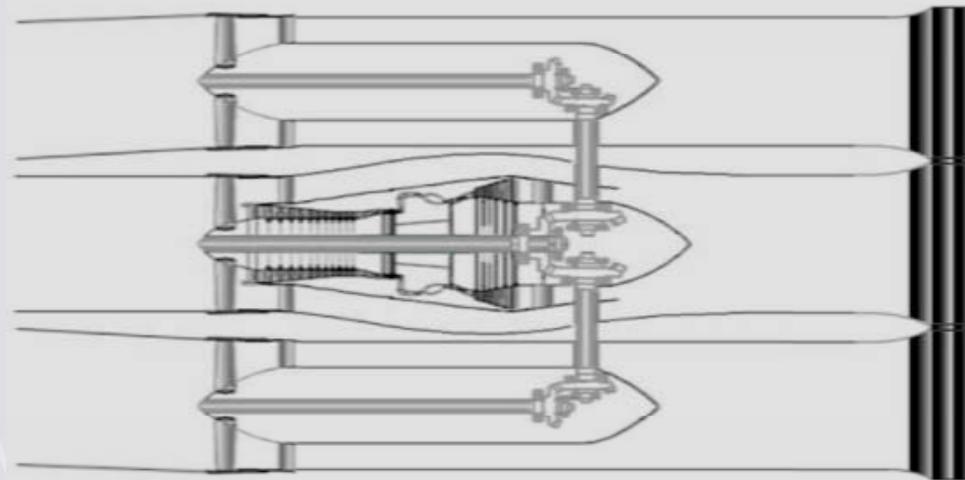
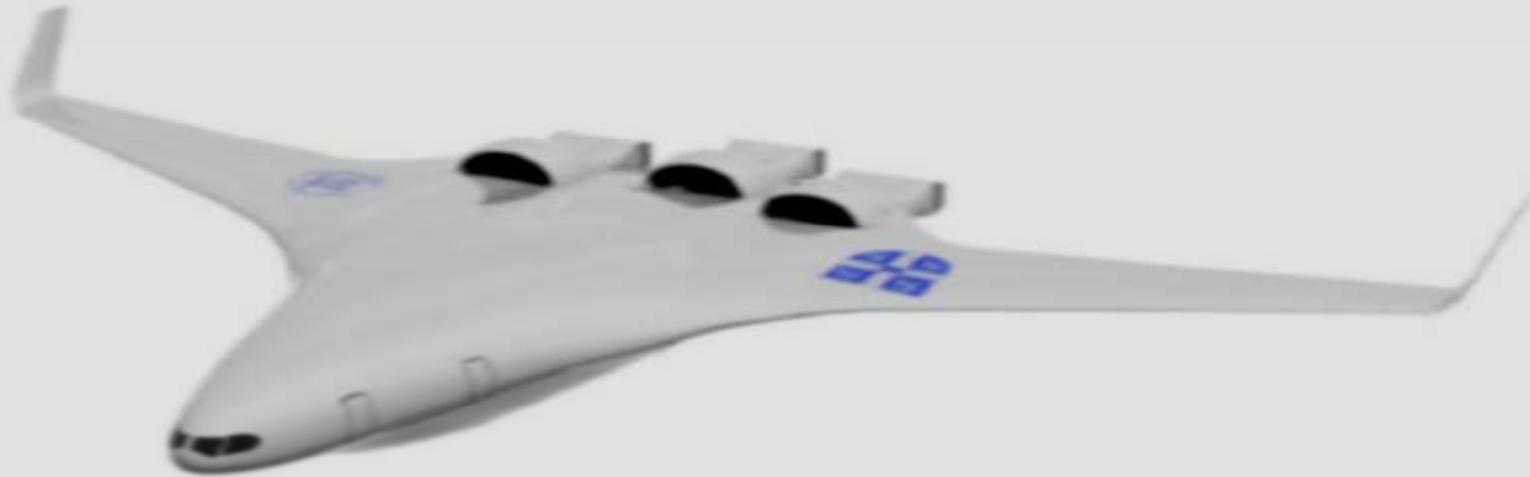




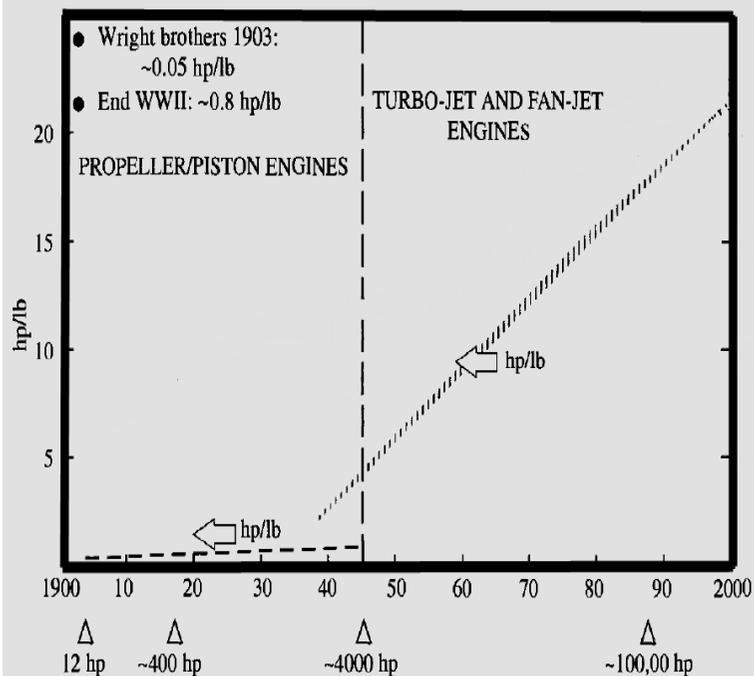
TURBOFANES AVANZADOS : Tendencias



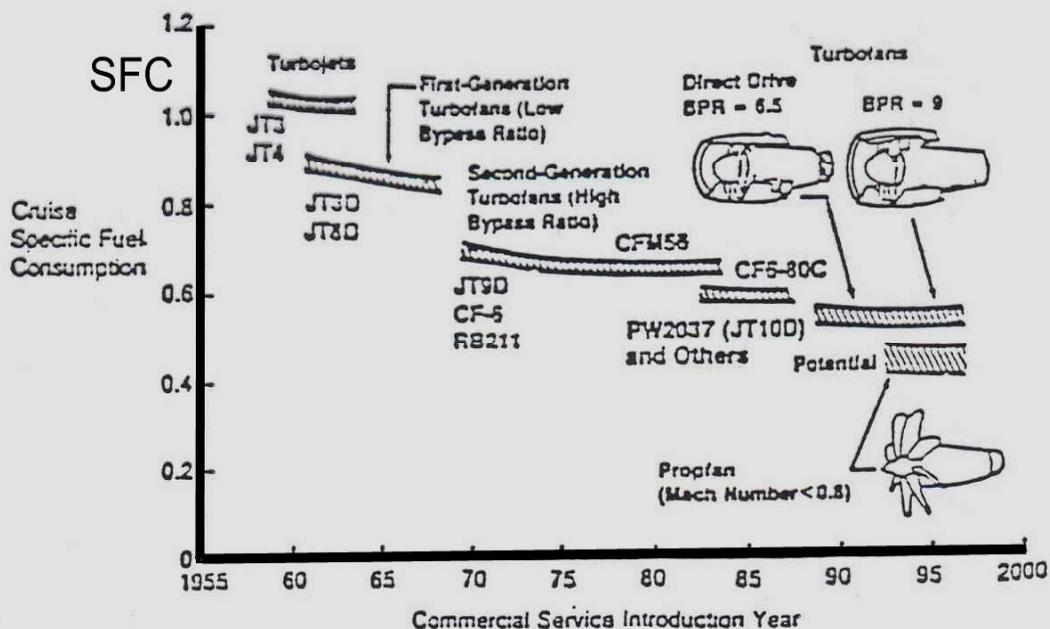


Evolución de los motores de reacción

Aumento de la potencia/peso (Empuje/peso) y disminución del consumo específico de los aerorreactores



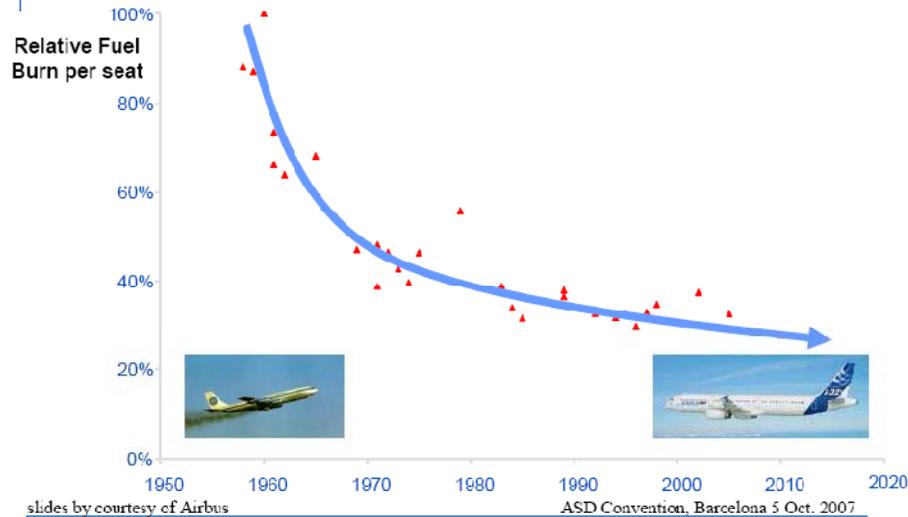
Trends of power per weight (hp/lb)



Resultado: menores costos →

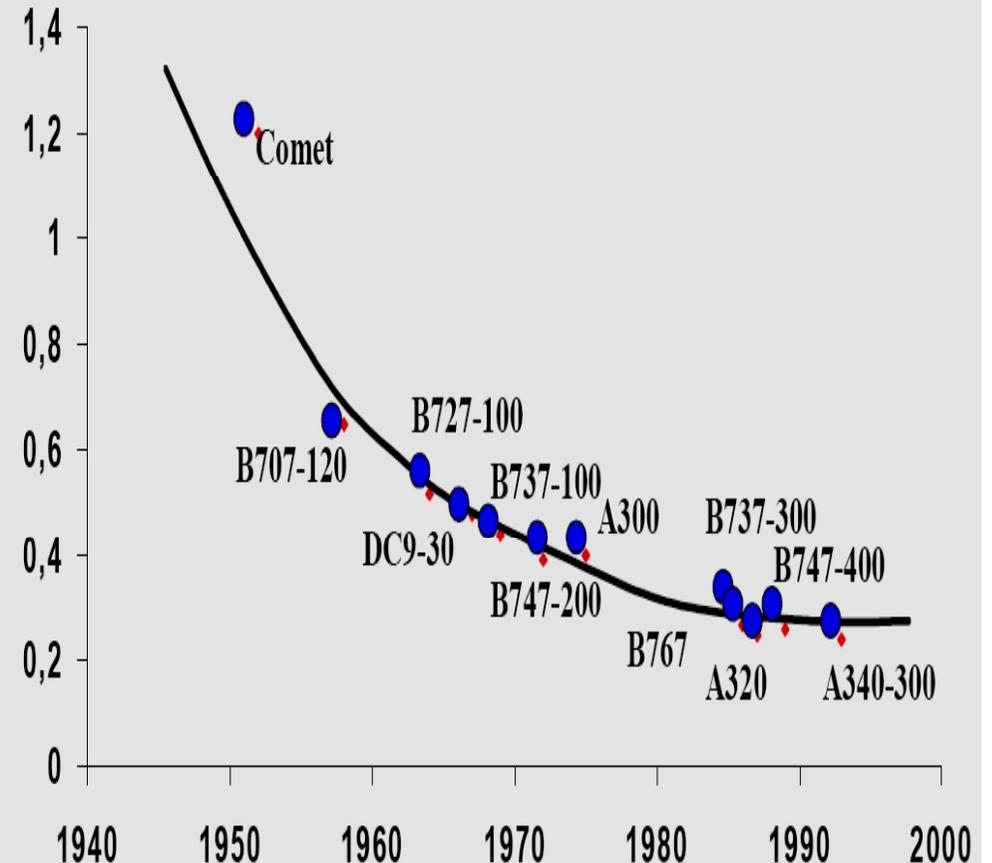


Achievements: 70% reduction in fuel burn



Litres/10 km/passenger

Source DLR/EC 99



$$\text{Stage Length} = \frac{V(L/D)}{g \cdot \text{SFC}} \ln \left(1 + \frac{W_{\text{fuel}}}{W_{\text{payload}} + W_{\text{structure}} + W_{\text{reserve}}} \right)$$

○ = Technology
 = Operations

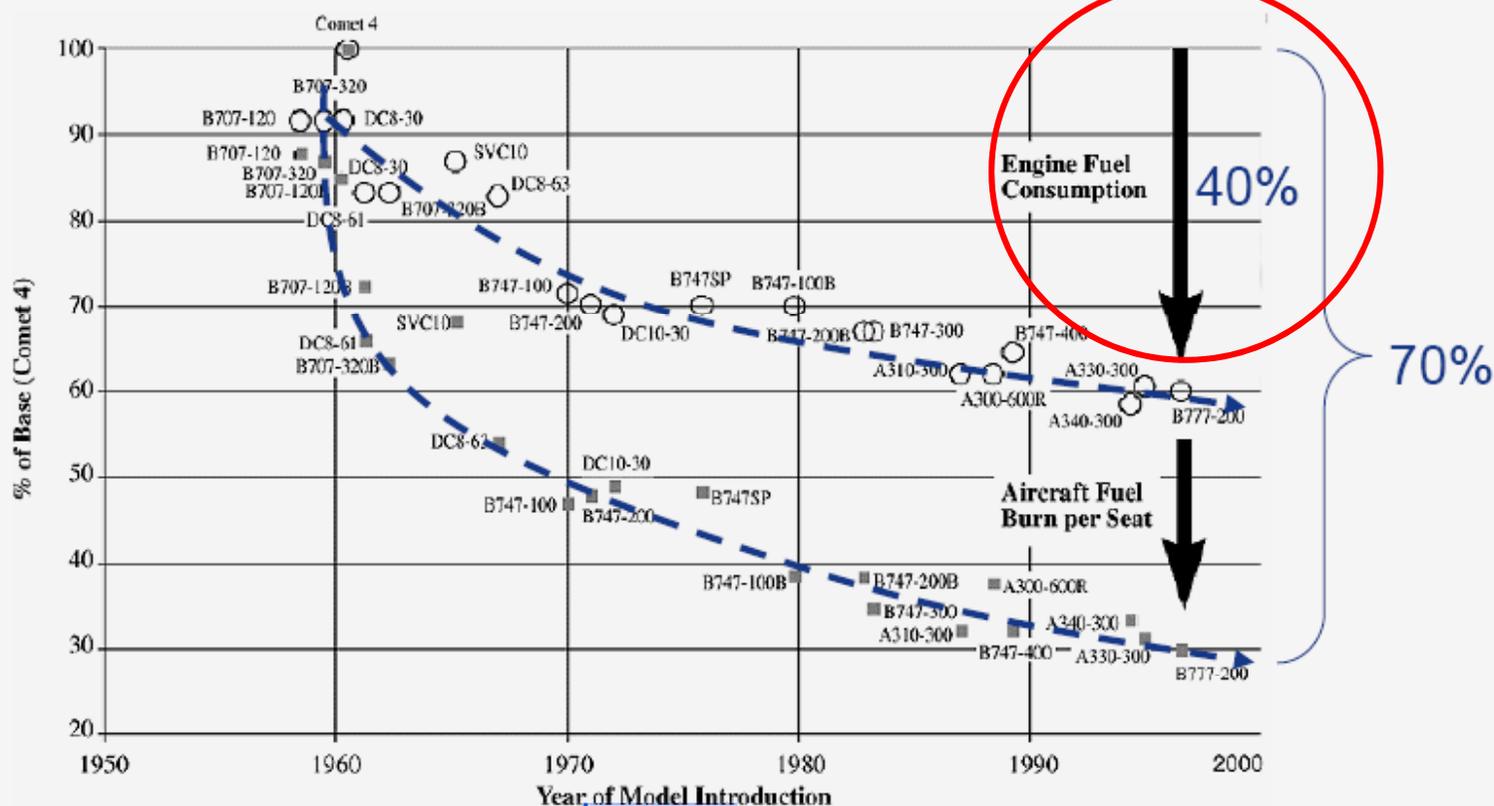
$$\text{Efficiency} \propto \frac{W_{\text{payload}} \cdot \text{StageLength}}{W_{\text{fuel}}}$$

$$\frac{\text{ASK}}{\text{kg}_{\text{fuel}}} = \frac{\text{Stagelength} \cdot \# \text{ seats}}{W_t/g}$$

Available seat-kilometers (ASK)



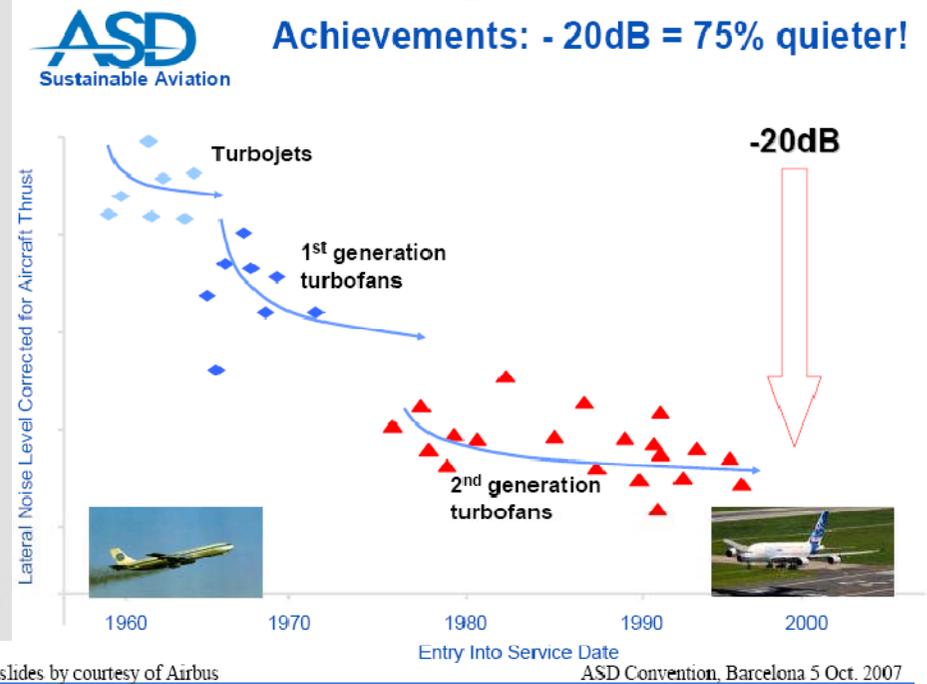
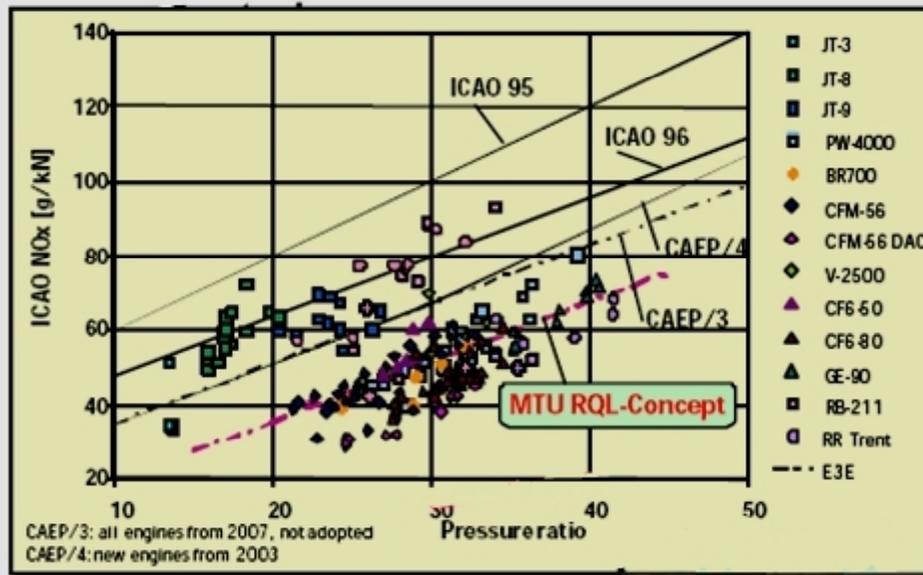
Over 70% efficiency gain in the past 40 years



<http://www.grida.no/climate/ipcc/aviation/133.htm>



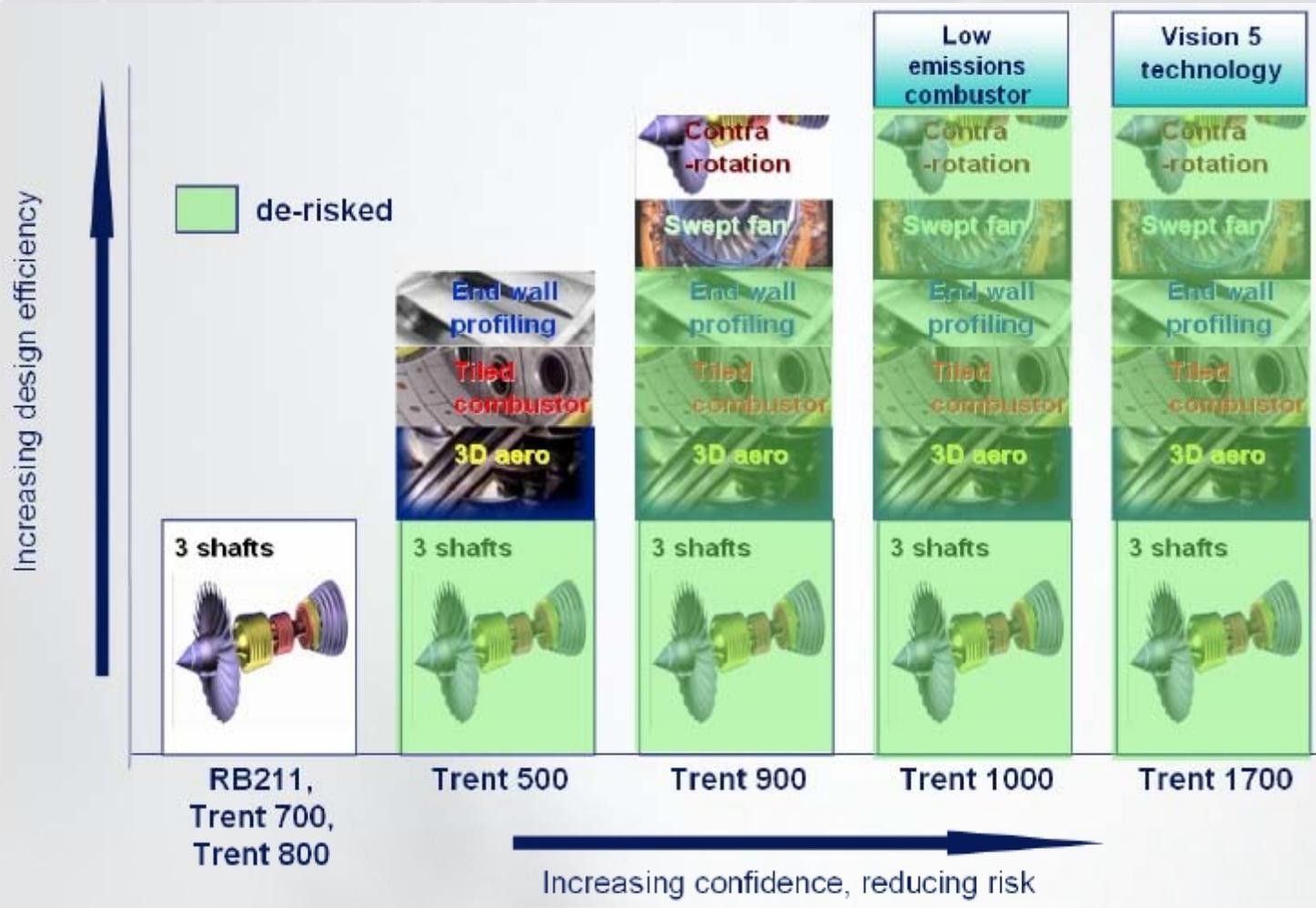
Y además : reducción de emisiones y ruido





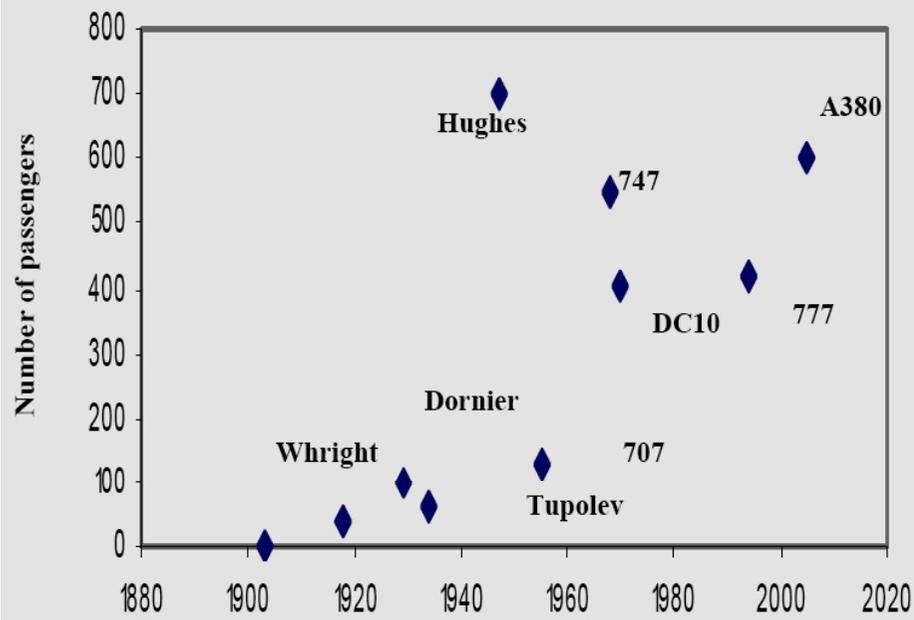
Todo ello con un aumento de la fiabilidad

Ejemplo de evolución : RB-211 –Familia Trent





Y un aumento del tamaño de los motores



The bypass engine led to a rapid increase in the size of aircraft

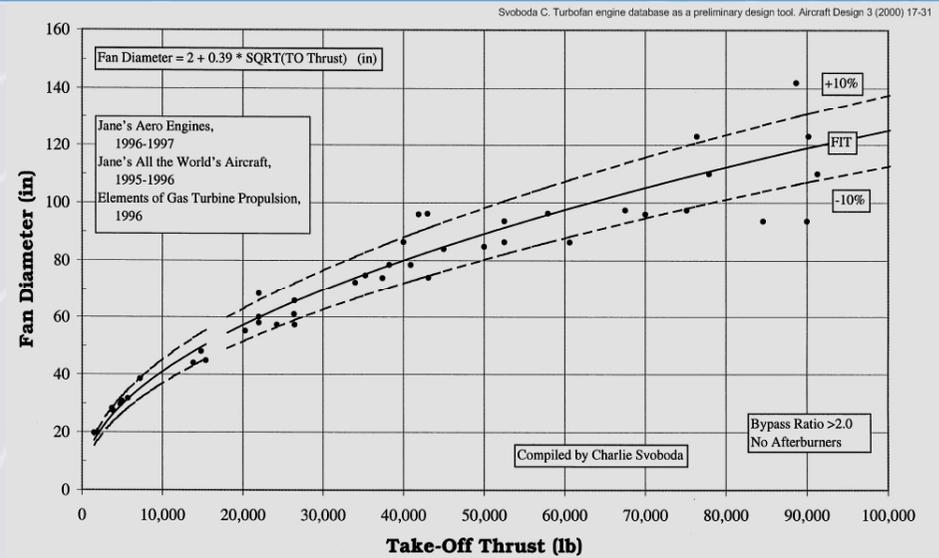


Fig. 3. Fan diameter.

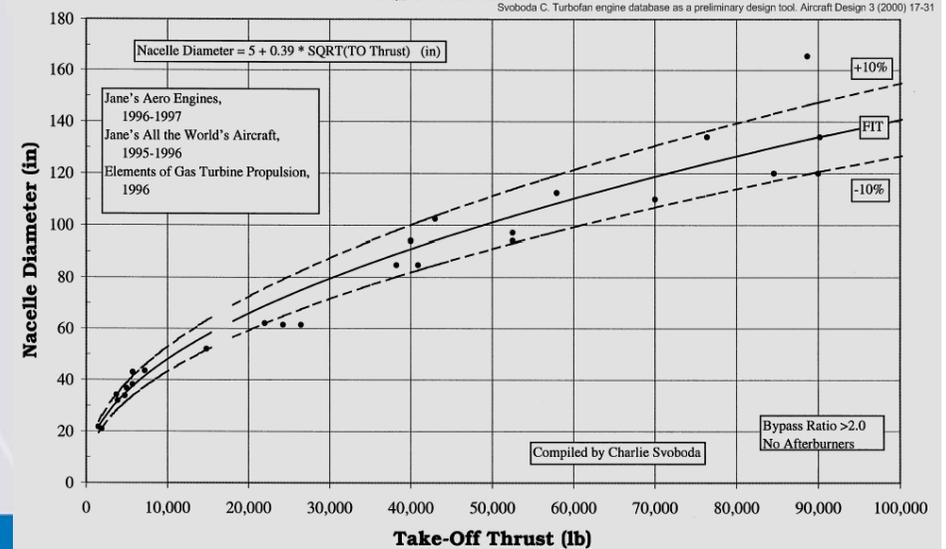
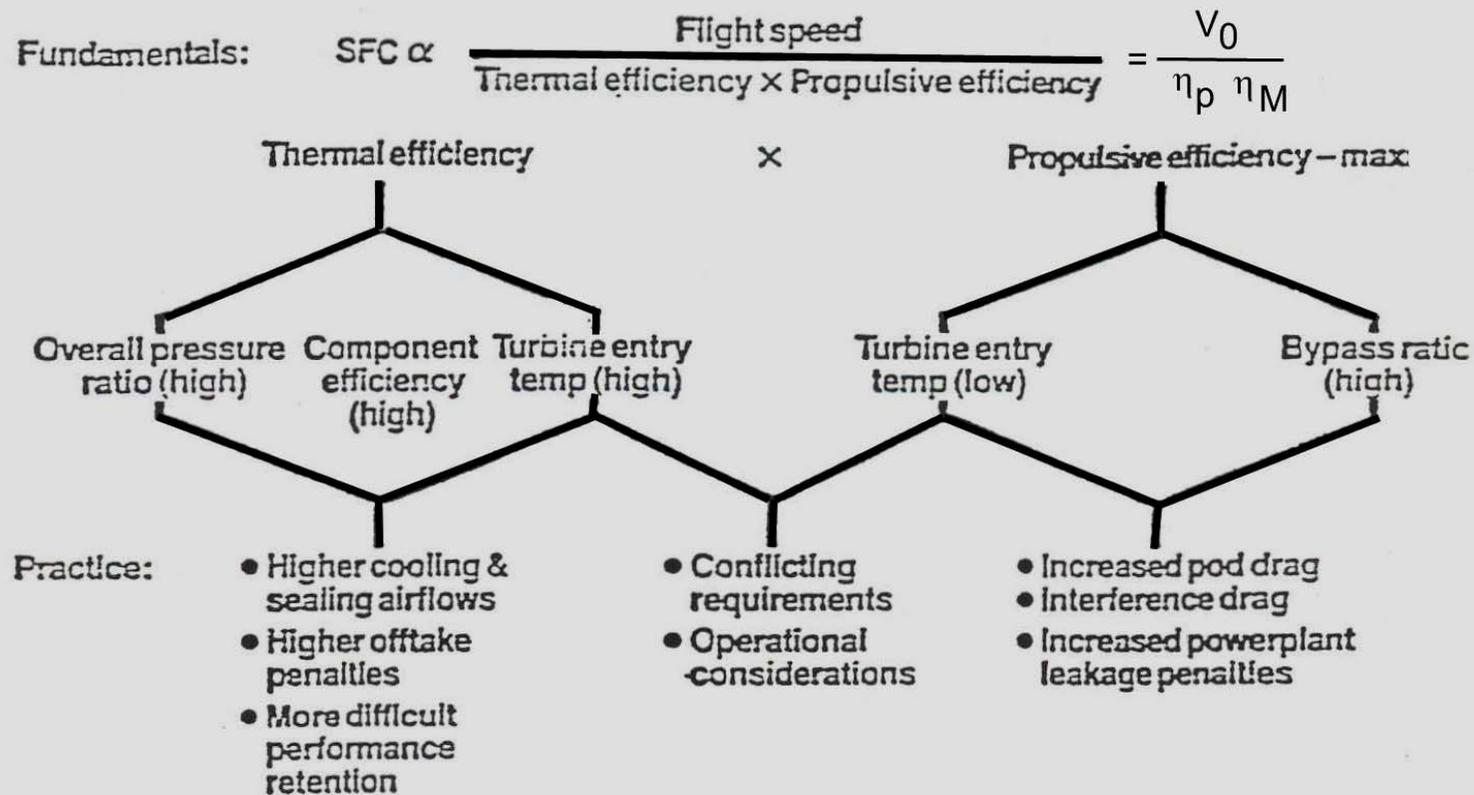


Fig. 4. Nacelle diameter.



Claves de la reducción del consumo específico

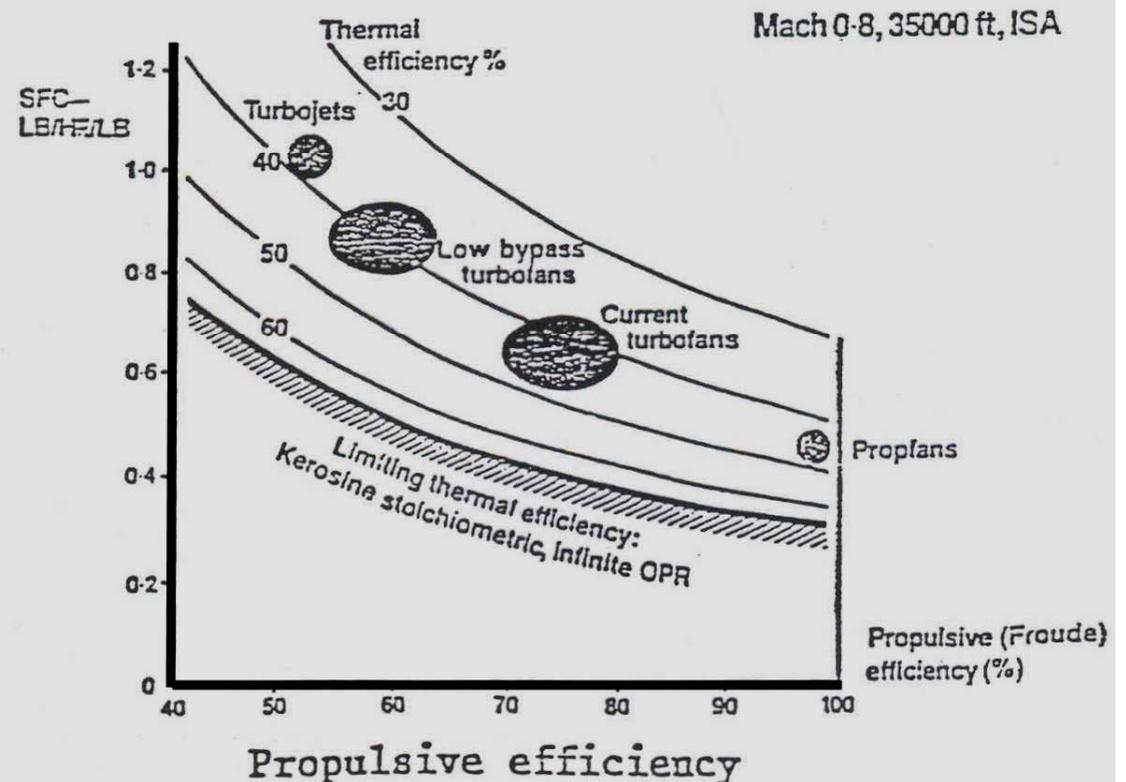


Elementos clave del consumo específico



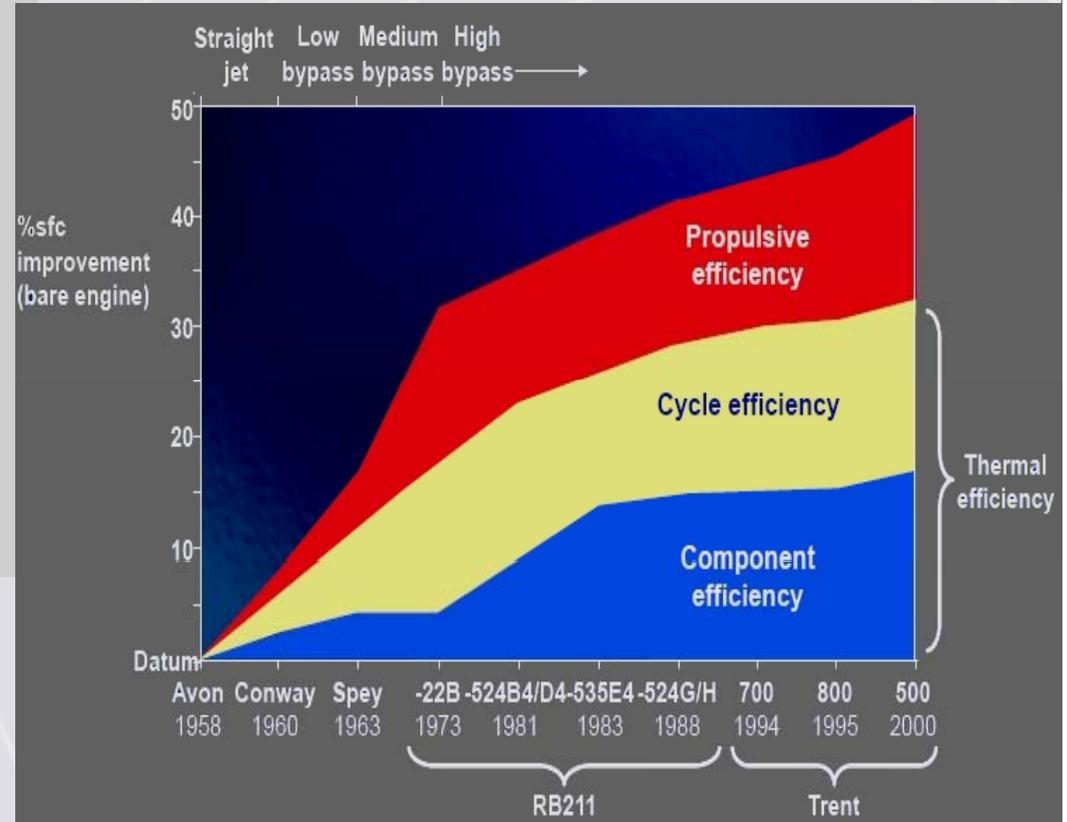
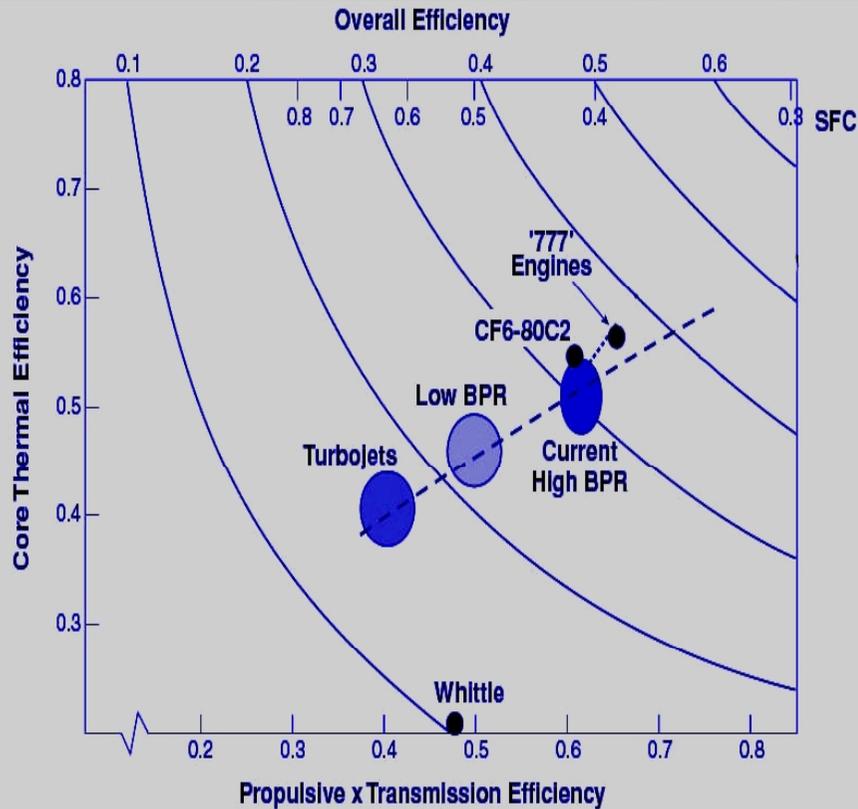
La reducción del consumo específico se obtiene por :

- Mejora del rendimiento motor y
- Mejora del rendimiento propulsivo
- La **mejora del rendimiento del ciclo** se puede obtener, aumentando la relación de compresión global y la temperatura máxima del ciclo, la cual esta limitada por los materiales disponibles y las técnicas de refrigeración. También mediante la mejora de la eficiencia de los componentes.
- El **rendimiento propulsivo**, mediante un cambio de configuración (turbofan) y en el turbofan, disminuyendo V_{19} , bajando la relación de compresión del fan y aumentando la relación de derivación
- El aumento de Δ y disminución conlleva aumentar G/E



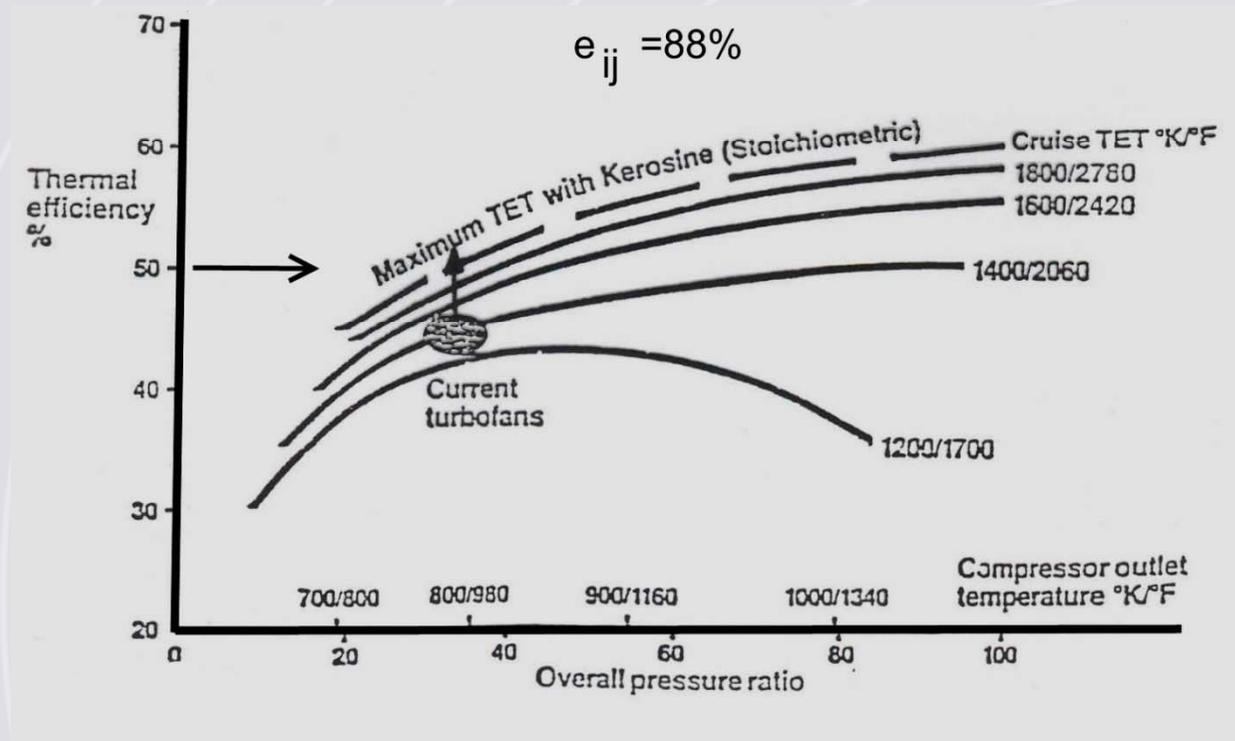


Aumento de η_M , y η_p \longrightarrow aumento de η_{Mp} , disminución de C_E





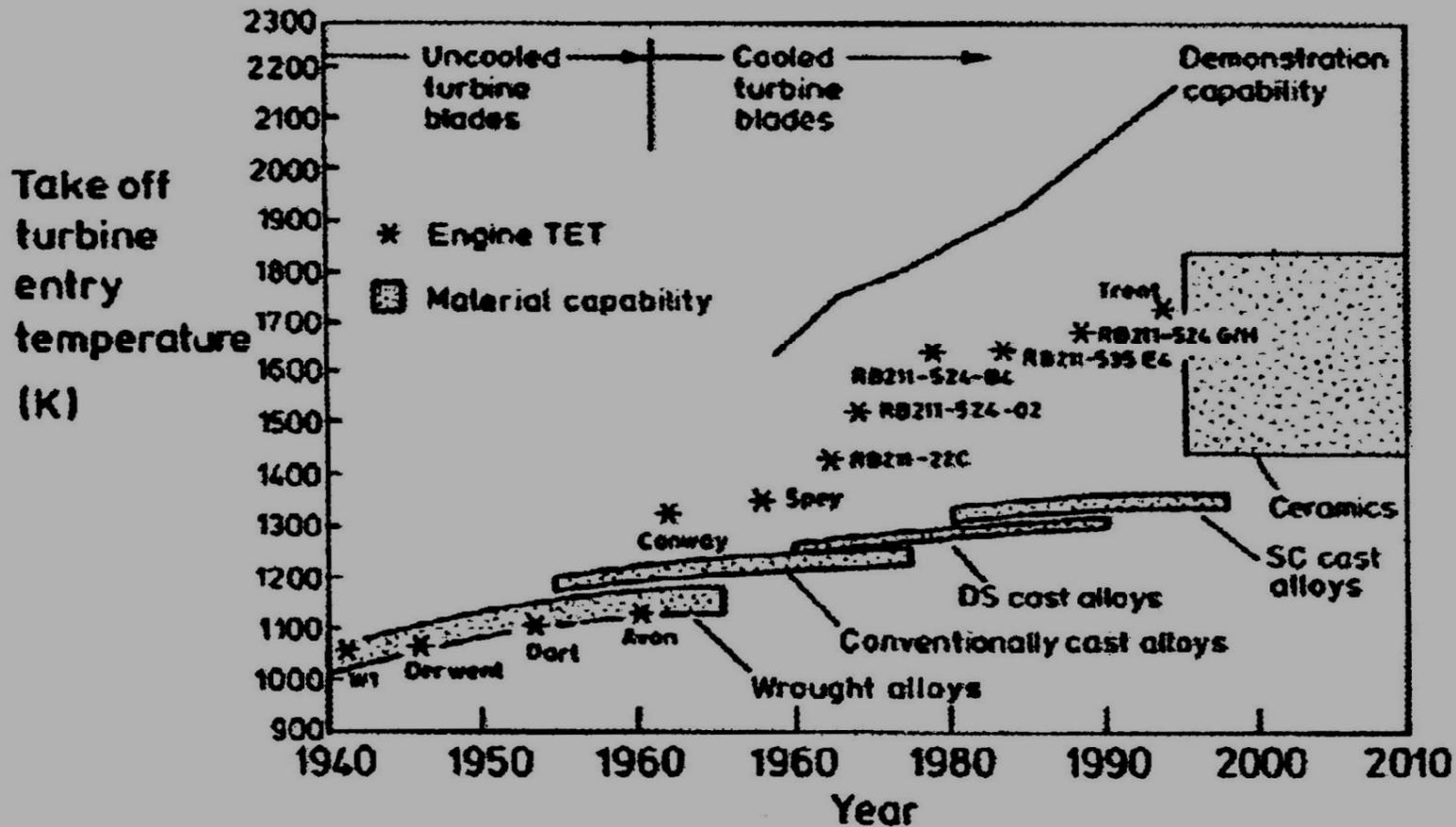
Rendimiento motor función de relación de compresión global y temperatura máxima



Limitado por: materiales de turbina (T_{4t}) y compresor ($\pi_{23} \Rightarrow T_{3t}$)

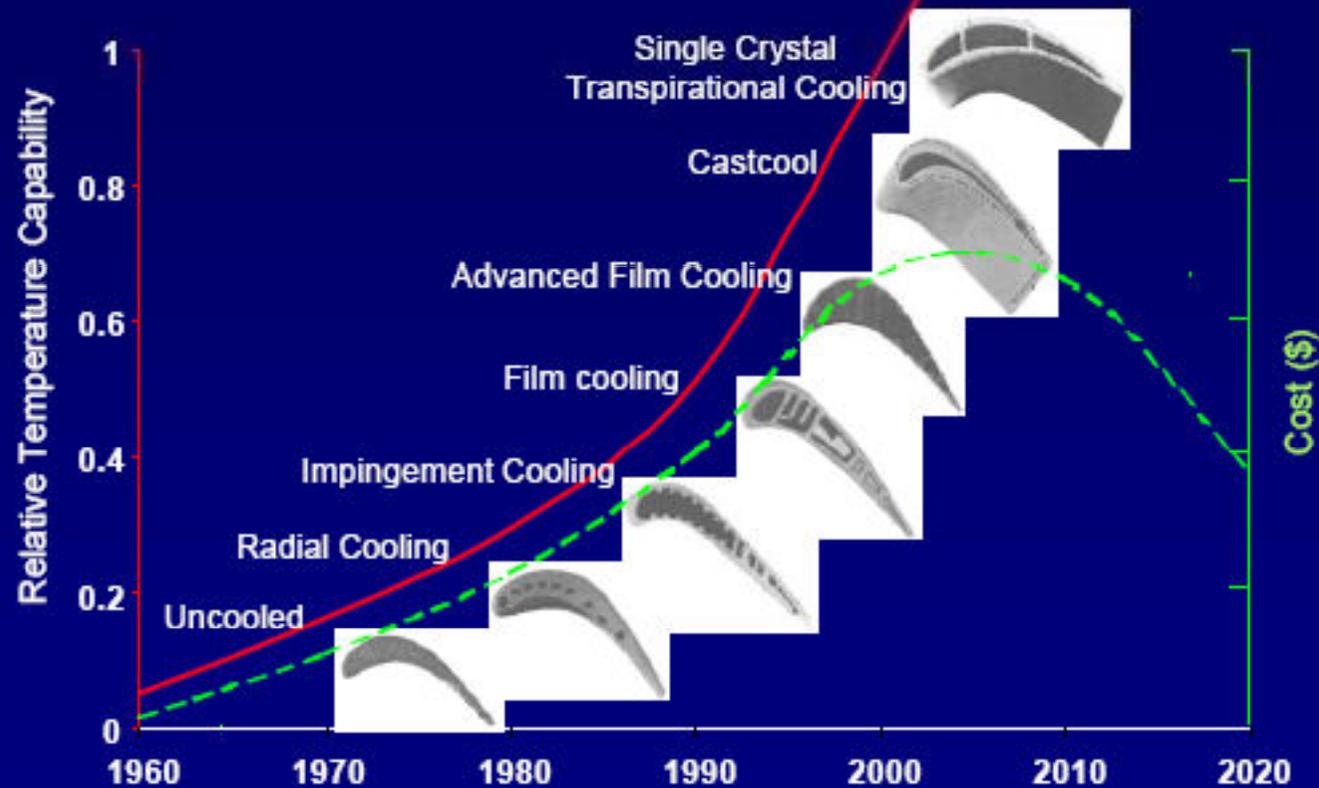


Materiales y refrigeración (T_{4t})



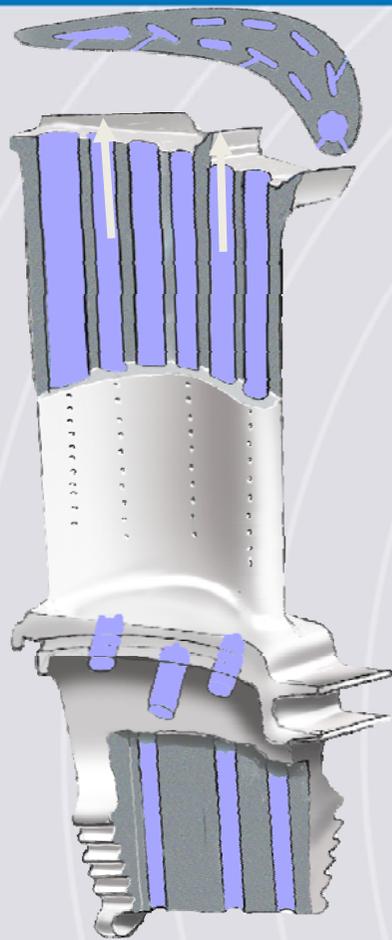


Turbine cooling technology has greatly enabled performance & reliability

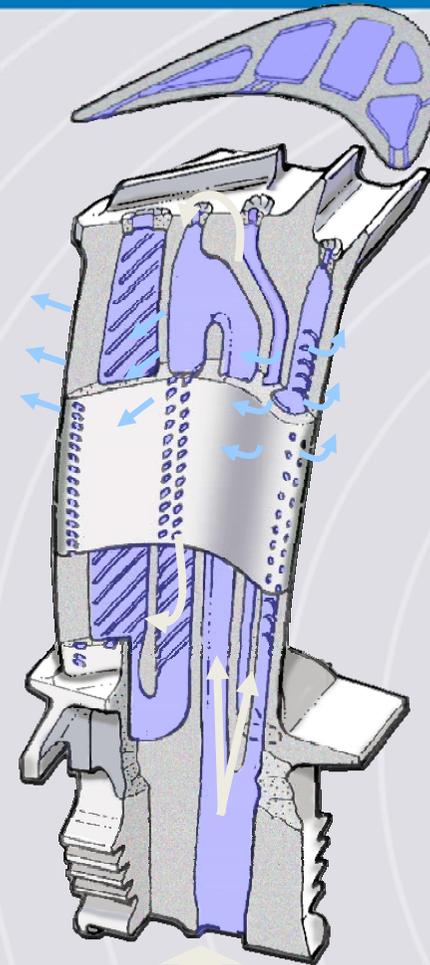




Turbine Cooling



Single pass



Cooling air

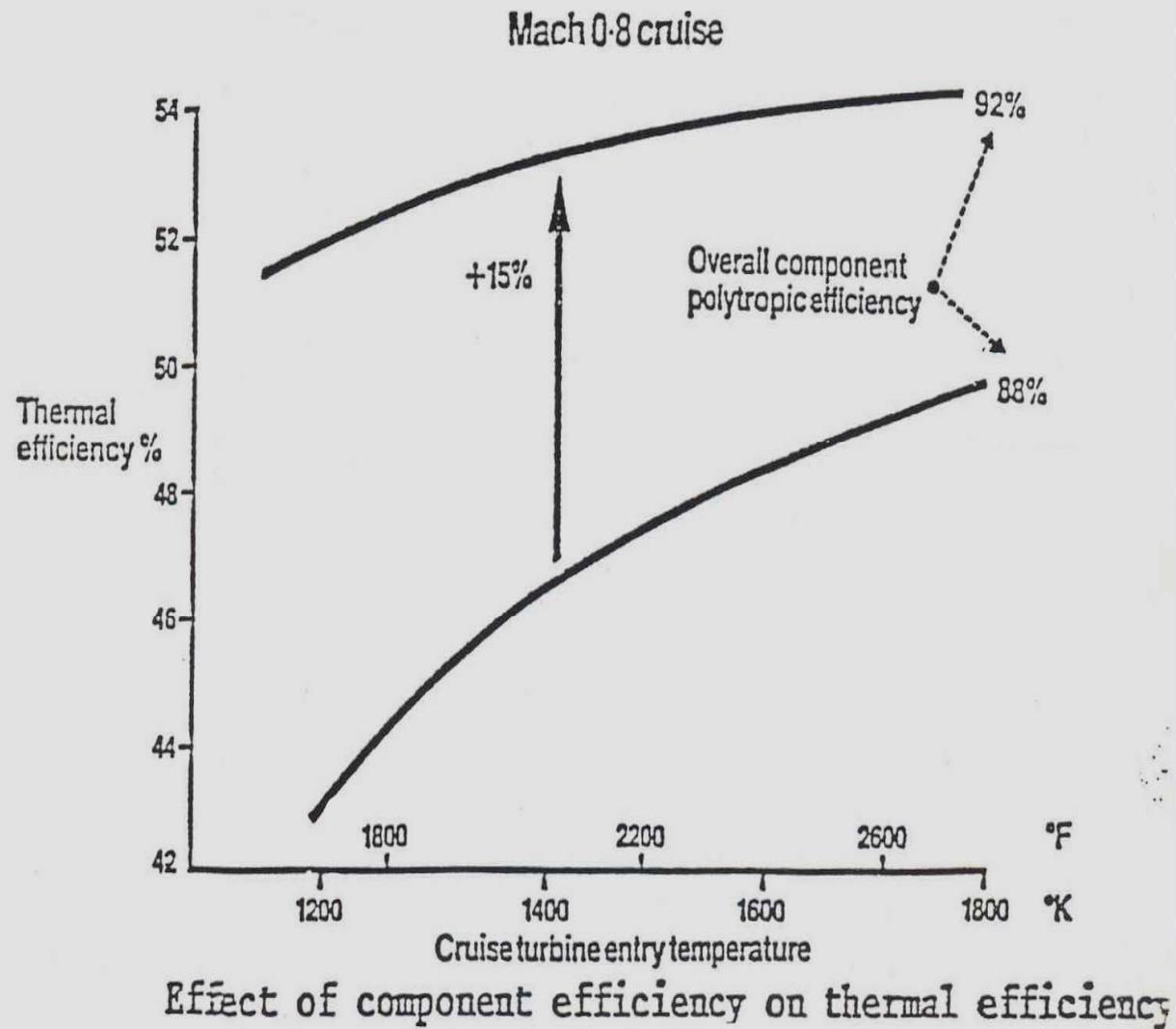
Multi-pass



Thermal Barrier Coating

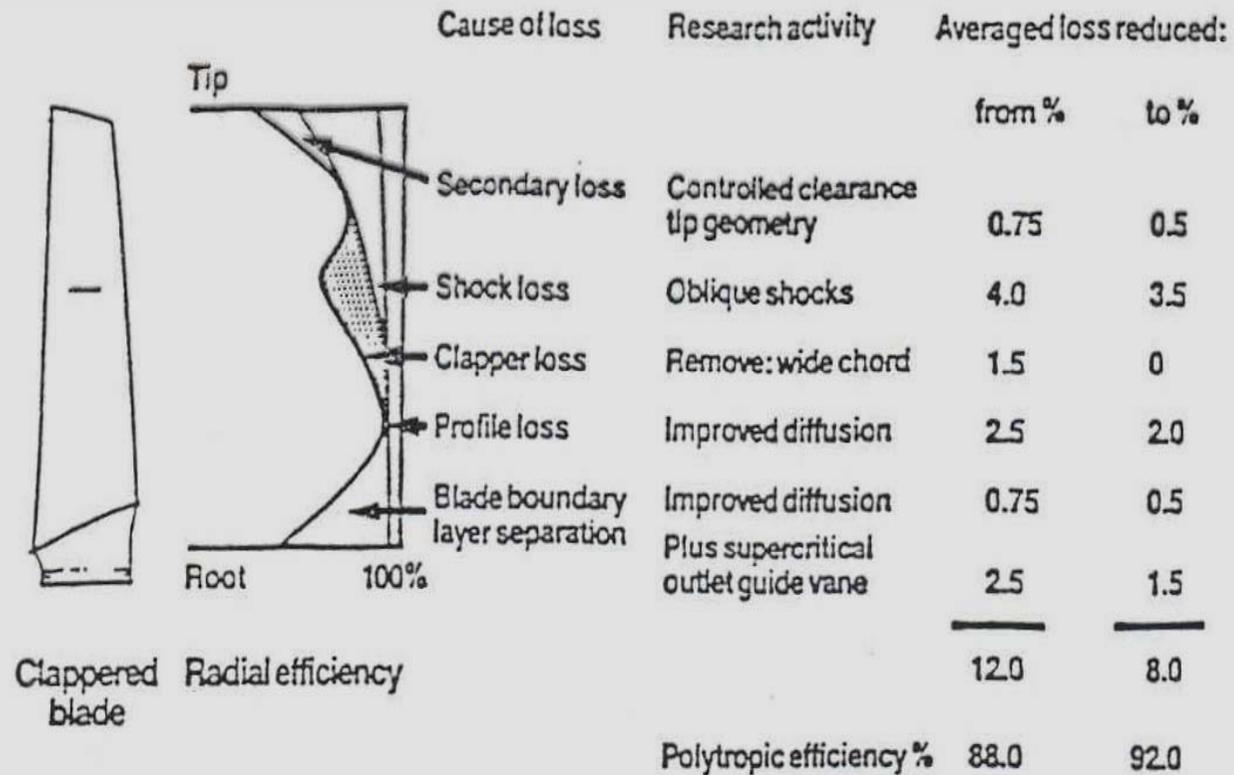


Mejora del rendimiento de componentes (ejemplo)





Ejemplo de mejora de eficiencia de componentes :Alabes de cuerda ancha



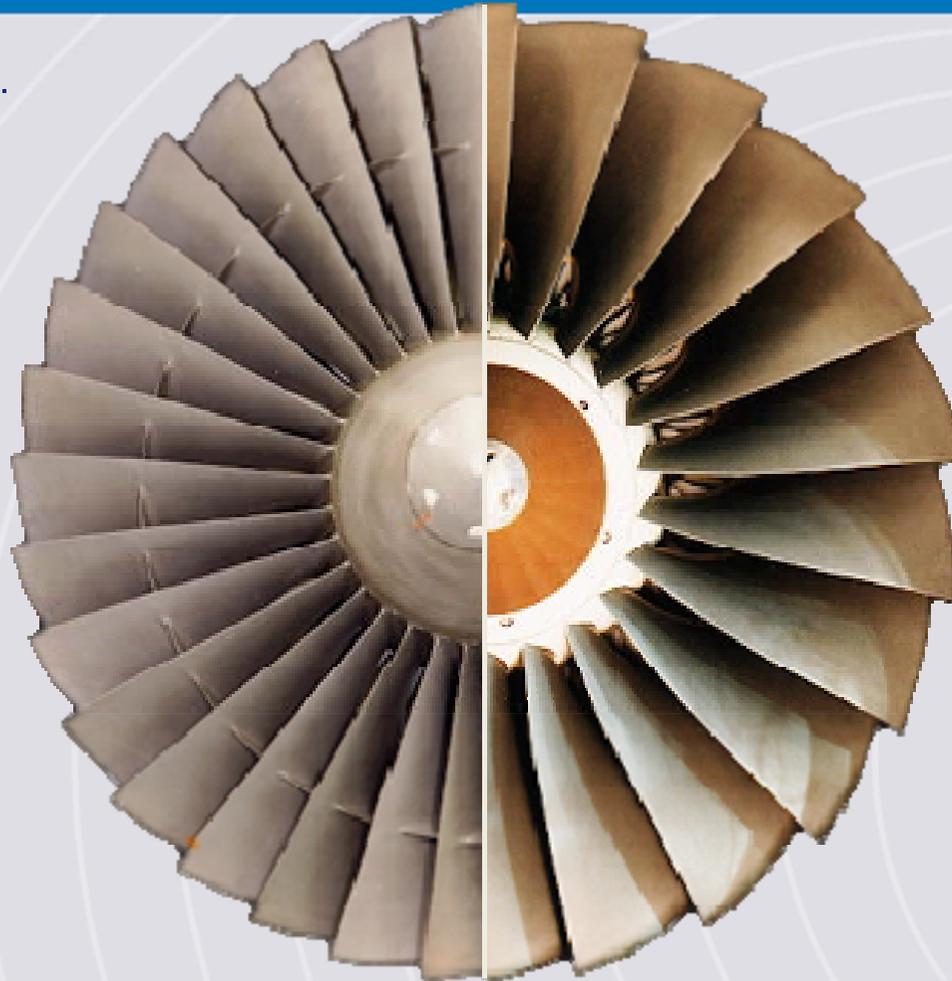
Component efficiency loss distribution and research activity - fans



Ejemplo de mejora de eficiencia de componentes :Alabes de cuerda ancha



Clappered



+ 4% efficiency

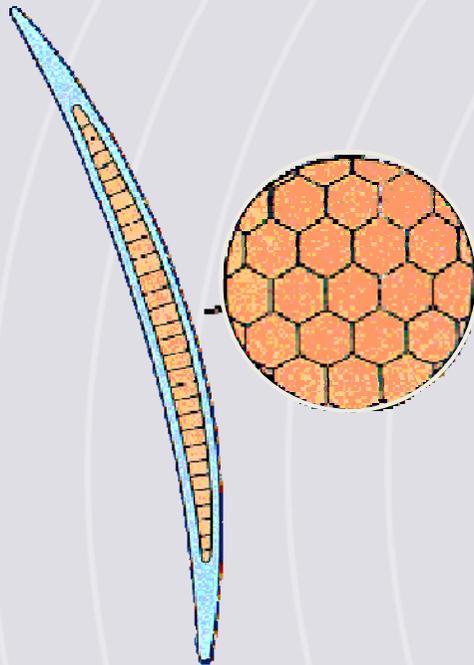


Wide-chord fan



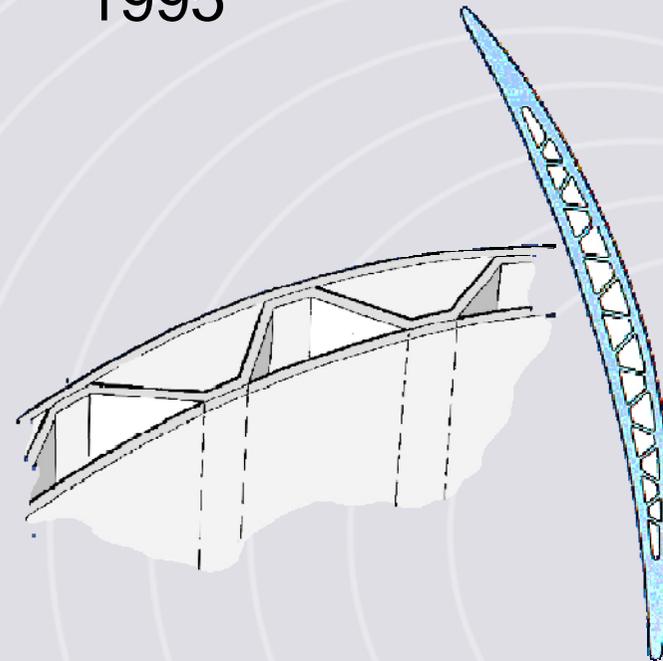
Alabes de cuerda ancha : fabricación muy compleja

1st generation:
1984

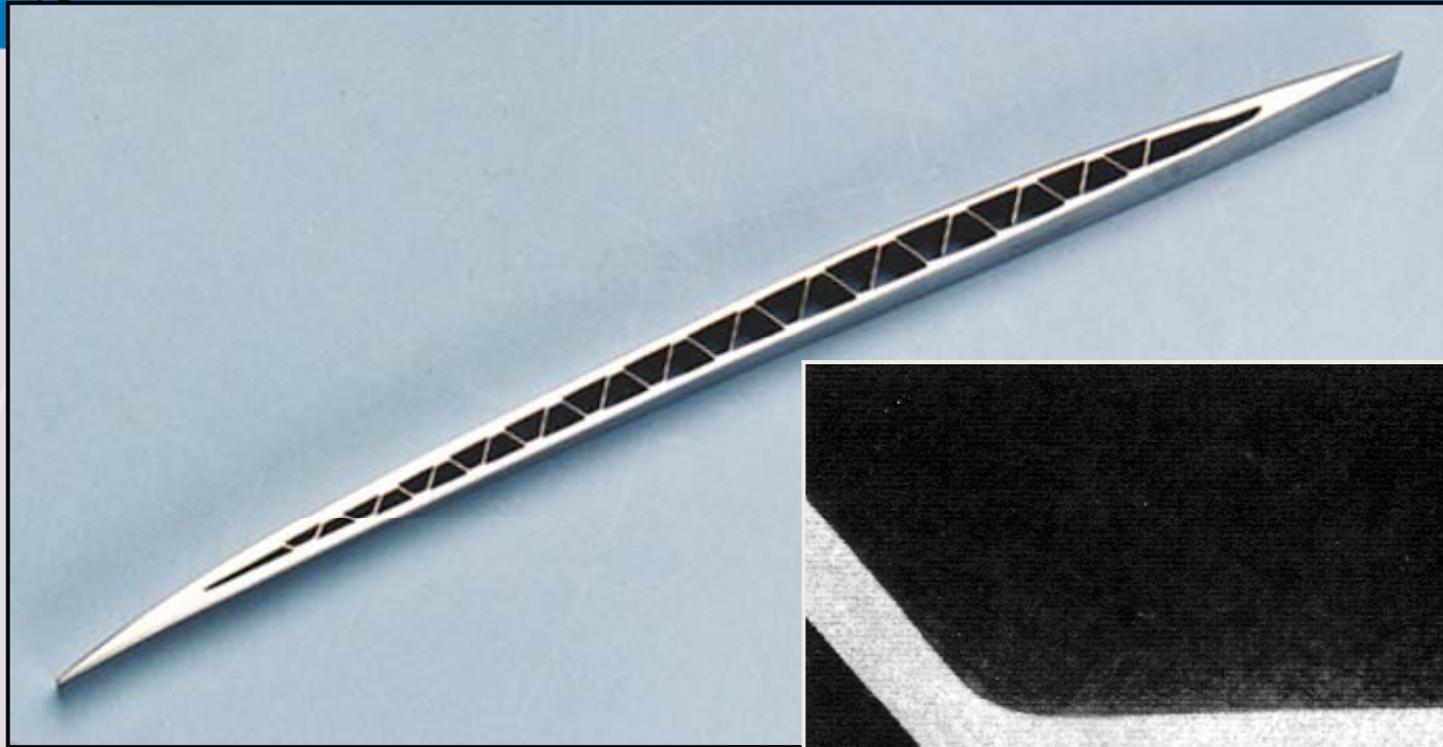


Honeycomb
construction

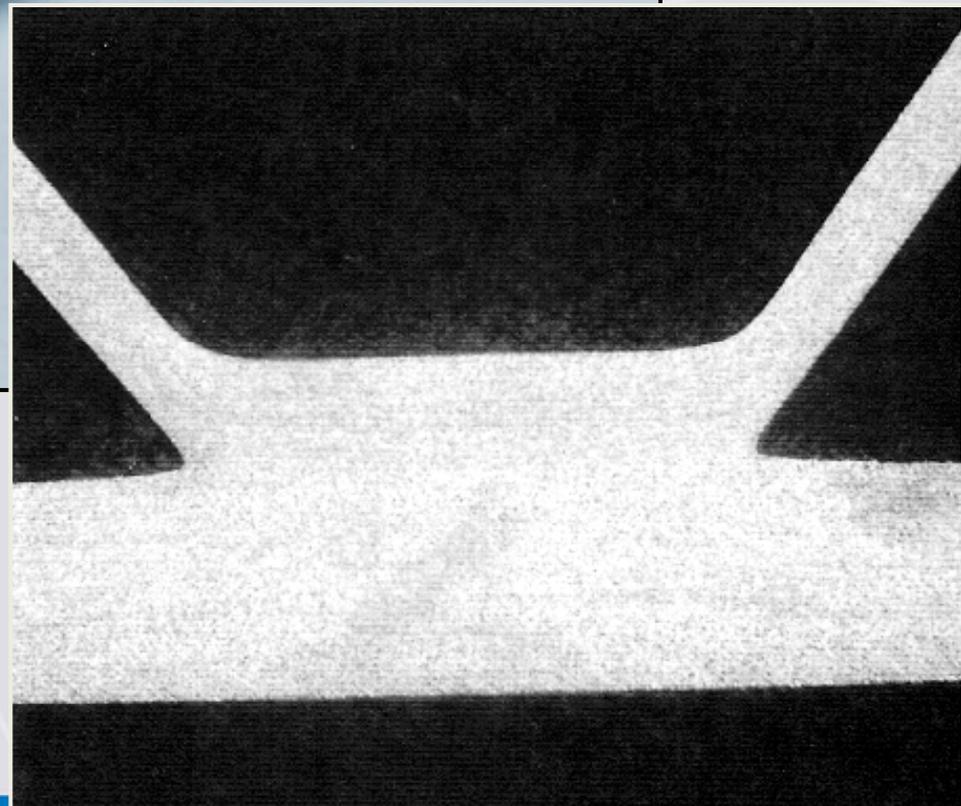
2nd generation:
1995



DB/SPF
construction



Sección del fan





Ejemplo de la influencia de eficiencia de componentes sobre el rendimiento motor

THE THERMODYNAMIC DESIGN OF A CIVIL JET ENGINE

	Effic
Datum engine (TIT=1800/OPR=80/FPR=1.6/ BPR=13.1)	41.6 %
+Fan efficiency +1 %	+0.4
+ Booster efficiency +1 %	+0.1
+Compressor efficiency +1 %	+0.5
+Combustor pressure loss -1 %	+0.1
+Turbine efficiency +1 %	+0.5
+Metal temperature +1 %	+0.1
Summary (FPR=1.6/ BPR=15)	43.3 %
Ideal engine (TIT=1800/OPR=80/FPR=1.6/BPR=20.1)	53.0 %

Valores típicos del rendimiento motor en los turbofanés actuales: alrededor del 50%



Influencia de la eficiencia de componentes sobre el consumo específico

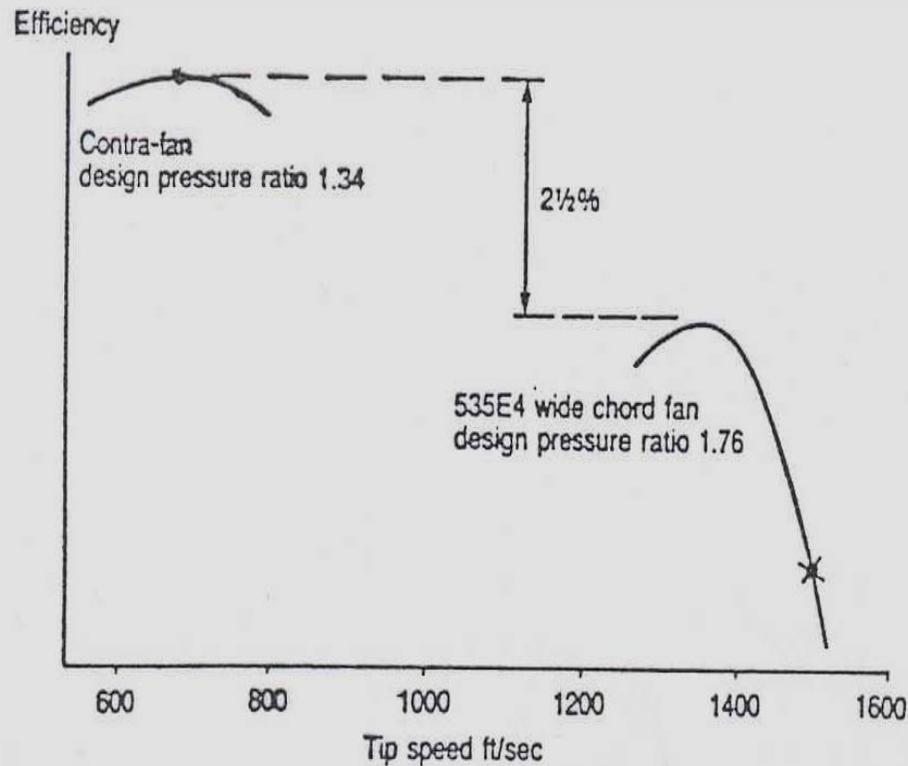
RB 211 PERFORMANCE EXCHANGE RATES
(TYPICAL, ROUNDED)

	CHANGE	Δ SFC % (CRUISE) FIXED THRUST	Δ TET °K (TAKE-OFF) FIXED THRUST
FAN EFFICIENCY (TIP)	+ 1%	- 0.55	- 2.5
FAN ROOT EFFICIENCY	+ 1%	- 0.10	- 1.0
IP COMPRESSOR EFFICIENCY	+ 1%	- 0.35	- 4.0
HP COMPRESSOR EFFICIENCY	+ 1%	- 0.35	- 4.0
COMBUSTION PRESSURE LOSS	- 1% Δ P/P	- 0.35	+ 2.5
HP TURBINE EFFICIENCY	+ 1%	- 0.40	- 2.5
IP TURBINE EFFICIENCY	+ 1%	- 0.30	- 2.0
LP TURBINE EFFICIENCY	+ 1%	- 0.60	- 3.0
BYPASS DUCT LOSS	- 1% Δ P/P	- 1.00	- 4.5
HP TURBINE BLADE COOLING AIR	- 1%	- 0.25	- 5.5

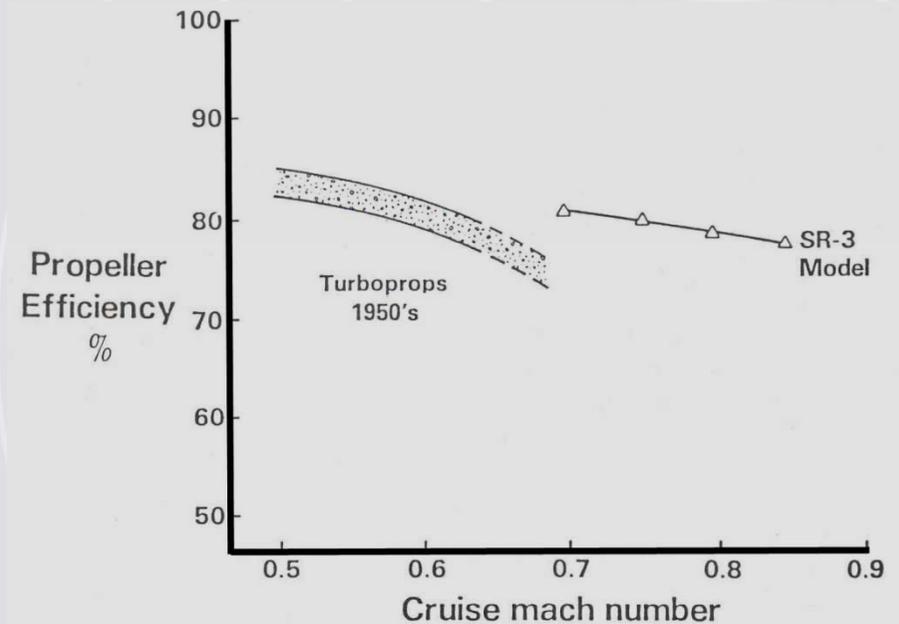
- NOTES
1. EXCHANGE RATES FOR DIFFERENT RB 211 TYPES ARE SIMILAR.
 2. EXCHANGE RATES INCREASE IN SIZE AT LOWER THROTTLE SETTINGS:
TYPICALLY 50% LARGER AT HOLD CONDITIONS.
 3. INCREASED COOLING AIR MAY ALSO INFLUENCE TURBINE EFFICIENCY.



Cambio de configuración



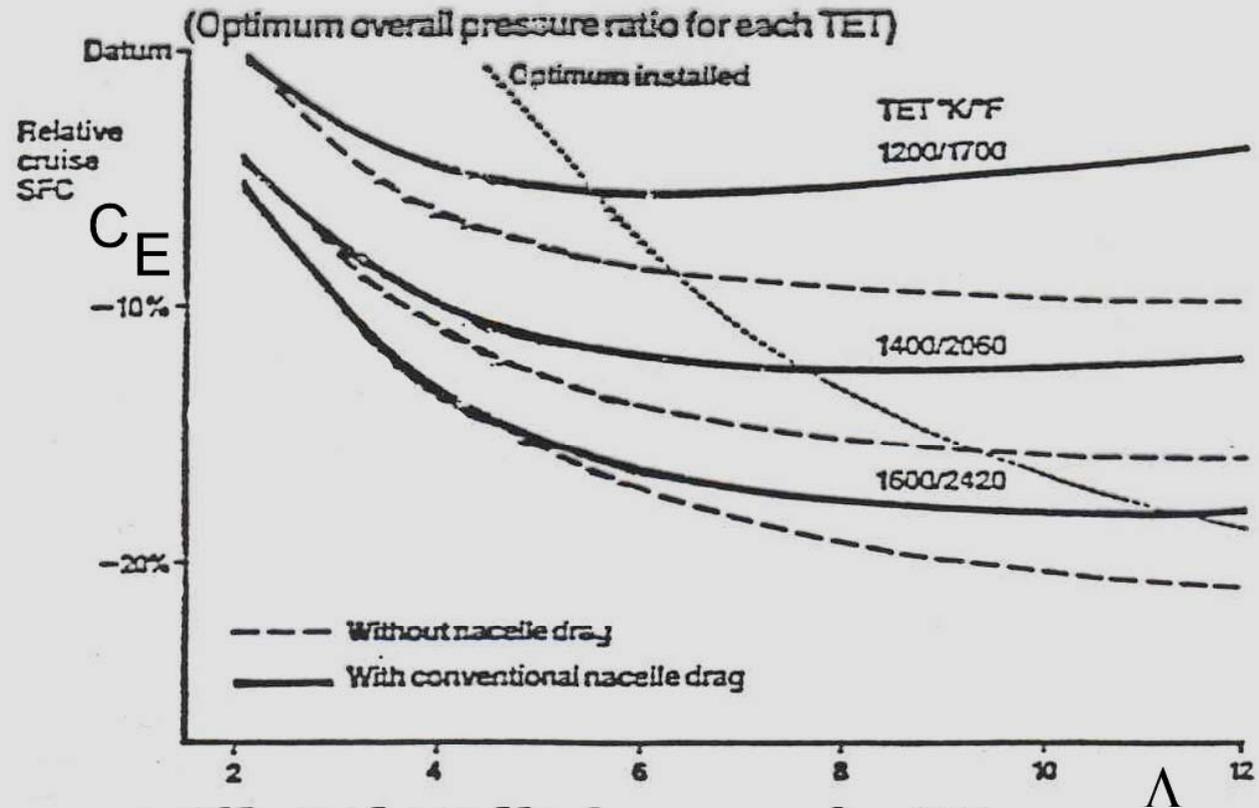
Comparison of Contra-Rotating Ultra High Bypass Ratio Fan with RB211-535E4 Wide Chord Fan





LIMITACIONES AL CAMBIO DE CONFIGURACIÓN

Aumento de Λ : aumento de diámetro, disminución de vueltas del fan y en fanes convencionales, de la turbina de baja



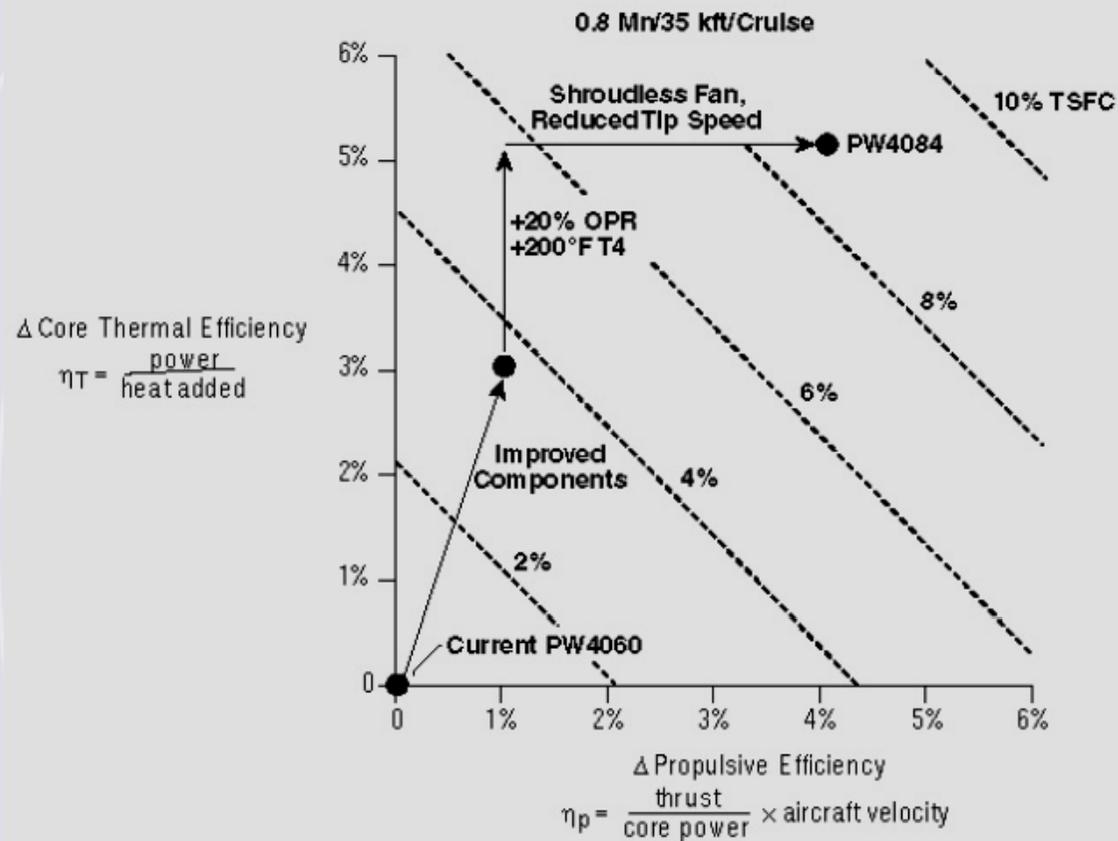
Effect of nacelle drag on cruise SFC

$$\pi_{23} \text{ óptimo para cada } T_{4t} \quad e_{ij} = 88\%$$

Teóricamente el rendimiento propulsivo crece con Λ , En los turbofanes valores típicos de Λ de 7-8 proporcionan rendimientos propulsivos del 80%.

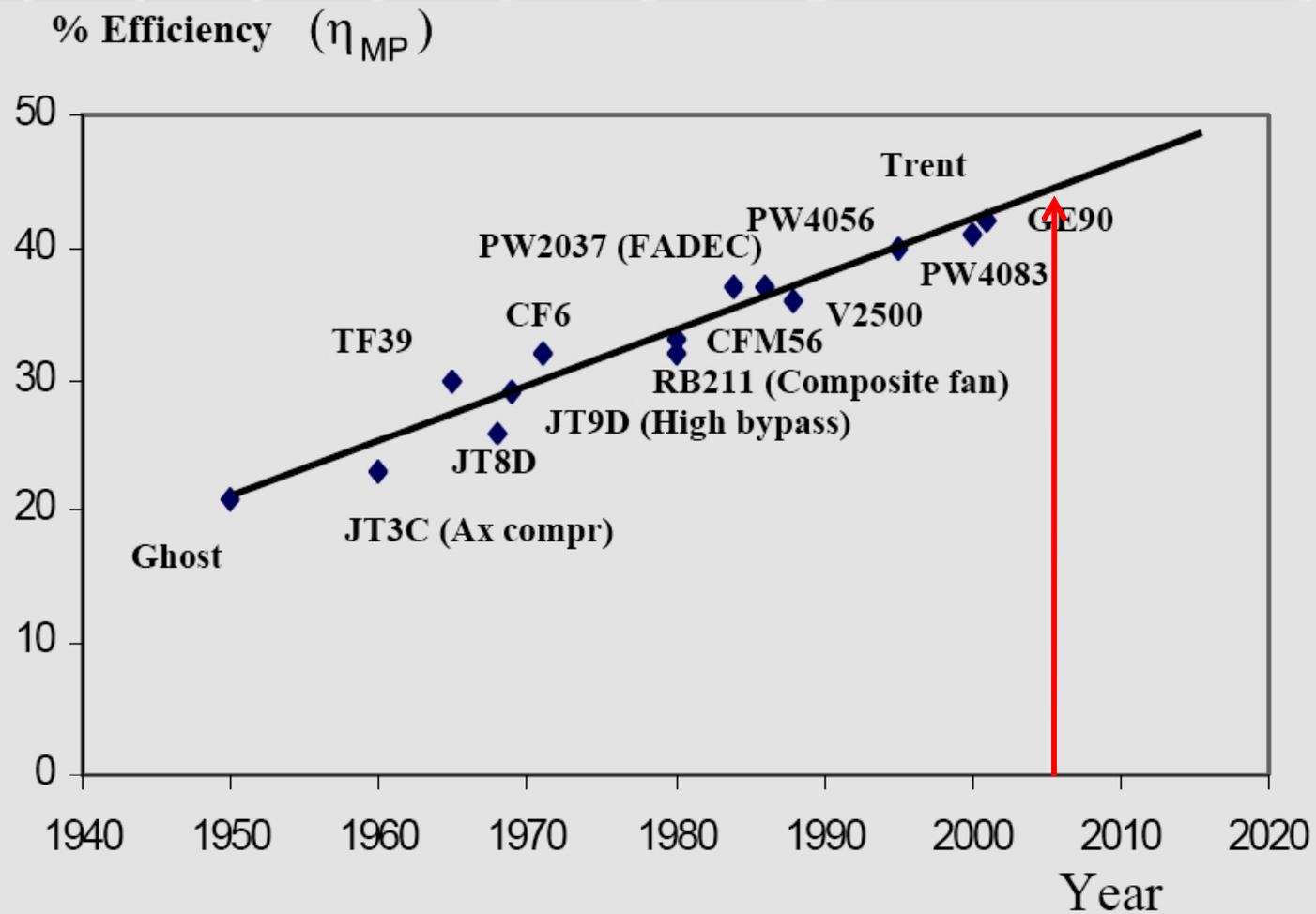


EXAMPLE OF CYCLE PERFORMANCE IMPROVEMENT





Resultado: situación actual

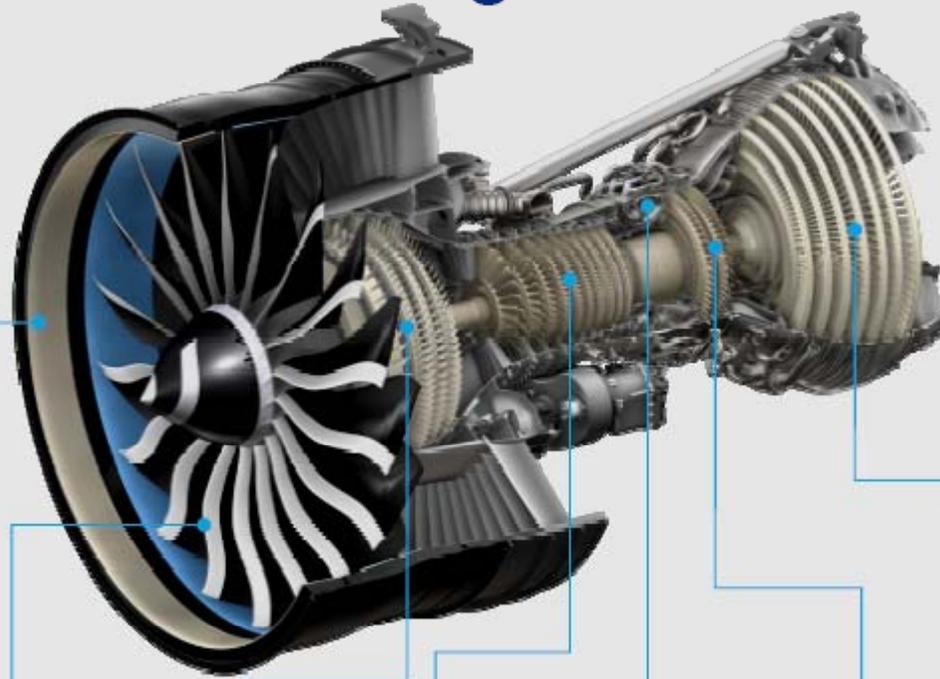


The engine efficiency has increased a lot



Situación actual

GE aircraft engine



Composite fan case

Material improves strength, is corrosion-free with lower weight than metal

Composite fan blades

Designed for fewer parts, greater efficiency, lower noise and most resiliency

Booster

Debris rejection system filters air to reduce downstream wear

Compressor

Advanced aerodynamics and high compression improve fuel burn with fewer parts

Combustor

Burns fuel at lower peak temperatures while delivering our lowest emissions

High pressure turbine

Advanced alloys and coatings withstand heat for long life and retain performance over time

Low pressure turbine

Fewer, more efficient parts and durable materials mean less waste and better performance



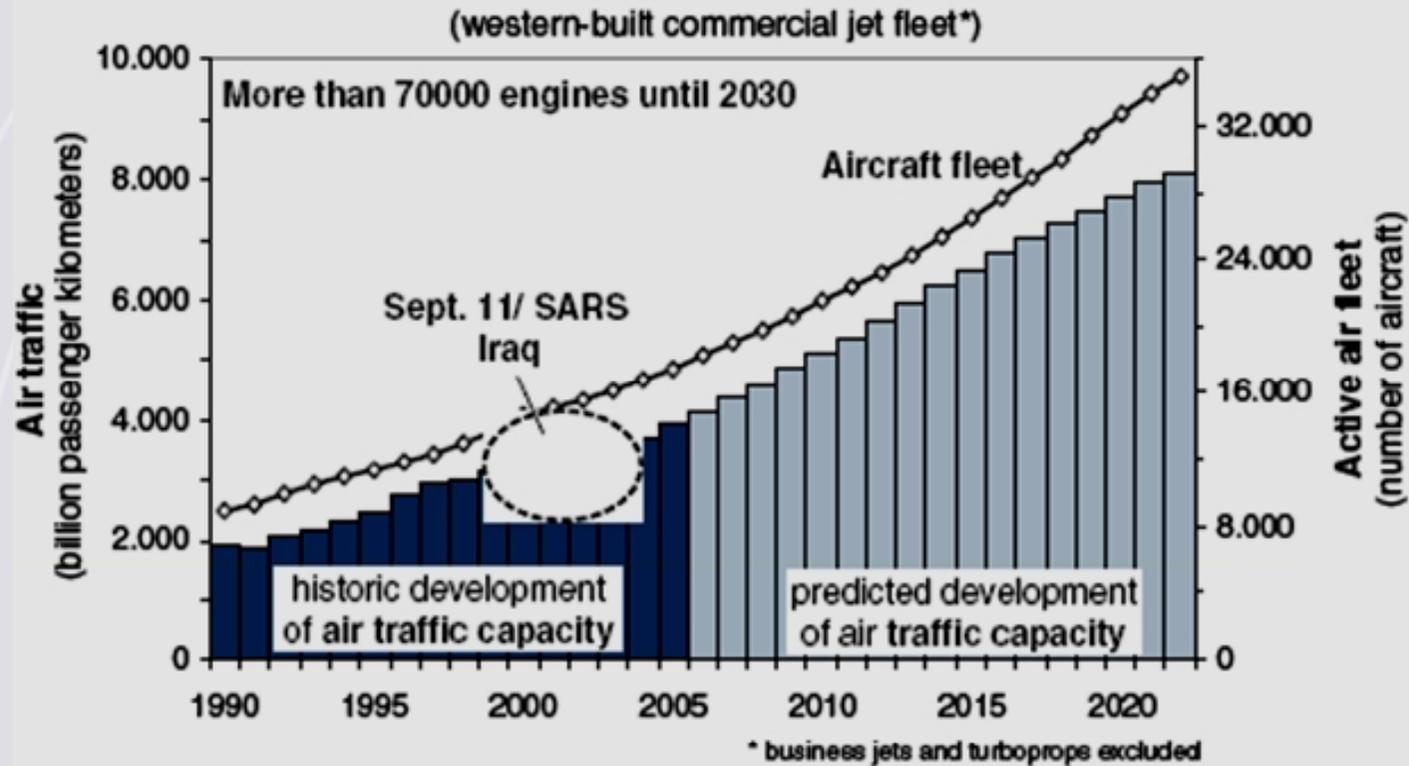
Imagination at work

GENx engine in 2008 will mark the introduction of generation of large engines for commercial aircraft



Situación actual : Objetivos

Crecimiento del tráfico aéreo: esta previsto siga creciendo alrededor del 5% anual

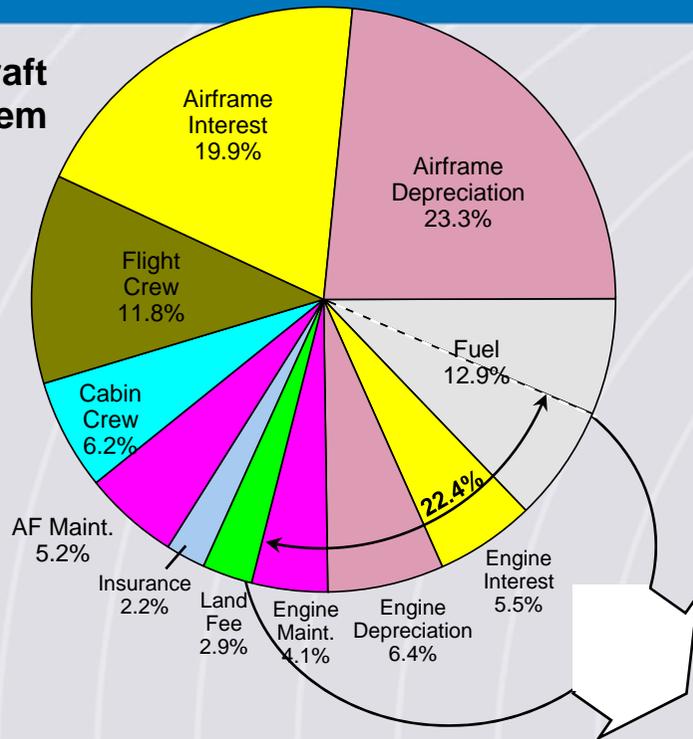


Objetivo : Reducción de costos →



COSTOS: 2000 NM Mission - 50 Cents / Gallon Fuel

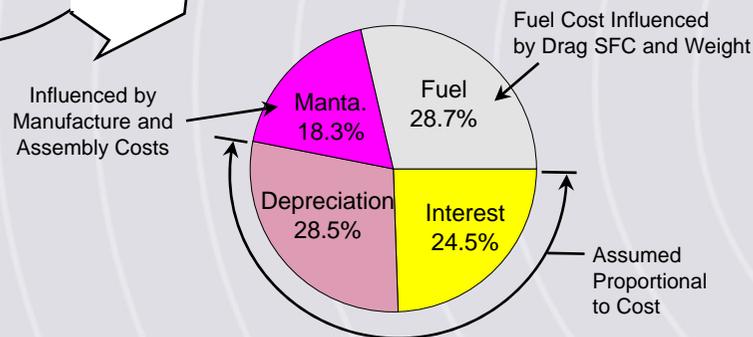
Aircraft System



- Goal: 50% Reduction in Engine Cost of Ownership

Las tecnologías avanzadas de motor están enfocadas a obtener mínimo consumo específico, reducción de costes de fabricación y mantenimiento y reducción de peso del motor

Engine Controlled Costs

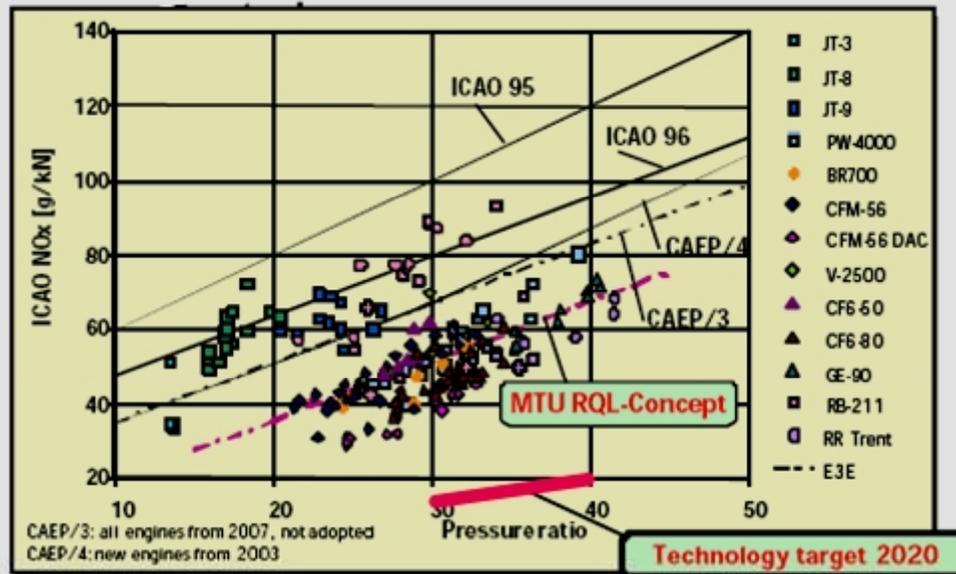


Engine Cost of Ownership Model

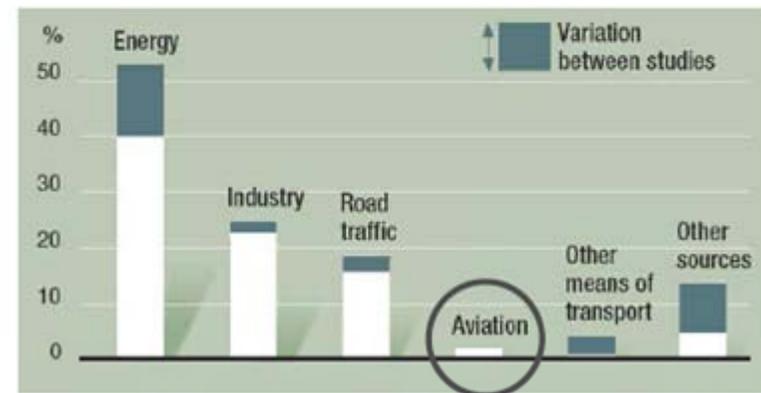


Y reducir el impacto ambiental de las aeronaves

Limitaciones de contaminantes, NO_x, CO, HC y efecto invernadero CO₂



- Aviation accounts for about 2% of total man-made CO₂ emissions...



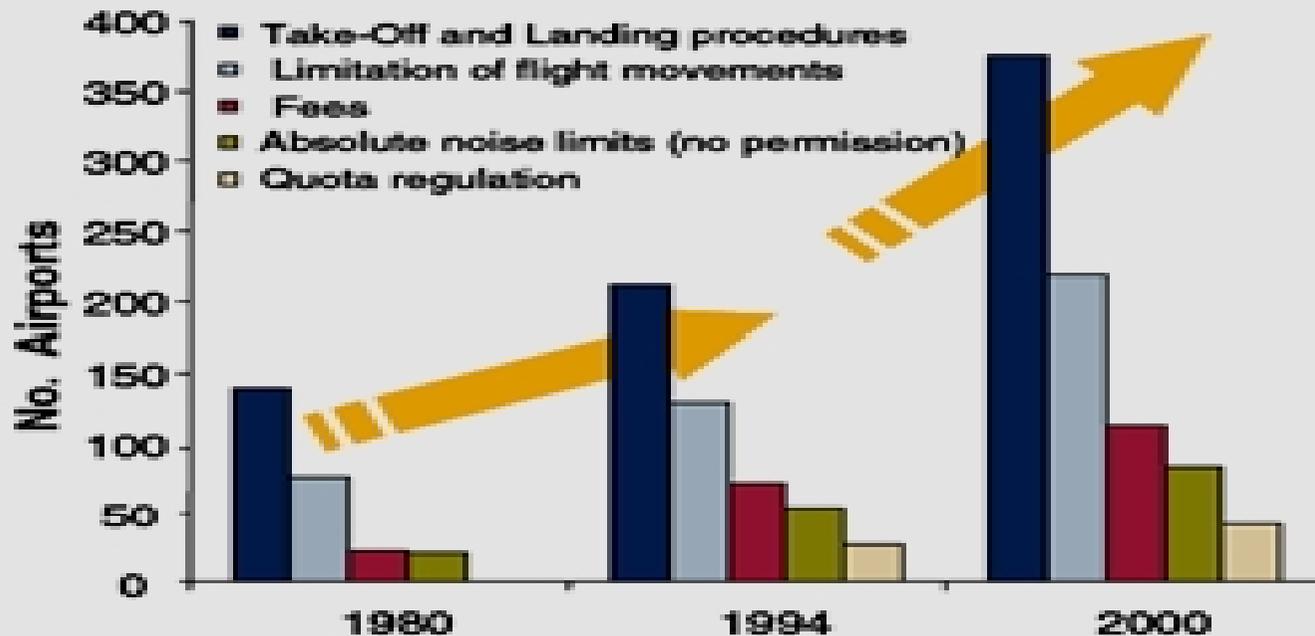
- ... aviation also contributes 8% of global GDP and supports 29 million jobs

slides by courtesy of Airbus ASD Convention, Barcelona 5 Oct. 2007



Limitaciones de ruido

No. of Airports with Noise Restrictions



Total number: 595
Thereof US/CND: 310
Europe: 168
Asia: 47

Source: The Boeing Company,
595 airports in database (2000)

Airport Noise Restriction Development.



Ejemplos de objetivos

EXAMPLE:

*Airbus targets
for industrial
operations by
2020*

- 30% reduction in energy consumption
- 50% reduction in CO₂ emissions
- 50% reduction in solvent emissions
- 50% reduction in waste production
- 50% reduction in water consumption
- 80% reduction in water discharge



Strategy for the next century ... Cleaner, Quieter, Faster, Affordable

Fuel burn	20%
Emissions (NOx)	85%
Noise	55%
Cost of ownership	30%
Reliability	50%





9 *Defining Technologies for the Next Millennium*

GE Aircraft Engines

Goals and Payoffs - Propulsion System

GOALS	PAYOFFS
<ul style="list-style-type: none">• 10% Reduction in Fuel Burn *	<ul style="list-style-type: none">• Reduced Greenhouse Gas Emissions• Reduced Cost of Travel• Reduced Dependence on Fossil Fuels• Conservation of Nonrenewable Energy
<ul style="list-style-type: none">• ~50% Reduction in NO_x, CO, and HC **	<ul style="list-style-type: none">• Improved Air Quality around Airports• Reduced Depletion of Ozone Layer
<ul style="list-style-type: none">• 50% Reduction in Ownership Costs*	<ul style="list-style-type: none">• Reduced Cost of Travel• Improved Safety and Reliability• Improved Airline Customer Solvency• Improved Airport Throughput
<ul style="list-style-type: none">• 10% Reduction in CO₂ Emissions *	<ul style="list-style-type: none">• Reduced Greenhouse Gases
<ul style="list-style-type: none">• 30 dB Reduction in Noise ***	<ul style="list-style-type: none">• Quieter Neighborhoods around Airports/ Increased Traffic Throughput
<ul style="list-style-type: none">• 50% Reduction in In-Flight Shutdowns and Engine-related Delays and Cancellations *	<ul style="list-style-type: none">• Improved Air Safety Ease of Travel and Improved Airport Throughput
<ul style="list-style-type: none">• 2X Increase in Thrust / Weight *	<ul style="list-style-type: none">• Increased Range / Payload or Reduced Fuel Burn

* Relative to 1998 State-of-the-Art Operational Aircraft

** Relative to ICAO Requirements

*** Relative to FAA Stage 3 Limits



Actuaciones :

Ejemplo de acciones típicas para mejorar el consumo específico

Higher propulsive efficiency

- Unconventional configuration to minimise nacelle drag allowing higher optimum bypass ratio

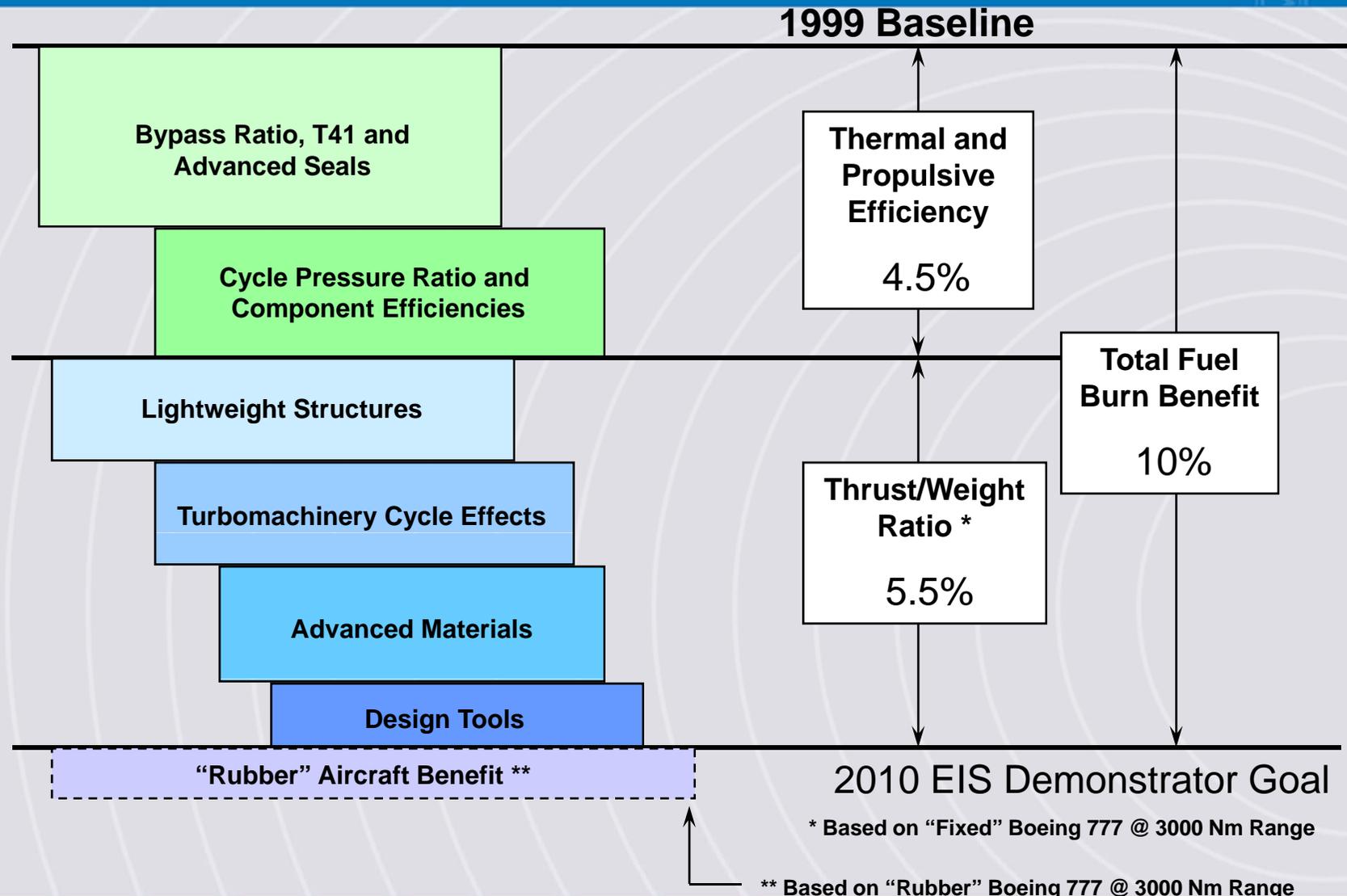
Better component efficiency

- Further reduce turbomachinery blading losses by application of 3D viscous flow techniques
- Materials development to reduce hot end parasitic losses
- Remove LP shaft to allow low hub/tip ratio, high blade speed and hence higher efficiency gas generator core

Performance Strategy for Next Generation
Turbofan Engines



Fuel Burn Benefits Stackup





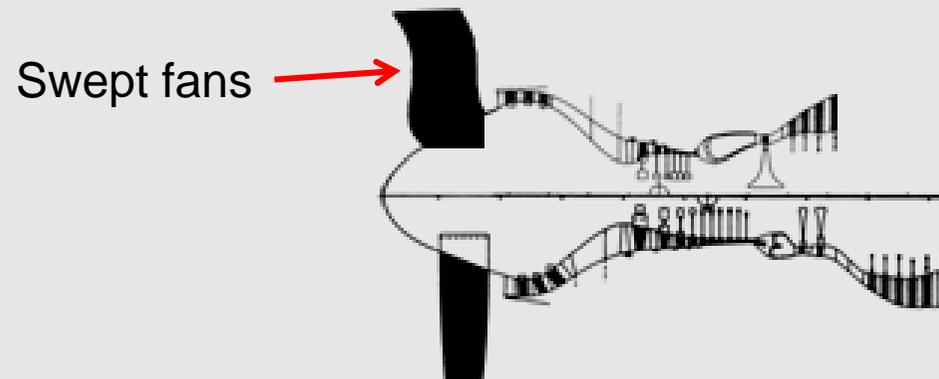
9 Defining Technologies for the Next Millennium

GG Aircraft Engines

Cycle and Configuration Comparisons with Current Engine

Equal Thrust Size Comparison

Top View: 21st Century Configuration - BPR = 10, $PR_{Overall} = 60$ Class



Bottom View: 1999 Baseline - BPR = 8, $PR_{Overall} = 40$ Class



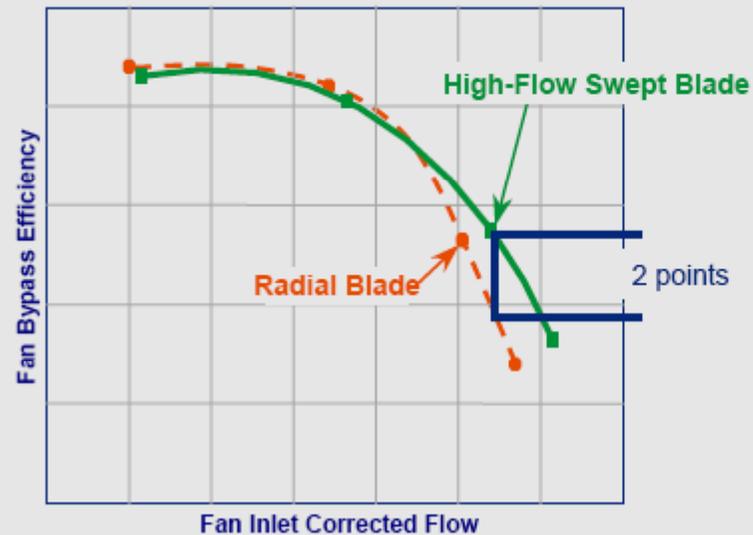
New Fan-Concepts: Swept Fans





GE90 Swept Fan Blade Feature...

demonstrated world class fan flow and efficiency

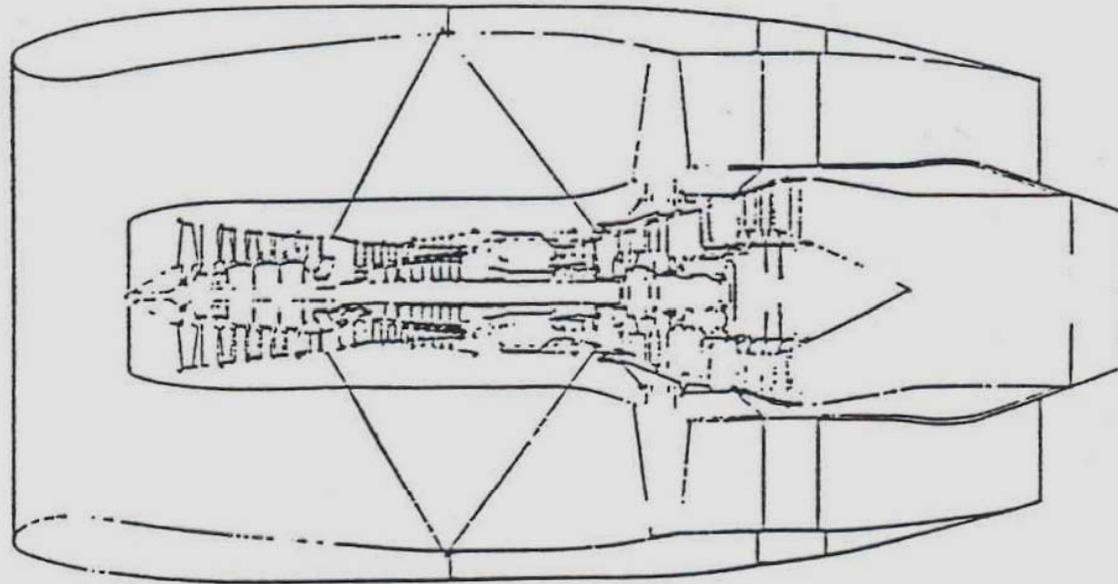


0.6% lower fuel burn on short/ medium range routes
\$8.9M/ aircraft NPV for a typical 777-300ER operator



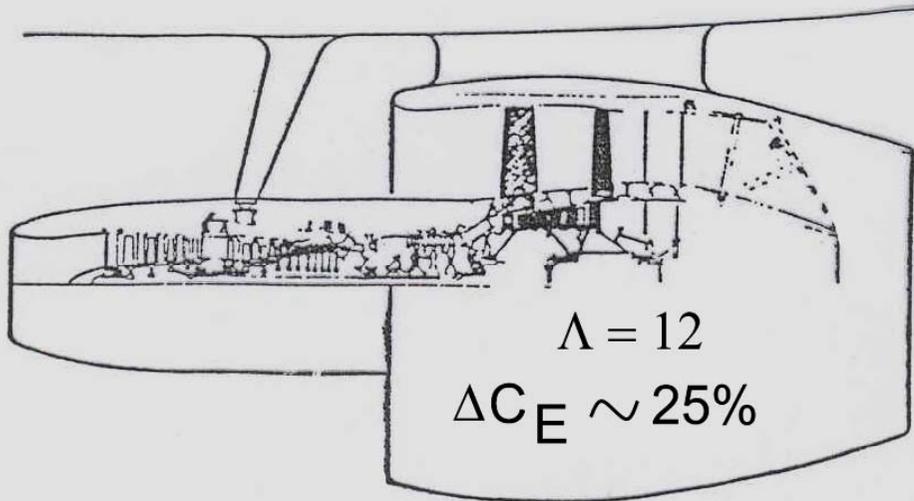
Alternativas

Remover el eje de baja : permite diseños del compresor de alta con r_i/r_e más bajos, mejorando el rendimiento del compresor de alta : Turbofanes paralelo



Ultra-high bypass ratio mid fan concept

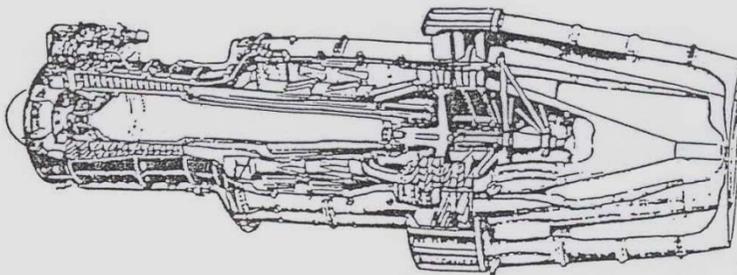
$$\pi_{23} = 40:1 \quad \Lambda = 6.5 \quad T_{4t} = 1720 \text{ K} \quad \Delta C_E = 20\%$$



$$\Lambda = 12$$
$$\Delta C_E \sim 25\%$$

Ultra-high bypass ratio contra-fan concept

Concepto ya explorado



Axial Type Jet Propulsion Engine with Ducted-Fan - Metropolitan-Vickers F.2/3 engine (1947)



Fan paralelo + contrarrotatorio :
Aumentar Λ \rightarrow bajar vueltas del fan \rightarrow bajar vueltas de la turbina que mueve el fan, \rightarrow aumenta numero de escalones
Soluciones contrarrotatorios o independizar el fan de la turbina



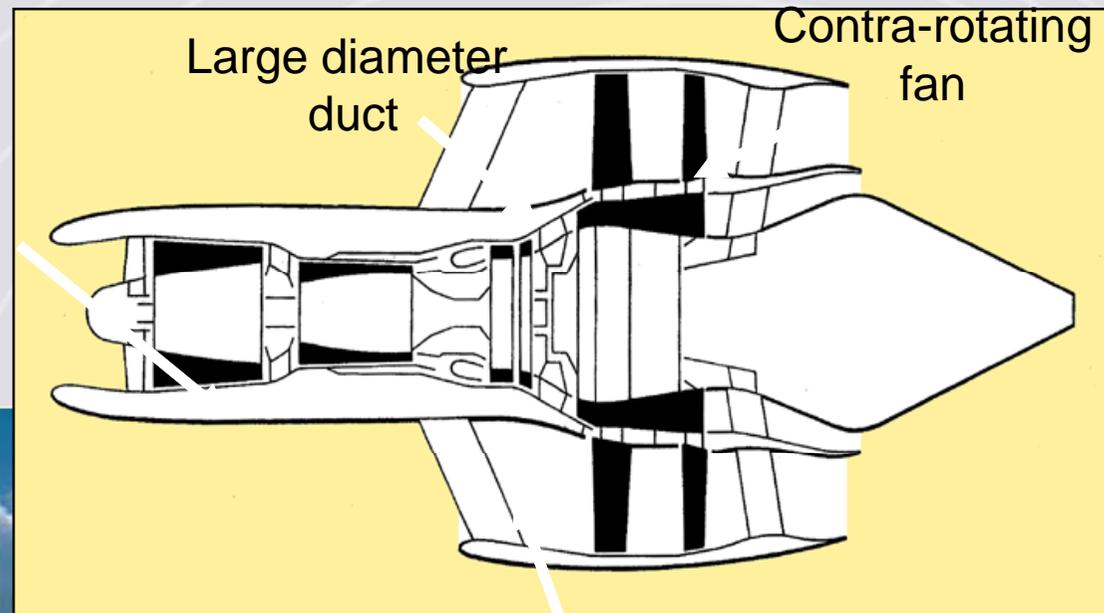


Future Aircraft and Engine Configurations

Gas generator



Flying wing



Large diameter duct

Contra-rotating fan

Contra-rotating turbine

Blended wing aircraft may offer up to 30% reduction in fuel consumption - 40% if combined with electric engine concepts



Nuevos conceptos



Innovative Engine Architecture

Innovative Turbofan Architecture

- Geared Turbo Fan
- Counter-Rotating Fans



Counter-Rotating Propfan Engines

By Pass Ratio up to 80 thanks to open Rotor technology

Fuel burn saving up to 25%.

slides by courtesy of Airbus

ASD Convention, Barcelona 5 Oct. 2007



Turbofán con reductor

Un concepto prometedor investigado durante dos décadas es introducir un reductor entre el fan y la turbina de baja. Independizando el fan del resto de la turbomaquinaria del eje de baja permite al diseñador ganar un grado de libertad que le permite optimizar la turbomaquinaria independientemente. El principio general de los turbofanes con reductor es sustanciales aumentos de la relación de derivación de los actuales turbofanes para mejorar el rendimiento propulsivo y reducir ruido al mismo tiempo. Esto se consigue reduciendo las revoluciones del fan y la relación de compresión del fan, para fanes de alta relación de derivación, y aumentando las revoluciones de las turbinas, manteniendo su eficiencia alta y la carga aerodinámica.

$$\tau = u(V_{\theta 2} - V_{\theta 1})$$

$$u = \Omega r$$

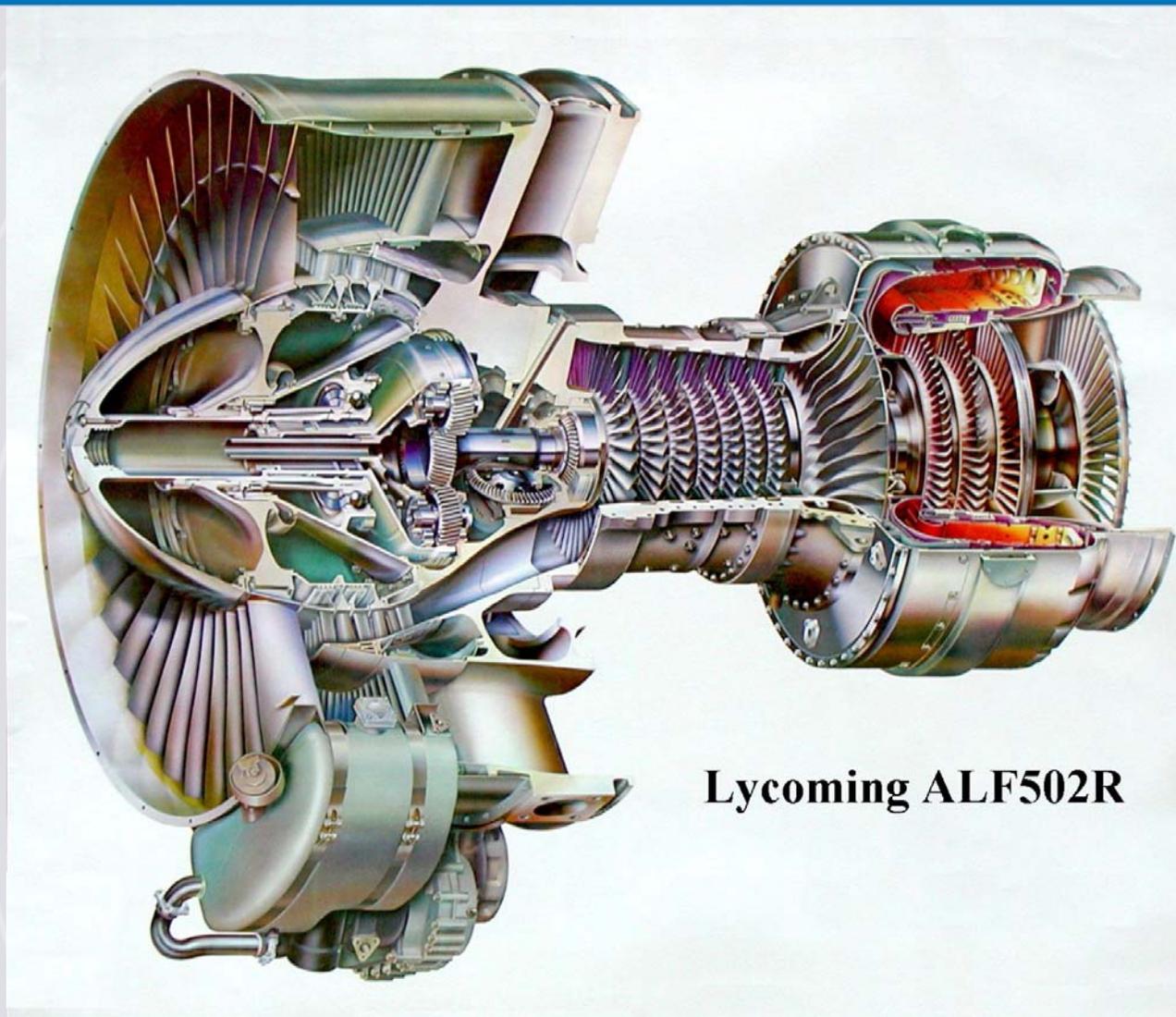
En resumen los turbofanes con reductor ofrecen:

- Baja velocidad del fan
- Baja relación de compresión del fan y velocidad de salida del secundario
- Alto rendimiento propulsivo
- Bajo ruido del fan y del chorro
- Reducir costos de mantenimiento

Y evita los inconvenientes de los fanes movidos directamente

- Bajo rendimiento del compresor de baja y la turbina de baja
- Aumento de la longitud global del motor y del peso, especialmente de los componentes del eje de baja

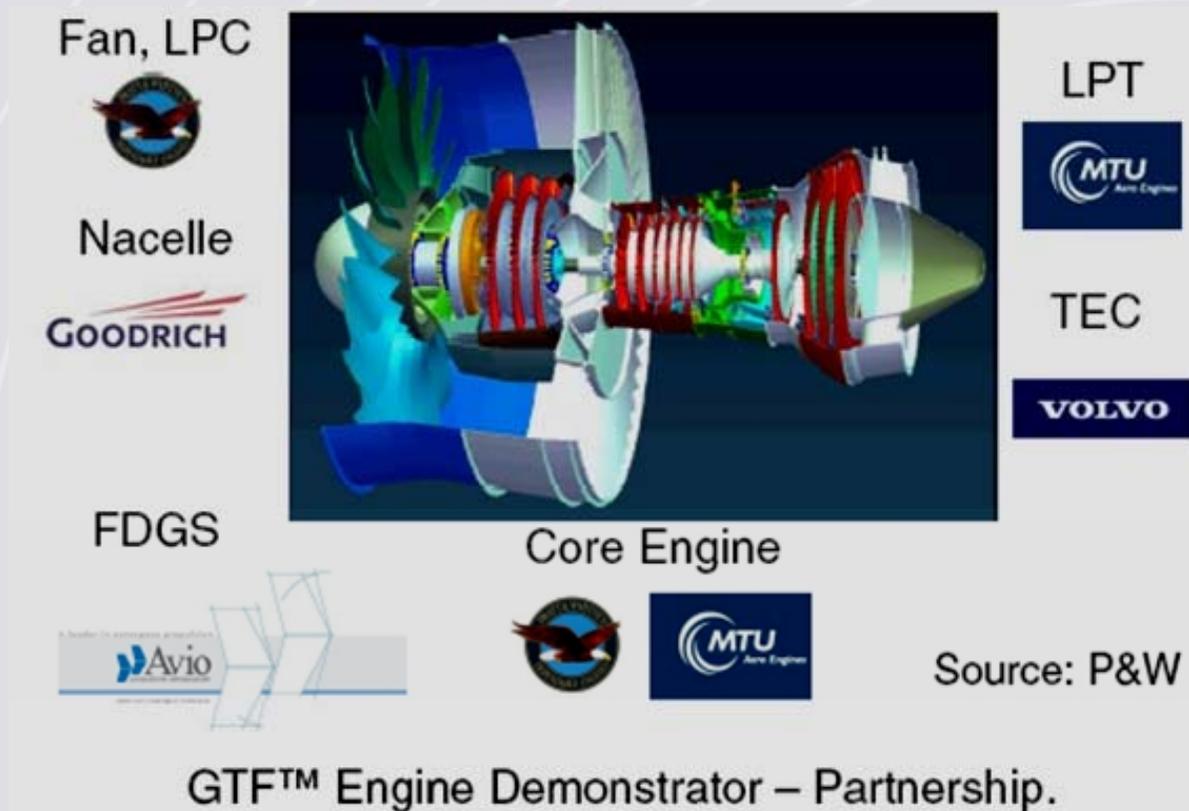
El concepto no es nuevo 

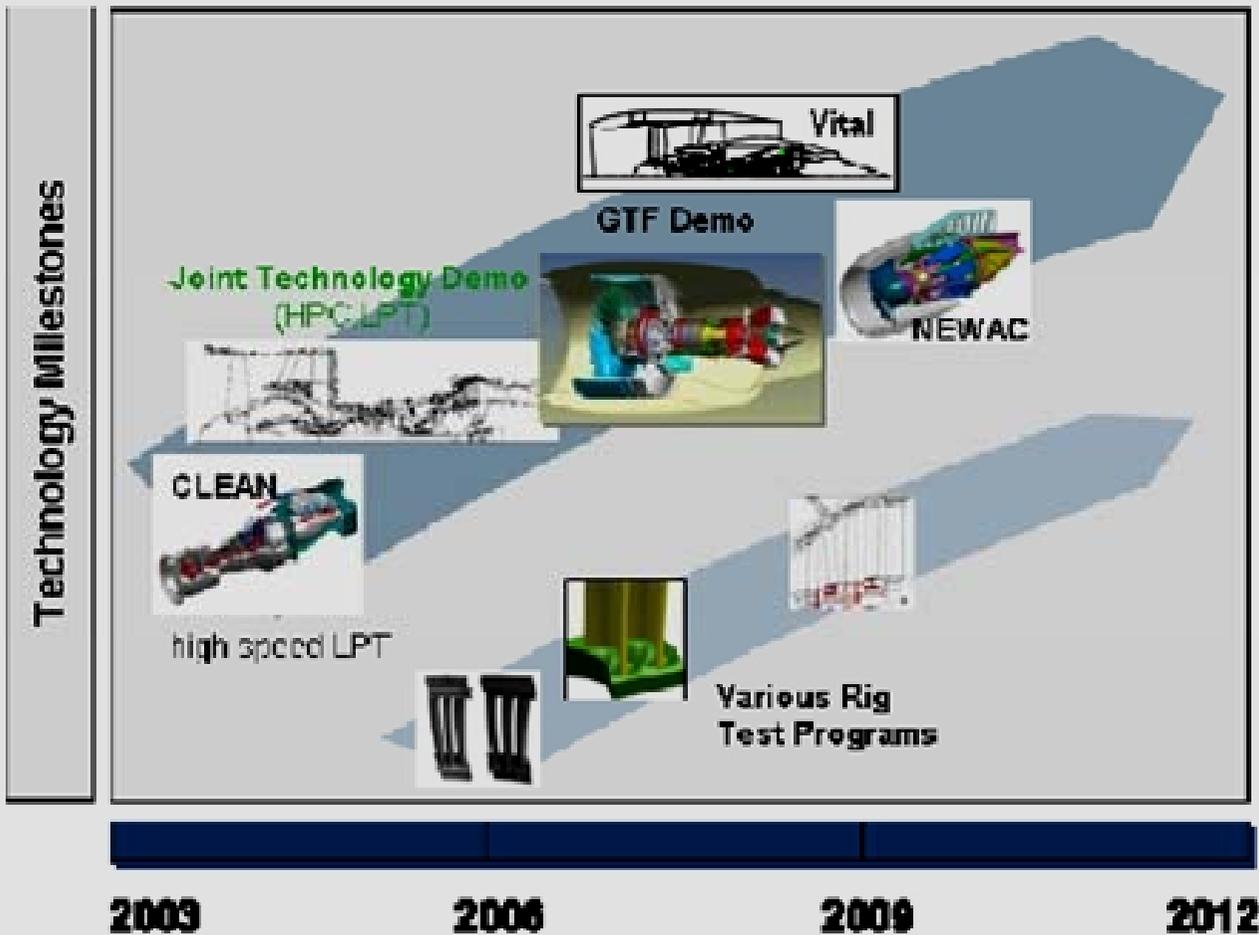


Lycoming ALF502R

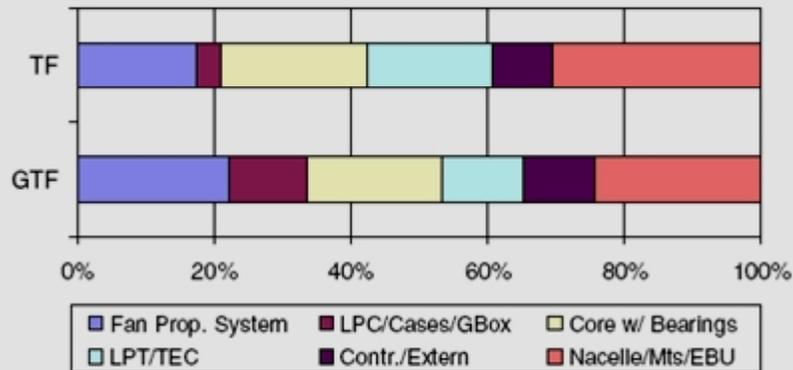


Turbofán con reductor

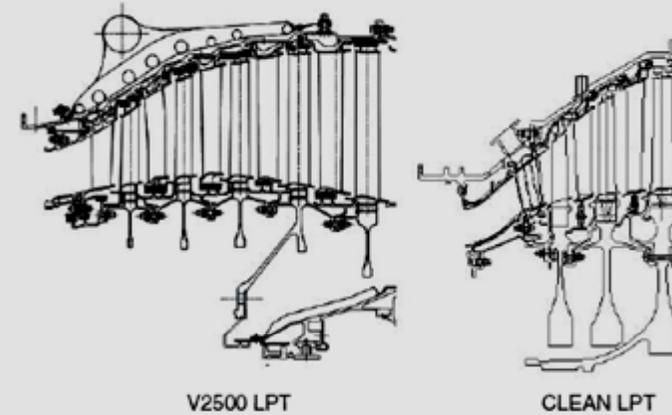




LPT Technology Maturation Plan.



Weight Breakdown GTF™ Engine versus Direct Drive TF.



Reduction of Part Numbers with High Speed LPT.

Aumento de revoluciones requiere cambios en el diseño de la turbina

advanced 3D aerodynamics (high lift airfoils, end wall contouring) especially for high Mach number and low Reynolds number applications,

- low noise designs taking into account the elevated blade passing frequencies due to the high speed design,
- light weight low density materials especially for rotating airfoils (TiAl),
- high AN2 blade design (high mean stress levels), and brush seals for reduced leakage, low deterioration

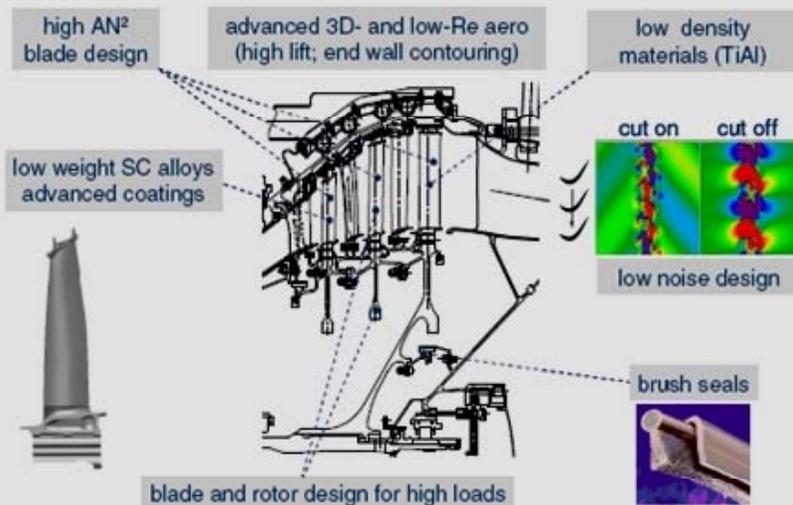


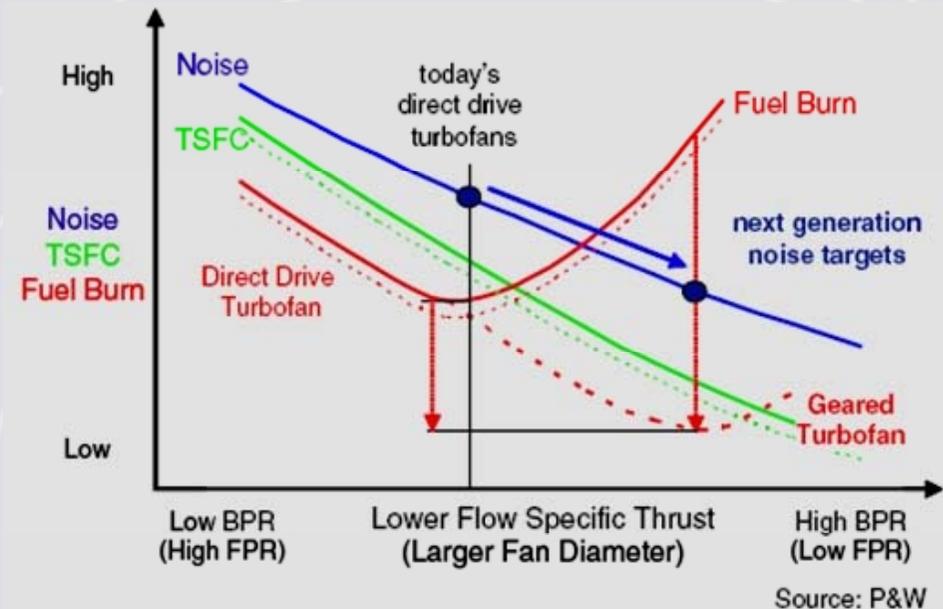
FIG 20. LPT Technology Activities.



Turbofán con reductor



Ducted Direct Drive Turbofan Noise, TSFC and Fuel Burn Trends.



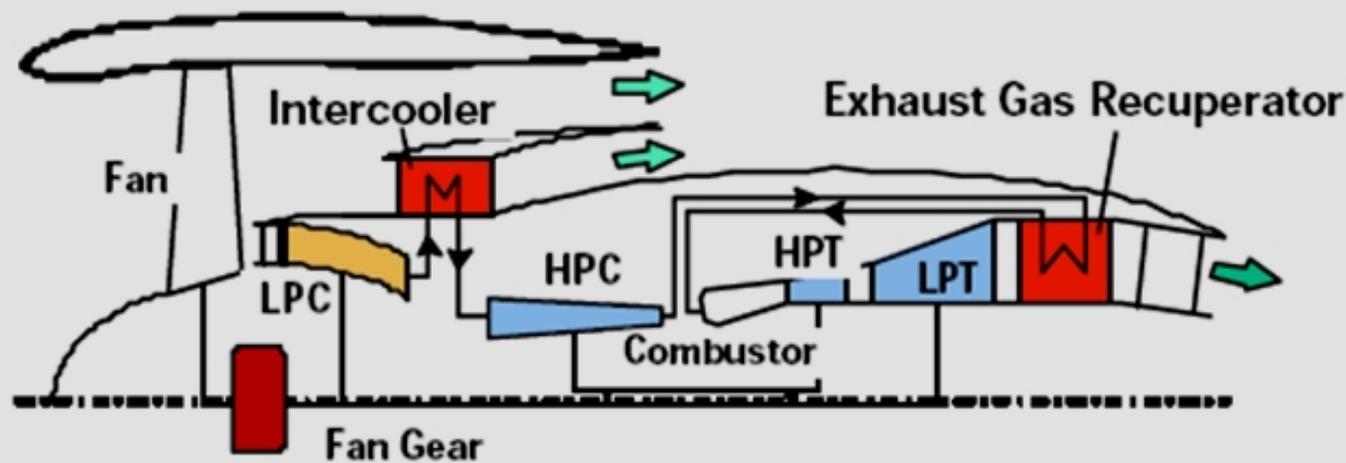
The Geared Turbofan Concept as the Enabler of High Bypass Ratio Turbofan Engines.



Otras tecnologías

Utilización de cambiadores de calor entre el flujo secundario y el flujo primario:

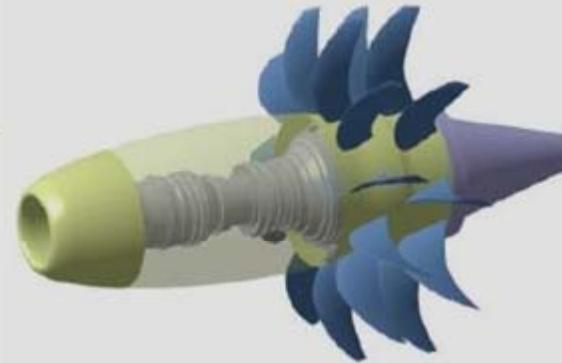
- Permite la utilización de elevadas relaciones de compresión globales
- Reduce el trabajo del compresor
- Reducir emisiones de NOx



**Intercooled, Recuperative Engine
Concept**



Direct Drive Contra Rotating Open Rotor

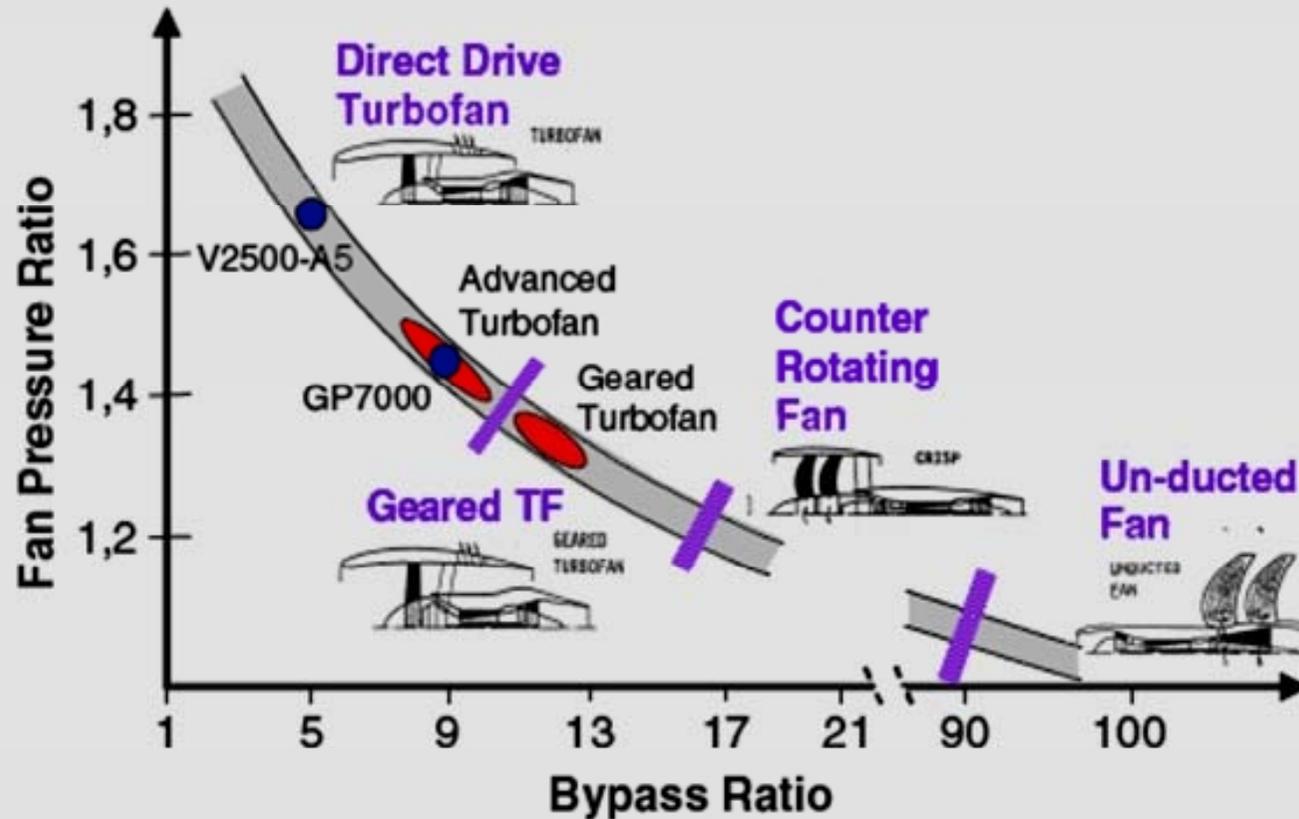


Desarrollo de rotor abiertos contrarrotatorios, con palas de paso variable pueden proporcionar reducciones de consumo de combustible del 10 al 15%, pero son más ruidosos que los fanes de alta relación de derivación.

Progresos recientes en modelos y diseños aeroacusticos pueden permitir que esta arquitectura sea reconsiderada para corto/medio radio de acción



Resumen



Turbofan Engine Concepts with Varying Bypass and Fan Pressure Ratio.

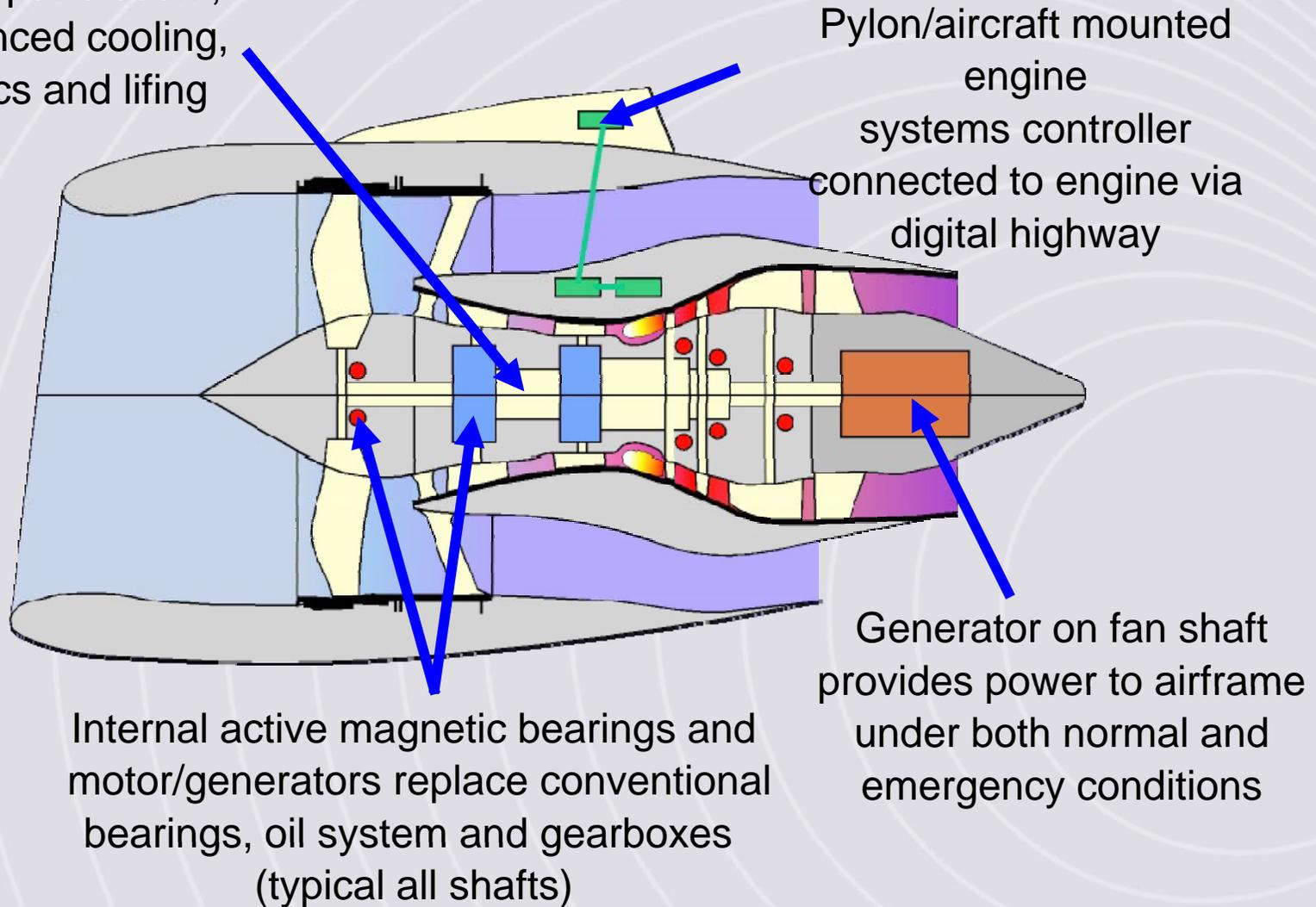


Air for pressurisation/cabin conditioning supplied by dedicated system

New Engine Architecture

Electric Engine Concepts

with reduced parts count, weight, advanced cooling, aerodynamics and lifing





COMPONENTES

Component Weight and Cost Summary

	% Weight	% Cost
Fan Assembly	15.6*	14.6*
Booster	6.1	4.7
High Pressure Compressor	12.5*	11.8*
Combustor	3.9	4.4
High Pressure Turbine	7.5	14.0*
Low Pressure Turbine	20.4*	16.7*
Frames	16.3*	15.0*
Controls and Accessories	11.4*	8.7
Bearings and Seals	3.5	3.3
Miscellaneous and Assembly	2.8	6.8
Total	100	100

**5 out of 10 Major Components
Contribute 70% to 75% of
Engine Weight and Cost**

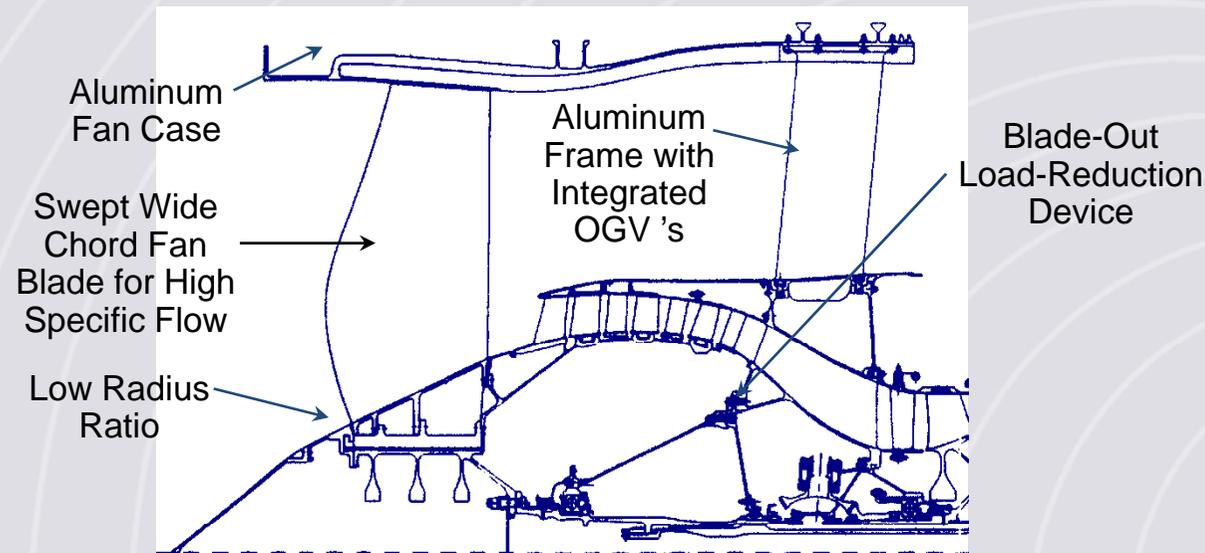
Focus Design on:

- Two-Frame Architecture
- High Speed Low P/P Fan
- High P/P per Stage HPC
- Single-Stage HP Turbine
- High Loading LP Turbine

* Major Contributors



Fan / Booster / Structures

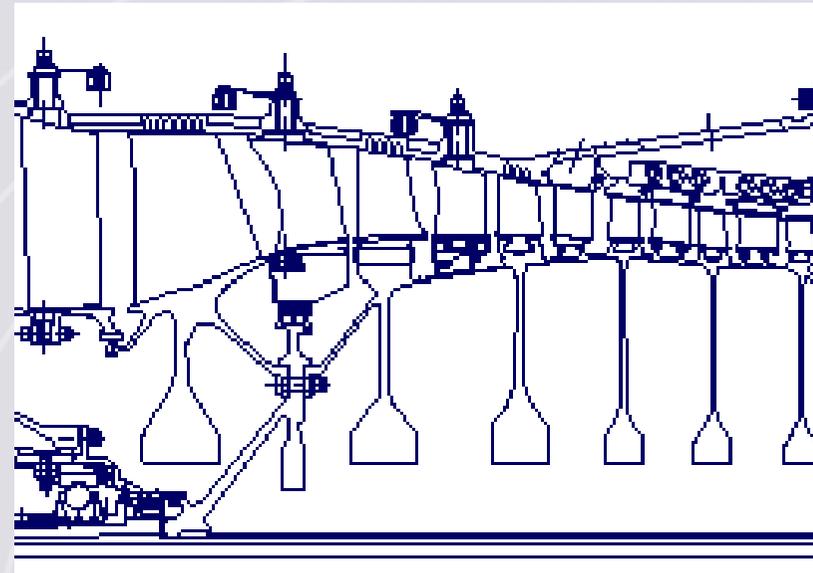
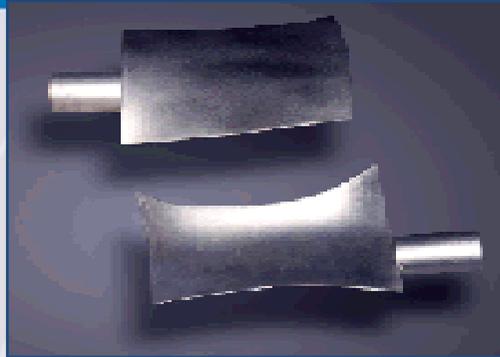


- > 1% Fuel Burn
- > 150-pounds Weight Savings

High Flow, High Efficiency, Lightweight Fan



Low Stage Number Compressor



- **Reduce Stages from 10 to 6**
 - **New Blade Design**
- **Lower Weight**
- **Improved Maintenance Capability**



Turbine Aerodynamics

- **3D Aerodynamic HPT Vane**
- **Convergent-Divergent HPT Blade**
- **Improved Performance**
 - ***0.5% Fuel Burn***
 - ***6°-10°C Benefit in EGT Margin***

HPT Stage 1 Vane



Conventional

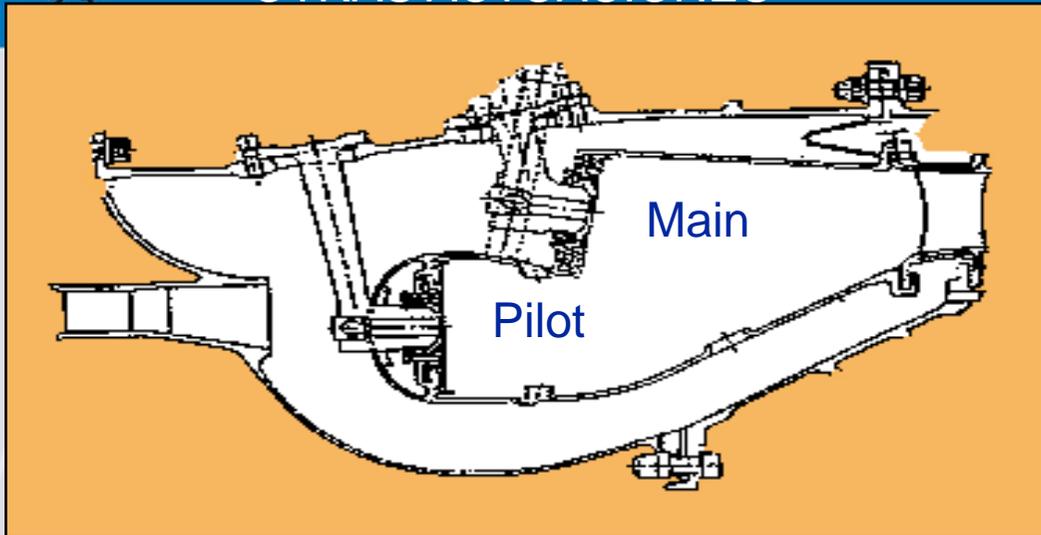


3D Aero

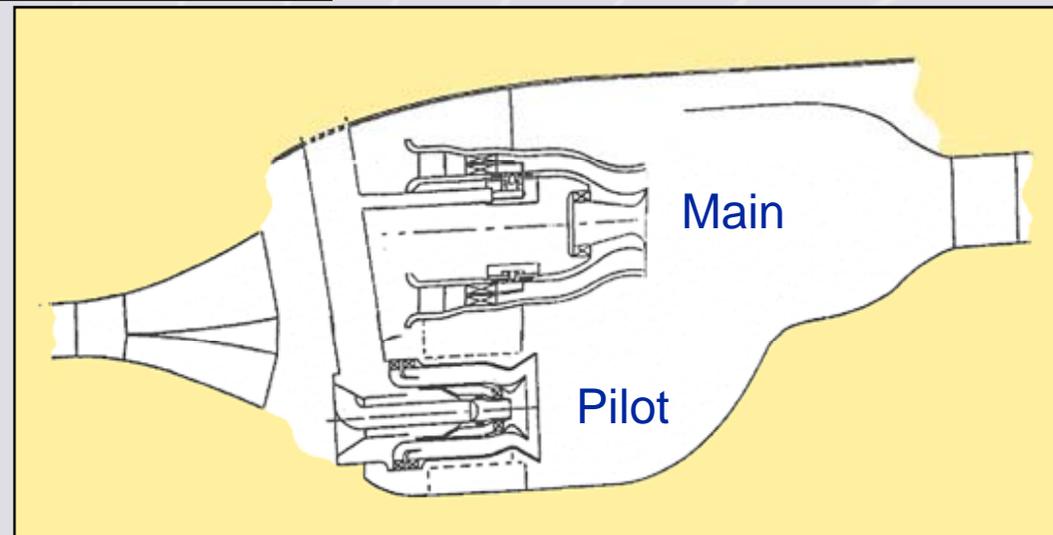


OTRAS ACTUACIONES

Future Emissions Improvements



Double-annular combustor



Pre-mixed double-annular combustor



PROGRAMAS EUROPEOS

VISION 2020 Targets defined by ACARE
(Advisory Council of Aeronautical Research in Europe)

Environment

- Reduce perceived noise by half
- Reduce NO_x by 80%
- Reduce CO₂ by 50%

Safety & Security

- Reduce accident rate by 80%
- Zero successful hijack

Quality & Affordability

- Half time to market
- Fall in travel charges

Air Transport System Efficiency

- On time arrival/ departure 99% within 15 minutes
- Increase movements of aircraft times 3



Engine Contribution

- Reduce specific fuel consumption by 20%
- Reduce NO_x by 80%
- Reduce noise by 10 dB per operation
- Reduce accident rate by 80%
- Reduce operational costs
- Half time to market

Technology Roadmap for Innovative Engine Concepts

ACARE Reference

Year 2000 in service engine

Trent 700/CFM56



European Framework Programmes

Validation at Engine Level

SILENCER



EEFAE - ANTLE



EEFAE - CLEAN



Component Validation for Low spool/ Core



- Active Core
- Flow Controlled Core
- Intercooled Core
- Intercooled Recuperative Core

Engine/ Component Level Validation

Open Rotor



Other Innovative Engine Concepts

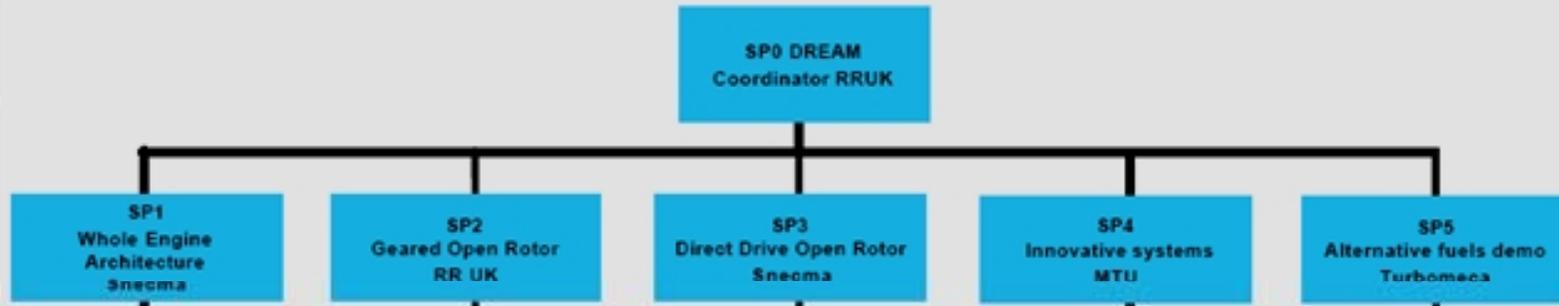


CLEAN SKY

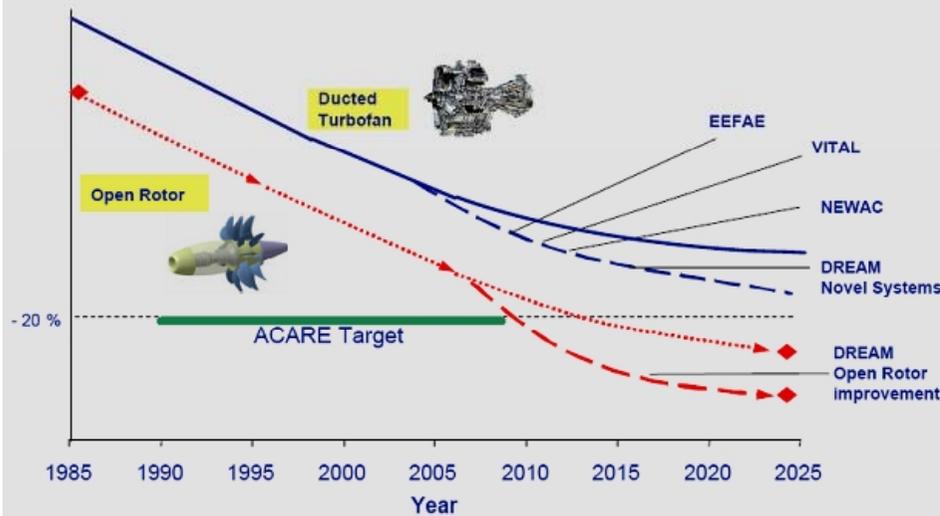




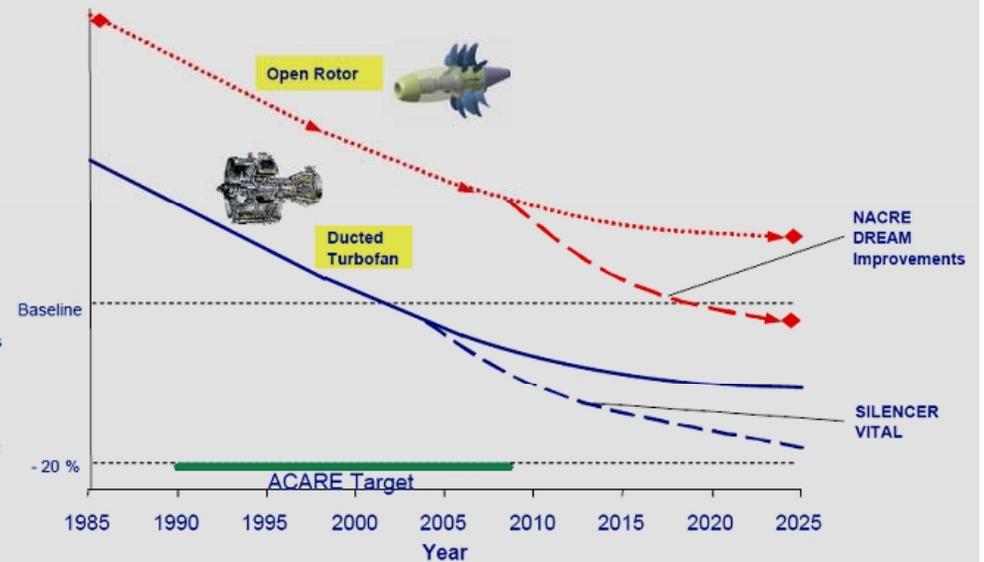
DREAM – Project Structure



Impact of Engine Architectures on Efficiency



Impact of Engine Architectures on Noise





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¿ preguntas ?

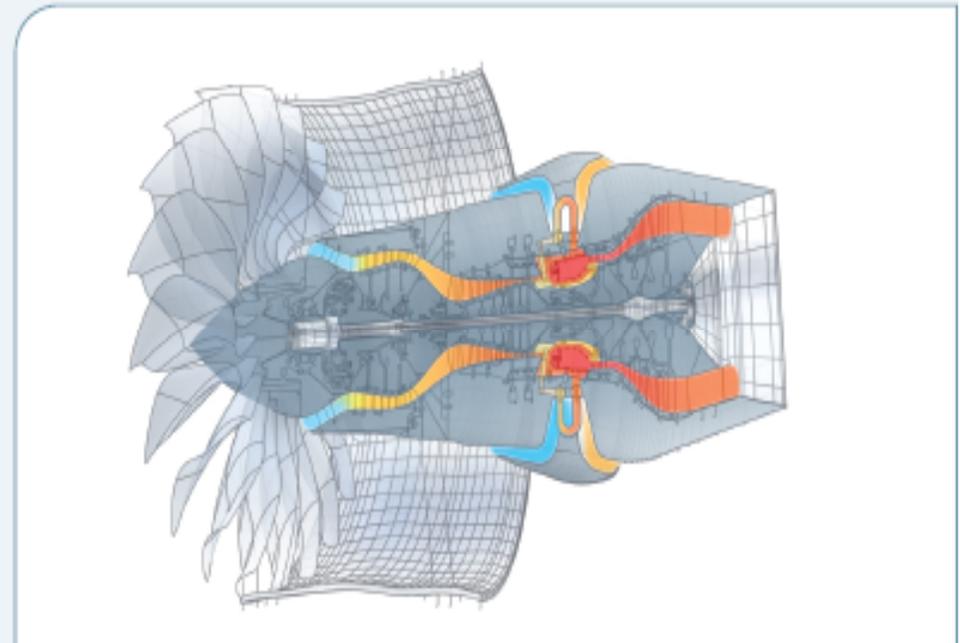


Active Core

Active systems open up a new area of technological opportunities. They offer the possibility to adapt the core engine to each operating condition of the mission and, therefore, have the potential to optimise component and cycle behaviour. The most promising active systems for core engine applications will be investigated and compared with passive alternatives:

- Active cooling air cooling system for reduced cooling air consumption
- Active and semi-active clearance control system for the rear HPC stages
- Active surge control system for the front HPC stages

The candidates with the highest overall potential will be developed and validated in a final core test. A Partially Evaporating Rapid Mixing (PERM) combustor is best applicable to the active core engine and will be investigated under NEWAC.



Active clearance control system (rear stages)

- Improvement of tip clearance with an active clearance control system (thermal or mechanical)
- Comparison with alternative technologies for tip clearance improvement

Active surge control (front stages)

- Development of active surge control with air injection
- Comparison to the passive alternative of multi stage casing treatment

Active cooling air cooling

- Concept study for active cooling air cooling
- Proof of concept for an appropriate combustor case
- Exploration of new design and manufacturing options for a cooled HPC rear cone