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Transport Airplane Turbofan Engine Controls & Displays

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Airbus A330s Fully/Half Covered Engines

A330 & GE
(mixed exhaust)

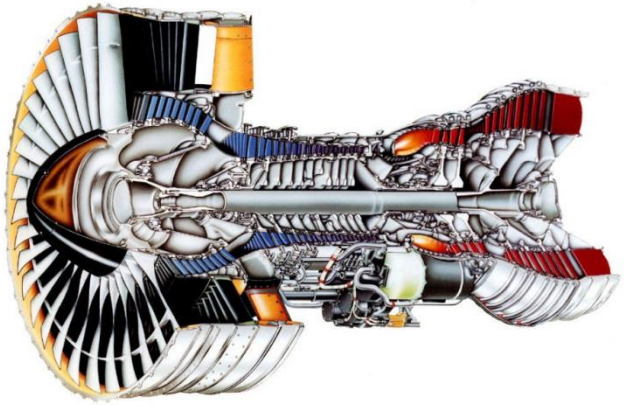
A330 & RR
(fully covered)

A330 & P&W
(unmixed exhaust)

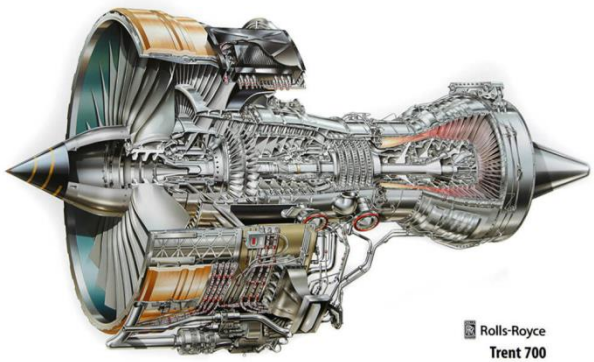
A330 Turbofan Engine Choices

Engine	Manufacture	Thrust lb (kN)	Sfc lb/h/lb	Dimensions length/fan dia (m)	Configuration fan, comp/turb
CF6-80E1A1-A3	General Electric	64,500-69,500 (287-309)	0.562	4.34/2.36	1, 4, 14/2, 5 **Twin-Spool**
PW4168	Pratt & Whitney	68,000 (302)	0.563	3.37/2.46	1, 5, 11/2, 4 **Twin-Spool**
Trent 772/775	Rolls-Royce	71,100/75,000 (316.4/333.7)	0.565	3.91/2.47	1, 8, 6/1, 1, 4 **Triple-Spool**

GE CF6-80E1



PW4000



RR Trent 700

Which is best at making aircraft engines (1/3)

- The twin-engine **A330** was **Airbus's** first airliner that offered a choice of **three engine** types: General Electric CF6, Pratt & Whitney PW4000, and Rolls-Royce Trent 700.
- The market share for all three engine manufacturers differ for each type of aircraft and its developed versions.
- In the A380 market Rolls-Royce's share is 40%, with Trent 900 engine. P&W and GE joint venture GP7000 engine has the remaining market.
- In the B777 market, GE holds about 65% share with GE 90 engine, Rolls-Royce 20% with Trent 800 engine, and P&W 15% with PW4000 engine.

Which is best at making aircraft engines (2/3)

- In the B787 market, Rolls-Royce has 40% share with Trent 1000 engine, GE has the remaining 60% with GEnx series engines. P&W is out of competition.
- There is also a phenomenon of exclusivity in the market. Rolls-Royce is the exclusive supplier of Trent 500 series engines for A340-500/600, Trent XWB series engines for A350XWB, and Trent 7000 series engines for A330 NEO.
- GE90-115B and GE90-110B are the exclusive engine series for the currently manufactured 777 variants - the 777-300ER, 777-200LR, and the 777F freighter. GE is also expected to remain the sole source supplier with a new upgraded engine GE9X on new 777X versions.

Which is best at making aircraft engines (3/3)

- The technologically off all three suppliers for large commercial engines are equally competent to meet the specific requirements of the airframe manufacturers.
- For an aircraft OEM, the engine controls and displays would have a different interface for each engine. However, the safety of flight would need to be the same for all engine options. Crew workload would be about the same, although the checklists would differ for each engine.

Architectural Differences (1/2)

- Compressors are basically split into two or three spools to prevent compressor stall or surge during acceleration from idle to 100% power. Without compressor anti-stall architecture; it may surge or stall when the throttle is suddenly moved forward to come out of a difficult situation in the air.
- Rolls-Royce differs from its American counterparts GE and P&W in engine compressor architecture. Rolls-Royce design consists of **triple-spool** compressor - HP (High Pressure), IP (Intermediate Pressure) and LP (Low Pressure) compressor - whereas American engines have **twin-spool** compressors - HP & LP.

Architectural Differences (2/2)

- Both concepts - European and American - have merits of their own. Rolls-Royce claims that its three-spool compressor design makes the engine shorter in length and a relatively cooler engine, requiring less maintenance. The design also eliminates or reduces the need for variable stator vanes as an anti-stall device used in two-spool compressor engines. It also enables the fan to spin at a relatively slow speed - increasing its efficiency.
- P&W geared turbofan (GTF) engines have the same purpose of achieving fan efficiency.

Engine Pressure Ratio (EPR)

- Older “pure” single spool jet engines, and low bypass jet engines describe **engine pressure ratio (EPR)**, as the total pressure ratio across a jet engine, measured as the ratio of the total **pressure** at the exit of the propelling nozzle divided by the total **pressure** at the entry to the compressor. Jet **engines** use either EPR or compressor/fan RPM as an indicator of thrust.
- The same definition holds good even today. On the Airbus A330 displays in the cockpit, the EPR display goes until a numbered 1.8.
- The maximum go-around EPR on the thrust ratings charts is 1.660, with the PW4168.

Cockpit Controls & Displays (1/3)

A330 Engine Display (Upper ECAM)

- The thrust that the engine of a jetliner is delivering is expressed to the flight crew either as N1, or Engine Pressure Ratio (EPR).
- Crews use these figures every day, however, confusion exists in the minds of most of them to what these parameters really refer to.
- Not helping is that the flight crews operating manuals do not describe these parameters in sufficient detail.
- **The A330 display the engine EPR, EGT, N1 and N2 on the PW4000, or EPR, EGT, N1 and N3 on the RR Trent 700. Those fitted with the GE engines display only the N1, EGT and N2**.

Cockpit Controls & Displays (2/3)

A330 Engine Display (Upper ECAM*)

GE CF6-80E1

PW4000

RR Trent 700

*ECAM - Electronic Centralized Aircraft Monitor

Cockpit Controls & Displays (3/3)

A330 Engine Display (Upper ECAM)

- Below the EPR is the Exhaust Gas Temperature (EGT), which is the temperature of the air that is exiting the LP turbine.
- Below the EGT, is displayed the N1, or the fan speed, or the speed of the inner coaxial shaft. As per the manufacturer (P&W), the previously mentioned fan speed of 3,600 rpm is treated as 101% N1.
- On the sides of the semicircular N1 gauges are the N2 readings of the corresponding engine. The N2 is the speed of the outer coaxial shaft, or the shaft that drives the high pressure compressor. As per the manufacturer, the previously mentioned 10,450 rpm is treated as 103% N2.

EPR vs N1 indication (1/8)

- Rolls Royce and Pratt & Whitney engines use EPR as the thrust reference parameter. GE uses the N1 as the thrust reference parameter.
- With the chosen thrust reference parameter, thrust is controlled to target the thrust at takeoff, and climbs. Cruise is a speed based reference, while descent is usually at idle thrust.
- The advantage with EPR is that it is a pressure ratio, and is indicative of engine thrust: Force (Thrust) = Pressure multiplied by the Area of application. According to Boeing, EPR is more directly related to, and a much better indicator of thrust than the compressor speeds (N1 and N2), and therefore it is more advantageous in terms of accuracy to utilize EPR to control engine operation.

EPR vs N1 indication (2/8)

- The disadvantage of EPR is that in multi-spool engines, there is the issue of stability in control of thrust.
- Because changes in thrust setting take time to respond, and the filtering of noise from sensors delays response time, there is a negative impact on stability. EPR is dependent on the prevailing local atmospheric conditions, as pressure is affected by temperature and aircraft altitude.
- With a parameter such as fan speed, or N1, the response is much better and the measurement of speed is a lot more accurate than the measurement of pressure difference, which allows for excellent stability in control. N1 is simply the fan rotational speed, which is independent of the prevailing local atmospheric conditions.

EPR vs N1 indication (3/8)

- EPR is the measure of a quantity that relates to the performance of the engine. N1 relates to a parameter which is responsible for the performance of the engine.
- However, N1 does not take into account the other variables which may affect thrust such as engine performance degradation after several years.
- For example, 50,000 lbs of thrust demanded an hypothetical EPR of 1.27, no matter what the status of the engine, an EPR of 1.27 in the same atmospheric conditions is guaranteed to deliver the same amount of thrust.

EPR vs N1 indication (4/8)

- If this thrust required around 90% N1, and the engine gradually degraded over time, the N1 required to deliver the same thrust in the same environmental conditions will now be higher. In this way, N1 is not a reliable parameter for thrust setting over very long periods of time, while it is the presence of an N1 indication that enables crew to recognize performance degradation.
- Consider an engine suffering a bird strike. Blades will get damaged and the pressures developed across the engine will suffer. If at that point, the N1 and N2 are held constant, the EPR may fall below the expected EPR.
- This way, the crew can ascertain that the engine has been damaged. By the extent of deviation of EPR from the expected EPR at the given speeds of N1 and N2, the extent of damage can be gauged.

EPR vs N1 indication (5/8)

- Under such a condition, advancing the thrust/throttle levers till the EPR value is close to the desired values will ensure almost the same engine thrust, albeit at higher engine rotational speeds. Therefore, a display with N values only, will not be able to convey as much information to the pilot.
- But EPR relies on two pitot probes: one that is ahead of the fan, and the other that is aft of the fan. The pressure sensed by these two pitot probes results in the indicated EPR.
- However, they are faced with the same operational issues as other pitot probes: they are susceptible to foreign objects, such as insects and ice, clogging the opening.
- This can lead to faulty EPR readings, which are not indicative of the actual thrust generated by the engine.

EPR vs N1 indication (6/8)

- The N1, N2 or N3 (RR engine) sensors are not susceptible to failures like the EPR probes.
- This makes the N readings very reliable. The N readings do not fluctuate as a result of atmospheric variations, unlike the EPR.
- For this reason, when penetrating a turbulent region in flight, N1 values are used as reference, even if EPR readings are available.

EPR vs N1 indication (7/8)

- The A330 with P&W or RR has two modes of power setting, EPR mode and N1 mode. In normal mode, the engine thrust setting is made through control of the EPR. The required EPR is set by controlling the fuel flow to the engines.
- The command EPR is computed by processing the pilot's input (thrust lever angle), altitude, Mach number, ambient temperature, and the status of the engine bleeds.
- In case the pressure sensors used to compute EPR fail, the engine control reverts to **"rated N1 mode"**. In this mode, the N1 power setting is determined as a function of the thrust lever angle, altitude, and engine inlet total temperature.

EPR vs N1 indication (8/8)

- In the event that the engine inlet total air temperature probe fails, or the ambient pressure sensors fail, the engine reverts to the **“unrated N1 mode”**, where the power setting is determined solely as a function of the thrust lever angle, limited to the maximum N1, or the N1 that results in an engine overheat, if the engine inlet total air temperature probe is available.

Case Study #1: Air Florida 90, 1982

- The crash of Air Florida Flight 90 (1982) into the Potomac river was a result of the EPR probes having been clogged due to improper de-icing practices. The Boeing 737-200 took off with thrust lesser (EPR ~1.7 instead of 2.04) than what was required in the icing conditions, despite the faulty EPR readings showing the desired value of 2.04 EPR.
- When the crew realized that they were low on thrust, the throttle levers were advanced to full thrust position, too late to salvage the situation, taking away the lives of 70 persons.

Case Study #2: Fokker 70/RR Tay 620 at Munich, 2003

- After a prolonged time under moderate icing conditions and low engine thrust, ice developed on the rotors of the low pressure compressors of both engines.
- The crew noticed that by pushing the thrust levers forward, the EPR on both engines did not increase to the required value. The speeds N1 and N2 and the exhaust gas temperatures (EGT) of both engines increased, the EPRs, however, remained at values of around 1.0.
- No noticeable thrust was produced any longer, although the engines were still running.
- N1 only indicates how fast the shaft is spinning, not how much thrust is actually resulting.

Summary (1/4)

- There are different engine temp/press limits, different ratings per flight phases but all applicable to the cross-crew qualification and enabling mixed fleet flying on the various models.
- While N readings are not true indicators of thrust, an undamaged engine over a substantially long period of time will hold a good correlation between generated thrust and N readings in known atmospheric conditions.
- EPR may provide the crew with better awareness about the engine performance, but the EPR itself is nowhere as reliable as the robust, independent and highly reliable N readings.
- Solely relying on EPR without the crosscheck of N1 can be a fatal trap.

Summary (2/4)

- In modern engines with Full Authority Digital Engine Control (FADEC), which essentially sets engine thrust using EPR or N1 based of physical thrust lever position, EPR gives the pilot a more linear response. This is because N1 is not linearly correlated with thrust. Thrust exponentially increases with increasing N1.
- Effectively, while a thrust lever at the halfway position in an EPR engine gives 50% of maximum thrust, an N1 engine may only give 30% of the total thrust, despite that the engine N1 being halfway to maximum.
- However, the EPR control depends upon two probes providing a minimum of four data variables, in contrast to the N sensor which needs only rotational speed data from a single sensor.

Summary (3/4)

- In case of an inability to control thrust using EPR, the thrust control system always falls back upon a more reliable N1. In fact, when setting thrust, crews always cross check the developed EPR with the engine N1**. <u>This increases crew workload</u>.**
- An analyses performed on crew workload at Airbus they did not go into these differentiations rather concentrating on differences between models of different engine OEM in basic type certification FAA 14 CFR 25.1523 and its Appendix D [*Criteria for determining minimum flight crew*].
- Airbus instructors suggested that P&W might maintain this ratio **<u>traditionally</u>**. However, they do not look at their EPR ratings as this number is small and hardly varies.

Summary (4/4)

N1 is preferred for several reasons:

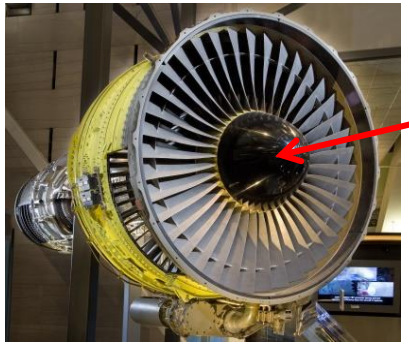
- There is no easy estimation of what EPR should be for a given phase of flight, as it changes markedly with temperature & altitude.
- 2-spool EPR-controlled engines 1.0 means no net thrust (idle descent), RR Trent uses integrated EPR and reads less then 1.0.
- Engines that synchronize on N1 are much quieter that those that use EPR and provide reduction of phasing vibration in cruise and longer service life for other component in the aircraft.
- N1 is directly coupled to something physical whereas EPR is derived and therefore more liable to error/miscalculation.
- One less gauge required.

New Design Approach…

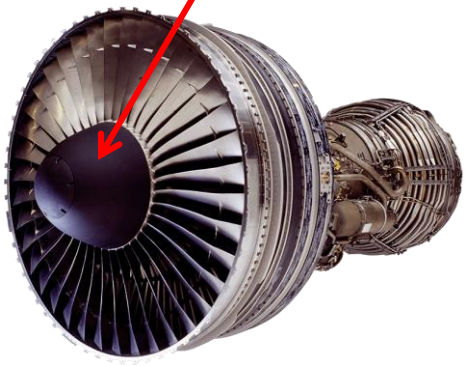
Airbus A380 (Trent 900 or GP7000)/A350(Trent XWB) uses % THRUST as thrust parameter. 0% THRUST equals wind milling thrust. 100% THRUST equals Takeoff/Go-around (TOGA) bleed off. % THRUST is based upon N1. N1 is the parameter for the thrust setting in degraded mode.

When flex (FLX) thrust is selected during take off, the engine controller produces maximum thrust for the assumed (flex) temperature. If necessary, the crew can push the throttles into the Takeoff/Go-around (TOGA) detent and request full power.

Why Turbofan Engine Nose Cone/Spinner are Different ?



GE CF6



PW4000

Tapering portion
(polyurethane)

RR Trent 700