

— Evoluzione dei Motori Aeronautici

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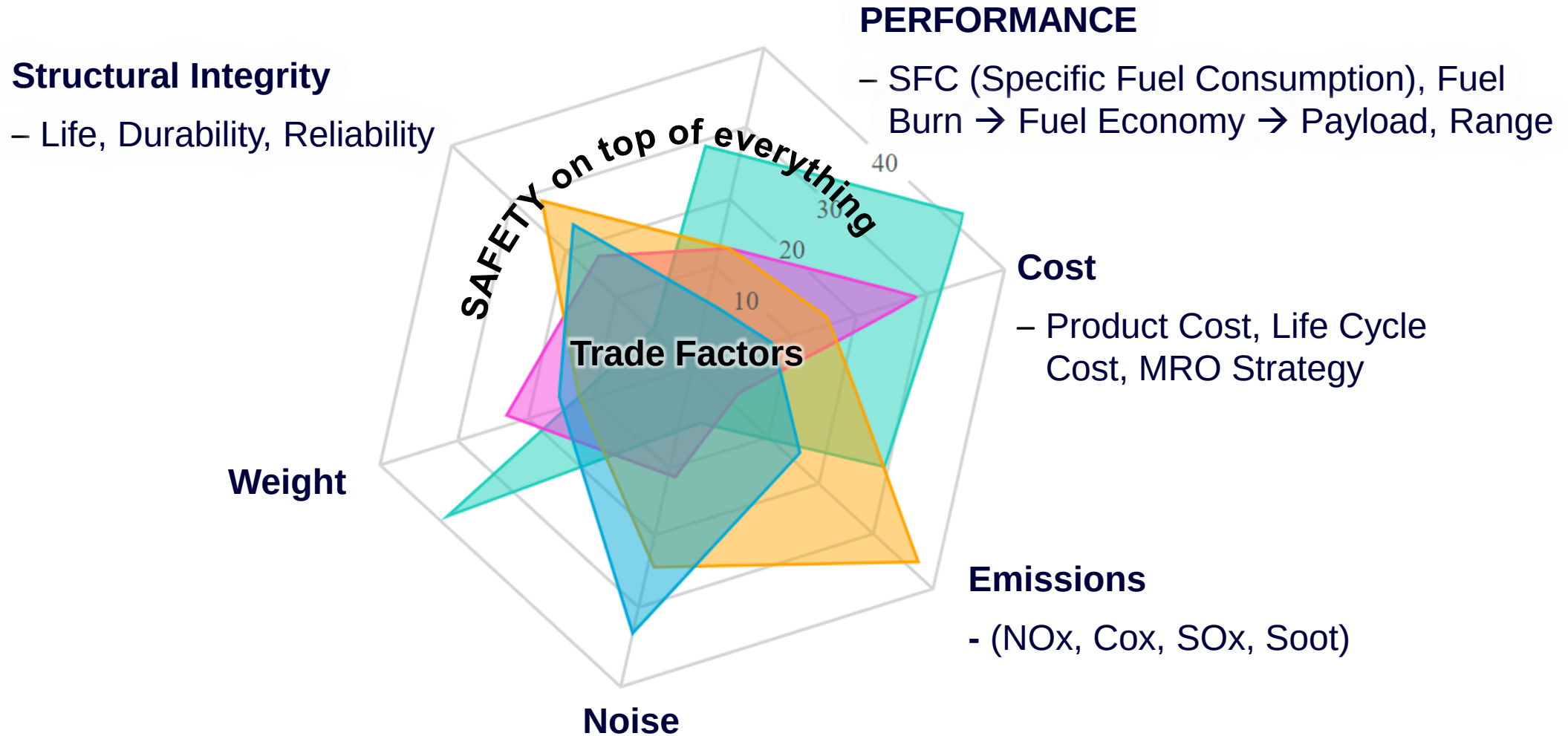
— Catalyst Product Line

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Roma, 24 ottobre 2024

La propulsione aeronautica dal 1908 al 2024 – dal motore automobilistico al Catalyst

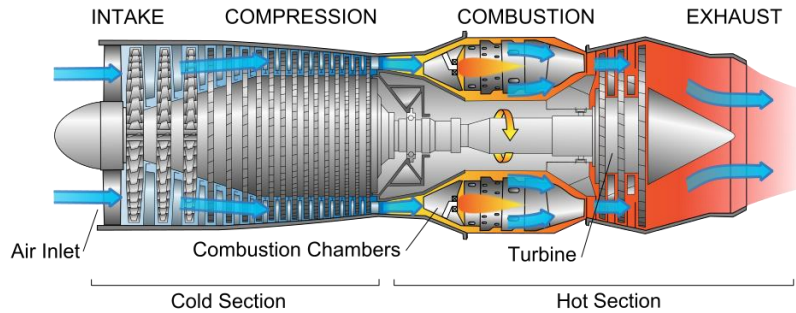
AeroEngine Basic Technical Requirements



AEROENGINE Design is a complex mix of Technology vs Economics

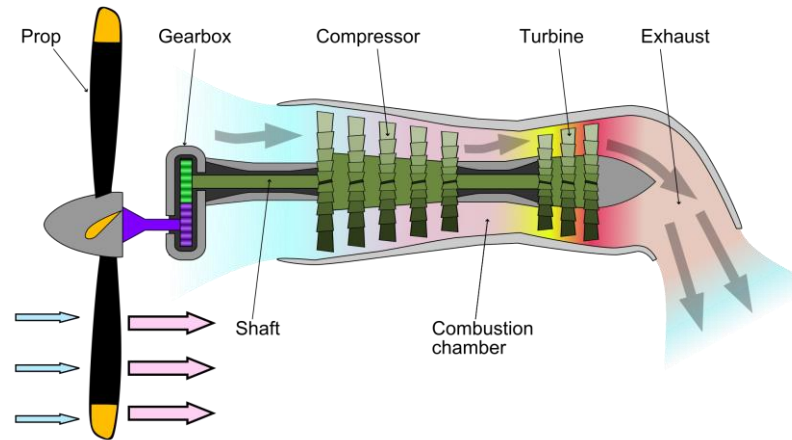
Jet Engine Architectures EVOLUTION

TurboJet (40's-50's)



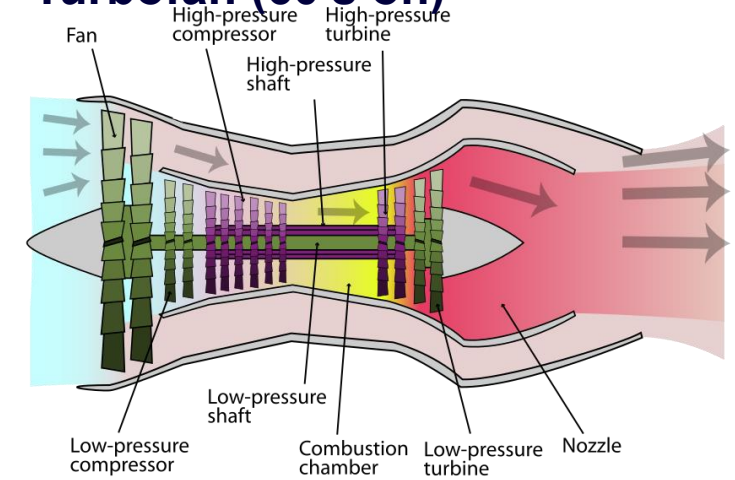
- This is a simple turbine engine that produces all of its thrust from the exhaust from the turbine section. (BPR=1)
- First turbo engine designed
- Low efficiency
- High noise

Turboprops (40's on)



- The turbine primarily drives a propeller at the front of the engine.
- The propeller provide all the thrust.
- There is no cowl around the prop.
- The propeller is geared.
- many turboprops have two shafts, with an LP shaft driving the propeller.

Turbofan (60's on)



- The turbine primarily drives a fan at the front of the engine.
- The fan is surrounded by a cowl which guides the air to and from the fan.
- Part of the air enters the engine and the rest is bypassed around it.
- Fan produce most of the thrust
- **Greater efficiency at high altitudes, enabling much longer direct flights**

$$\text{Thrust } F = \text{mass flow} * (V_{\text{out}} - V_{\text{in}})$$

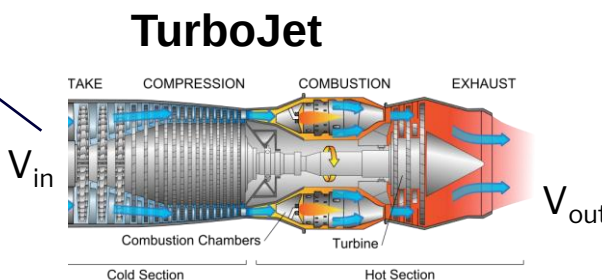
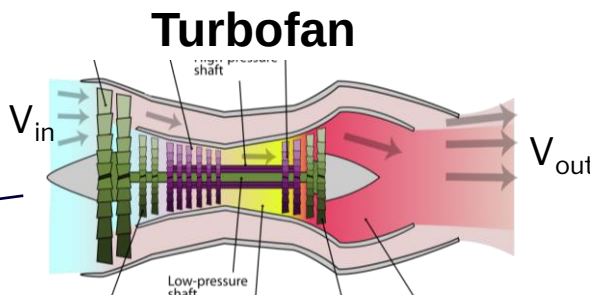
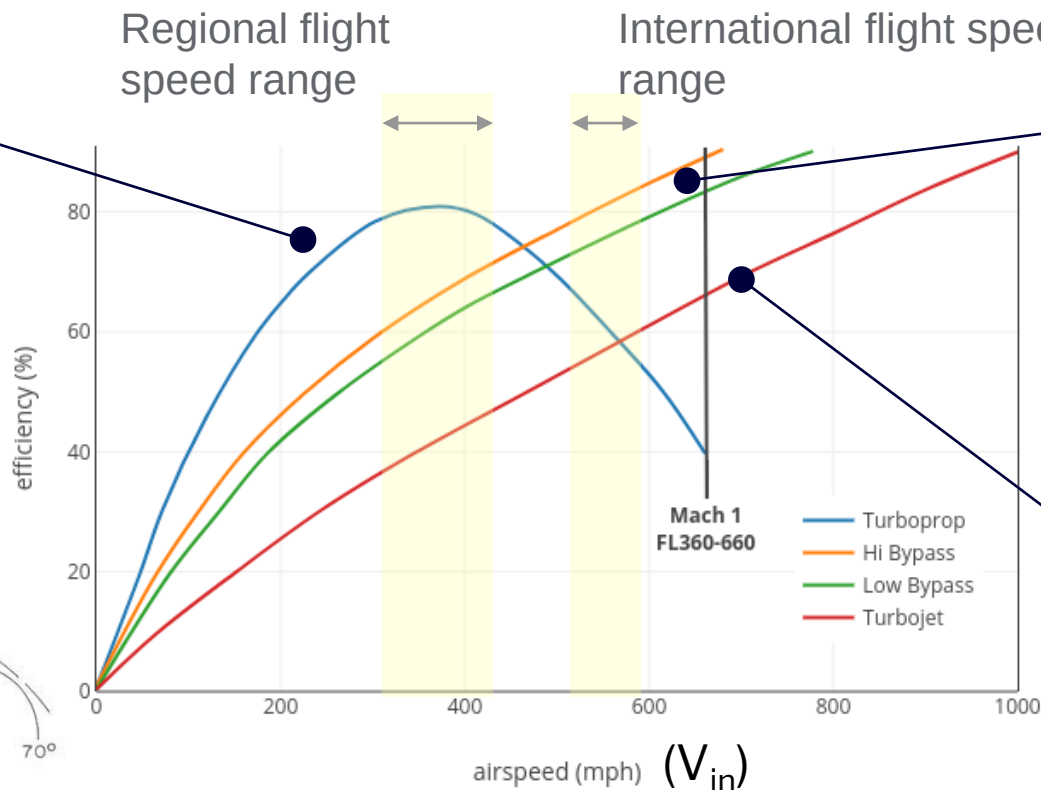
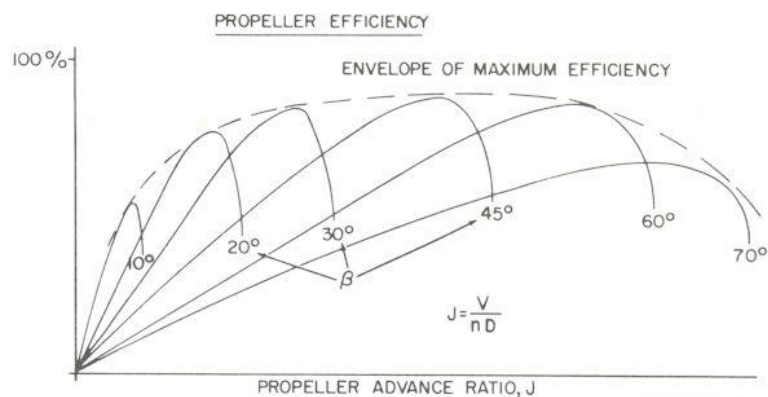
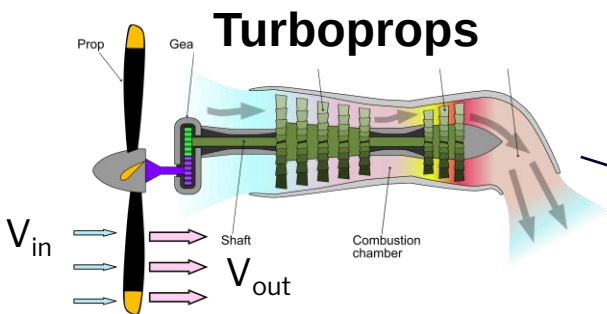
The benefit of speed for turbofans results in shorter flights being more efficient in turboprops and longer flights more efficient in turbofans

AeroEngine effective range comparison

Considering thrust formula is **F= mass flow * (V_{out}-V_{in})** and the propulsive efficiency to be obtain the thrust increasing the Mass flow instead of the exhaust air flow speed (V_{out})

$$\eta_{pr} = \frac{2}{1 + \frac{V_{out}}{V_{in}}}$$

, the better solution is to



Turbofan is always better than turbojet. Turboprops are the most efficient at lower speed.

Jet Engine Architecture: Turbofan

SFC: Specific Fuel Consumption (rate of fuel burned / thrust value)

BPR: By Pass Ratio (ByPass air mass flow vs Core air mass flow Ratio)

2 spools(in some cases a 3rd spool IP):

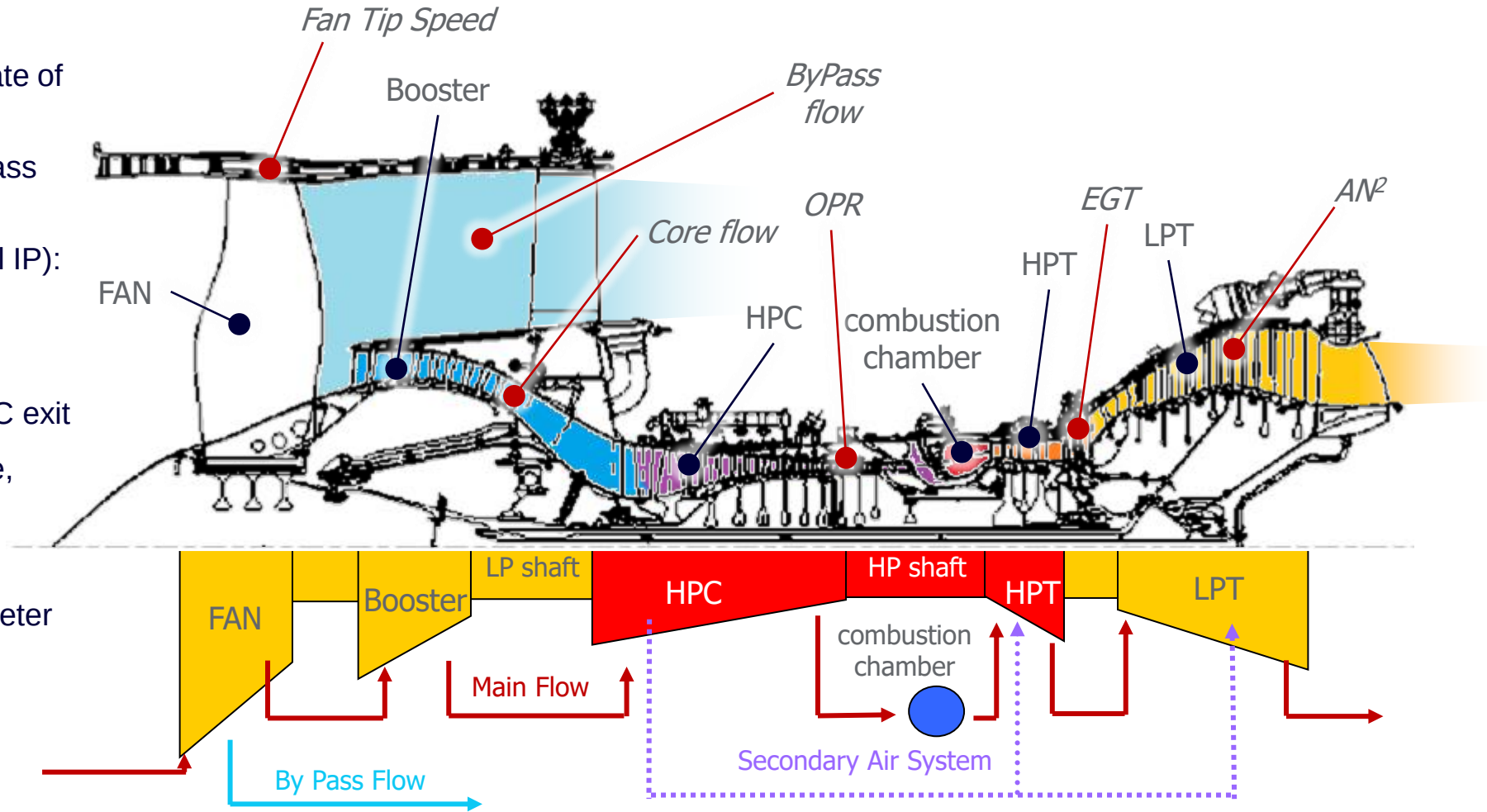
- LP Spool → Low Speed
- HP Spool → Higher Speed

OPR: Overall Pressure Ratio at HPC exit

EGT/TIT: Exhaust Gas Temperature, (temperature at the exit of the HPT)

Mechanical Constraints:

- Fan Tip Speed: limiting Fan Diameter
- AN^2 : Parameter defining LPT mechanical limits



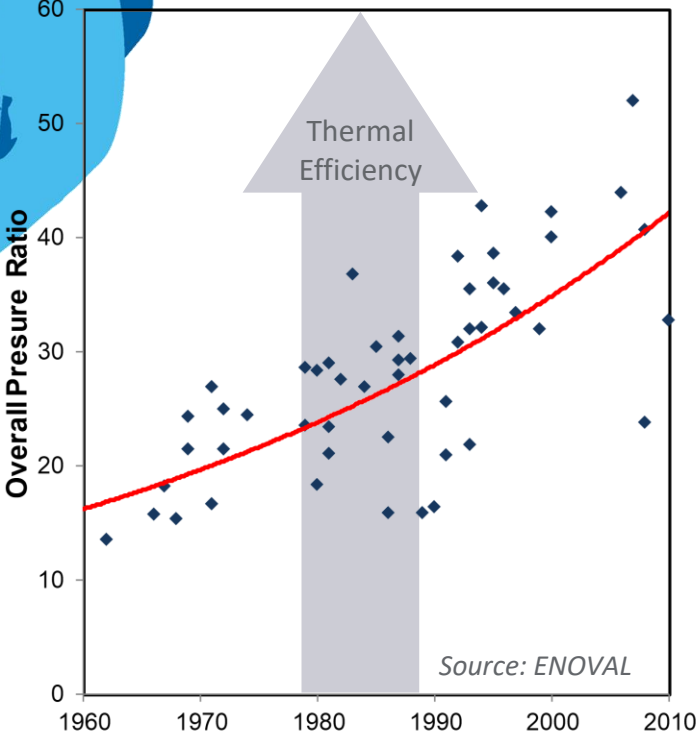
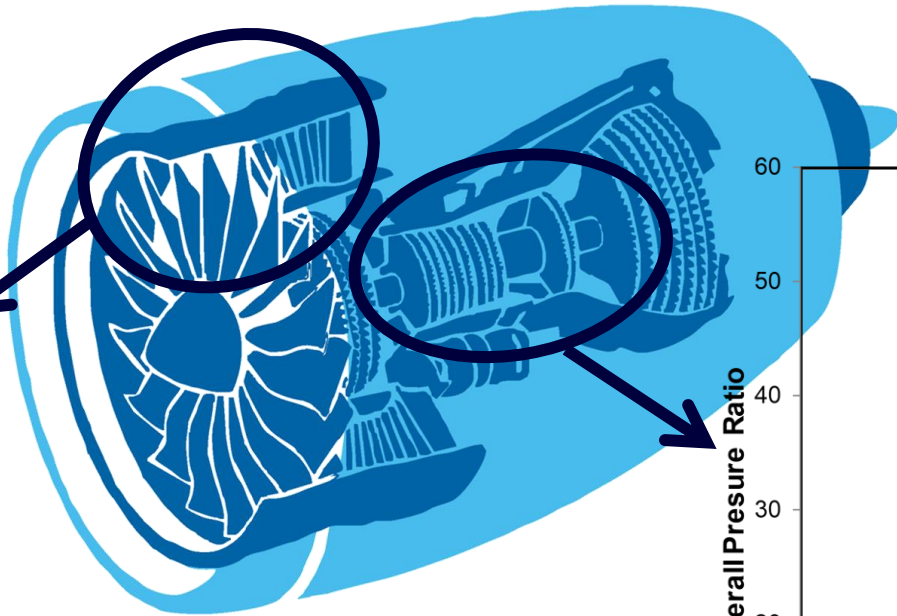
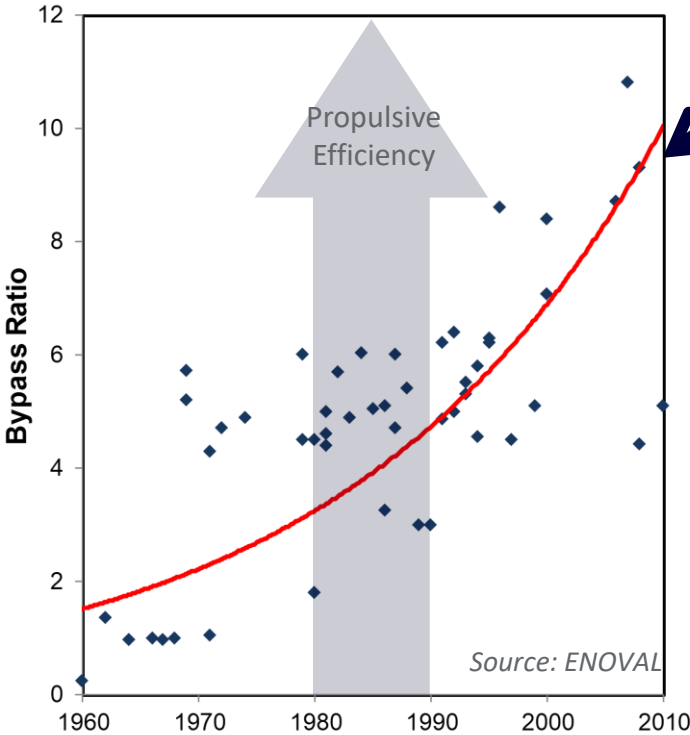
The Low Pressure Turbine converts the main flow potential energy into the mechanical energy to drive the low pressure spool (Fan and Booster)

Development of Major Design Parameters

$$\eta_{\text{total}} = \eta_{\text{propulsive}} \cdot \eta_{\text{thermal}}$$

$$\eta_{pr} = \frac{2}{1 + \frac{V_{out}}{V_{in}}}$$

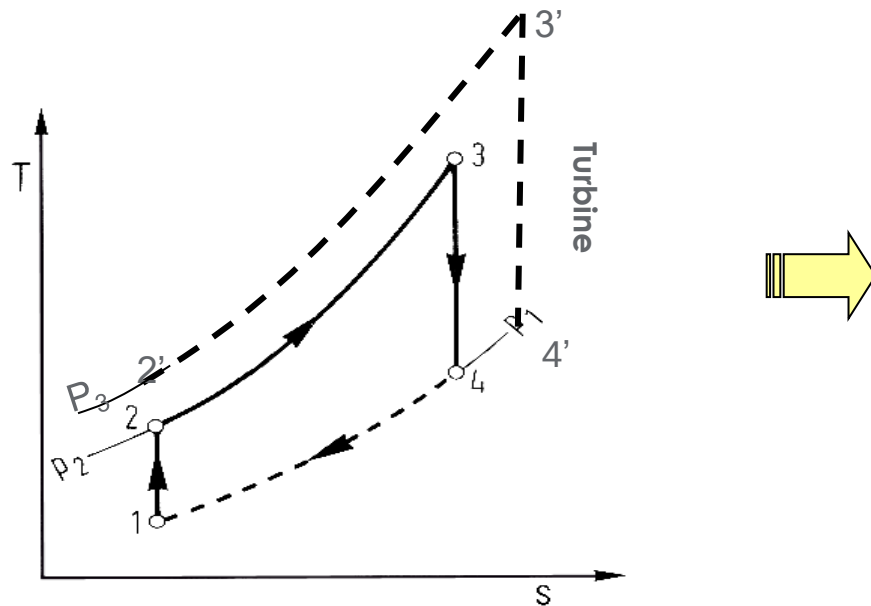
$$\eta_{th} = 1 - \frac{1}{OPR^{\frac{\gamma-1}{\gamma}} \left(1 + \frac{\gamma-1}{2} M_0^2 \right)}$$



Bypass Ratio & Overall pressure ratio increases

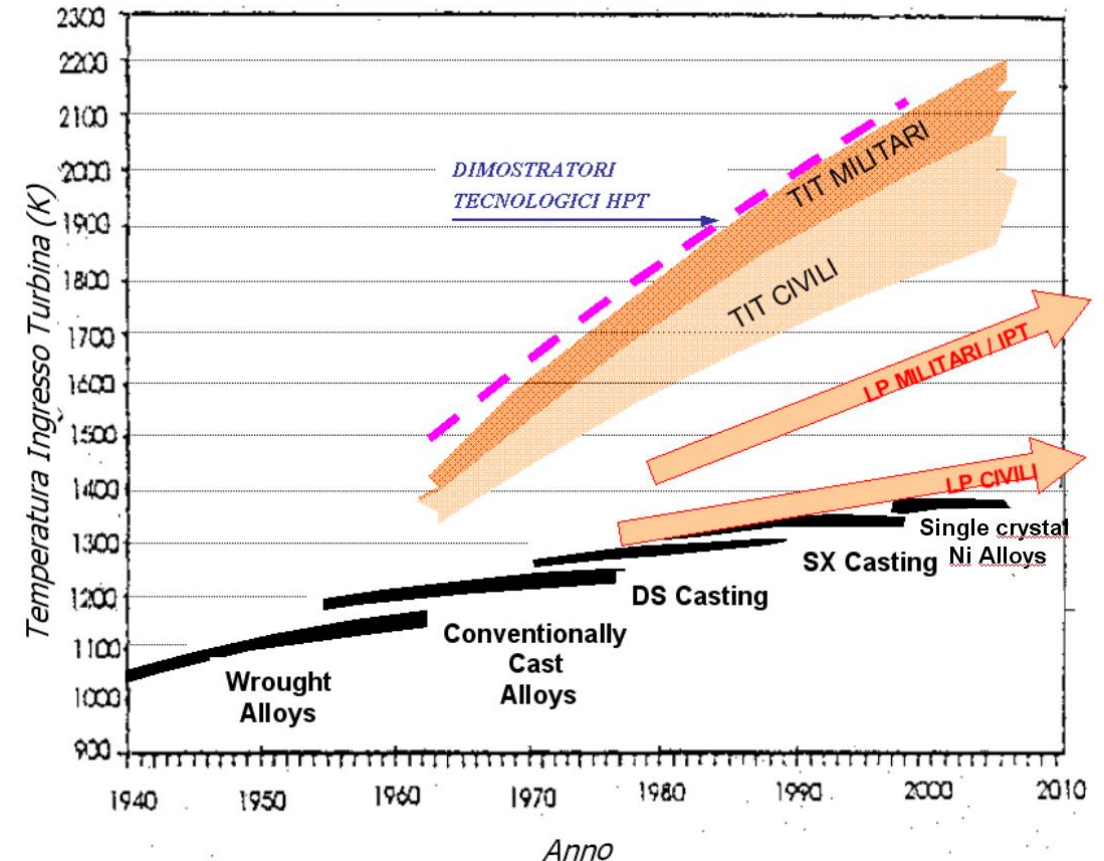
Thermal Eff. increase – LPT Temperatures trend

To increase the work extracted by the turbine you need to increase the inlet temperature ($T3' > T3$) acting on the overall pressure ratio (from $P2$ to $P3$) or increasing the combustor exit temperature (more fuel).



If $T3' > T3 \rightarrow \Delta T(3'-4') > \Delta T(3-4)$

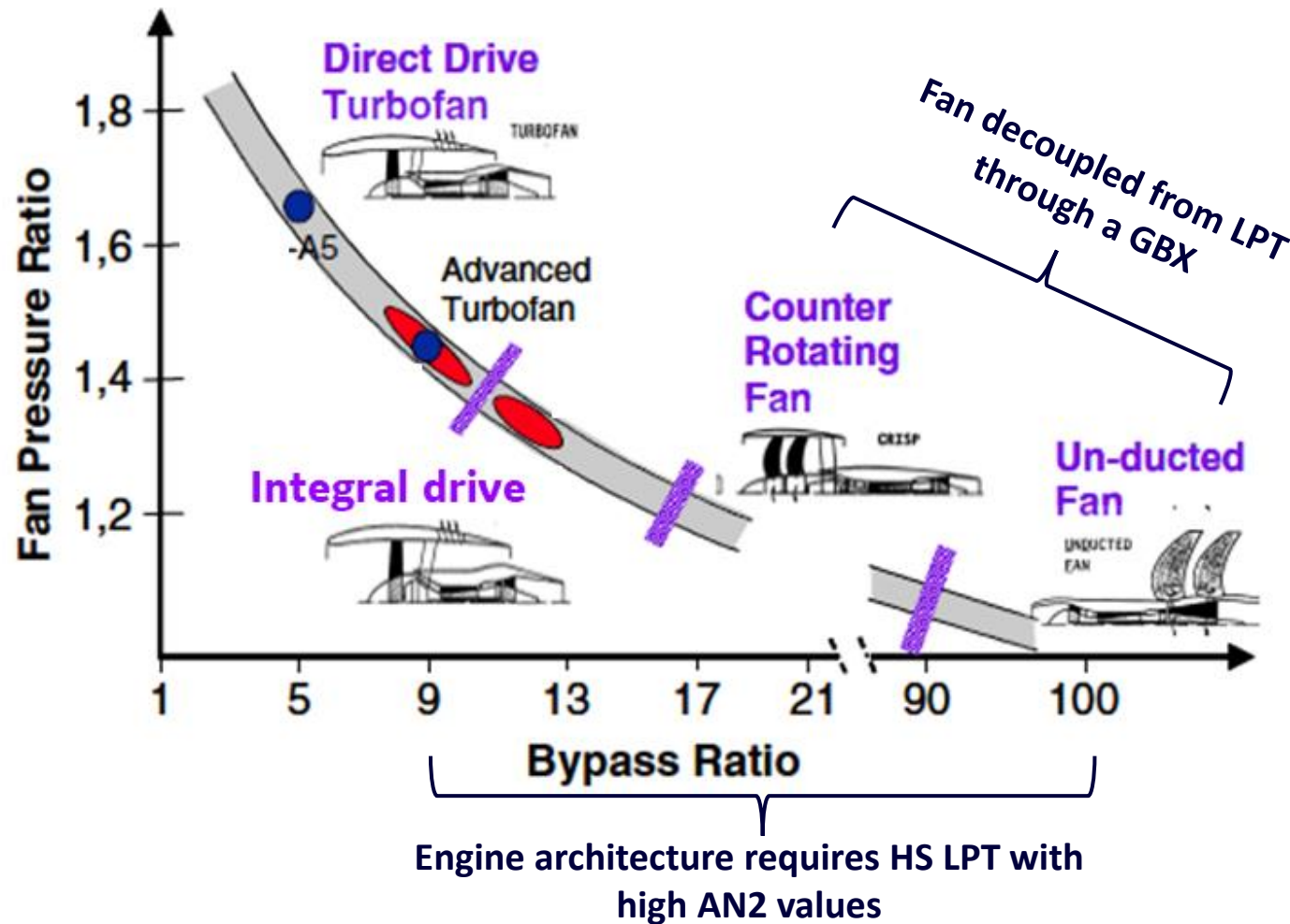
$\Rightarrow$ More work extracted from LPT



New materials and technologies must be developed to face the increasing trend in the inlet turbine temperature

Higher thermal efficiency $\rightarrow$ Higher Temperatures $\rightarrow$ Better materials needed

Propulsive efficiency increase reducing the exit velocity V_{out} , and this can be achieved by low Fan Pressure Ratio which requires large fan diameter. This results in a lower LP spool speed (to limit fan tip speed), not optimum condition for the LPT: **Fan Tip vs LPT speed AN² drives new architecture**



$$\eta_{pr} = \frac{2}{1 + \frac{V_{out}}{V_{in}}}$$

Jet Engine Architecture: Key disciplines driving technology

3D Aerodynamics: 3D Advanced codes able to predict and design super efficient Flowpath , both Compressor and Turbine

Advanced Materials: High Temp Alloys, High Specific Strength Materials (Ceramics, composite, Intermetallic)

Design Advanced Tool for Key Disciplines:

- **Engine System Disciplines:** Performance SS & Transient , TSD, Clearances, Air/Lube Systems, Engine Dynamics
- **Module/ Component Disciplines:** Combustion Aero, Aeromechanics, Aeroelasticity, Noise / Acoustics, Fracture mechanics, Stress

Testing Capabilities: Engine Testing, Aero Rig (Cold Flow, FAR Combustor rig) Controls Simulator (WET Rig, Ironbird), Component Testing...

Network with Universities : strong collaboration on Research

GE90 (1990's) vs GE9X (2020's) comparison

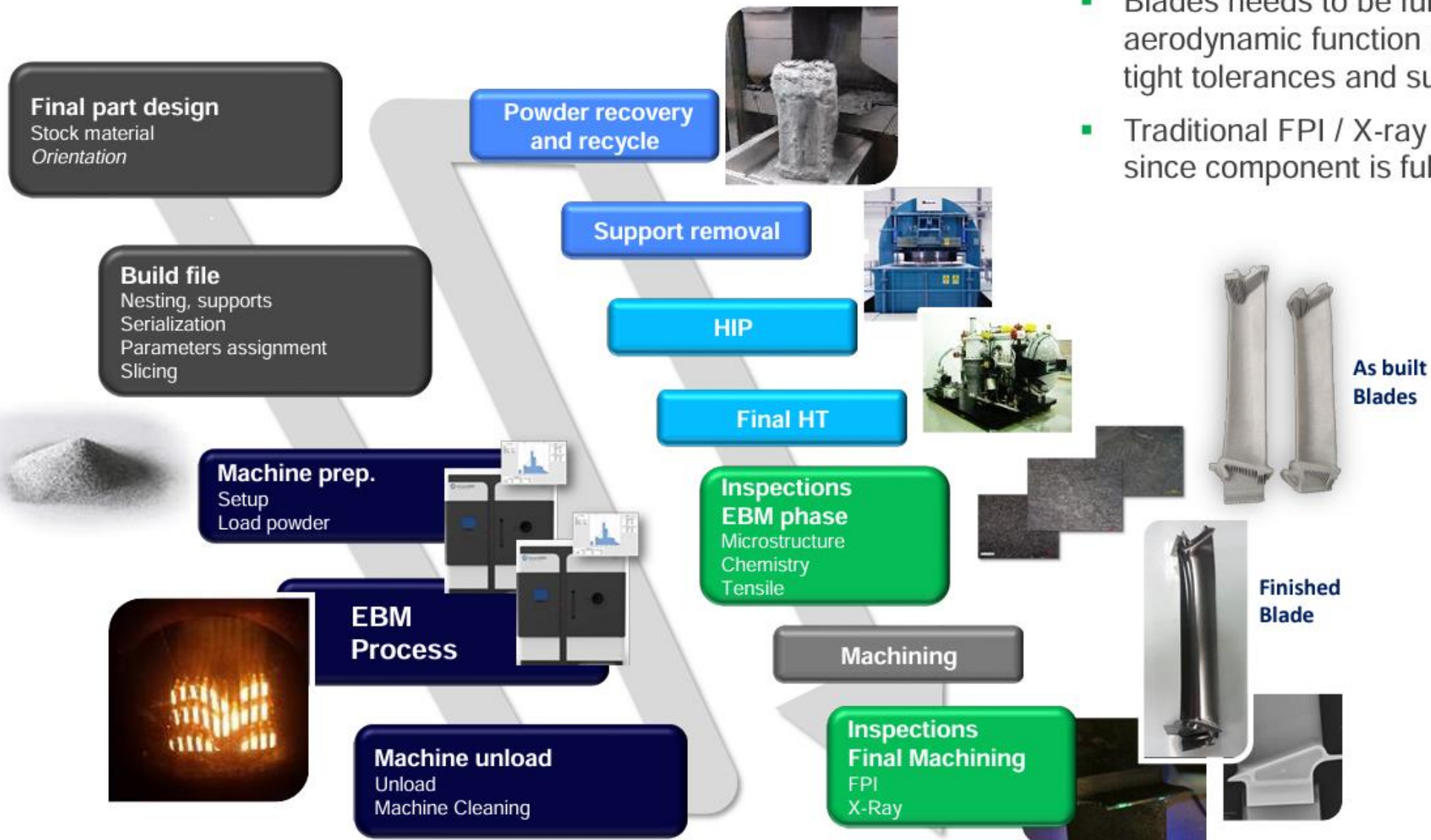


They apparently look very similar

Turbofan comparison along Decades : GE90 vs GE9X

Variant	GE90-115B	GE9X - 105B1A
Type	Dual rotor, axial flow, high bypass turbofan	Dual rotor, axial flow, high bypass turbofan
Compressor	1 fan, 4-stage LP, 9-stage HP	1 fan, 3-stage LP, 11-stage HP
Turbine	2-stage HP, 6-stage LP	2-stage HP, 6-stage LP
Fan	128 in (3.3 m) diameter, 22 wide chord composite blades	134 in (3,404 mm) diameter, 16 wide chord composite blades
Bypass ratio	9:1	10:1
Overall pressure ratio	42:1	60:1, HPC pressure ratio: 27:1
Weight	19,316 lb (8,762 kg)	21,230 lb (9,630 kg)
Max thrust	127,900 lbf (569 kN)	134,300 lbf (597 kN)
Takeoff thrust	115,000 lbf (511.2 kN)	110,000 lbf (489.3 kN)
RPM, 100%	LP 2355, HP 9332	LP 2355, HP 9561
SFC		10% reduction vs GE90
Innovative materials	Composit fan blades	CMC* HPT Nozzle and shroud Additive materials (TiAl blades)

TiAl blades – Production steps



- Blades need to be fully machined due to aerodynamic function requirements (very tight tolerances and surface roughness)
- Traditional FPI / X-ray inspections apply since component is fully machined



European – Technology Development Cluster (E-TDC) partners

A longstanding partnership ruled by one single contract agreement defined by legal to protect GE IP

