Civil vs Military aircraft engines

- What do these engines look like?
- Do same engines go to civil and military aircraft? - Yes and No!...
- Advancements in Civil aircraft engines
- Advancements in Military aircraft engines
- Military aircraft development at GTRE
- Summary

UPES, Dehradun, 04 Nov 2019

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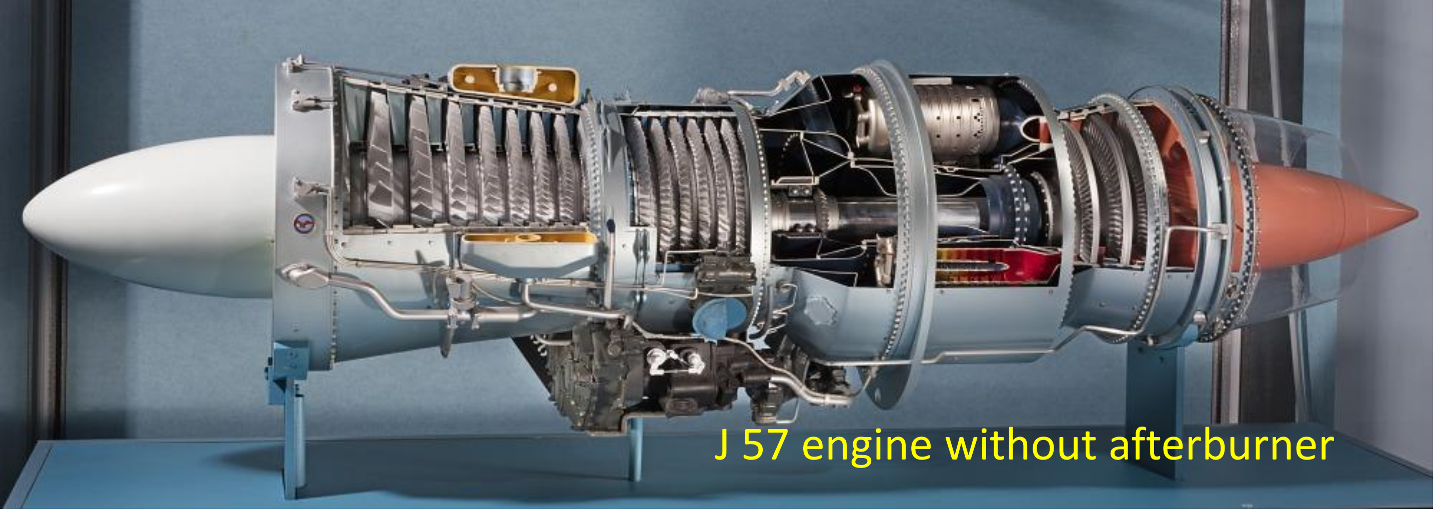

J 57 engine without afterburner

It is a twin spool axial flow turbojet engine.
0.78 kg/kgf h at take off and
0.9 kg/kgf h at cruise
Both dry and afterburner versions

J57 is military version – used on B52 bomber
It is also called JT 3C for civil version
used on Boeing 707

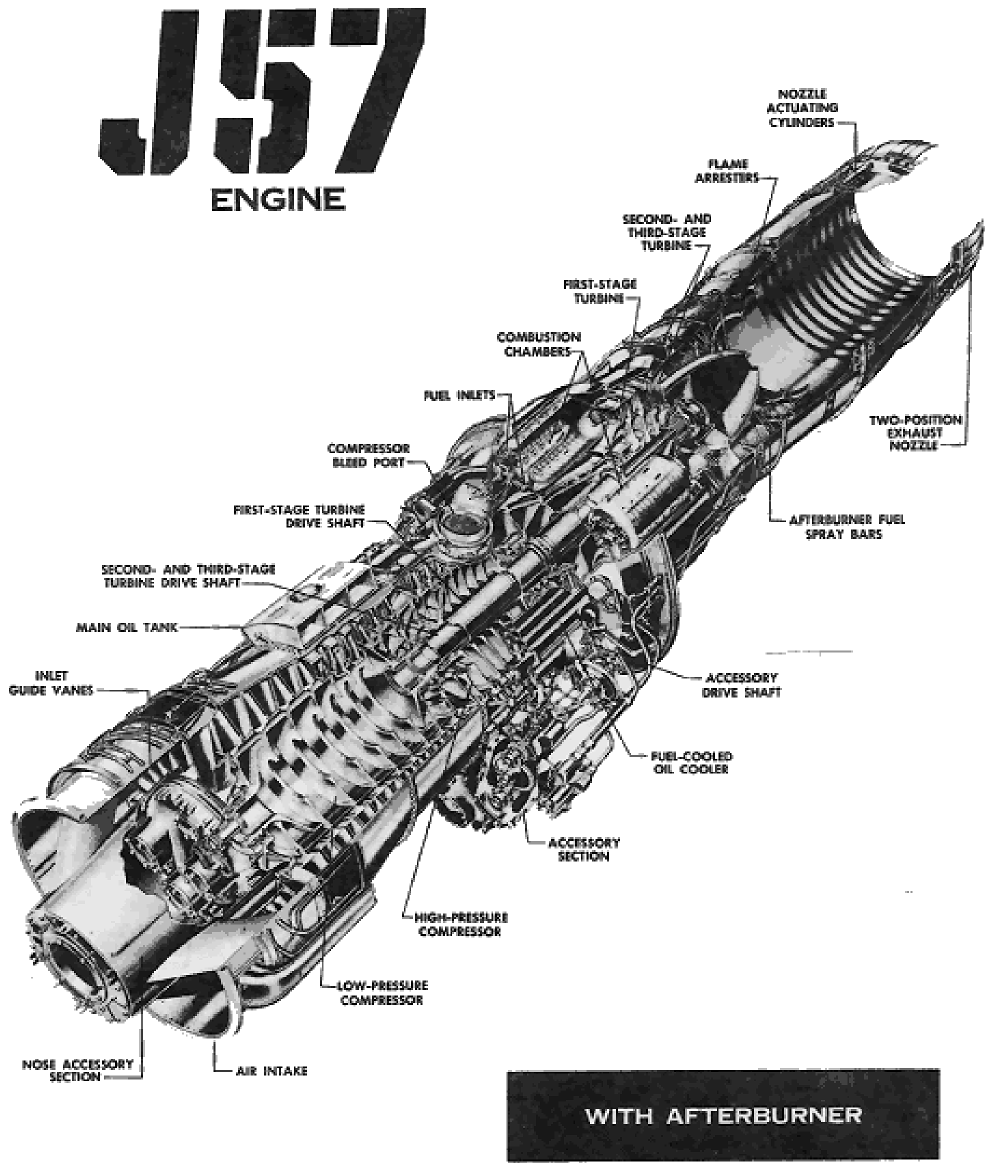
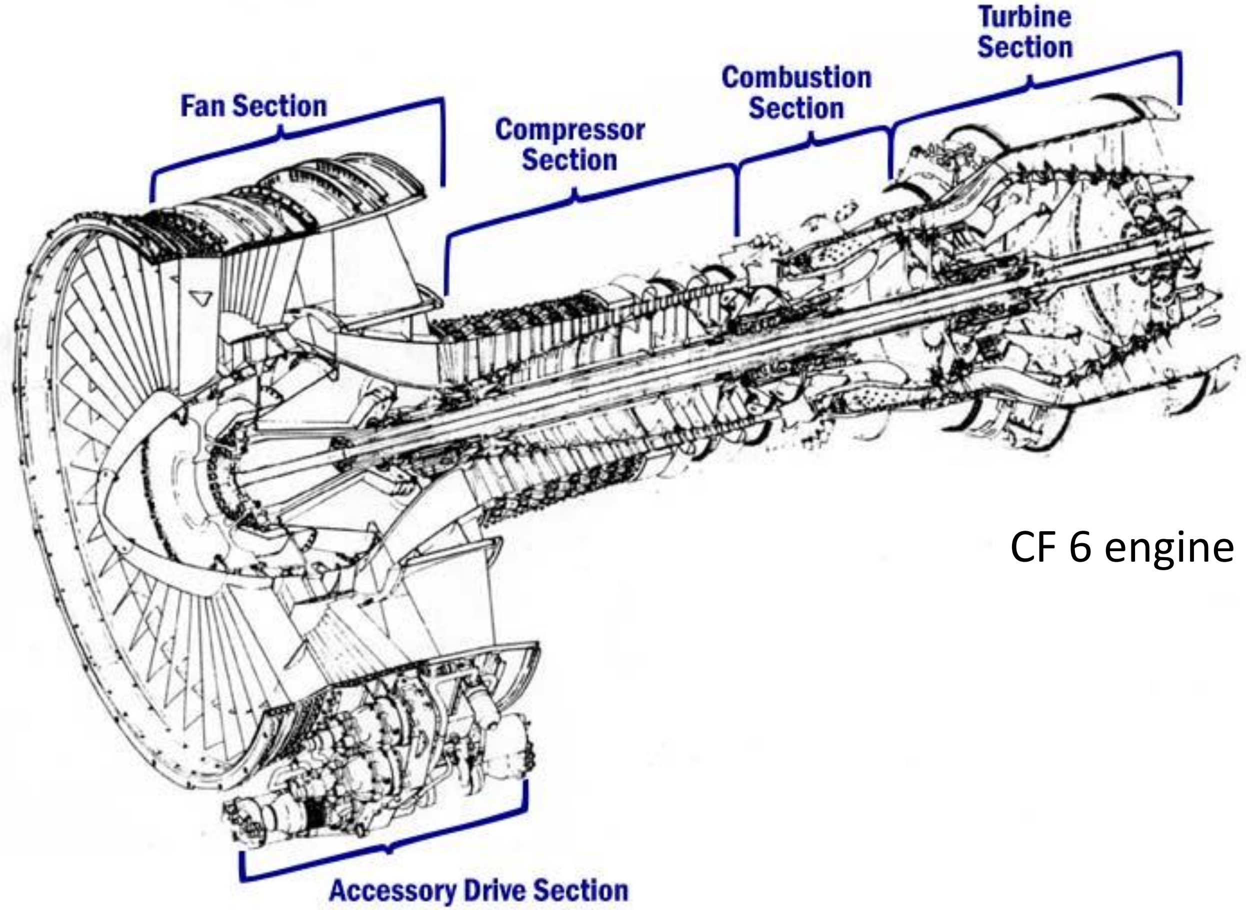
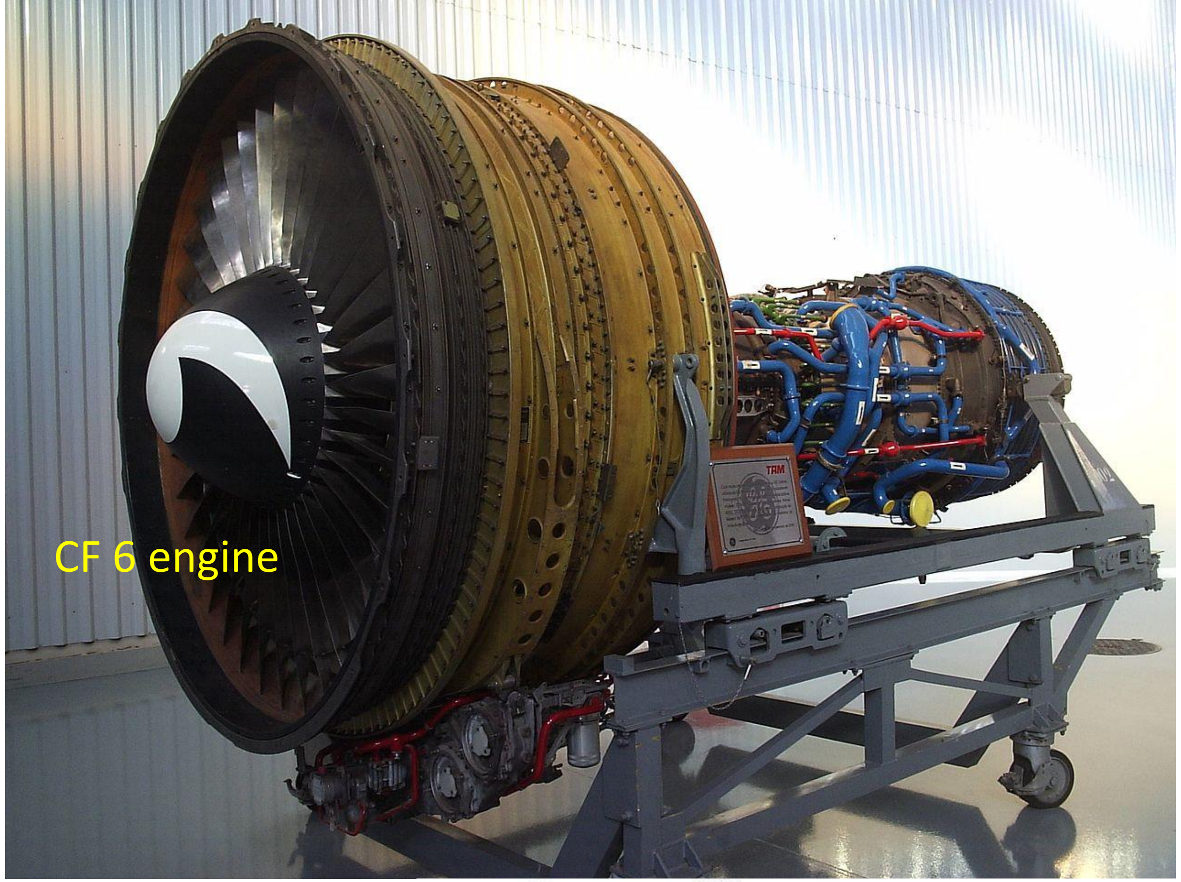
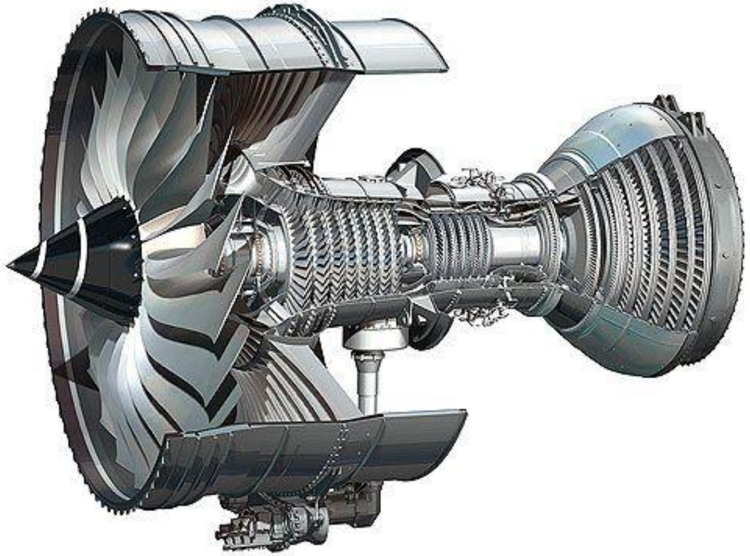


Figure 1-5



CF 6 engine

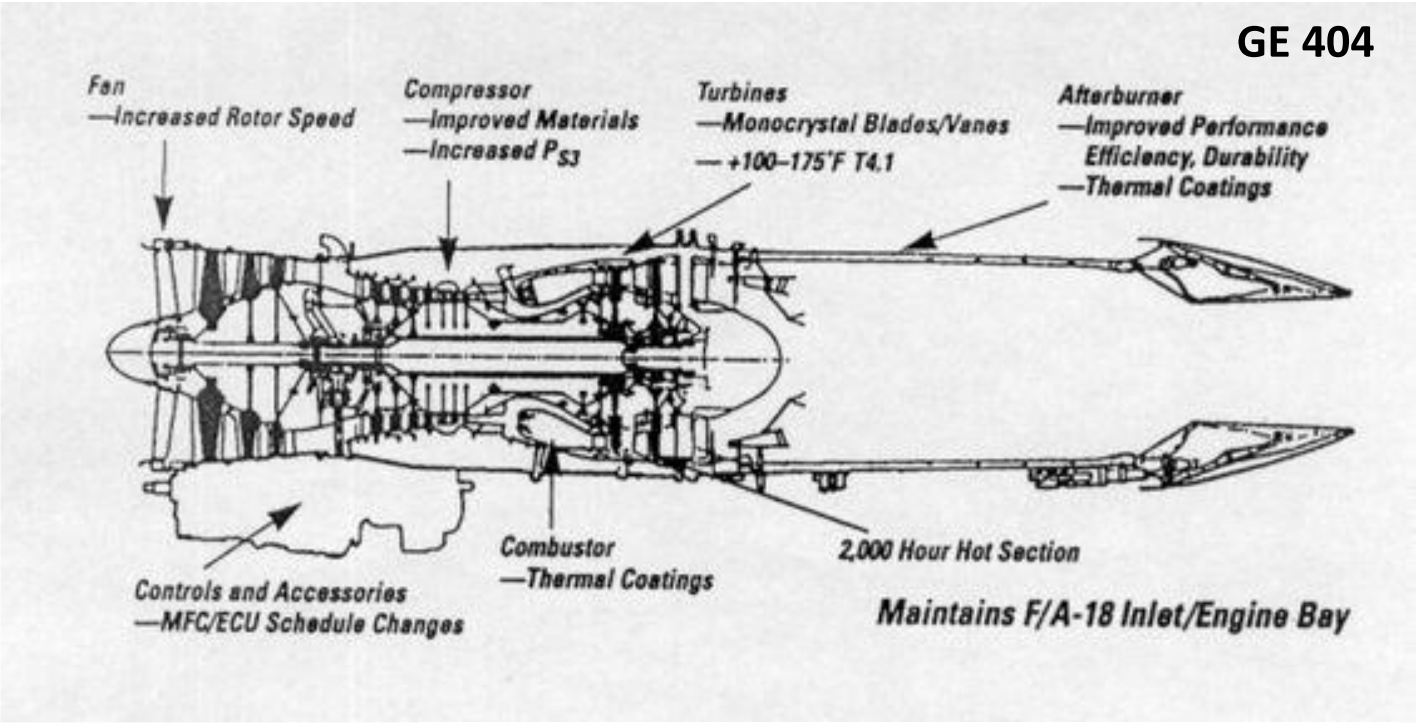


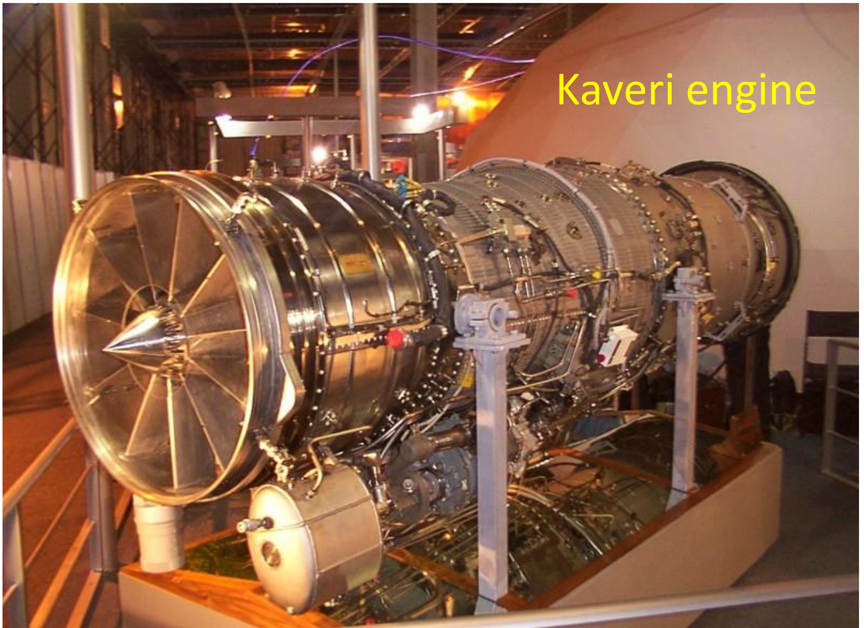


TF39 is what evolved into CF6

Bypass ratio ~ 8
CPR = 25

GE 404 – powers LCA aircraft





Military engines

Bypass ratio of original and variants ~ 0.2 to 0.3

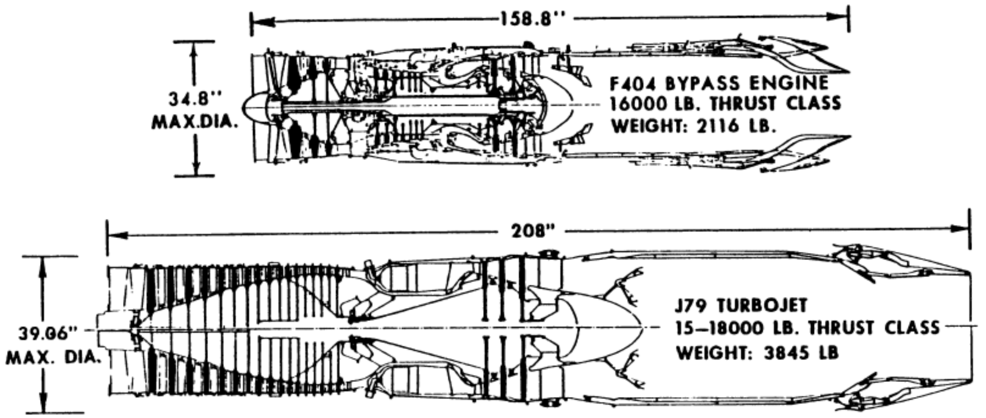


FIGURE 4-1. F404/J79 scaled cross-section comparisons.

Do same engines go to civil and military aircraft? - Yes and No!...

Yes

- B52 Bomber has J57 engine; Boeing 707 and DC 8 aircraft have JT – 3C engine
- Both J57 and JT- 3C engines are the same. Differences, if any are considered minor.

- C-5A Galaxy military transport has TF39 engine; Boeing 737 and Airbus 320 have CF6 engine
- Both TF39 and CF6 engines are essentially the same frame. Beginning as TF39, the engine benefited directly from new technology inputs in the form of components, materials, processes, manufacture, and repair processes that went into CF6 and also went into concurrent delivery of TF39 engines. Subsequently, TF39 was replaced by CF6.

Reason

The flight regimes are subsonic (M~0.8). Applications do not require maneuverability

While civil applications demand lower sfc that high bypass ratio engines promise, the military applications derive the same benefit – and why not?

Do same engines go to civil and military aircraft? - Yes and No!...

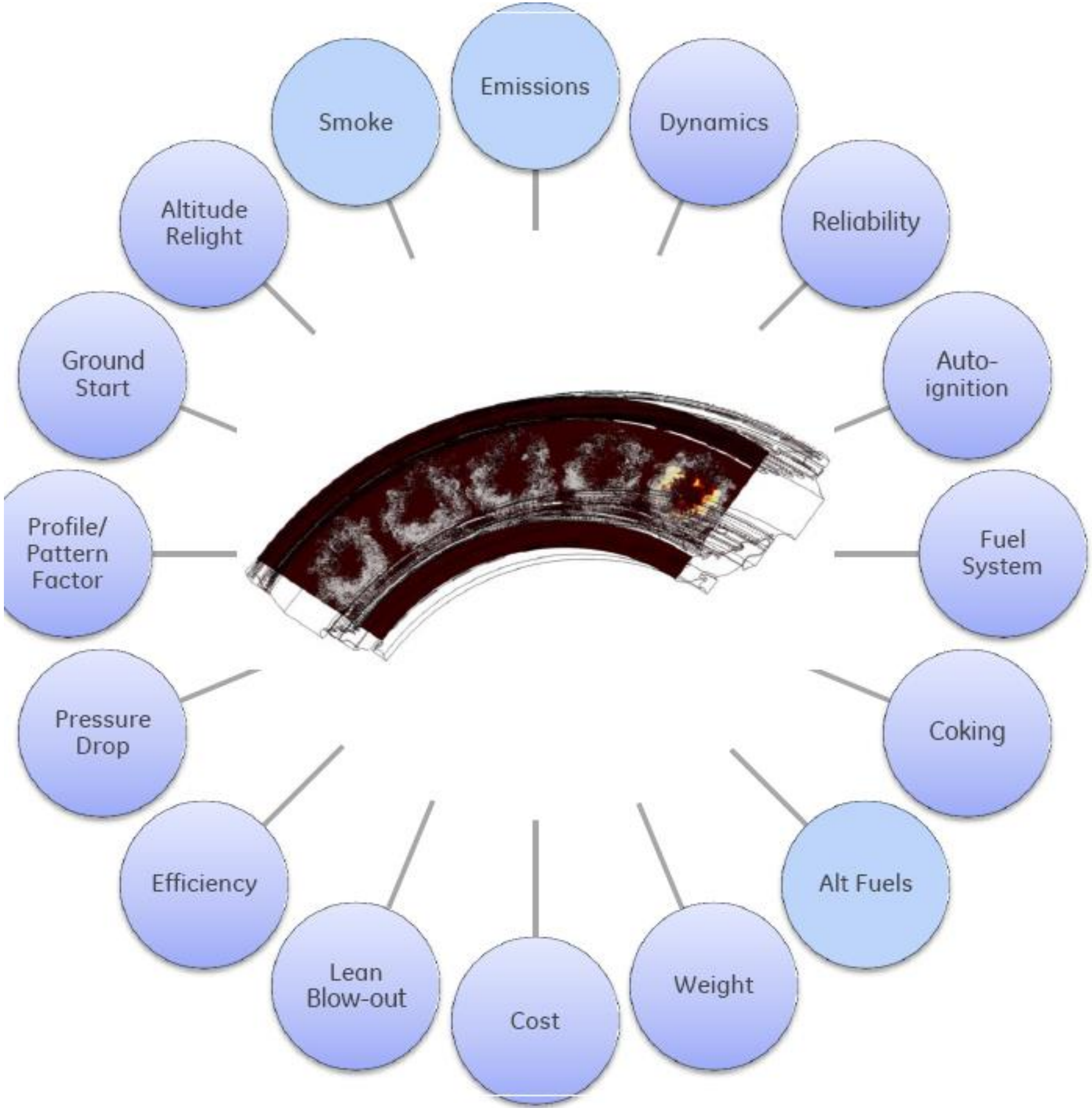
- The answer is NO for supersonic military aircraft – why?
- Supersonic military aircraft need high maneuverability. This requires substantial Thrust/(drag at cruise speed) to enable sharp acceleration, deep turn and fast climb, stealth and thrust-vector control
- Such engines should be carried in the belly to ensure reduced radar exposure (stealth need)
- Reduction of aircraft drag is promoted by reducing the engine cross-sectional profile. This means that Thrust/air mass flow rate must be large.
- This feature can only be met with by turbojets or low bypass ratio turbofan.
- Most military engines have a bypass ratio of 0.2 to 0.3.

Advancements in Civil aircraft engines

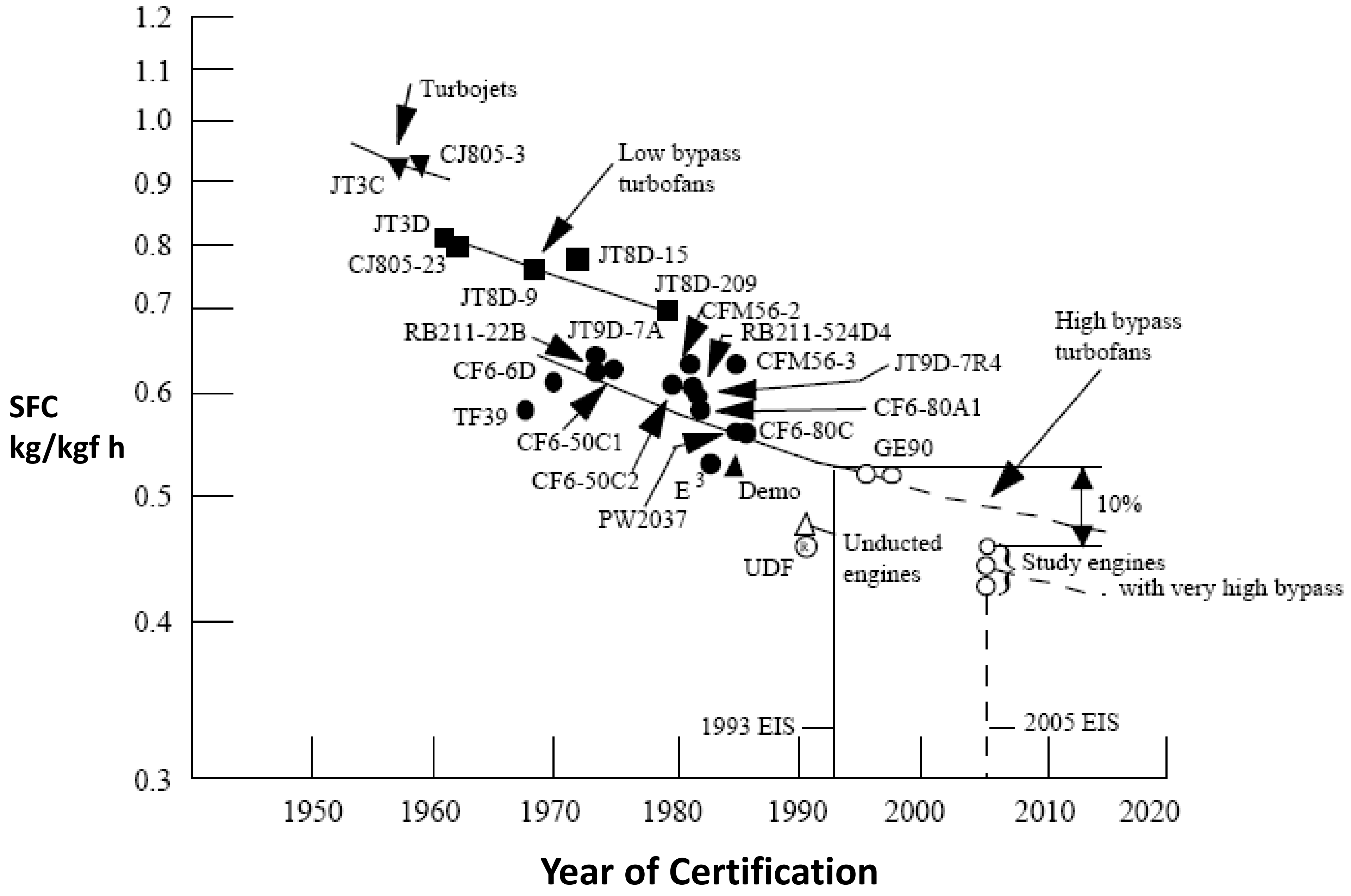
Specific fuel consumption

Emissions – NO_x, CO, UHC

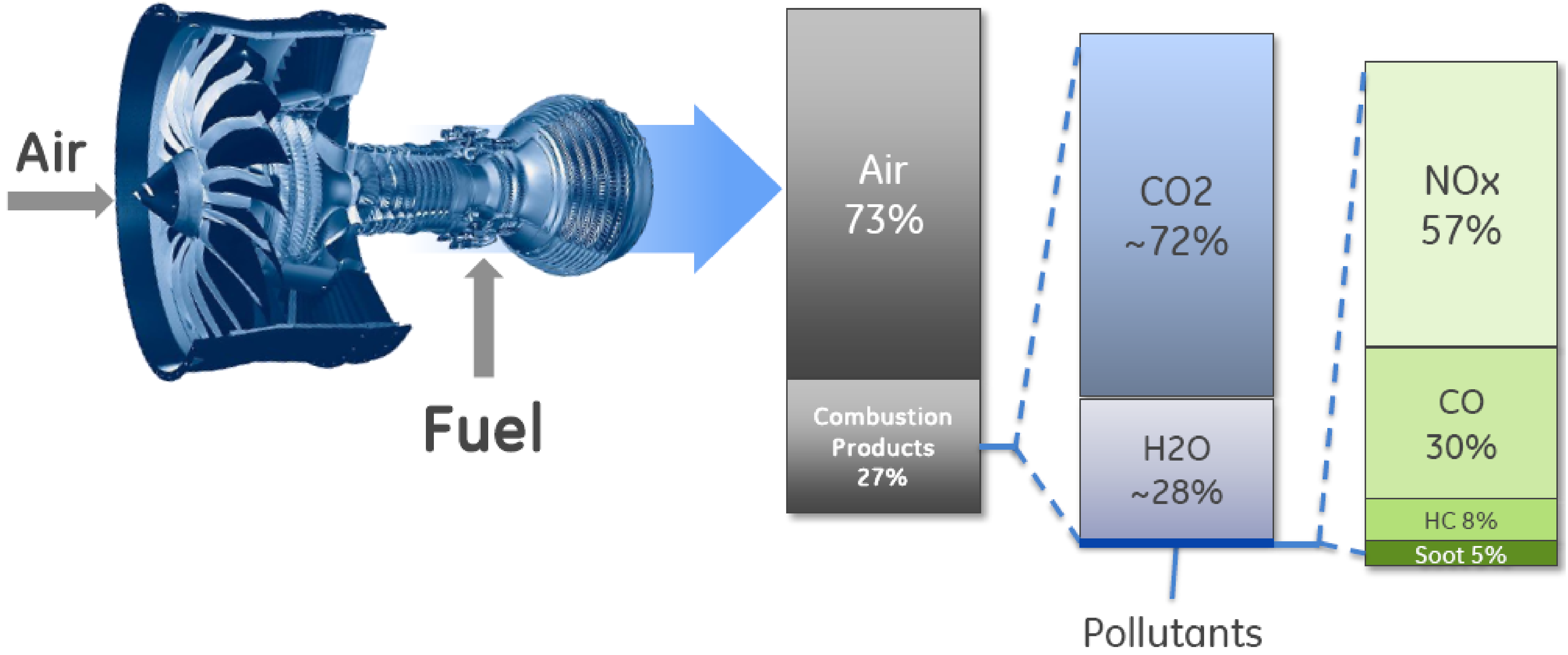
Demands on the realization of a Gas turbine engine for civil aircraft



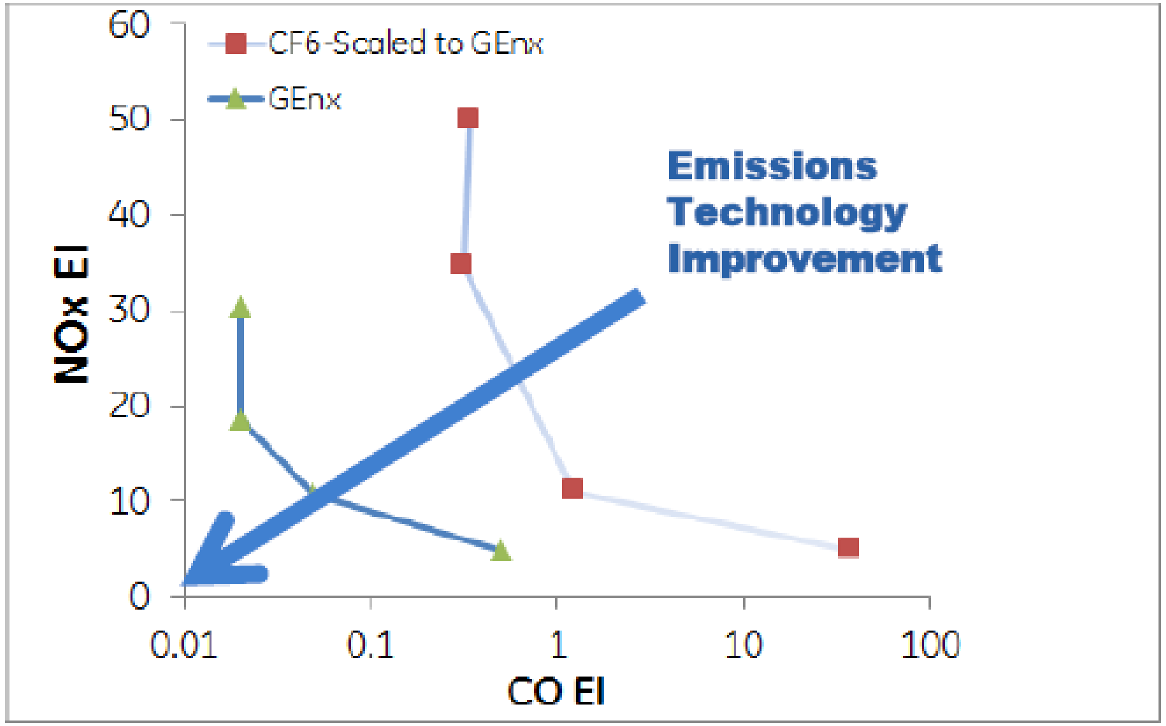
35,000 ft., 0.8M, Standard Day

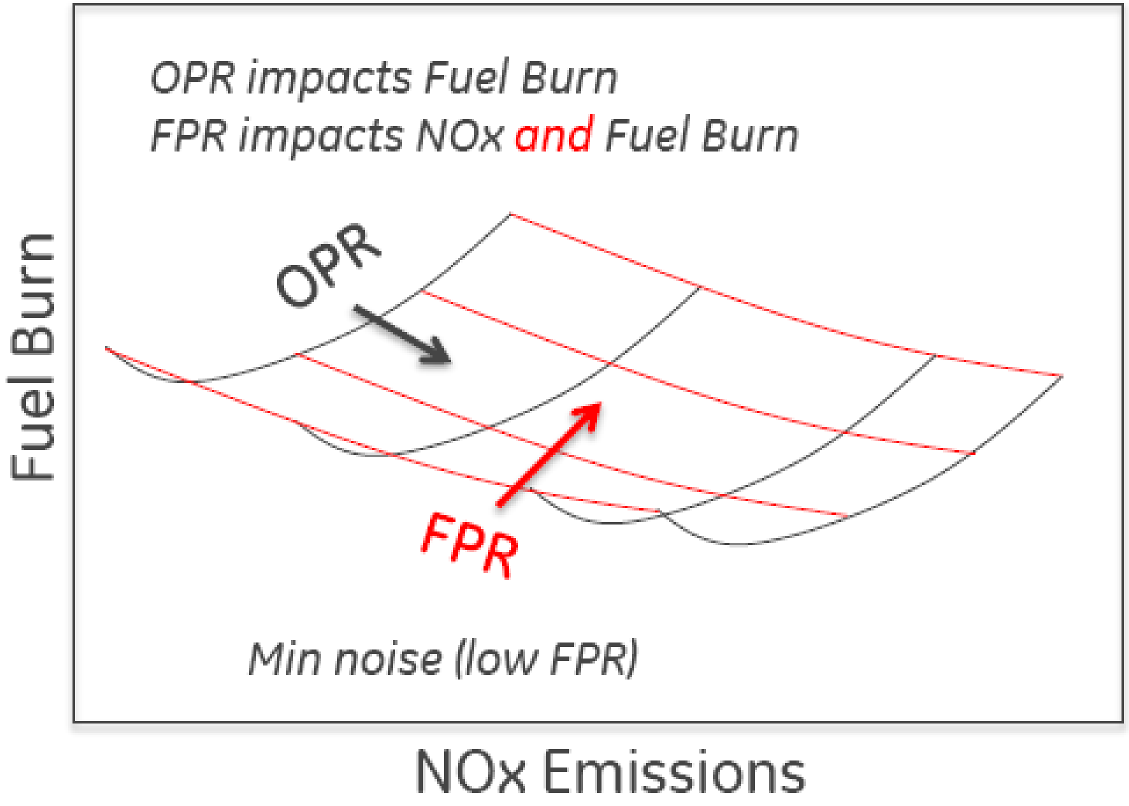


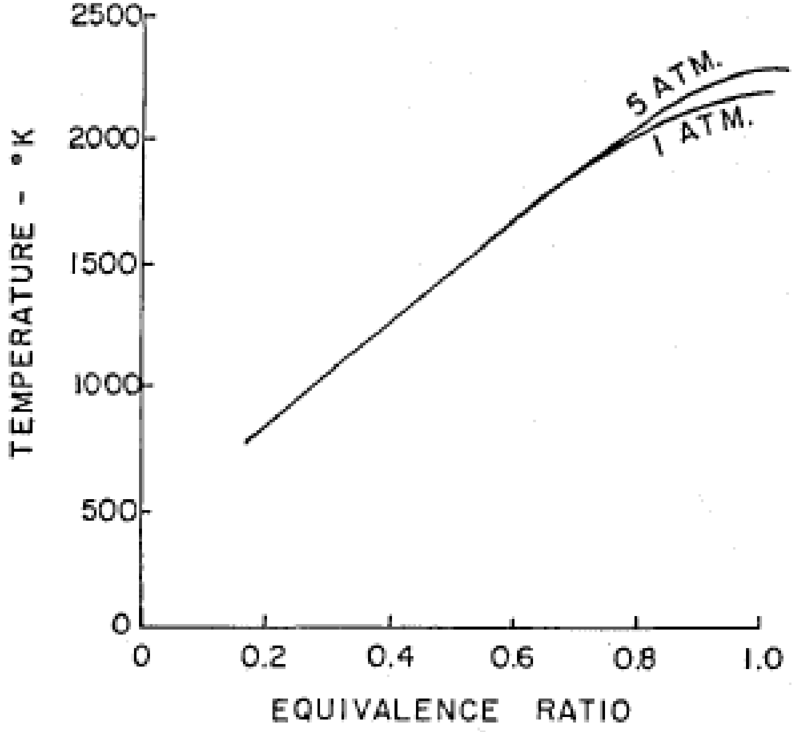
Pollutant emissions from engines

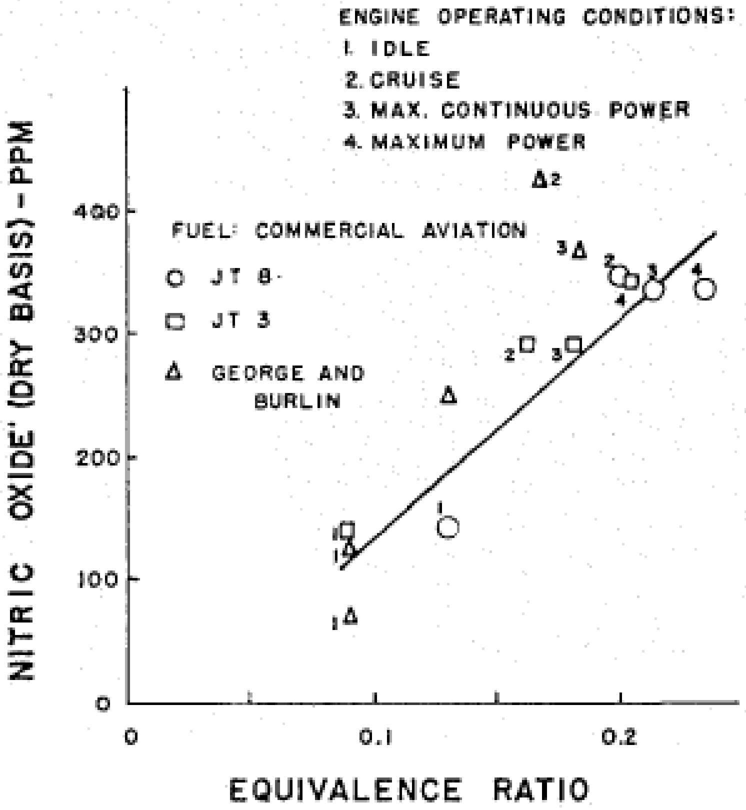


Low NOx a function of ***combustion technology*** and ***engine cycle***

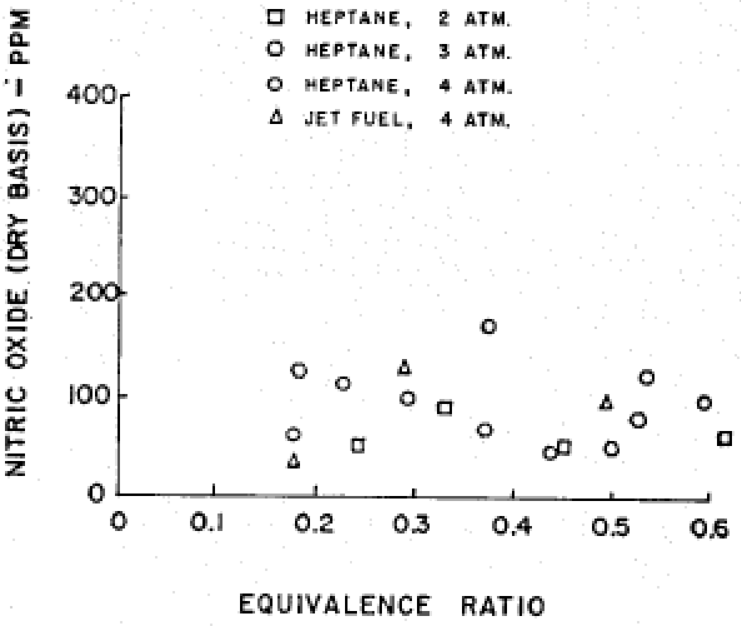








◀ **Fig. 7.** Nitric oxide in exhaust of aircraft turbine engines (adjusted to $\phi = 1$ basis).



Techniques to reduce NO_x:

NO_x production increases with temperature, But not that much under fuel rich conditions. This is because its generation is controlled by Zeldovich mechanism:

$$O + N_2 = NO + N,$$

$$N + O_2 = NO + H,$$

$$N + OH = NO + H,$$

$$d(NO)/dt = 2k_1 K_{c,f,o,Teq} (O_2)_{eq}^{1/2} (N_2)_{eq}$$

$$k_f = 2 \times 10^{14} \exp(-315/RT)$$

Smaller residence time = smaller NO_x production

Typical residence time ~ 3 to 5 ms

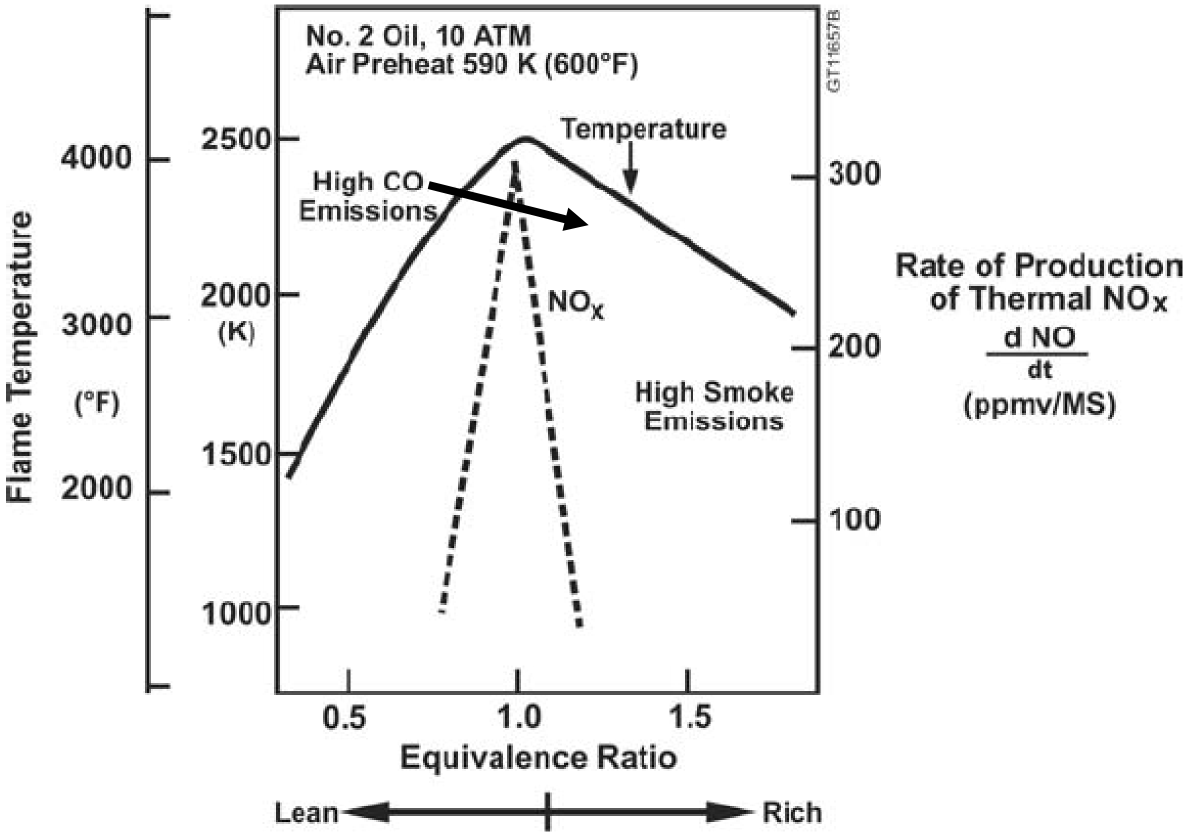
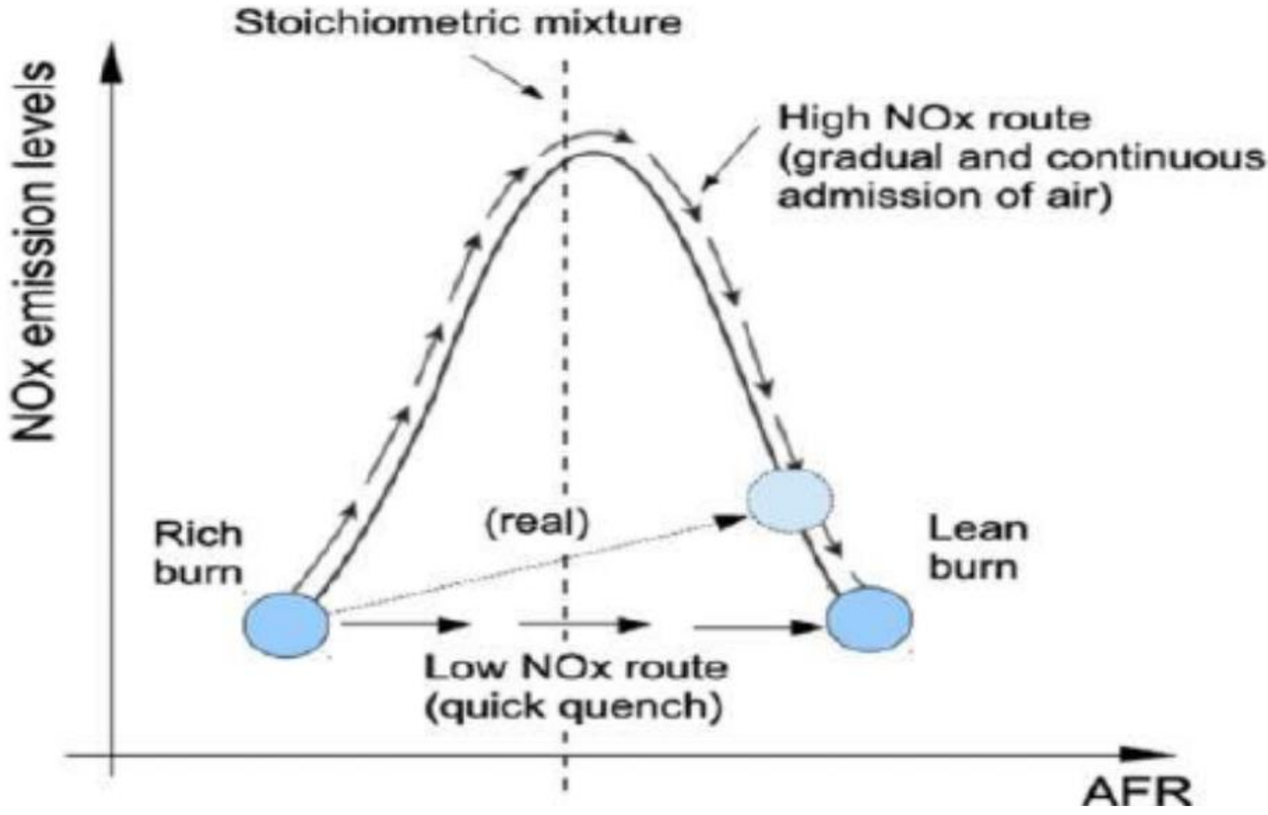
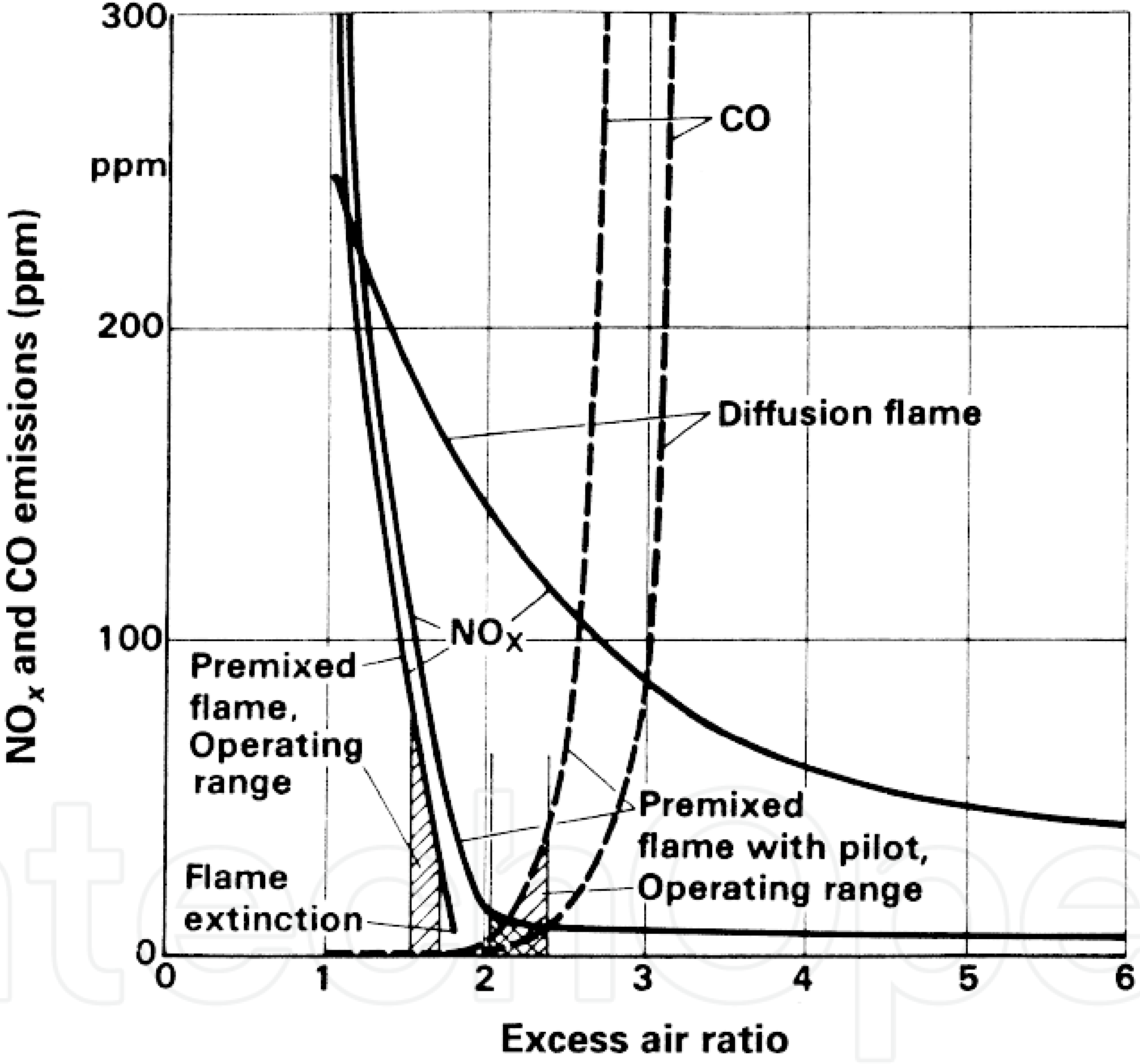


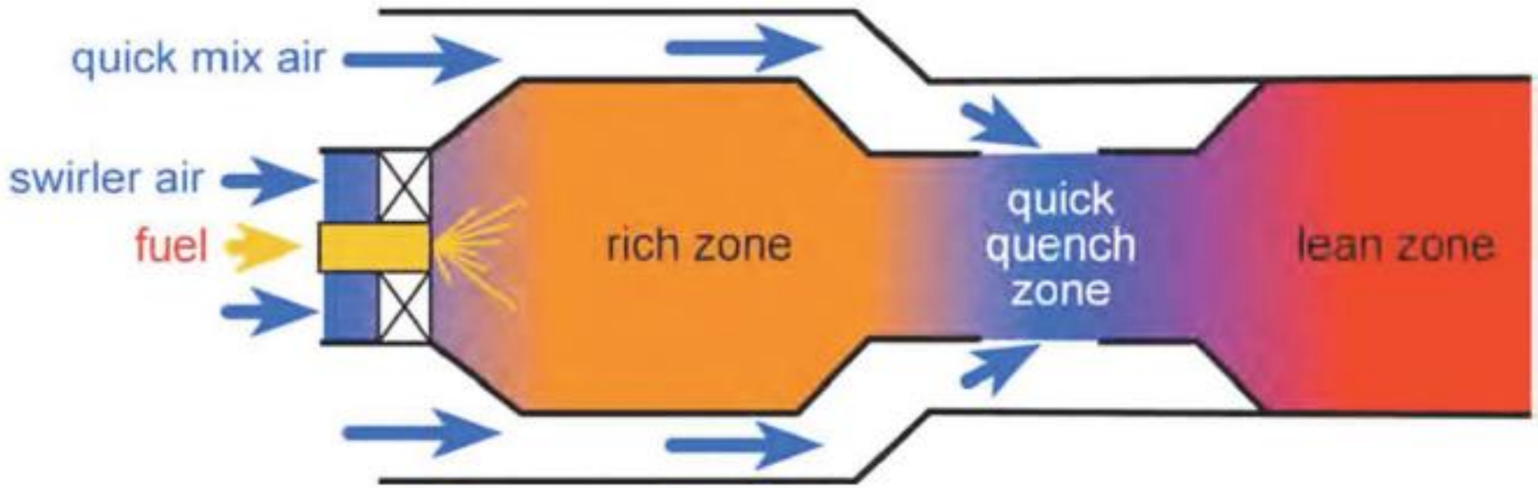
Fig. 3. NO_x Production Rate

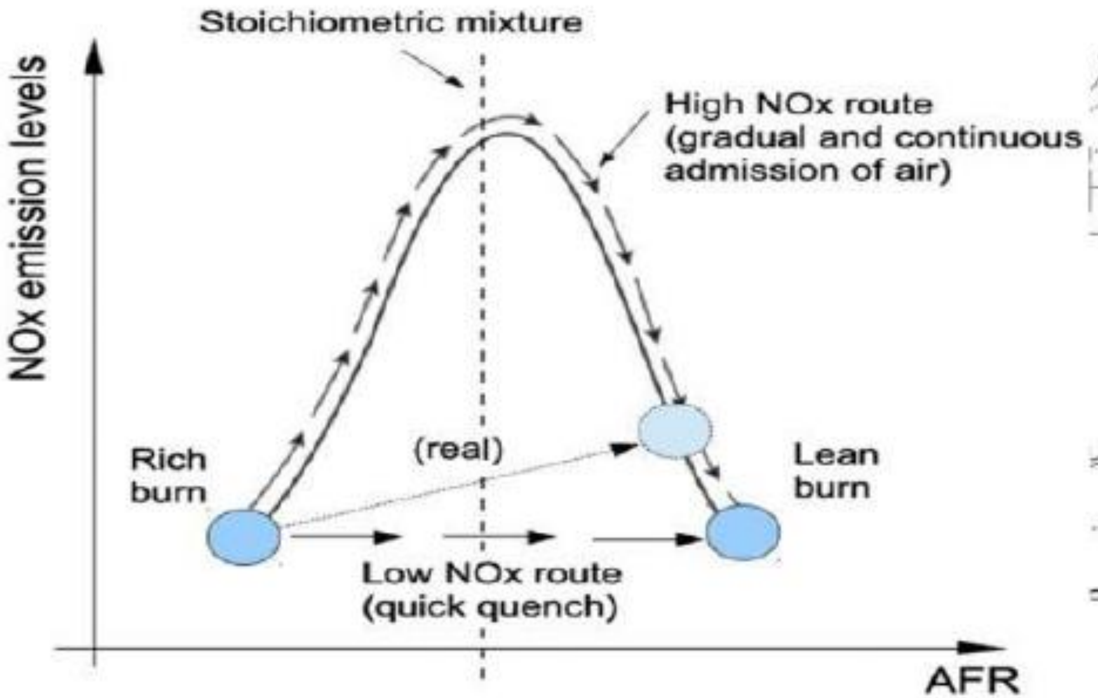


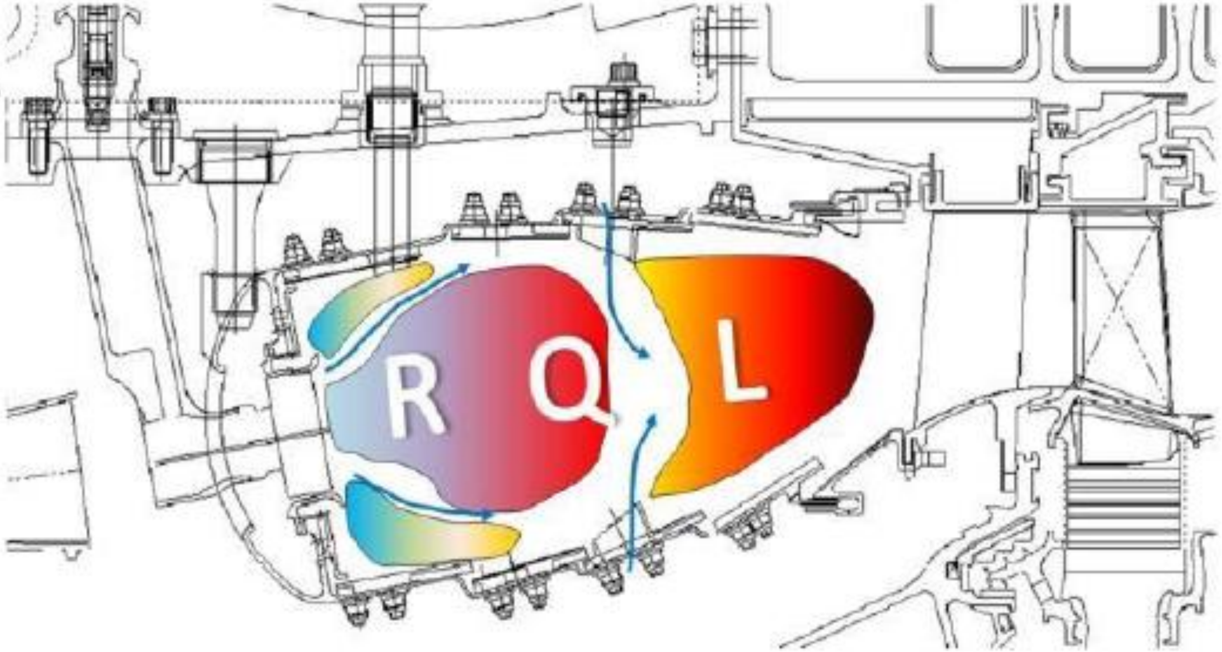


300
ppm
200
100
0
NOx and CO emissions (ppm)
0
1
2
3
4
5
6
Excess air ratio
CO
Diffusion flame
NOX
Premixed flame, Operating range
Flame extinction
Premixed flame with pilot, Operating range

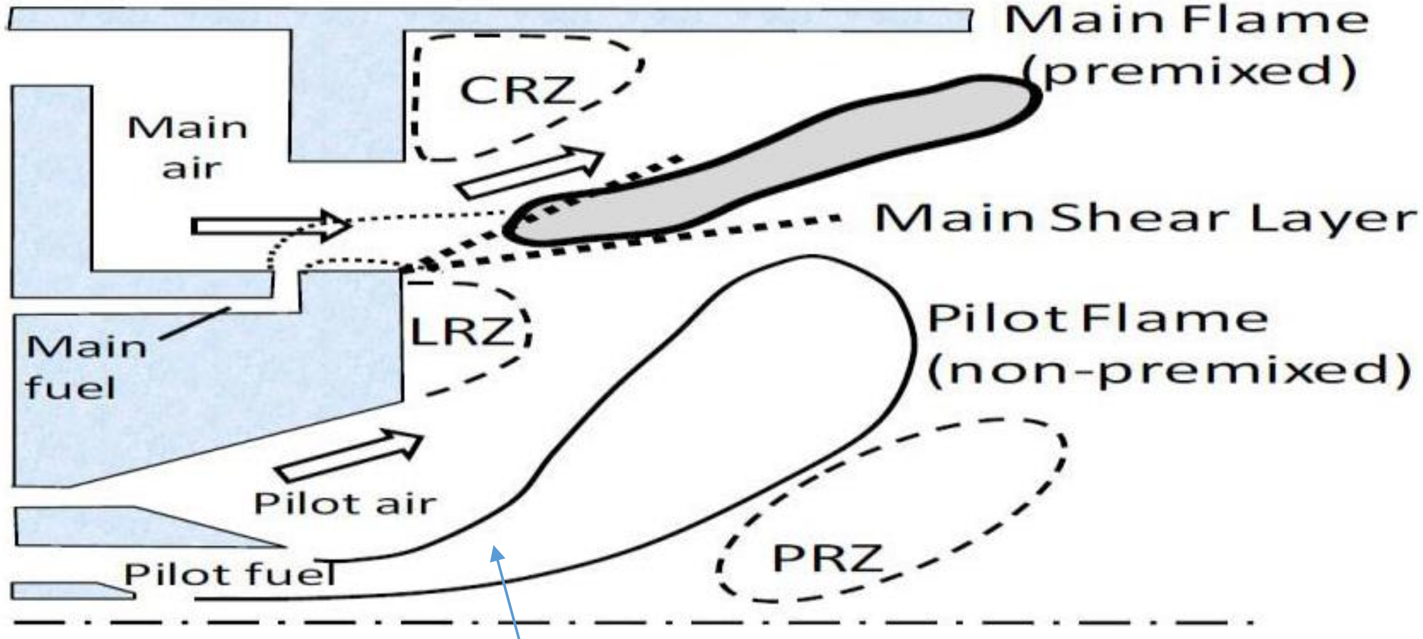

Heat Release Rate


quick mix air
swirler air
fuel
rich zone
quick
quench
zone
lean zone

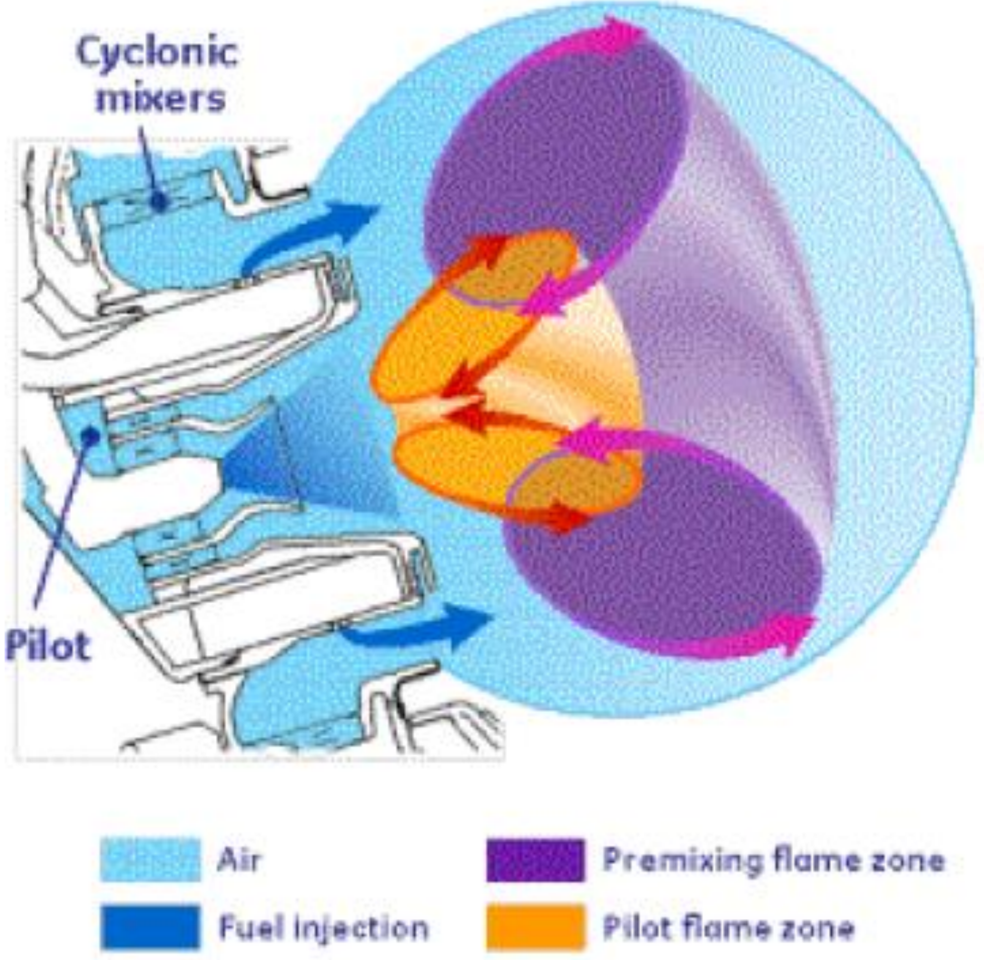

Stoichiometric mixture
NOx emission levels
High NOx route
(gradual and continuous
admission of air)
Rich
burn
(real)
Lean
burn
Low NOx route
(quick quench)
AFR


R
Q
L

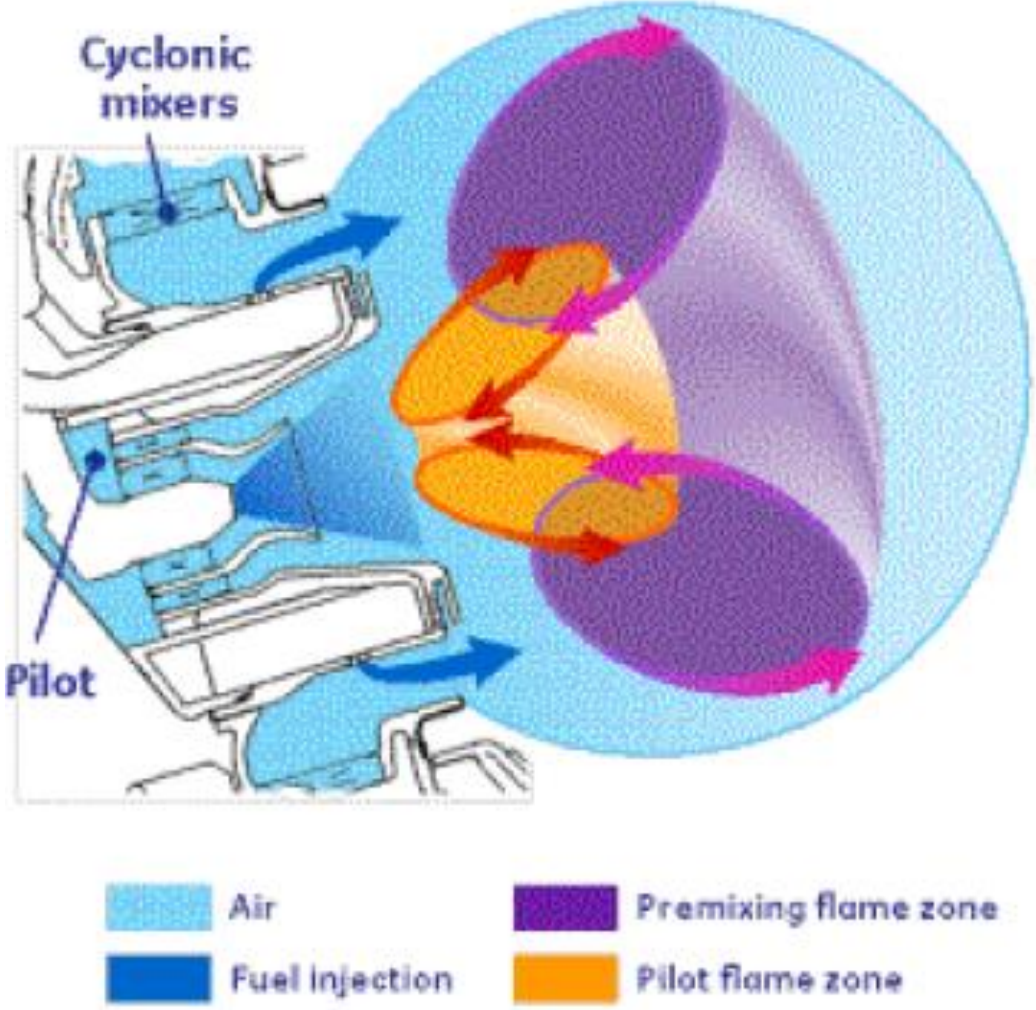
To reduce emissions, operate this part in premixed condition



Diffusion flame
for flame stability



Lean Premixed Pre-vaporized idea



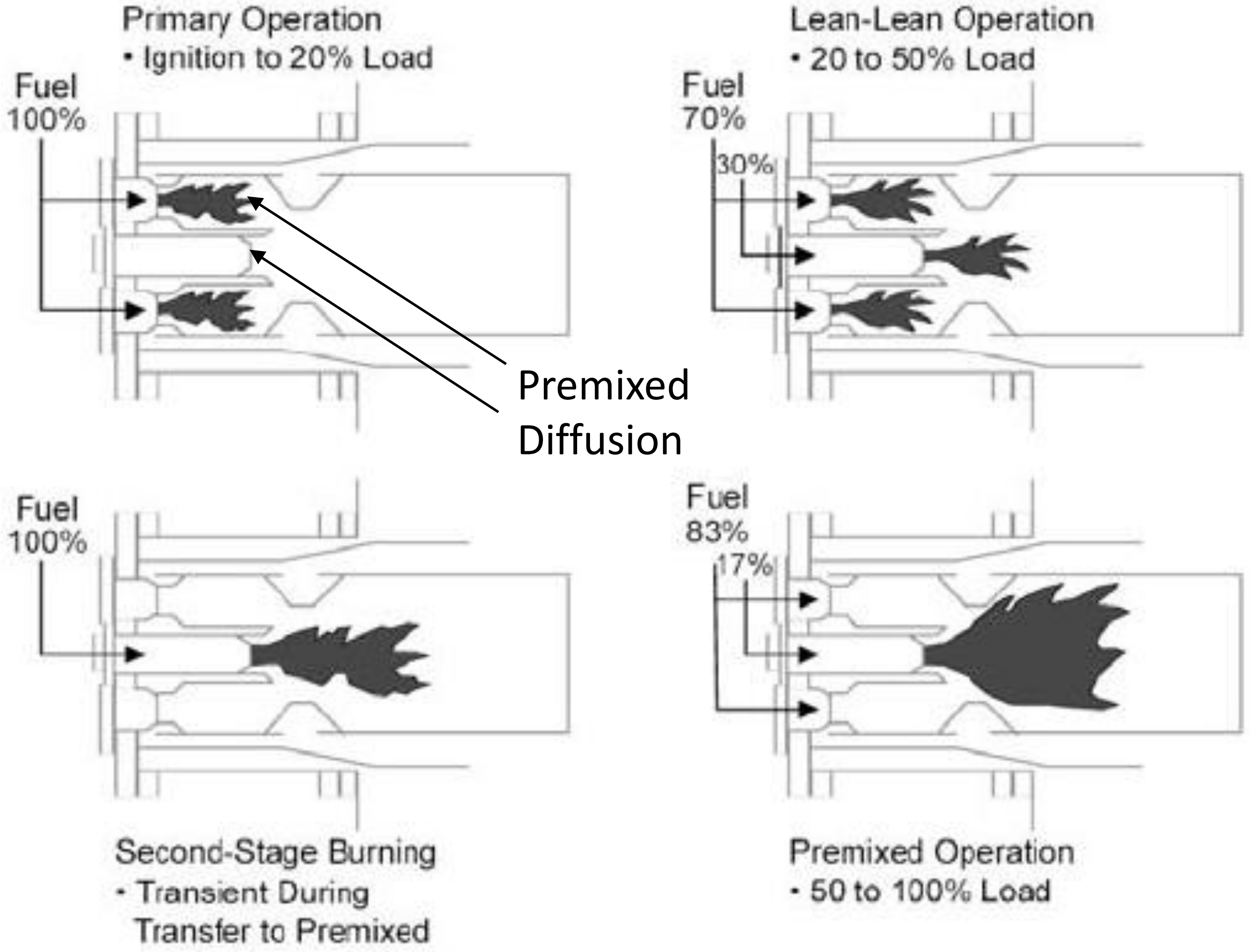
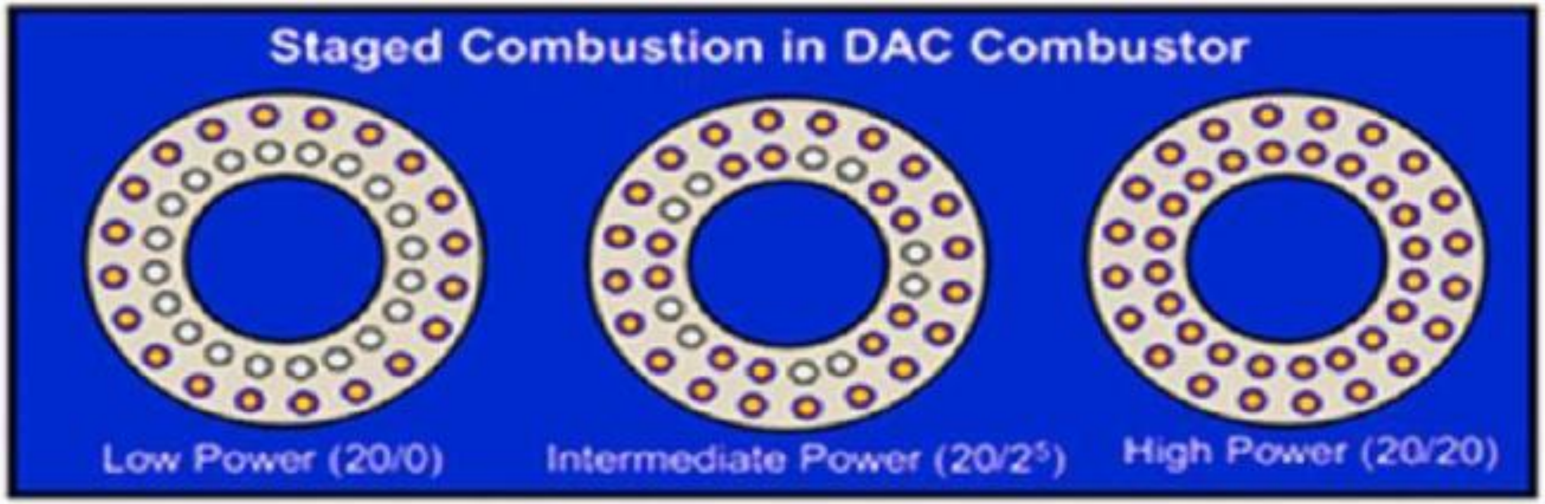
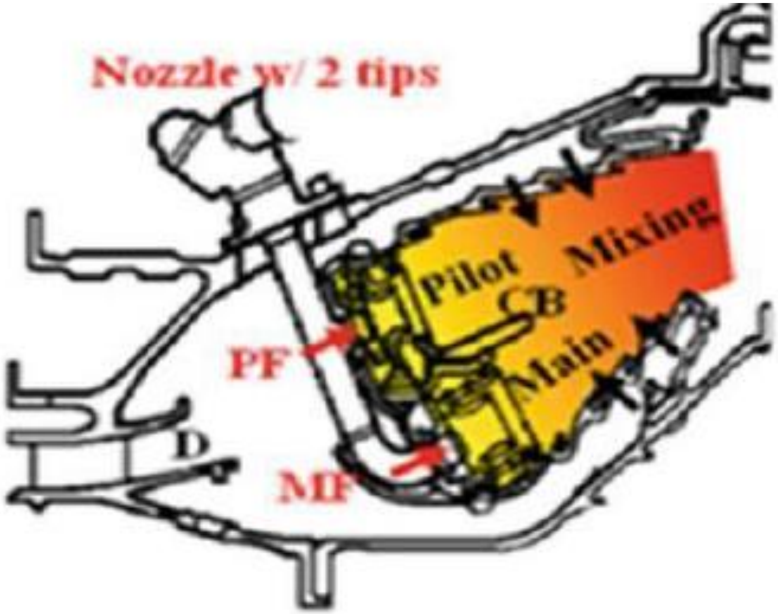


Fig. 2. Fuel-Staged Dry Low NO_x Operating Modes

Double Annular combustor – radially staged





Lean instability (flame-off, etc) is avoided by essentially maintaining a large number of diffusion flames that are far more stable than lean premixed systems

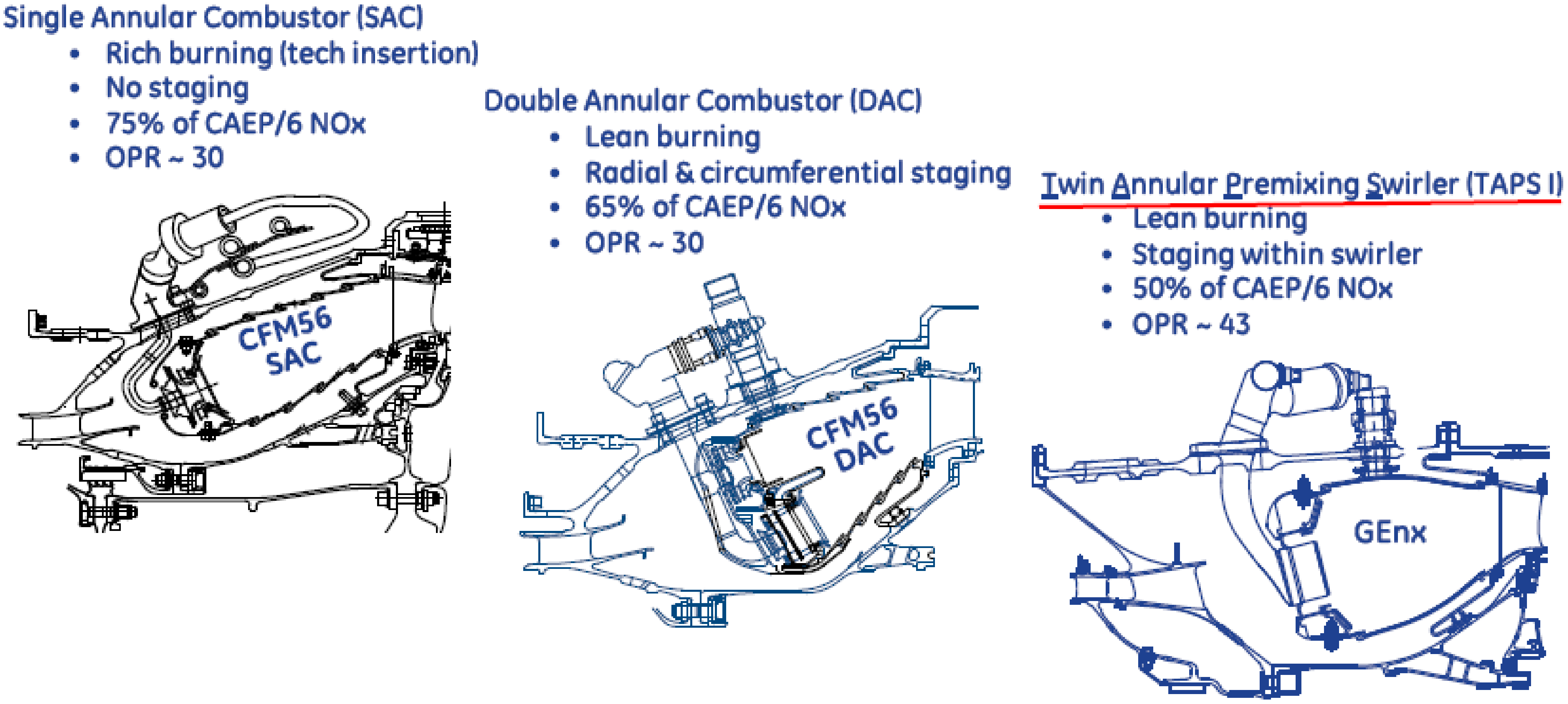
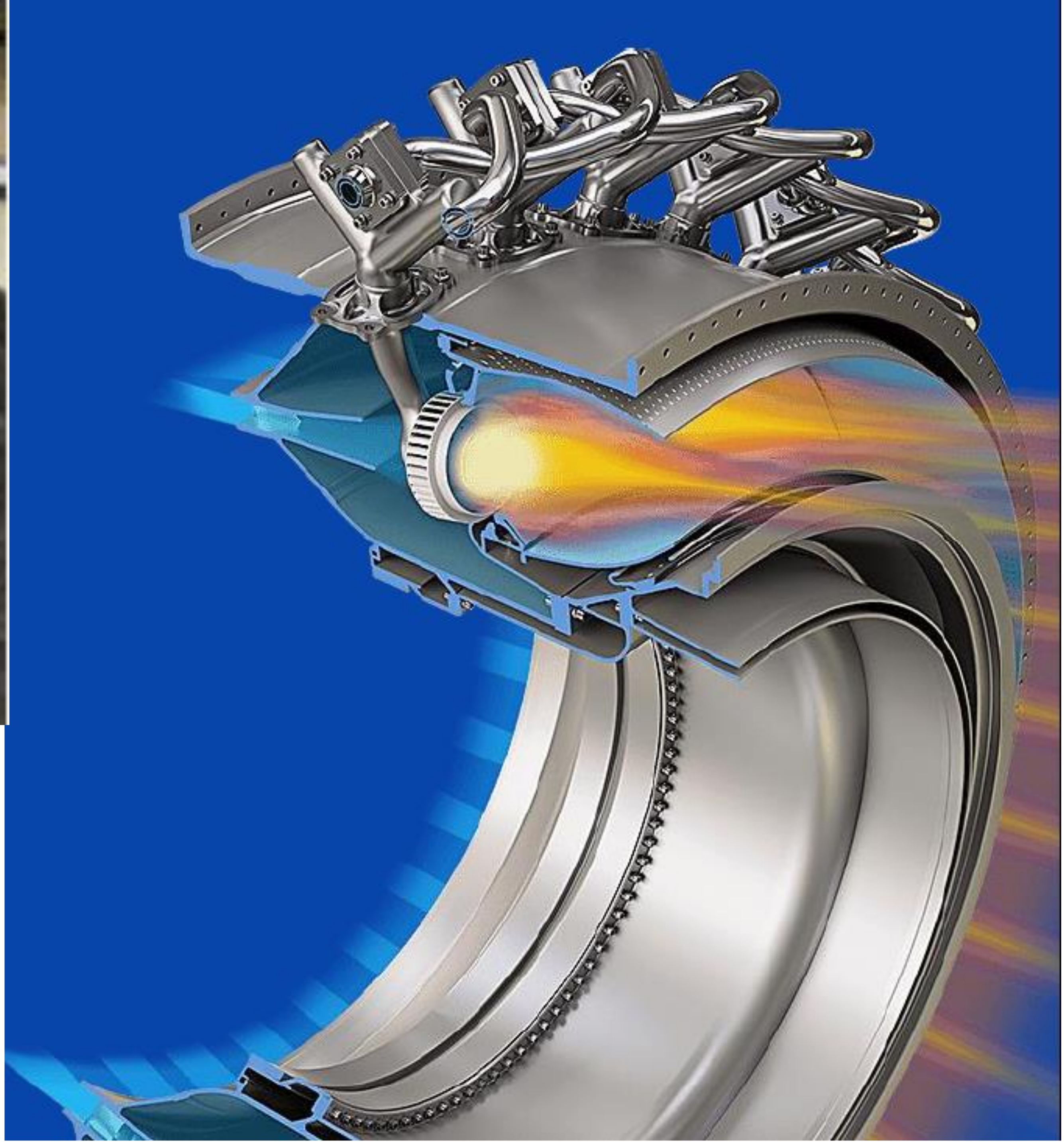


Figure 1. GE Combustor Technology Evolution

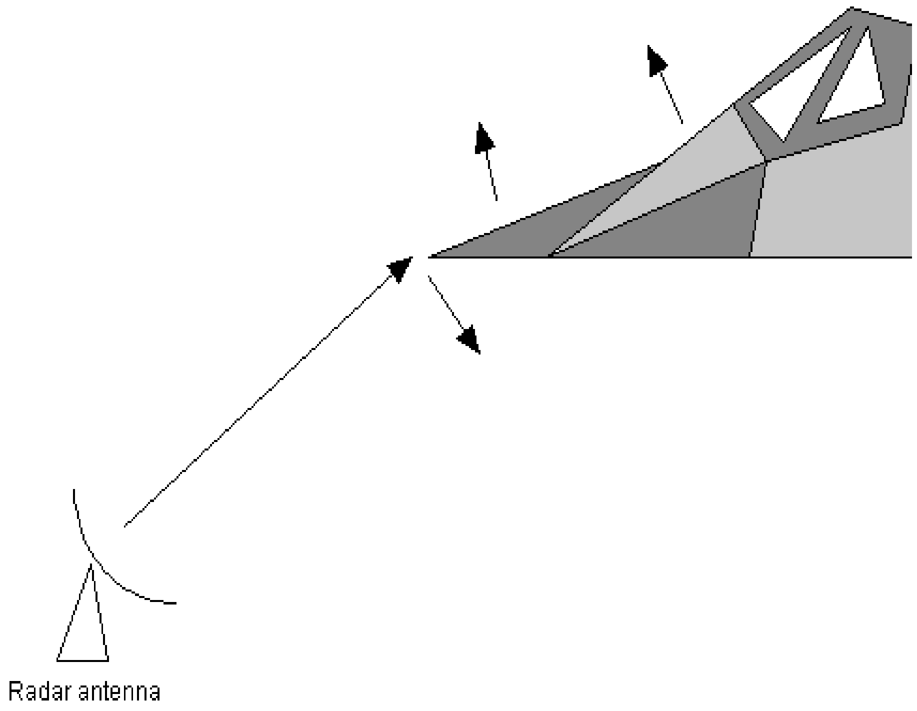



Advances in Military aircraft engines not needed in civil aircraft engines

1. Stealth
2. Thrust vector control
3. Life of turbine blades
4. Screech in afterburners

Stealth Technology

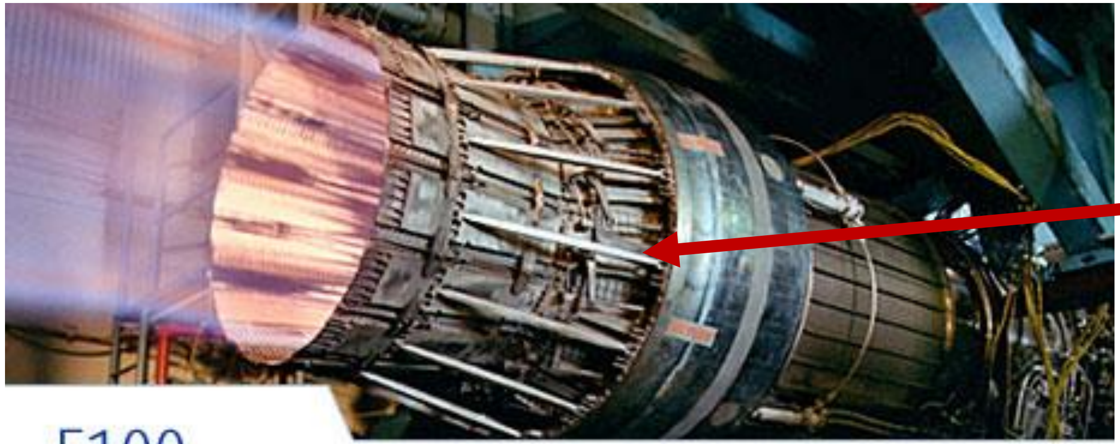
- A stealth aircraft is made up of completely flat surfaces and very sharp edges.
    - When a radar signal hits a stealth plane, the signal reflects away at an angle
- Surfaces on a stealth aircraft can be treated so they absorb radar energy.
- The overall result is that a stealth aircraft like an F-117A can have the radar signature of a small bird rather than an airplane.
- Exhaust temperature is also brought down through better mixing of the hot gases with air.



Stealth Technology

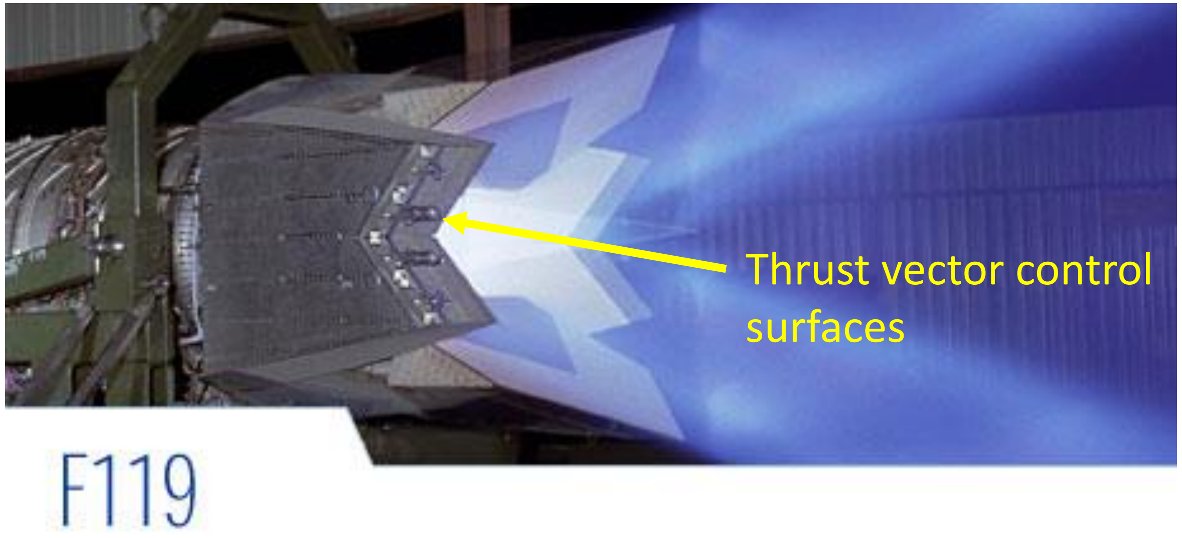
- Both F117 and YF 22 are stealth aircraft. YF22 has more modern inputs on stealth
- Engine exhaust passes over a portion of the wing surface with air being drawn between the exhaust jet and the wing surface. The net effect is that the perceived jet exhaust has a lower temperature – lesser infra-red signature.
- Both have thrust vector control

MILITARY ENGINES: P&W F100 – Powers F16

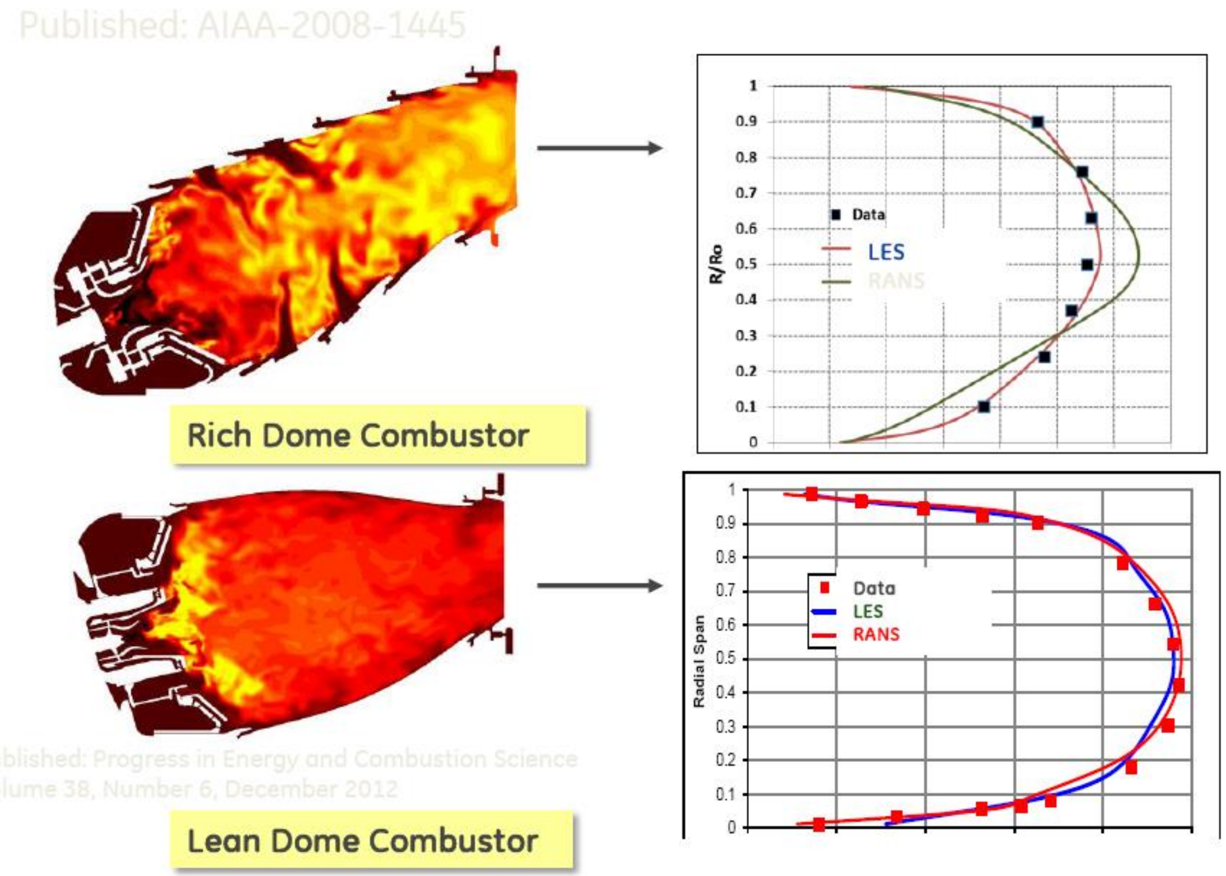


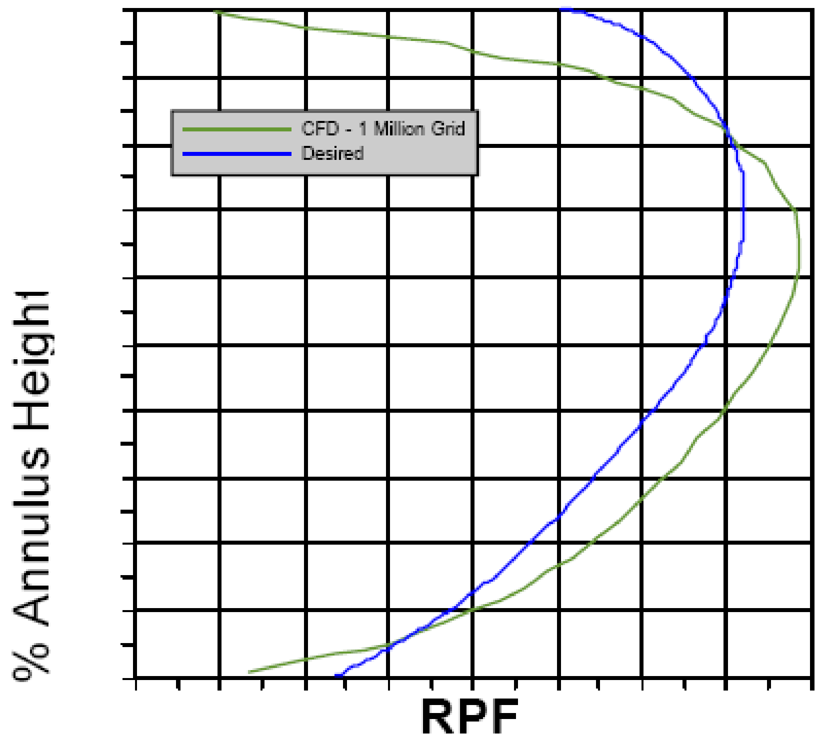
F100

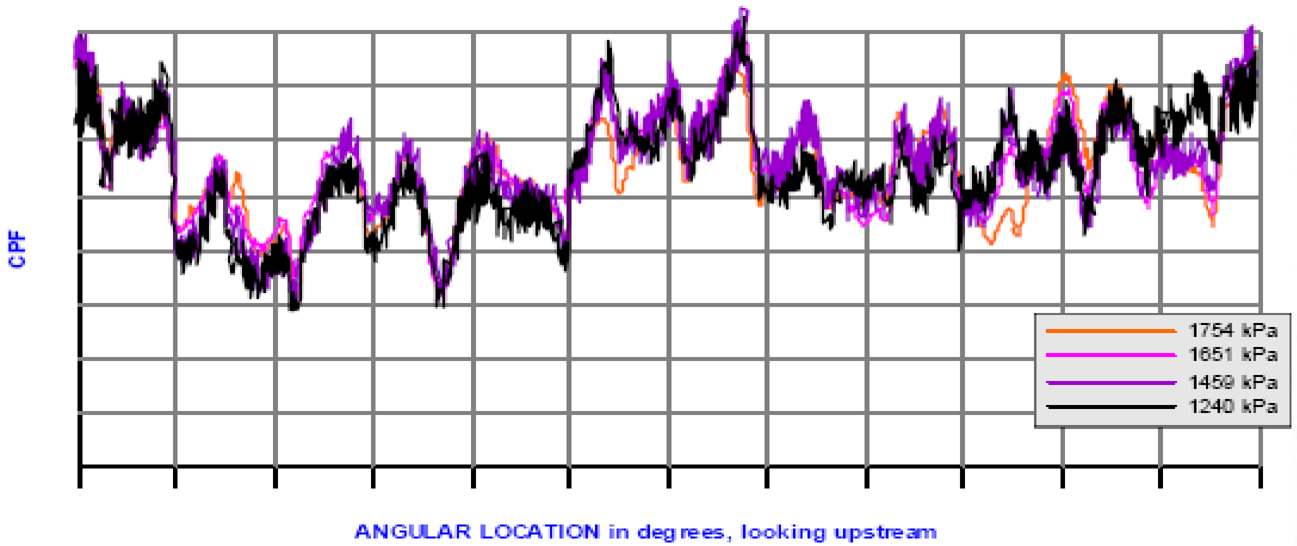
MILITARY ENGINES: P&W F119 - powers F22



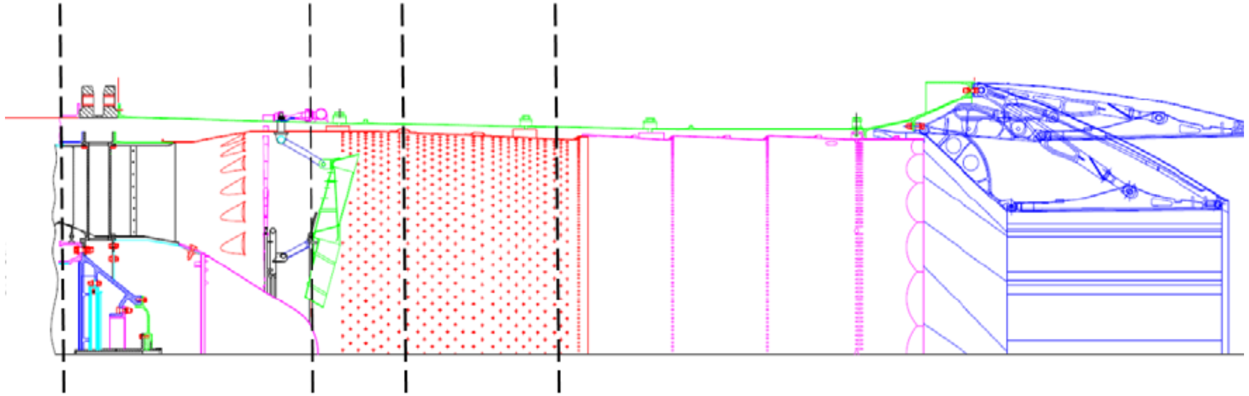
Life of Turbine blades – Pattern factor dependent

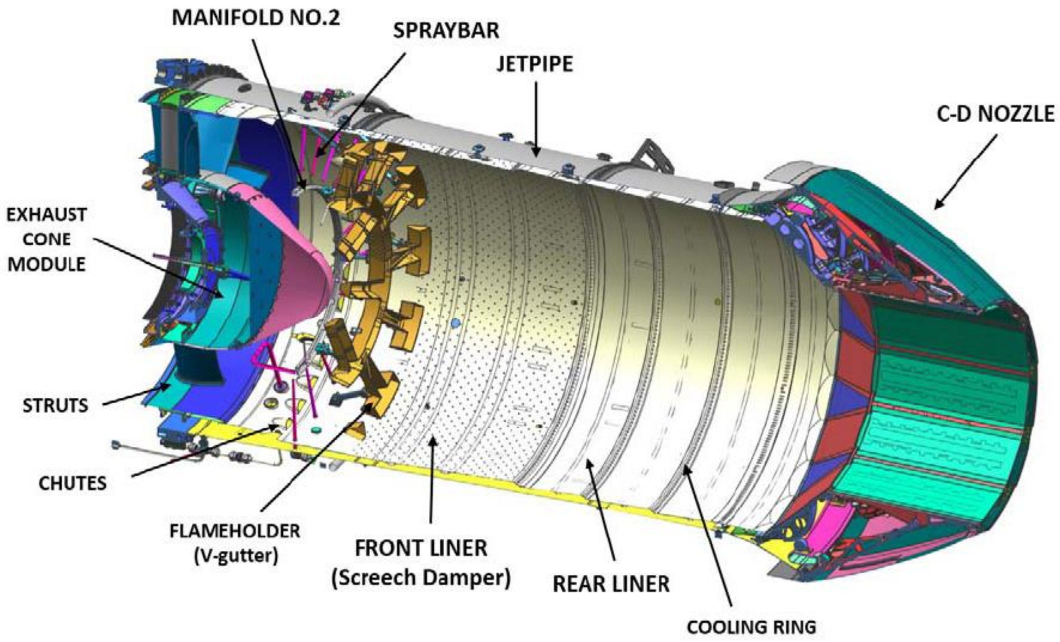






Screech (instability) in Gas turbine afterburners





- Screech is a serious problem in the afterburner of GT engines – 1st T mode, f ~ 2 kHz
- Afterburner operating conditions are: p ~ 3 - 5 atm, T ~ 2000 K.
- Heat release rates are much lower than in rocket engines where p ~ 100 atm, T ~ 3300 K.
- In rocket engines, instability is catastrophic to the hardware.
- In afterburners, it is unacceptable due to vibrations because the operation is man-rated
- The instability occurs despite acoustic damping provided by perforated liners
- The inference is that heat release (combustion) in the flow is phase-coupled with acoustics.

From: Italian work (1998)

6.2. Turbine Exhaust Diffuser

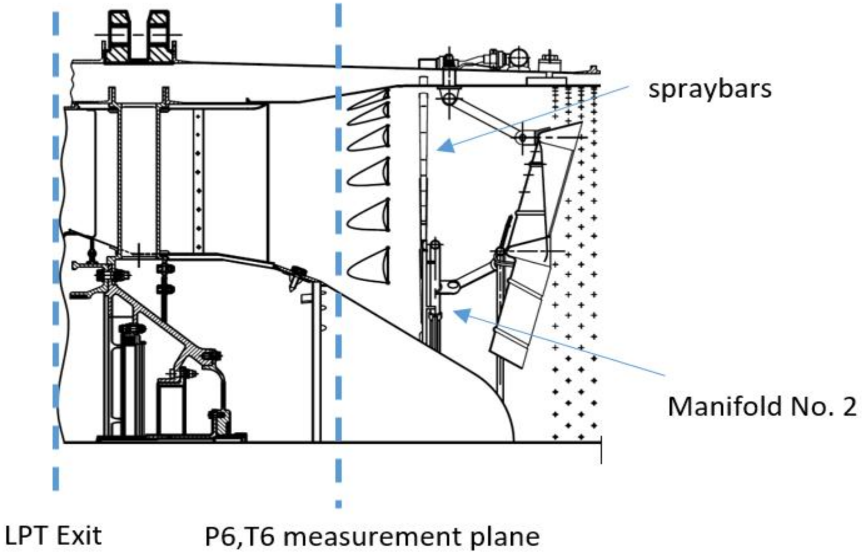
This component, placed downstream of Low Pressure Turbine (LPT) exit, has different purposes :

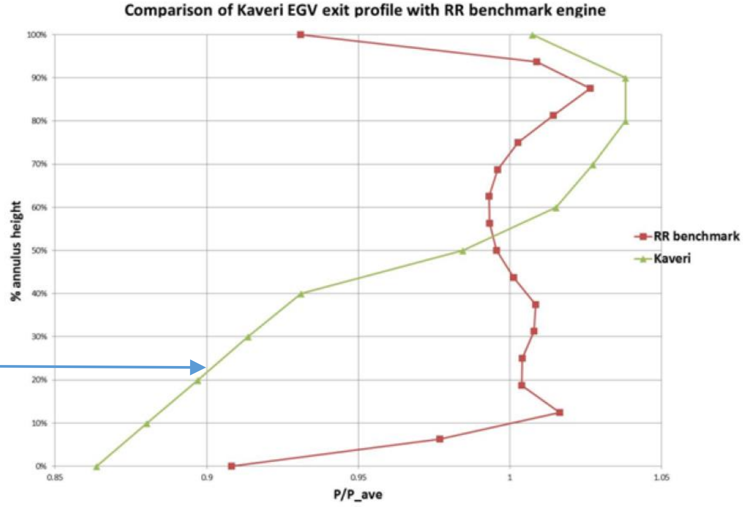
- to recover the residual flow swirl at the turbine exit, in order to ideally feed the afterburner "core" section with a no-swirl flow,
- to reduce flow velocity at R/H entry, in order to make combustion in the core stream stable,
- to straighten the flow in order to obtain a flow ideally parallel to engine centreline, maximising engine thrust.

The first of these functions is obtained with a row of vanes located upstream of the conical diffuser and giving a "counter-swirl" angle to the flow.

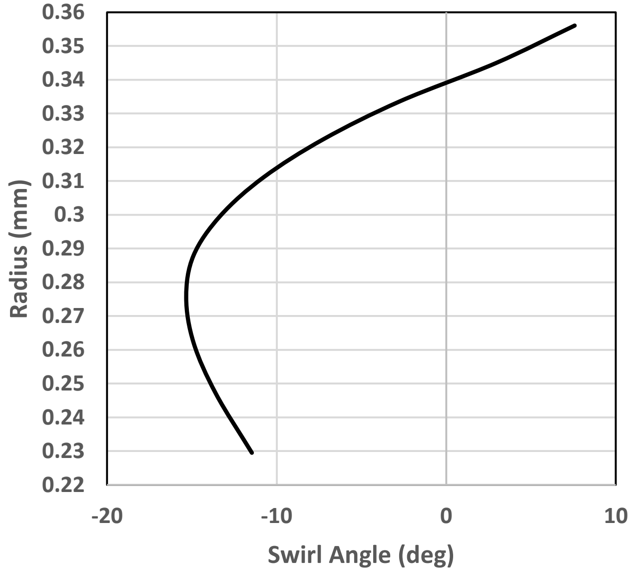
Troveti, A., Turreni, F., and Vinci, C., Afterburner design and development, Paper at RTO AVT symposium on Design principles for Aircraft gas turbines, Toulouse, 1998

The actual situation in the afterburner





More prone to instability



A stand alone test with uniform inlet conditions showed no instability

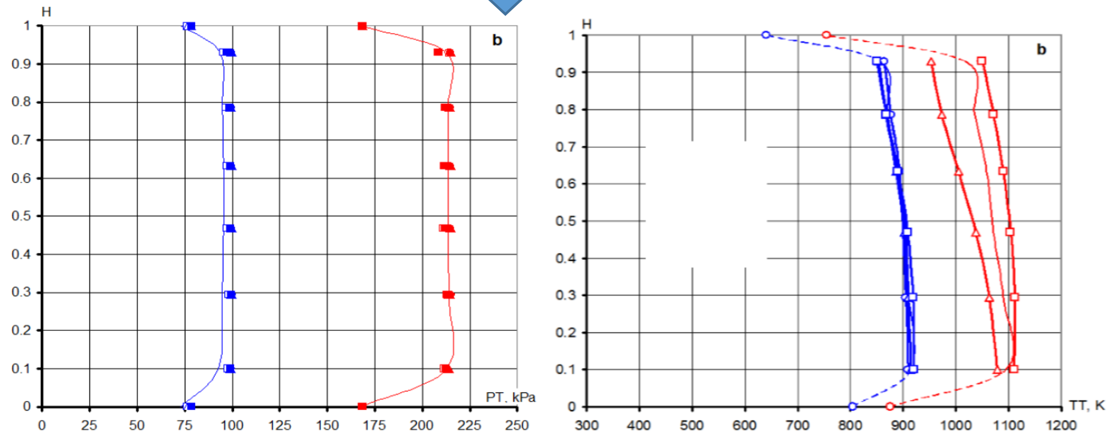


Figure 2 – Total Pressure (PT) and Total Temperature Profile (TT) for core flow at instrumentation plane 2-2 for 0.9 km/0 Mach (red) and 9 km/0.5 Mach (blue) condition

What is said

- Civil aircraft engines and military engines can be the same when military application involves subsonic speeds as it often happens in non-combat applications
- Military applications involving supersonic flights and combat agility need a different class of engines even if some segments of the technology are identical.
- Modern developments in civil aircraft engines are related to emission reduction. SFC reduction helps reducing emission of CO_2, the prominent green-house gas.
- Emission reduction of CO and NO_x have some conflicting demands on air-to-fuel ratio – richer zone helps reduce NO_x, but increase CO. Increased temperature close to desired values enhances NOx. These need judicious use of pre-mixedness, and staged combustion strategies.
- Military aircraft share technologies with civil aircraft in terms of turbine materials and production. Compressor design as well could be similar. Nozzle operations for advanced military aircraft require thrust vector control.
- Stealth feature needs integration of aircraft and engine in ways very different from civil aircraft that does not need stealth.
- Indian developments are around Kaveri dry engine and Small turbofan engine developments.

……………….Thank you.