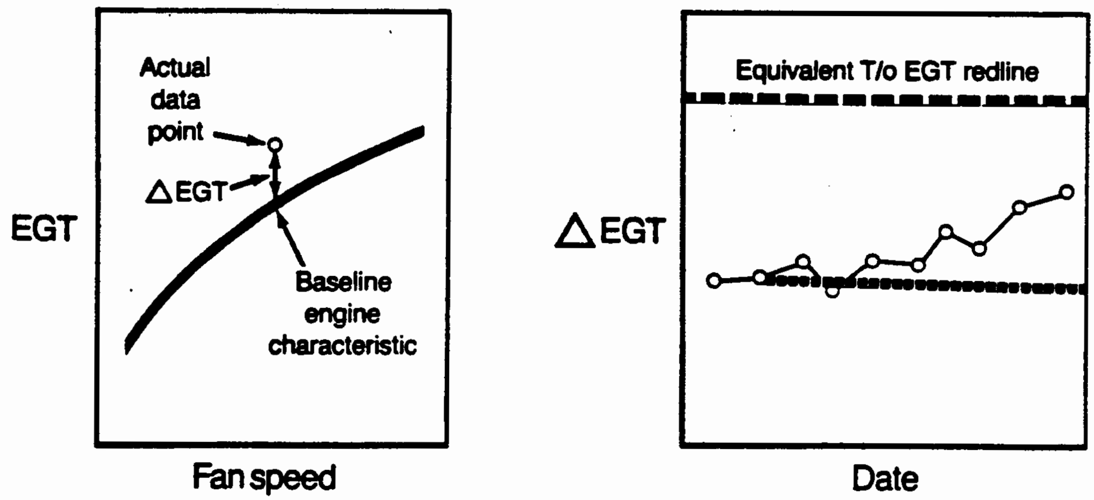
When an engine is scheduled into the shop, ECM data helps determine the nature and extent of work required.

Operators can make tradeoffs between the costs of operating an engine with a given degree of deterioration against the maintenance costs of pulling it and working on it.

Finally, it allows both the operators and the manufacturer to monitor guarantees.

NOTES

Basic Performance Trending Model



Similar models for fuel flow and core speed

28S-4878-020186

NOTES

Tools

- Recording
  - Manual
  - Automatic
- Trending
  - Airline unique programs
  - Aircraft Data Engine Performance Trending (ADEPT)
  - Divergence monitoring
  - Ground-based Engine Monitoring (GEM)

T815.38 - 880506

NOTES

Data Recording Conditions

- ATS off
- Autopilot altitude hold on - constant heading desirable
- Equal N_1's
- Minimum of five minutes stabilized cruise
  - Preferably more, particularly just after climb or descent thrust settings
  - Insures thermal stabilization of engine
  - Should also allow Mach stabilization period after ATS off
- Normal pneumatic bleed and power extraction
  - Note deviations

T1422.04 - 890214

NOTES

Data Recording

• TAT	Nearest 1°C
• IAS	Nearest knot
• Altitude	Nearest 20 ft.
• Mach	Nearest .001
• Gross weight	Nearest 100 lbs.
• N_1	Nearest 0.1%
• EGT	Nearest degree
• N_2	Nearest 0.1%
• Fuel flow	Nearest 10 lbs./hr.
• Vibration	Nearest .01 units
• Oil pressure	Nearest PSI

T1422.03 - 880202

NOTES

Data Recording (Continued)

- Stability criteria

- Altitude	±20 feet	- N1 (fan speed)	±0.2%
- Mach number	±.005	- EGT	±3.0°C
- TAT	±1.0°C	- N2 (core speed)	±0.1%
- Heading	±2.0 degrees	- Fuel flow	±50 pph

- High fidelity trend monitoring depends upon accurate data recording and flight stability

NOTES

Result of Recording Errors

Parameter	Recording error	EGT error	Fuel flow error	N_2 error
Altitude	+20 ft.	–	+.1%	–
Mach #	+0.01	–	-1.0	–
TAT	+1°C	-1.5°C	+0.4	-0.1%
N_1	+1%	-9.4°C	-3.1	-0.5%

NOTES

EGT
Divergence Monitoring

NOTES

EGT Divergence Monitoring

- Immediate indication of engine health

- Low impact on crew workload
  - No tools
  - One parameter

ST815.67 - 870603

NOTES

Monitoring Conditions

- N_1 aligned
- Symmetrical bleed load
- Auto throttle - off

T815.43 860506

NOTES

Example

- Aircraft: 99 GE
- Date: March 17
- Flight no.: 235

EGT #1	EGT #2
649°C	635°C

ST815.66 -870604

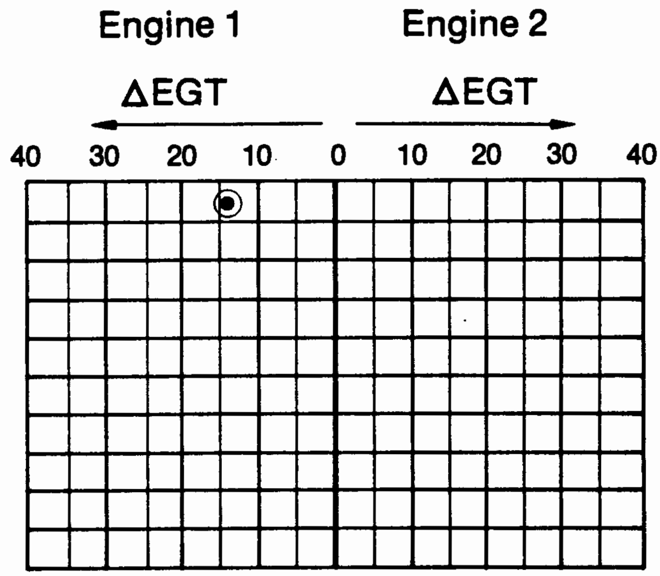
NOTES

EGT #1 649 — EGT #2 635

ACFT N99CFM

Day		Mo.	
1	7	0	3

Flt. No.			
0	2	3	5



(649-635 = 14°)
Engine #1 is High

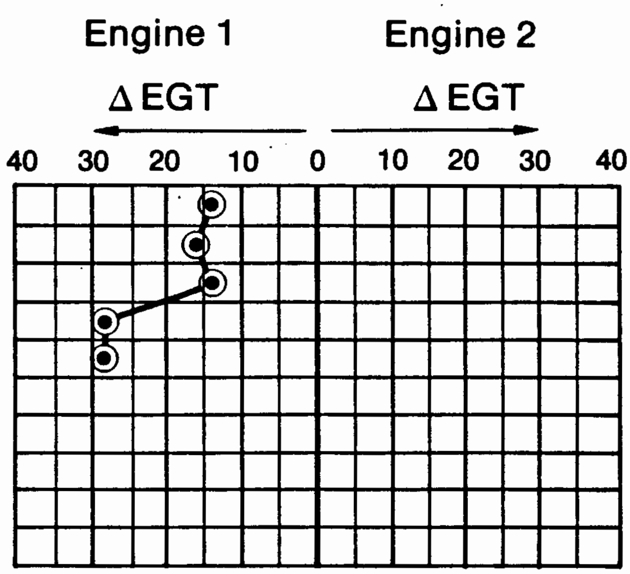
28S-4884-013186

NOTES

Example: Step Increase Engine #1

ACFT N99GE

Day	Mo.	Flt. No.
17	03	0235
18	03	0876
18	03	0543
19	03	0211
19	03	0423



28S-4885-013186

EGT usually shifts up, although instrumentation and CIT sensor malfunctions, or changes in exit nozzle areas can cause EGT to shift.

NOTES

Alert Levels

Determined by Local Operations/Maintenance Procedures

Example:

- 11°-25° ΔShift
  - Log Book Entry
  - Continue Operations
- >25° ΔShift
  - Maintenance Action

28S-4886-013186

NOTES

Erosive
FOD Prevention

T815.44 - 880506

NOTES

Erosive FOD

- What is it?
  - Dust, sand, volcanic ash

- Effect on engines:
  - Erodes airfoils resulting in:
    - Reduced parts life
    - Reduced EGT margin
    - Increased fuel consumption
  - May be incurred in single occurrence or cumulatively from frequent exposures to harsh environment

MAC9-567-021489

NOTES

Erosive FOD

- Sources:
  - — Contaminated runways, taxiways, ramp surfaces
  - — Airborne particles (dust, sand, volcanic ash) Due to:
    - - Wind
    - - Reverse thrust
    - - Jet wake
    - - Inlet vortex
- High FOD potential areas include:
  - — Desert and coastal airports
  - — Airports with construction activity
  - — Ramps/taxiways sanded for winter operations

88-568-071185

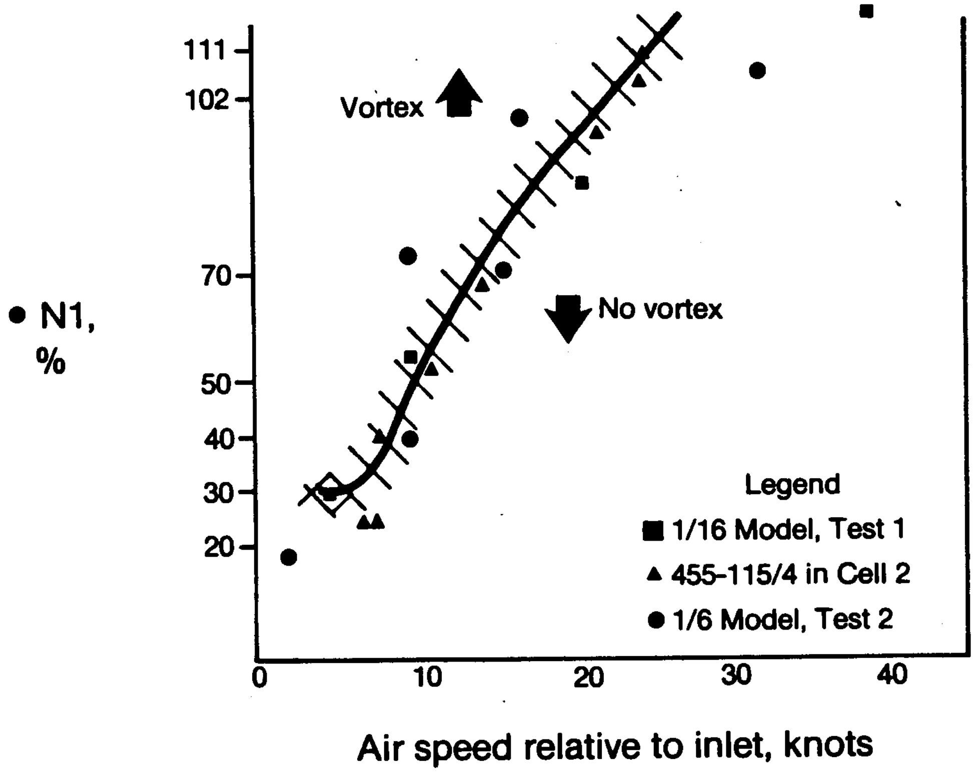
NOTES

Erosive FOD

- Engine vortices
  - Common cause of ingestion on ground
  - Related to high power, low IAS
  - Somewhat destroyed by:
    - Headwind
    - Airspeed
    - General rule: 10 knots wind/IAS will destroy vortices up to 40% N_1

NOTES

Airspeed Effect on Vortex Formation



58-571-071295

NOTES

Erosive FOD

- High exposure operations
  - Power advance for breakaway from stop
  - Power advance for crossbleed start
  - Power advance for takeoff
  - Power assurance runs
  - Reverse thrust at low speed

NOTES

Erosive FOD

Recommendations/Considerations

- Campaign for good airport housekeeping
- Start engines on clean surfaces
- Avoid engine overhang of unprepared surface
- Use minimum breakaway thrust
- Minimize taxi thrust

23S-572-112585

NOTES

Erosive FOD

Recommendations/Considerations

(Continued)

- Minimize power for crossbleed starts
  - Just high enough for adequate manifold pressure
  - Power up while rolling if possible
- Rolling takeoffs if possible
  - Airspeed destroys vortices

5S-573-071285

NOTES

Erosive FOD

Recommendations/Considerations

(Continued)

- Reverse thrust
  - More effective at high speed
  - Idle reverse by 60 KIAS
  - Forward thrust before clearing the runway
  - Minimize taxi reverse — none, if possible
  - On contaminated runways use minimum reverse

Note: In emergencies, use reverse as required

23S-574-112585

NOTES

Volcanic Ash

- Problem
  - Ash builds up on HPT nozzles and blades
  - Nozzle area reduced, cooling holes blocked
  - Engine surges/stalls, high EGT
  - Severe engine damage, power loss
  - Encounter at all altitudes
- Recognition
  - Ash difficult to detect at night
  - Weather radar ineffective
  - Smoke/dust in cockpit
  - Odor similar to electrical smoke
  - Multiple engine malfunctions/flame outs
  - St. Elmo's fire/static discharges
  - Orange glow in engine inlets

T2233.12 - 900104

In 1982, two 747 aircraft experienced multiple engine flameouts/shutdowns as a result of flying through volcanic dust at 37,000 ft and 30,000 ft. In one of these incidents, all four engines lost thrust within 50 seconds. In 1989, a 747/400 entered a cloud of volcanic ash at 25,000 ft resulting in immediate flameout of all four engines. In all cases, serious engine damage occurred, aircraft surfaces were eroded, windshield visibility was restricted and airspeed readings were unreliable due to blocked pilot systems. Successful airstarts were accomplished by 12,500 ft.

The volcanic dust affected the engine by causing rapid erosion of the compressor and build up of fused volcanic ash on the HPT nozzles and blades. The result is increased EGT, engines surges/stalls, torching from the tailpipe, power loss and flameout. It has been shown that the weather radar cannot be relied on to detect volcanic ash. Also, the ash is difficult to detect at night or in clouds but other indications may be present such as St Elmo's fire and an orange glow in the engine inlet.

NOTES

Volcanic Ash

- Procedures
  - AVOID FLIGHT NEAR VOLCANIC ACTIVITY
  - Fly on upwind side of dust
  - If in dust, exit immediately
  - Turn on continuous ignition
  - Turn off auto-throttle
  - Reduce thrust to idle or low as practical
  - Turn on all available airbleed systems
    - Wing and nacelle anti-ice
    - A/C packs on high
  - If engine is shutdown/flame out, restart using published procedures
  - Resume normal operations upon exiting dust

T2233.13 - 900108

Since severe consequences can result by flying through volcanic ash, the best policy is to avoid ash clouds. However, if volcanic ash is encountered, immediate action should be taken to leave the cloud by the shortest distance/time. Other procedures can be accomplished to reduce engine damage and possible loss of power. Turning off the auto-throttle prevents the EGT from automatically increasing as the HPT loses efficiency. By reducing power to idle when encountering ash, the lower EGT will reduce the debris build up in the HPT. Turning on all bleed systems increases the stall margin. If the engine is shutdown due to overtemperature/stalls or flames out, attempt restart(s) using flight manual procedures. Successful starts may not be possible until clear of the ash cloud and within the airstart envelope. At high altitude engines are slow to accelerate to idle which may be interpreted as a failure to start.

NOTES