THE PW1000G PURE POWER® NEW ENGINE CONCEPT AND ITS IMPACT ON MRO

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Pratt & Whitney

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Director, Business Development Commercial Engines
MTU Aero Engines

Av Week Engine MRO Forum
December 1, 2010

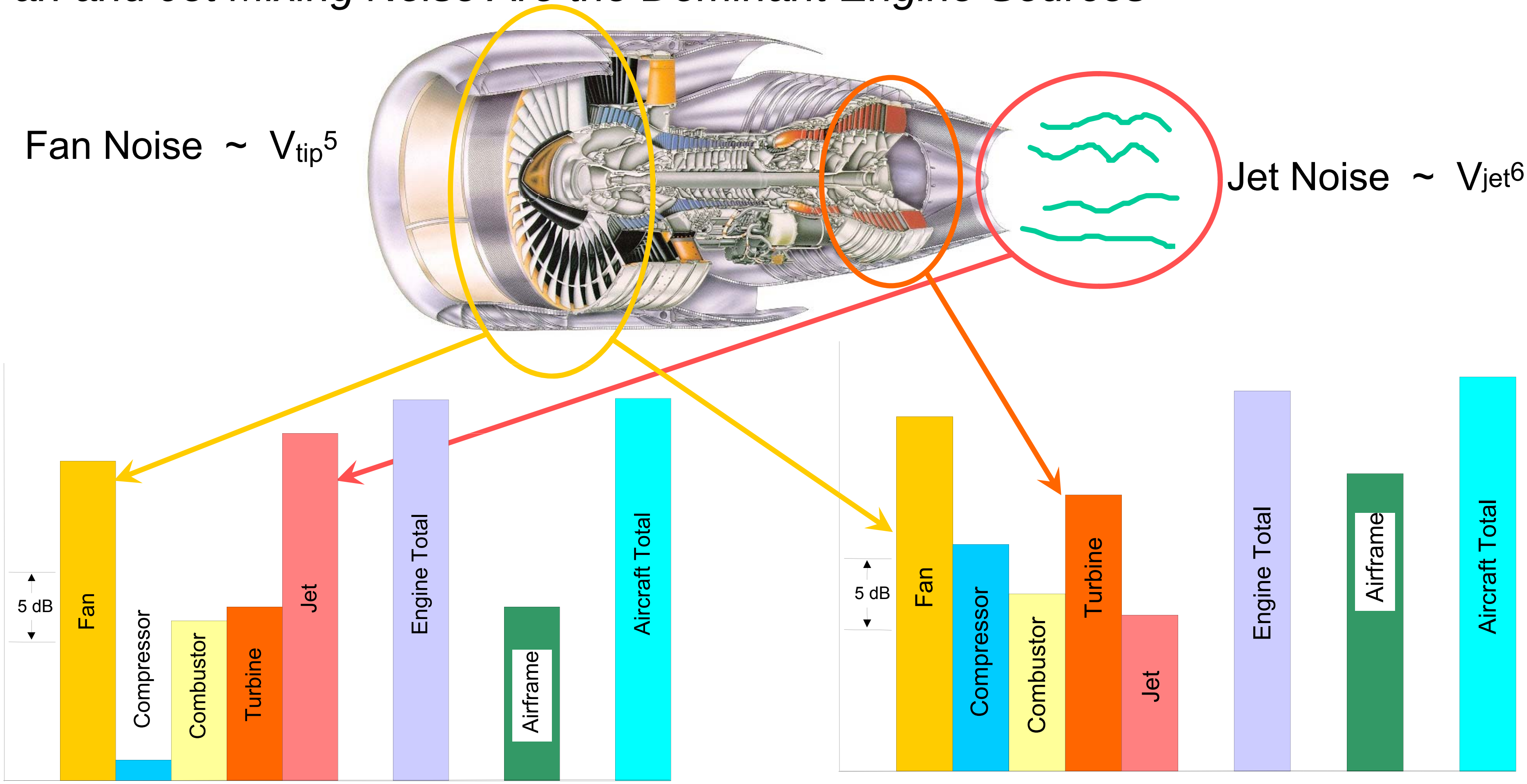
PROPULSION SYSTEM REQUIREMENTS

Lower Fuel Burn, Noise and Maintenance Cost

- Reduced Fuel Burn
  - Reduced TSFC
  - Reduced Propulsion System Weight
  - Reduced Propulsion System Drag
- Reduced Propulsion System Noise
- Reduced Maintenance Cost
  - Reduced Part Count
  - Reduced Exotic Materials
  - Maintainable Design

ENGINE SOURCE NOISE COMPONENTS

Fan and Jet Mixing Noise Are the Dominant Engine Sources



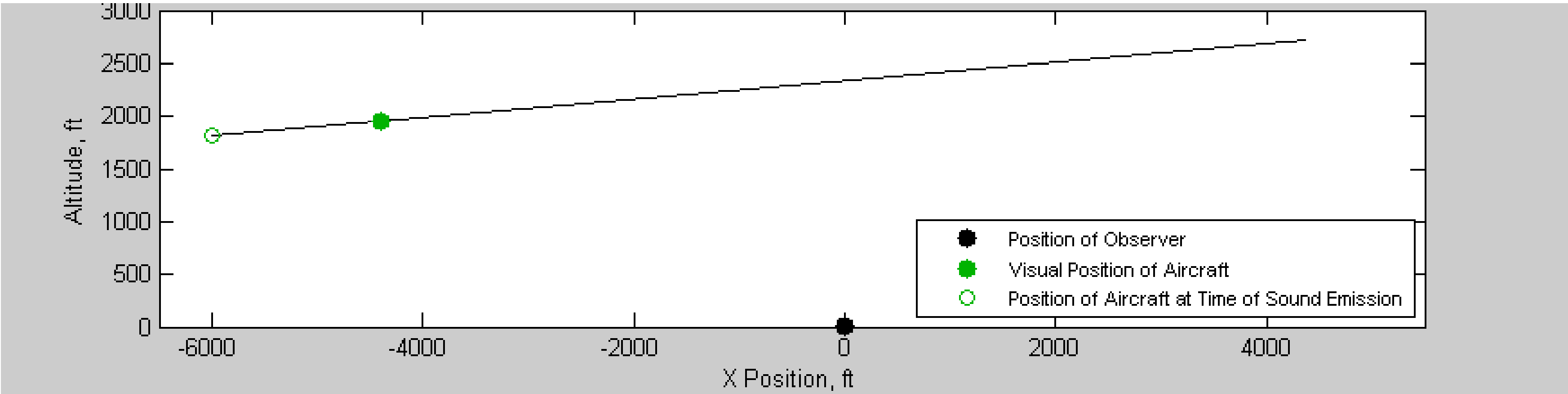
Typical Takeoff Distribution (Fan, Jet)

Typical Approach Distribution (Fan, Jet, Airframe)

Low Noise Requires Low Jet Velocity (hence Low FPR) and Low Fan Tip Speed

SIMULATION OF AIRCRAFT FLYOVER NOISE

Comparison of Conventional Turbofan Engine with Low FPR Turbofan Engine

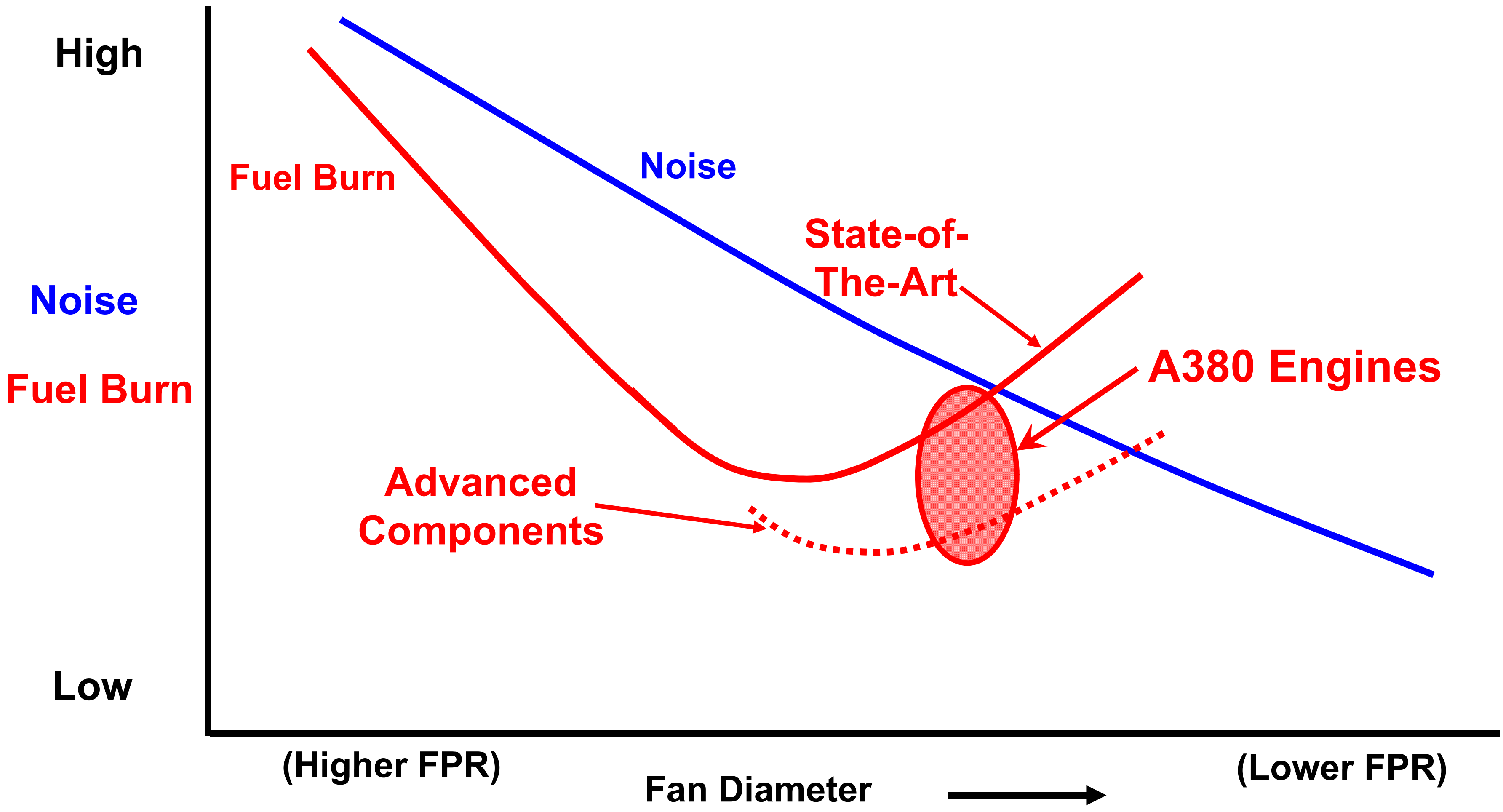


Typical “Flyover with Cutback” Departure Trajectory

Altitude over Microphone: 2339 ft

Both Engines at Same Thrust

Fuel Burn Reduction And Noise Reduction Are At Conflict With Each Other!



FUNCTIONAL DESIGN CHALLENGE

Reducing Fuel Burn AND Noise

1 December 2010

FUNCTIONAL ELEMENTS OF AIRCRAFT ENGINE

Propulsor, Gas Generator & Power Turbine

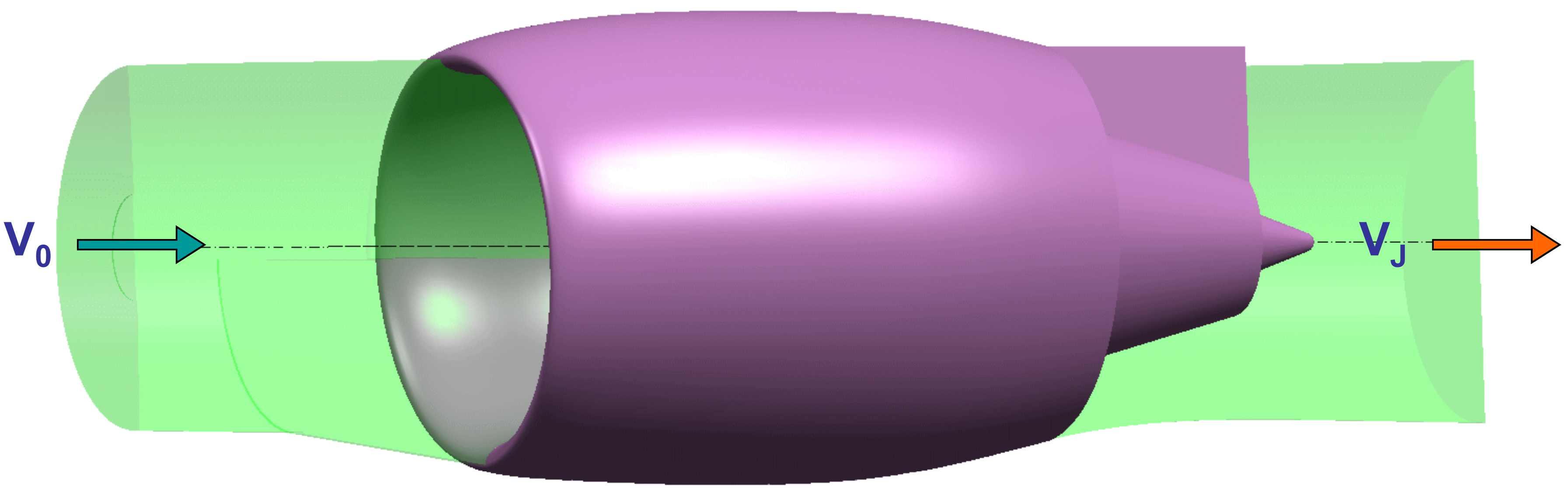
- PROPULSOR (PR)
  - Produce Thrust from Shaft Power (By Pushing on Air)
  - aka Fan / Propeller / Air Screw / Prop Fan / UDF / Open Rotor

- POWER PLANT
  - Produce Shaft Power from Chemical Fuel Energy

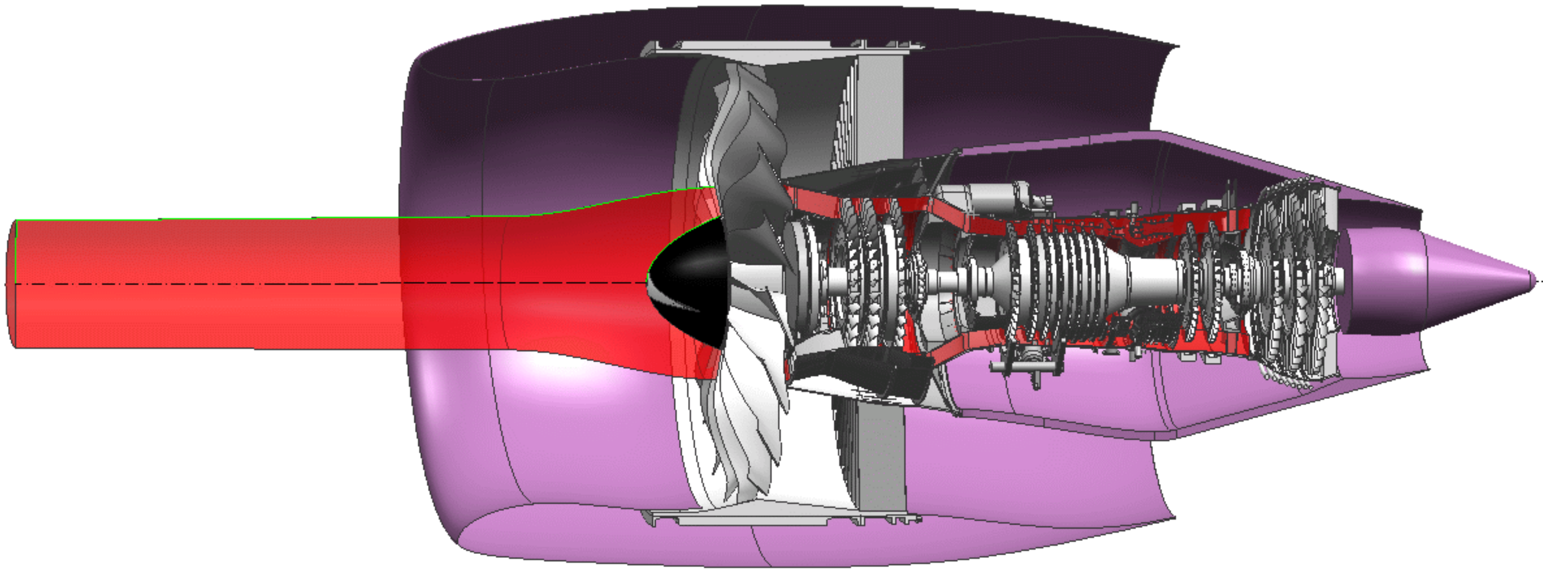
    - ➢ GAS GENERATOR (GG)
      - o “Heat Engine” to Convert Fuel Energy into Fluid Power
      - o Delivers High-Pressure, High Temperature Gas (Drives PT)

    - ➢ POWER TURBINE (PT)
      - o Convert Fluid Power to Mechanical (Shaft) Power
      - o Drives Propulsor

Three-Step Power Conversion Process

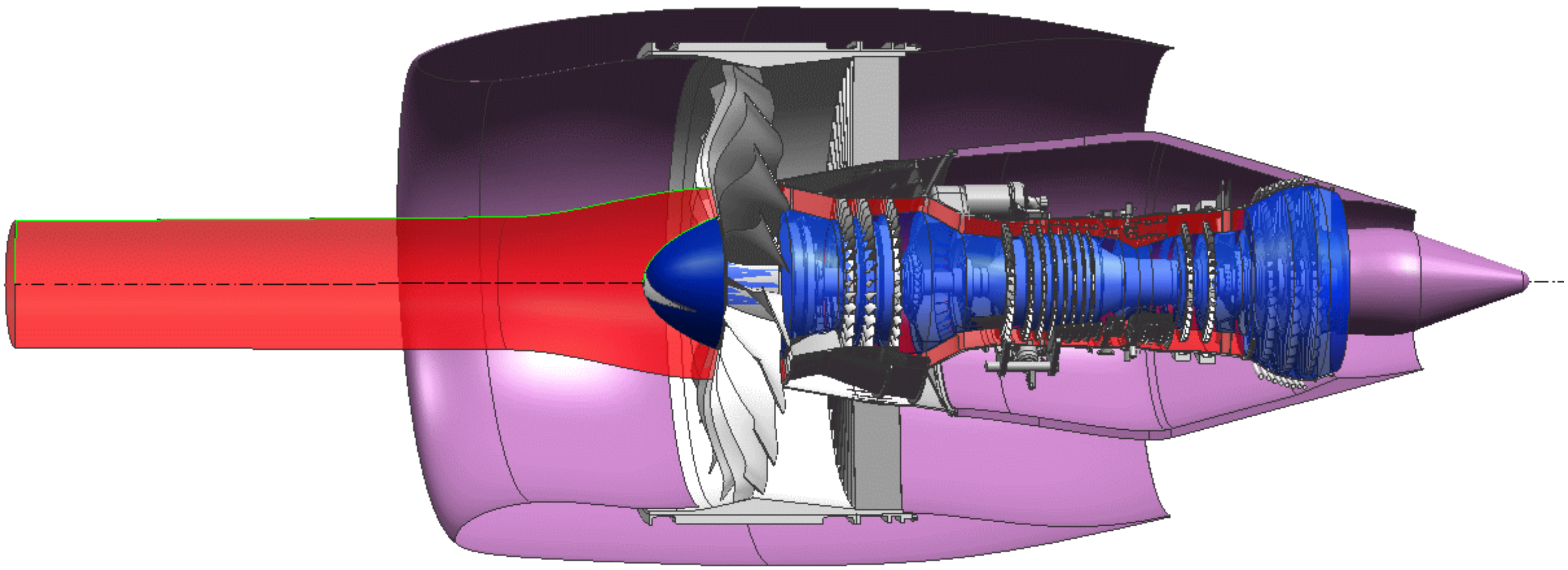


Three-Step Power Conversion Process



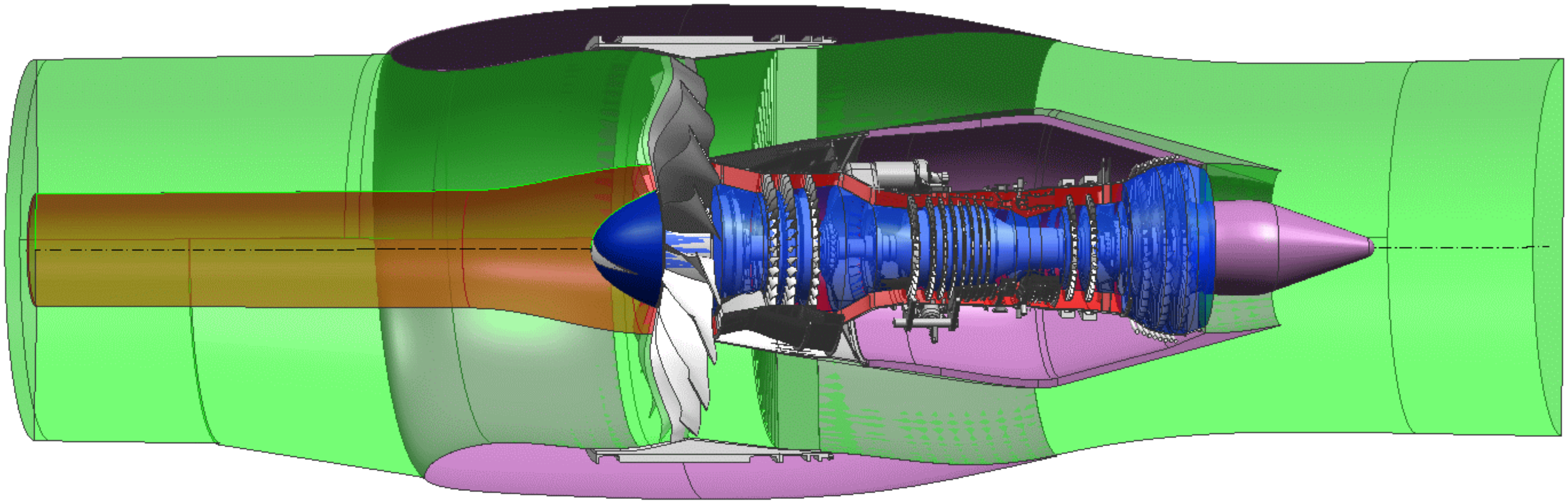
- Step 1 : Gas Generator (GG)
  - Convert Ambient Air Into High-Pressure High-Temperature Gas
  - Thermal Efficiency (η_{th} = GG Power / Fuel Heat Release)

Three-Step Power Conversion Process



- Step 1 : Gas Generator (GG)
  - Convert Ambient Air Into High-Pressure High-Temperature Gas
  - Thermal Efficiency (η_{th} = GG Power / Fuel Heat Release)
- Step 2 : Shaft Power
  - Convert GG Power Into Shaft Power To Propulsor
  - Transfer Efficiency (η_x = Shaft Power / GG Power)

Three-Step Power Conversion Process



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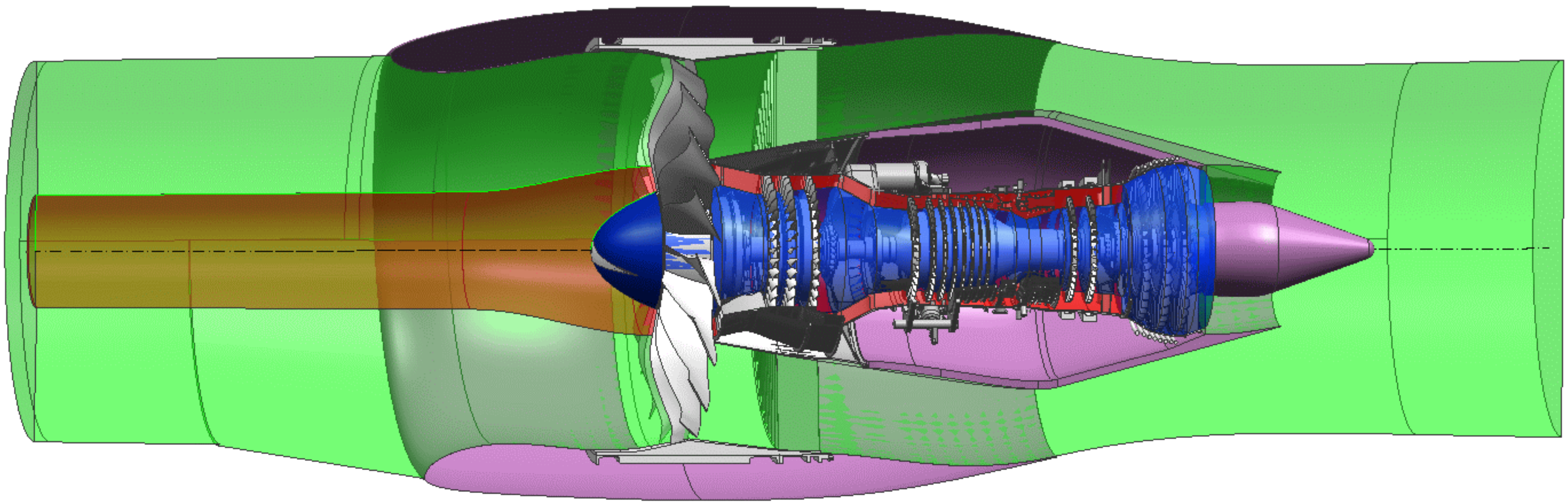
  - Thermal Efficiency (η_{th} = GG Power / Fuel Heat Release)
- Step 2 : Shaft Power
  - Convert GG Power Into Shaft Power To Propulsor
  - Transfer Efficiency (η_x = Shaft Power / GG Power)
- Step 3 : Propulsive Power
  - Convert Shaft Power Into Propulsive Power
  - Propulsive Efficiency (η_p = Propulsive Power / Shaft Power)

Three-Step Power Conversion Process

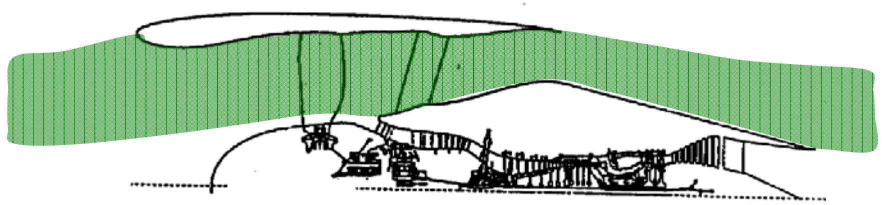


$$\text{Overall Efficiency } \eta_o = \text{Thermal Efficiency } \eta_{TH} \times \text{Transfer Efficiency } \eta_X \times \text{Propulsive Efficiency } \eta_P$$

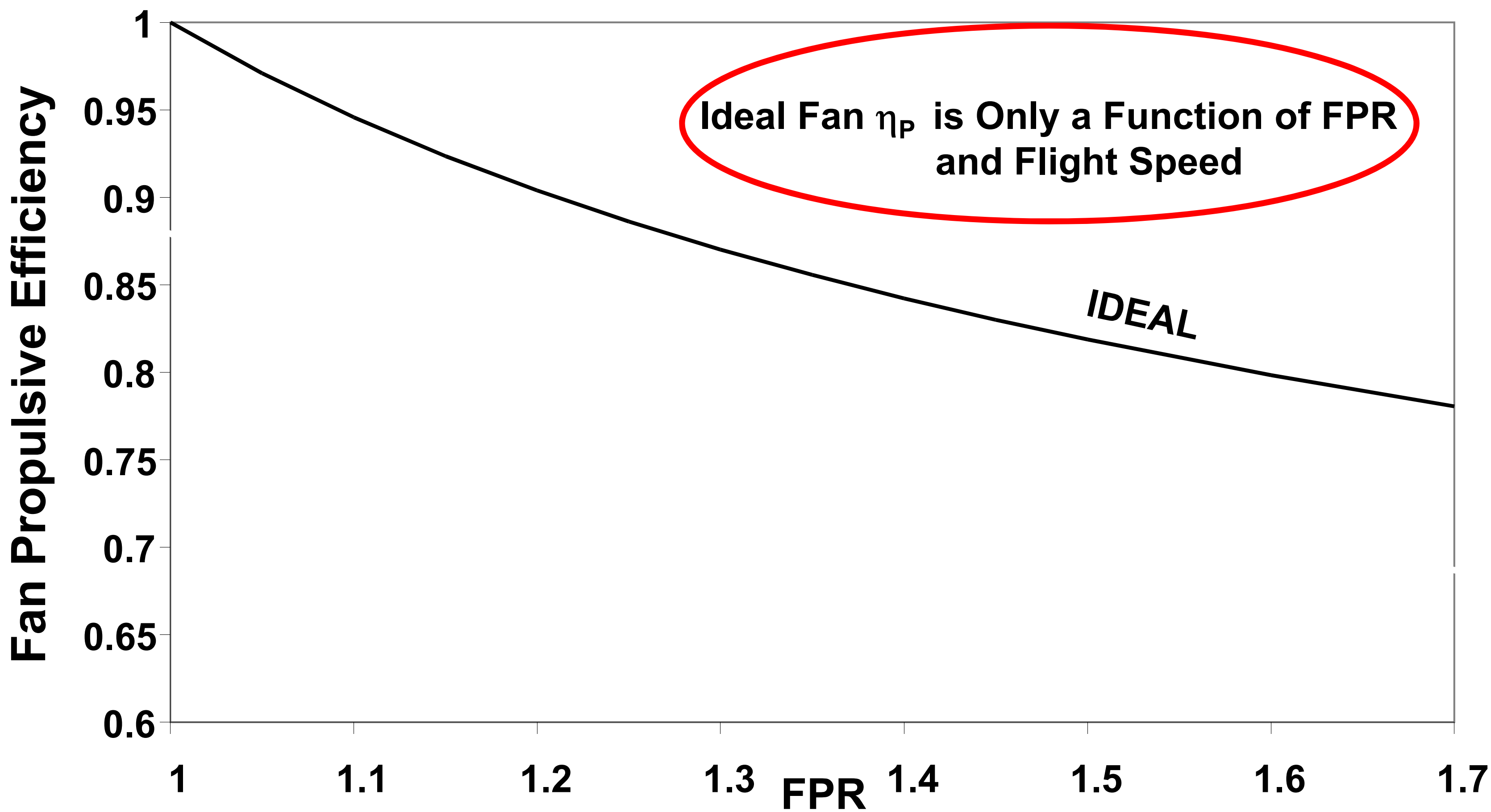
$$= \frac{\text{GG Power}}{\text{Fuel Heat Release}} \quad \frac{\text{Shaft Power}}{\text{GG Power}} \quad \frac{\text{Propulsive Power}}{\text{Shaft Power}}$$

PROPULSIVE EFFICIENCY FOR FAN BYPASS SYSTEM

Flight Mach = 0.80



$$\eta_{Pfan} = \frac{F_{Nfan} V_0}{SHP_{fan}}$$



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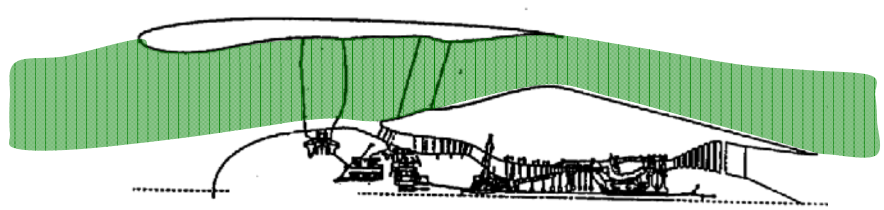

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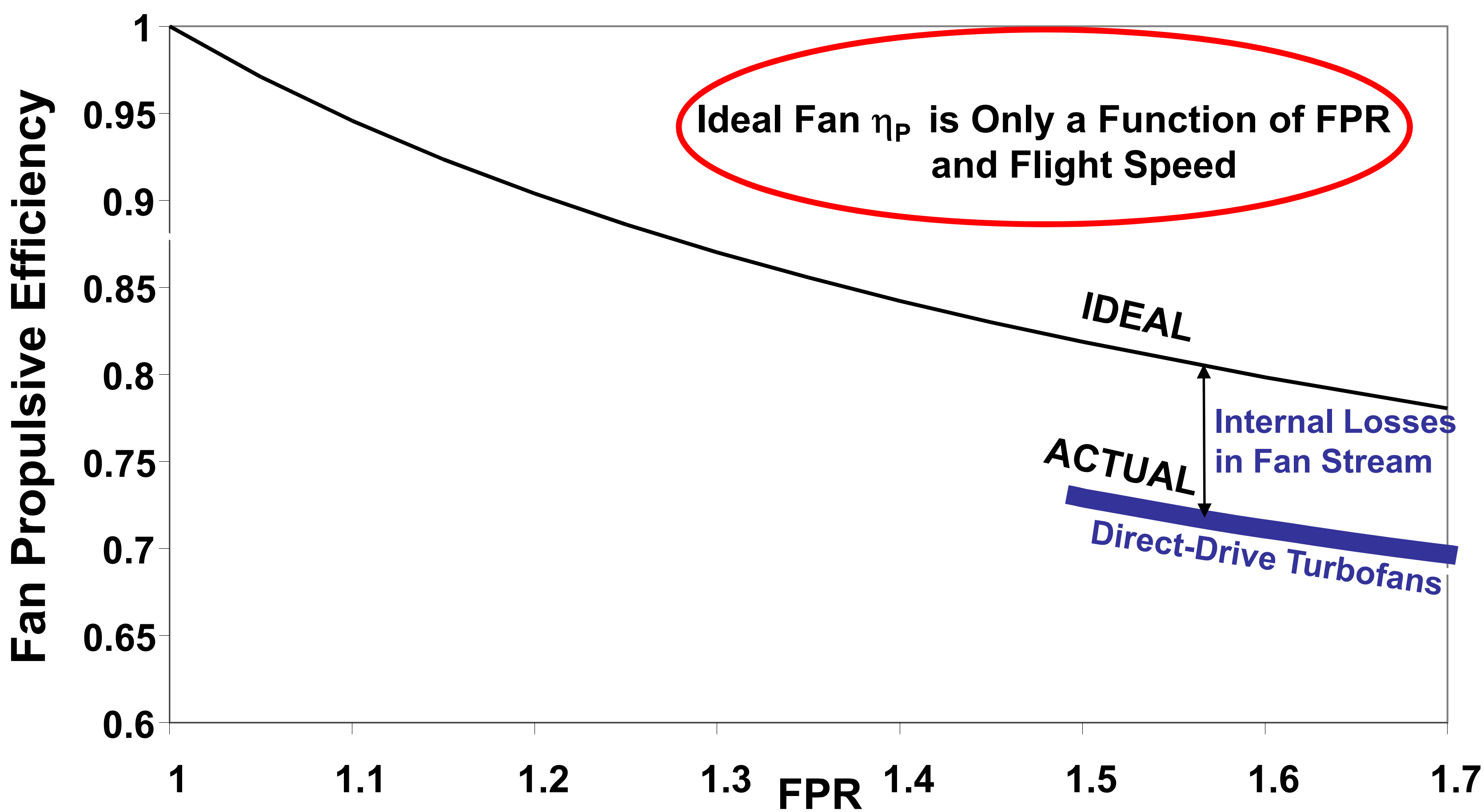

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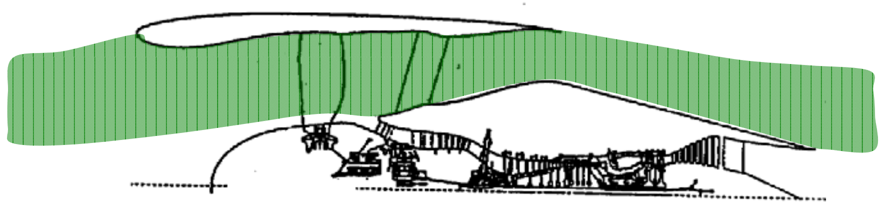

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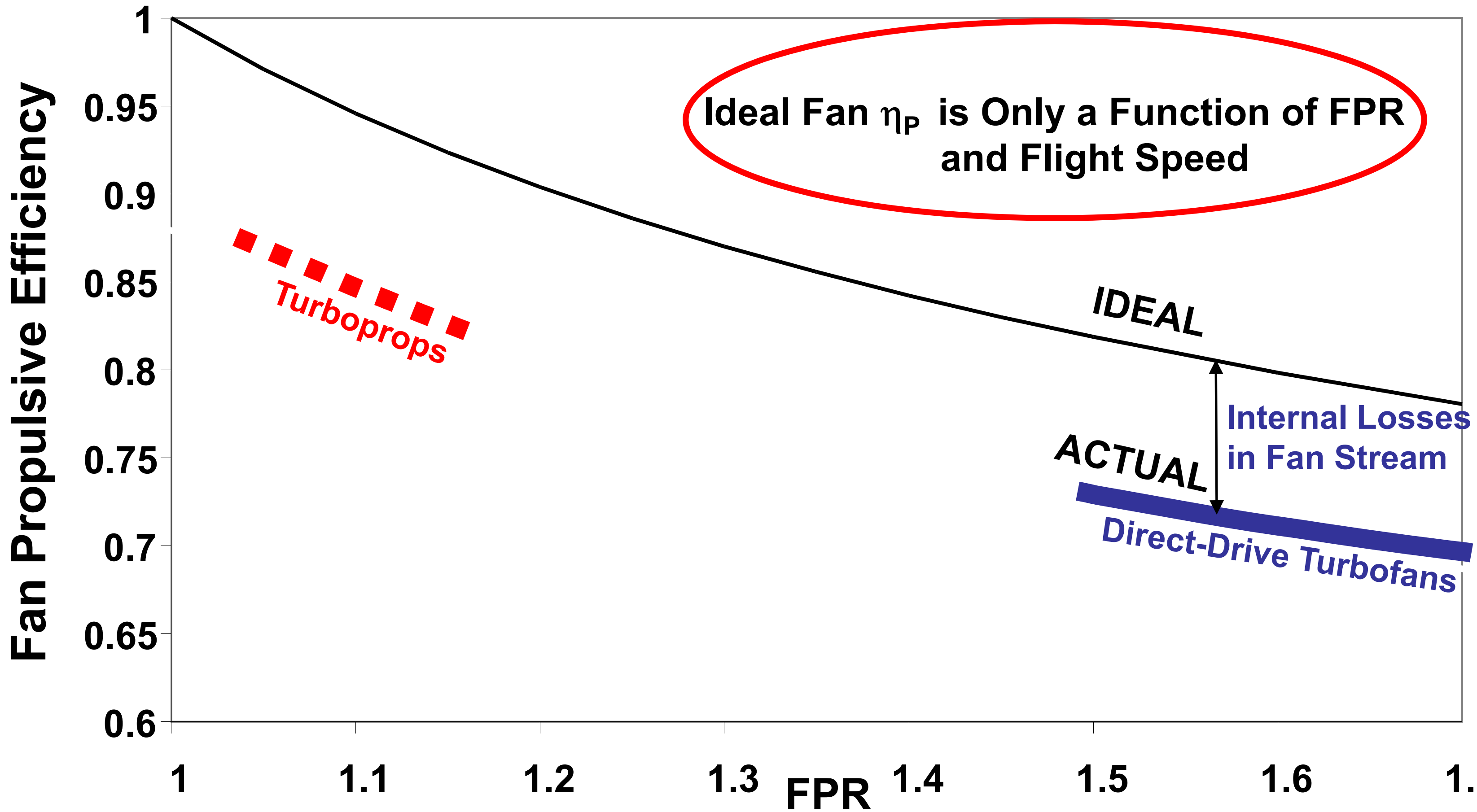

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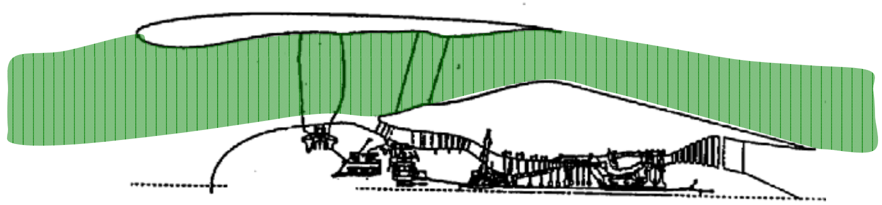

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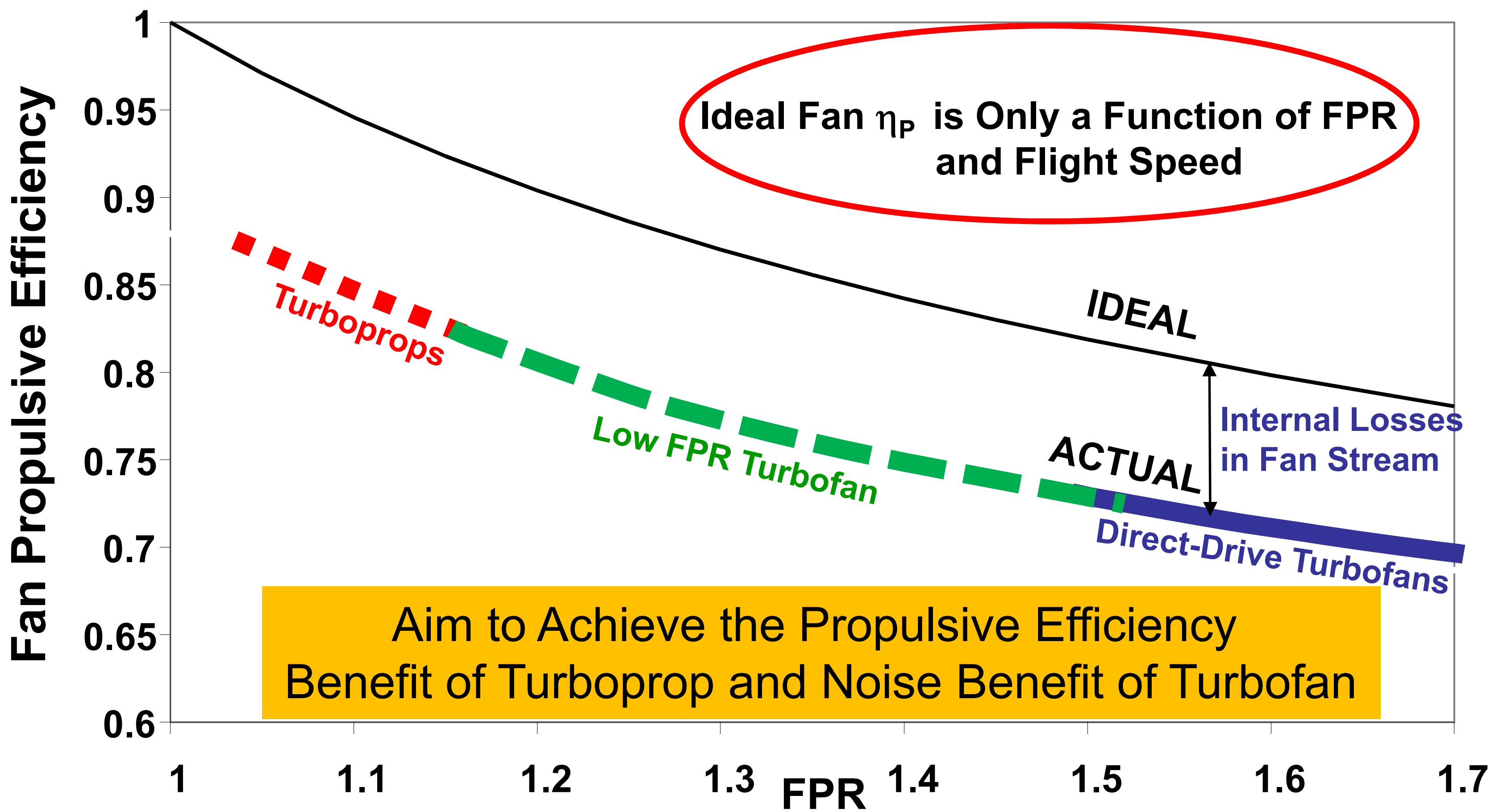
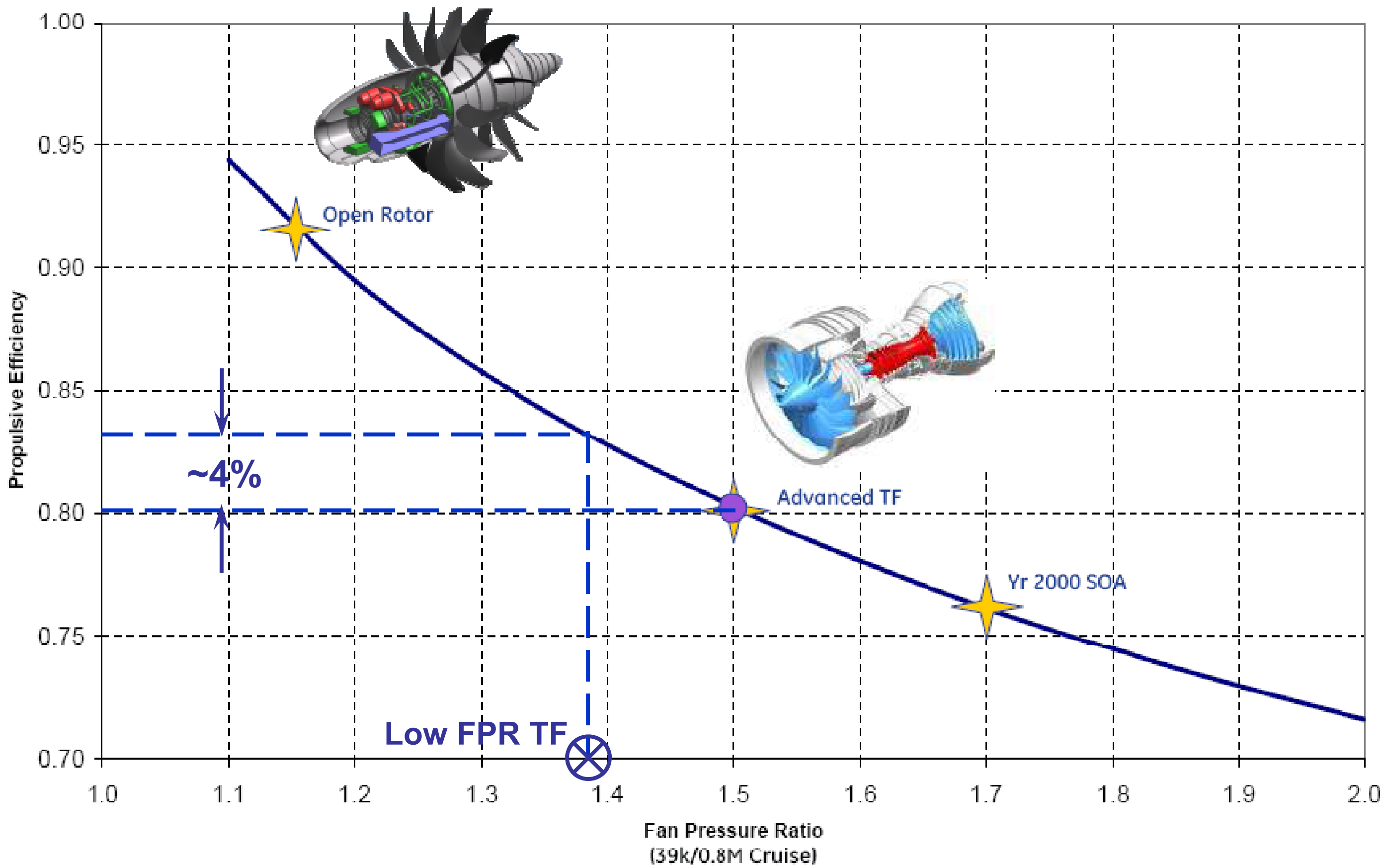


Propulsive efficiency



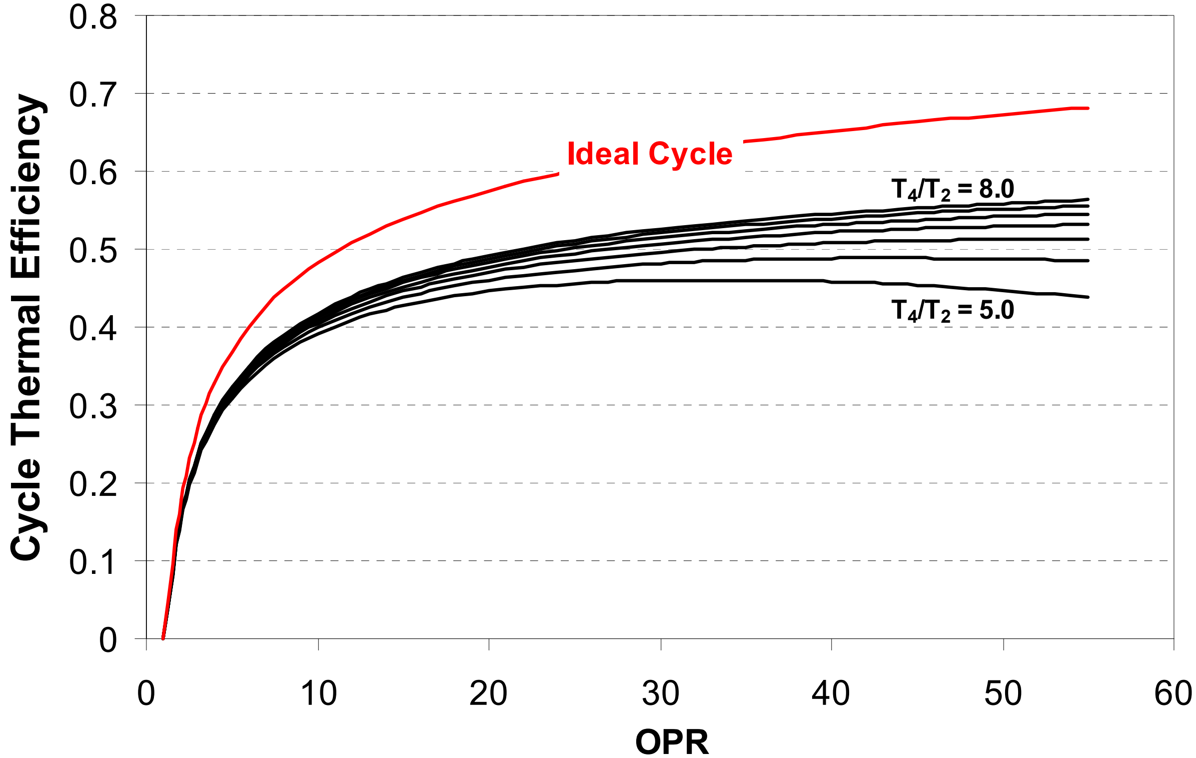
imagination at work

1
GE Aviation
9/16/2009

Source: 19th ISABE Conference, Montreal, CANADA, September 2009

GAS GENERATOR THERMAL EFFICIENCY

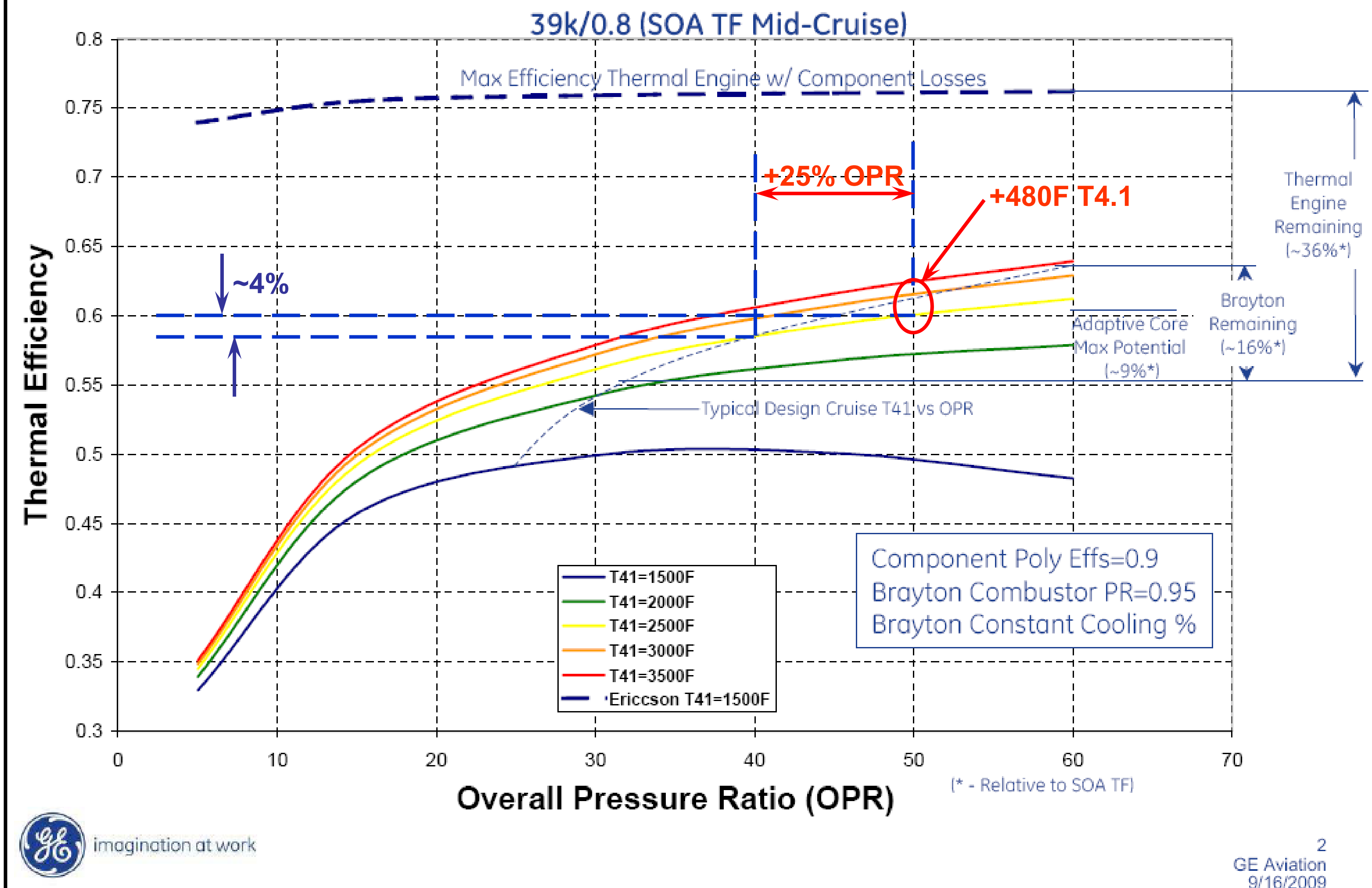
High η_{Th} Requires High-Speed, Low-Loss Turbomachinery & High OPR



- THERMAL EFFICIENCY IS DETERMINED BY OVERALL PRESSURE RATIO (OPR), TURBINE INLET TEMPERATURE (T_4), AERODYNAMIC EFFICIENCY AND PARASITIC CYCLE LOSSES (e.g. COOLING AIR)

THERMAL EFFCIENCY – ANOTHER PERSPECTIVE

Thermal efficiency

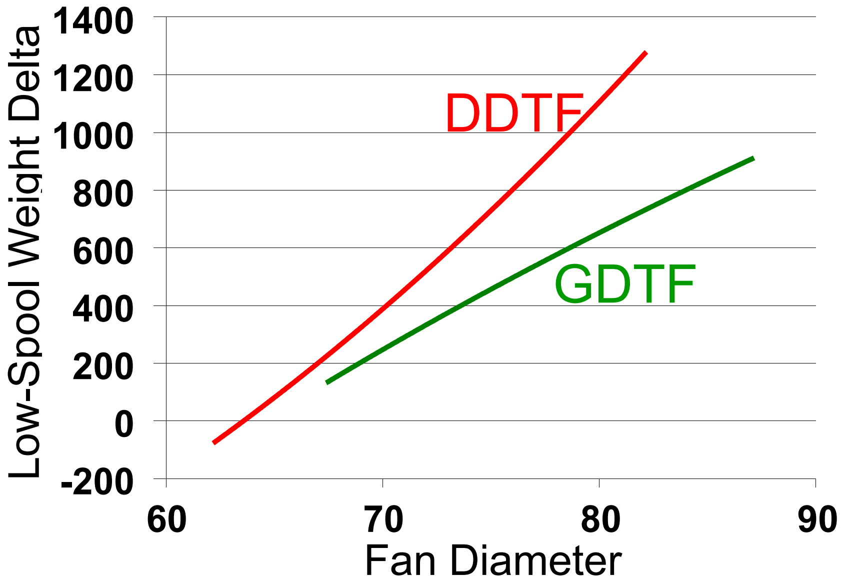


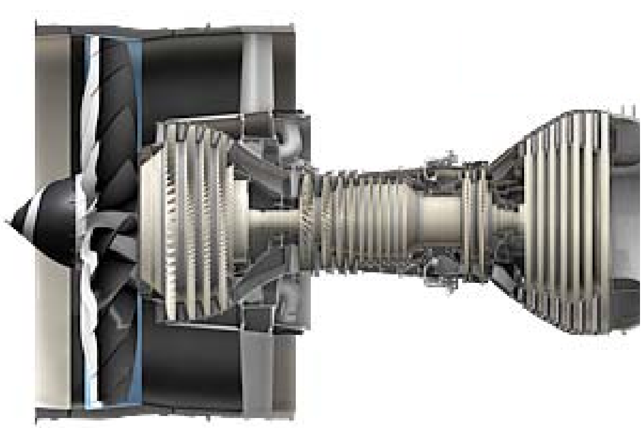
Source: 19th ISABE Conference, Montreal, CANADA, September 2009

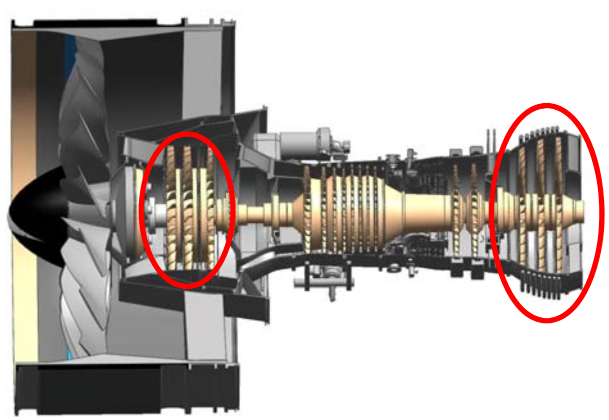
THE POWER TURBINE DILEMMA

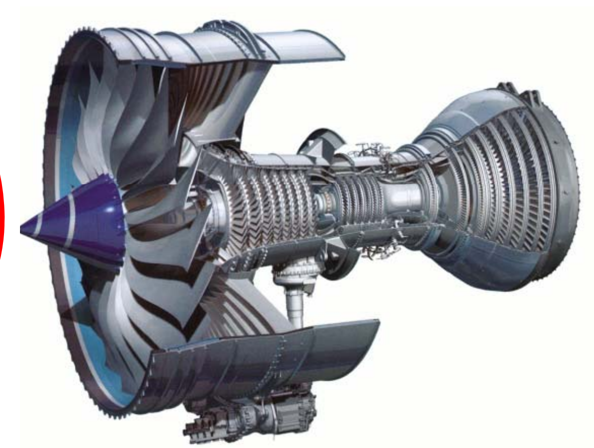
Direct Drive System Limits Potential of Low FPR Low-RPM Fan Engine

- Direct Coupling of Low-RPM Fan with LPT Drives Higher Stage Count and Larger Diameter for LPT.
  - Fan and LPT Efficiencies are Compromised and Weight and Maintenance Costs Increase
  - LPT Size Challenges Installation
- Paradigm Shift
  - Abandon Direct Drive
  - Gear System to Get High RPM Power Turbine with Low RPM Fan



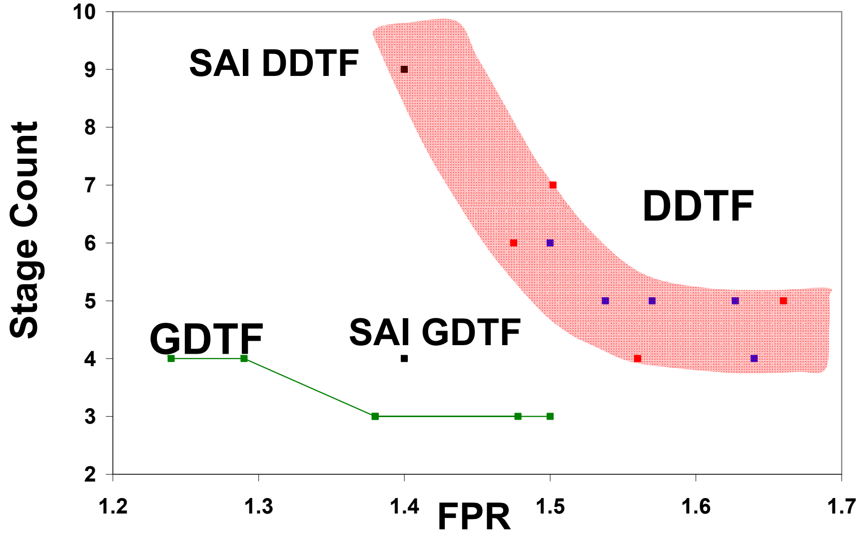


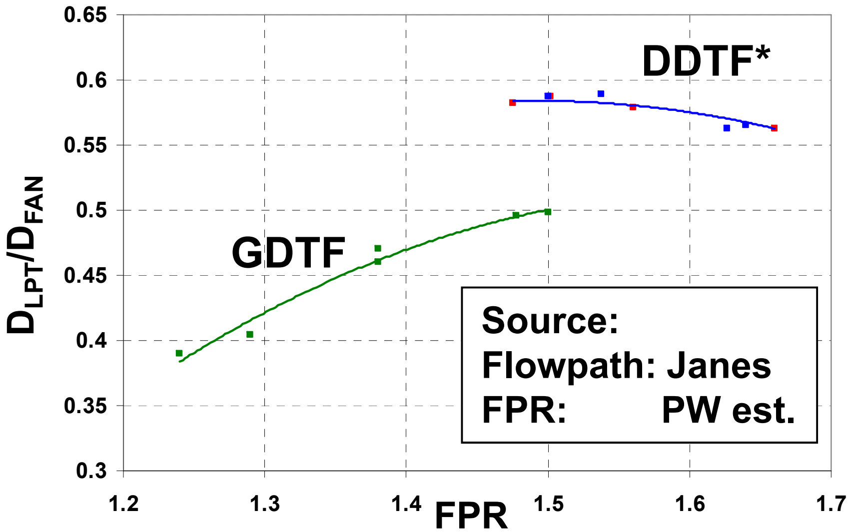


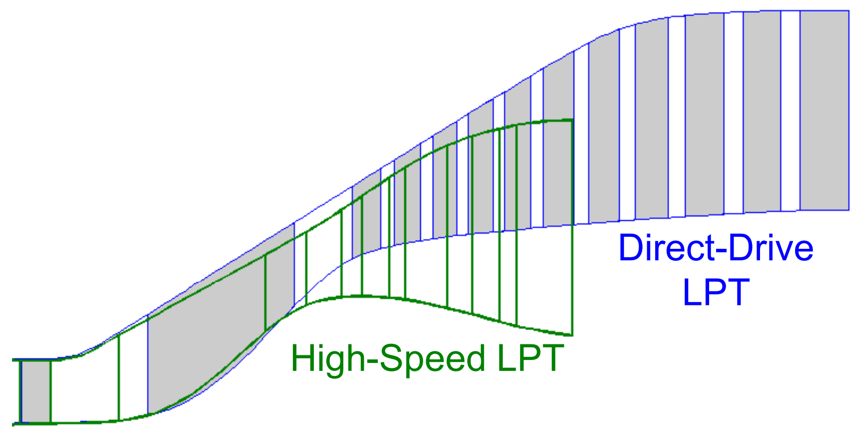


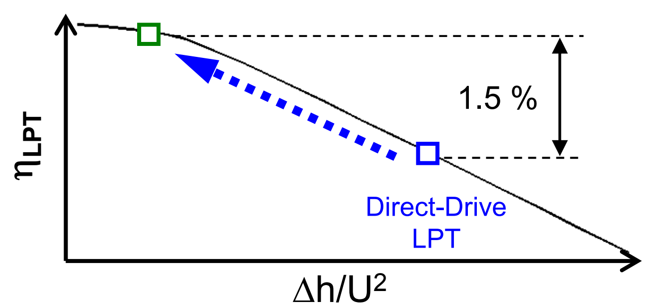
POWER TURBINE / TRANSFER EFFICIENCY

High-Speed Power Turbine Enables Installation, Low Weight &High Efficiency

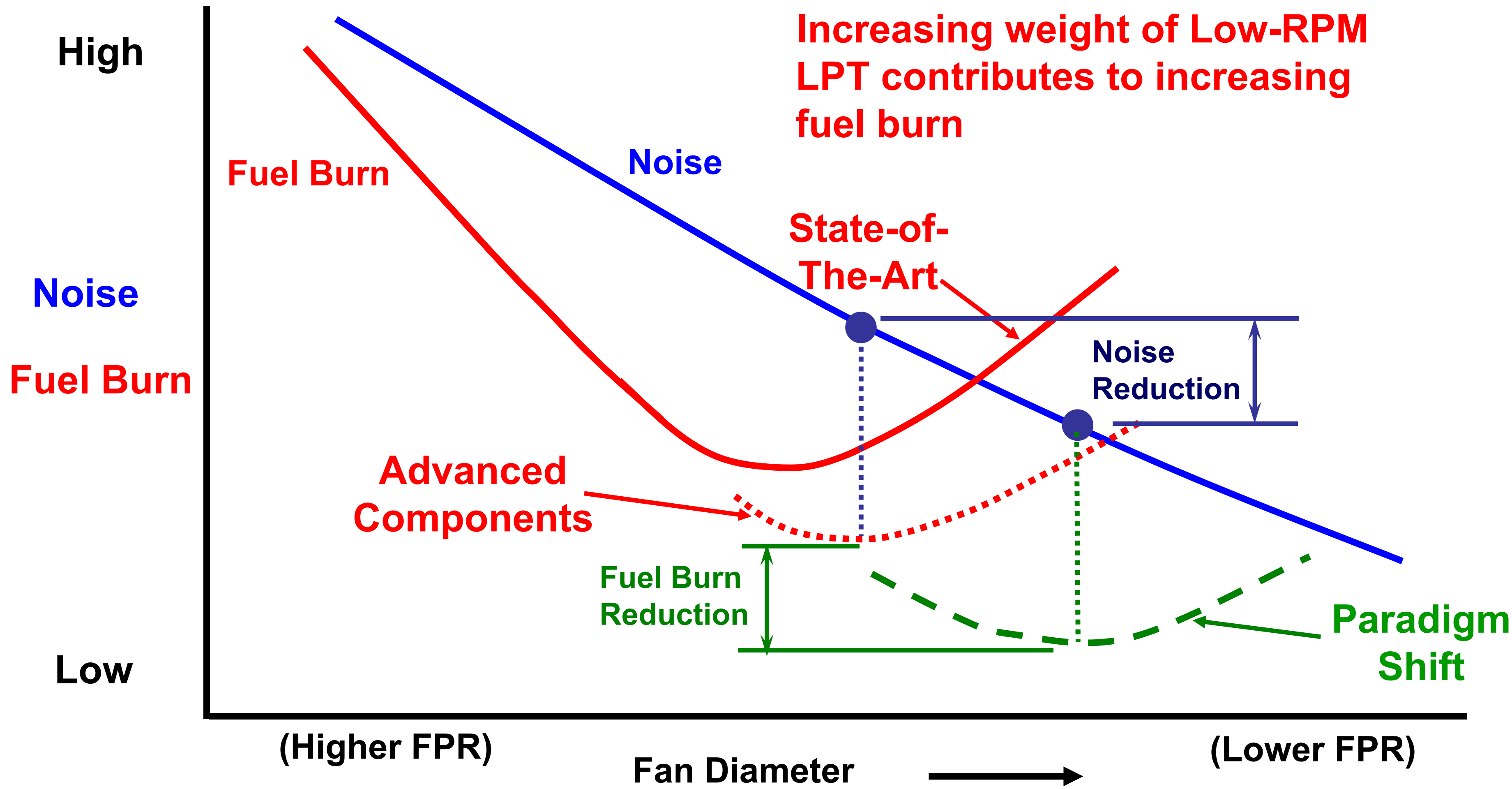


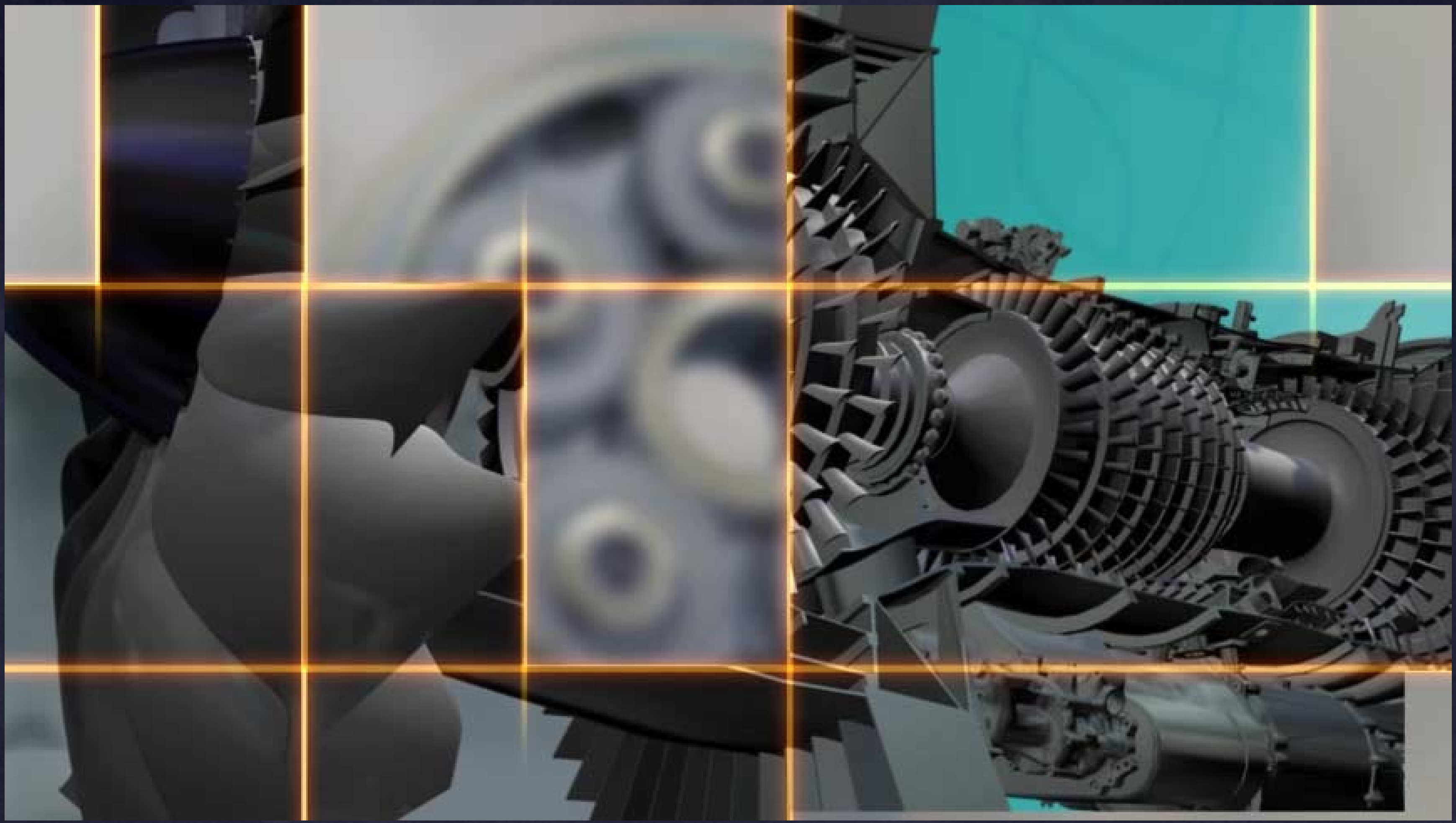






Paradigm Shift Required to Improve Fuel Burn AND Reduce Noise

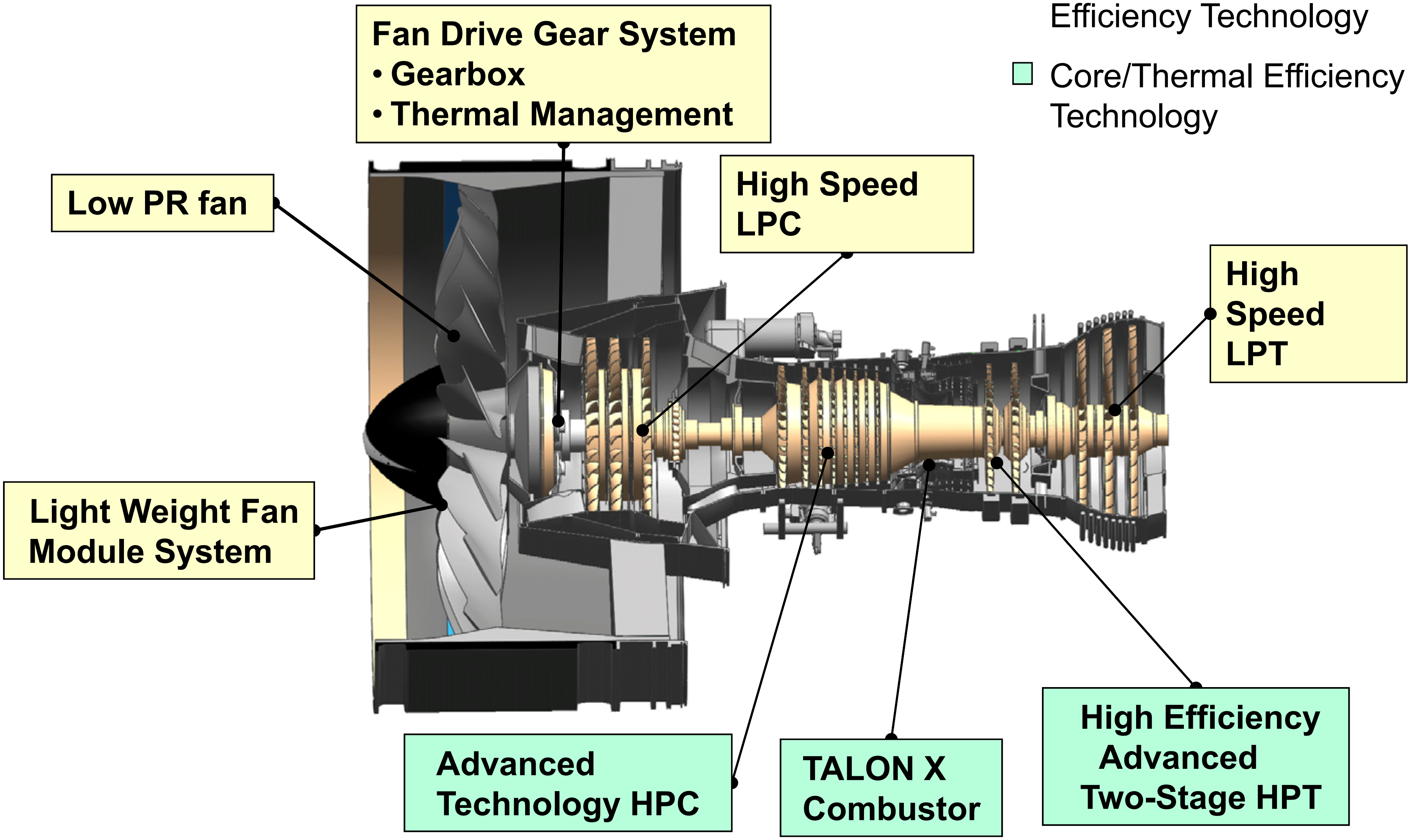




GTF ENGINE KEY FEATURES

Configuration Tailored to Cycle Needs

- Propulsor/Transfer Efficiency Technology
- Core/Thermal Efficiency Technology



Agenda – Part II

- Next Generation Turbofan design objectives
- GTF ™ technology development & validation

  - GTF ™ Demonstrator

  - Mitsubishi Regional Jet & Bombardier CSeries engine program

Next Generation Turbofan design objectives

Criteria	Existing engine	Objective
Fuel burn	Base	> -12% to 15%
Noise	-2 to -4 dB rel ICAO stg.4	> -20dB rel ICAO stg.4
Emissions	-40% rel ICAO 96	-60% rel ICAO 96
Maintenance cost	Base	- 20%
Reliability	Base	better than Base

Source: P&W

- **Fuel burn** is the most critical objective because of its most significant impact on airlines' operating costs and on the ability to meet the emerging CO2 standards
- **Community noise** is becoming more and more an economic factor for airlines
- **Reliability** and **maintenance cost** will continue to be amongst the most important focus areas and can not be compromised

  → Overall objective for airlines is minimum **cost of ownership**

  → Overall objective for engine manufacturer is highest **customer value**

Agenda – Part II

- Next Generation Turbofan design objectives
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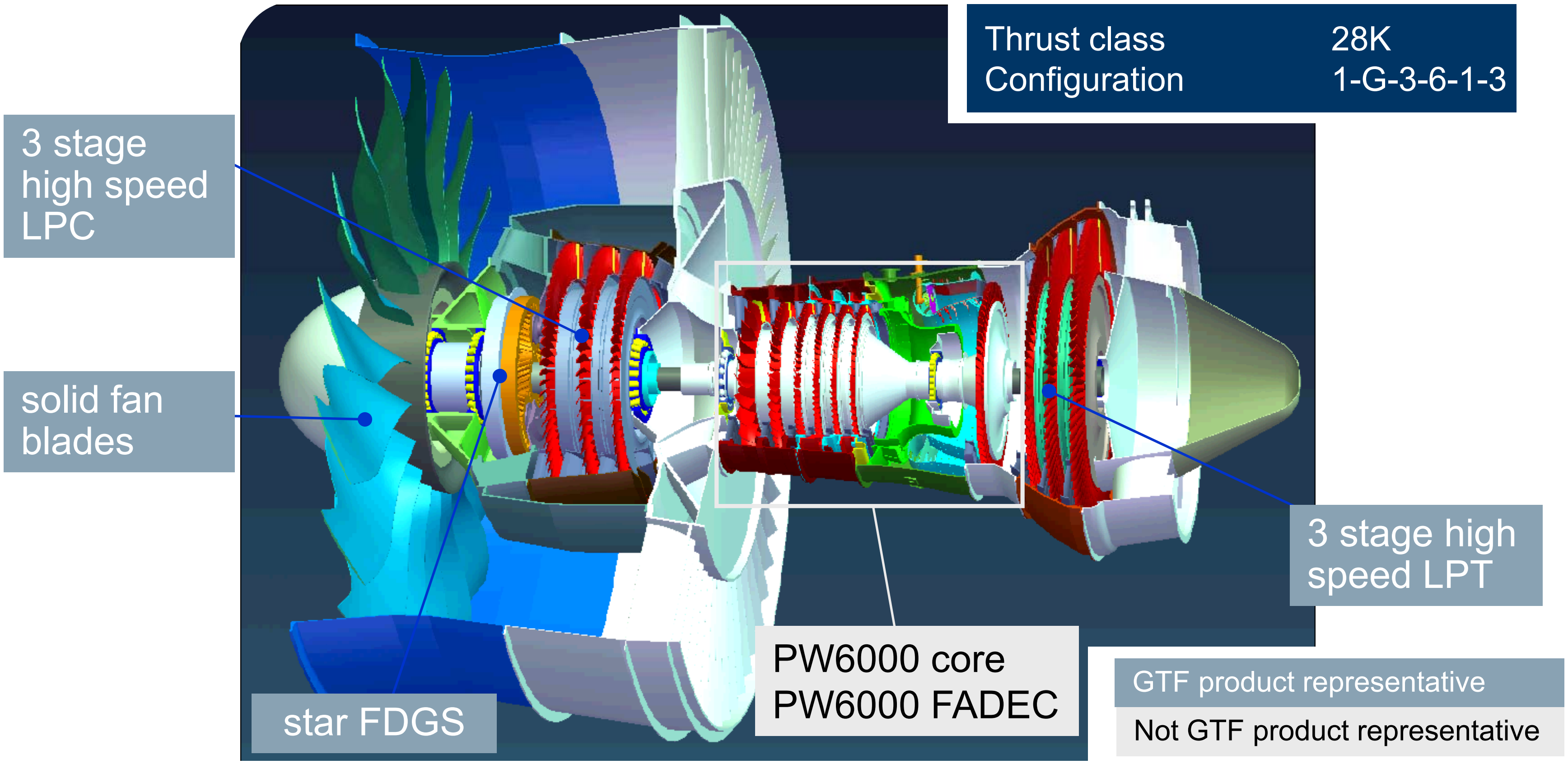
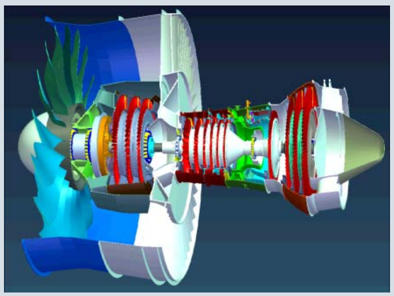
GTF™ demonstrator engine configuration

Thrust class	28K
Configuration	1-G-3-6-1-3



Configuration from new high speed low spool and a PW6000 core

GTF™ demonstrator program milestones



2007

Build Start
May 2007 ✓

Start Ground Test
Nov 2007
Phase 1 & 2 ✓

2008

747 FTB 1st Flight
July 2008
Phase 3 ✓

A340 1st Flight
Oct 2008
Phase 4 ✓

2009

▶ Technology readiness achieved end of 2008 to support product EIS end of 2012

Results & achievements

Accumulated run time

~ 400 hrs total running time all phases, ~ 120 hrs flight time, more than half at AI FTB A340

Metrics

• Thrust capability	- Full thrust requirement achieved
• Noise	- ICAO Stage 4 – 20 EPNdB requirement achieved
• Performance	- Engine only as predicted, FDGS and total low spool better than predicted
• Operability	- Fan & LPC operability and transient response within expectations

Customer attention

„I think it's going to be a good engine (the P&W-GTF™). We don't think the gearbox is going to be a problem. They've done their homework to make sure it's going to work" says Mike Bair, VP Boeing Commercial Airplanes Business Strategy and Marketing
(Aviation Week & Space Technology, September 1st, 2008)

► Key product relevant learning accomplished, gained significant attention

Agenda – Part II

- Next Generation Turbofan design objectives
- GTF ™ technology development & validation
  - GTF ™ Demonstrator
  - Mitsubishi Regional Jet & Bombardier CSeries engine program

PW1217G for the Mitsubishi Regional Jet MRJ 70/90

Mitsubishi Regional Jet

Status

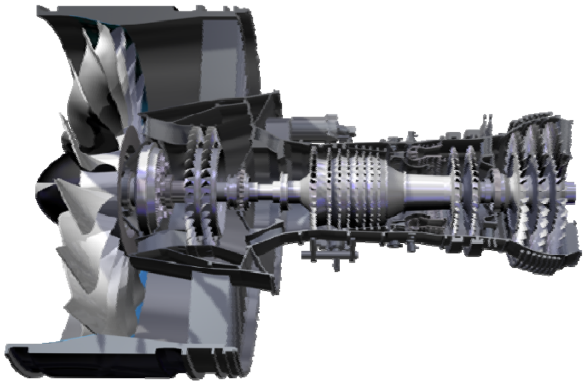
Pratt & Whitney launches Geared Turbofan engine with Mitsubishi

London, October 09, 2007

Mitsubishi launches MRJ programme

Flight International, March 28, 2008

Geared Turbofan PW1217G



Order book (# engines)

Total contracts: 130 / 120

All Nippon Airways (ANA)

Trans States

PW1524G for the Bombardier CSeries CS100/CS300

BA CSeries CS100/CS300

Status

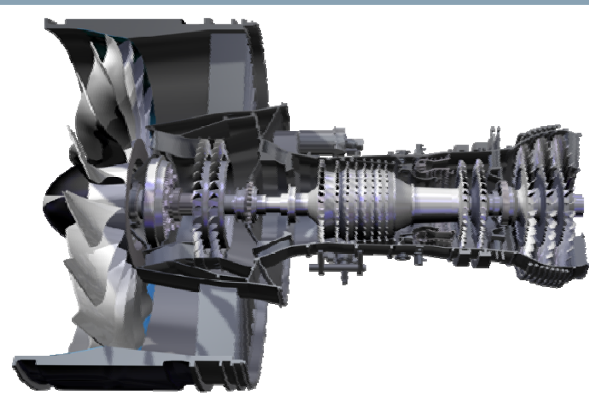
Pratt & Whitney Geared Turbofan™ engine to power CSeries aircraft for Lufthansa

Farnborough, July 13, 2008

Lufthansa's CSeries discussions with Bombardier advance

ATI, November 19, 2008

Geared Turbofan PW1524G



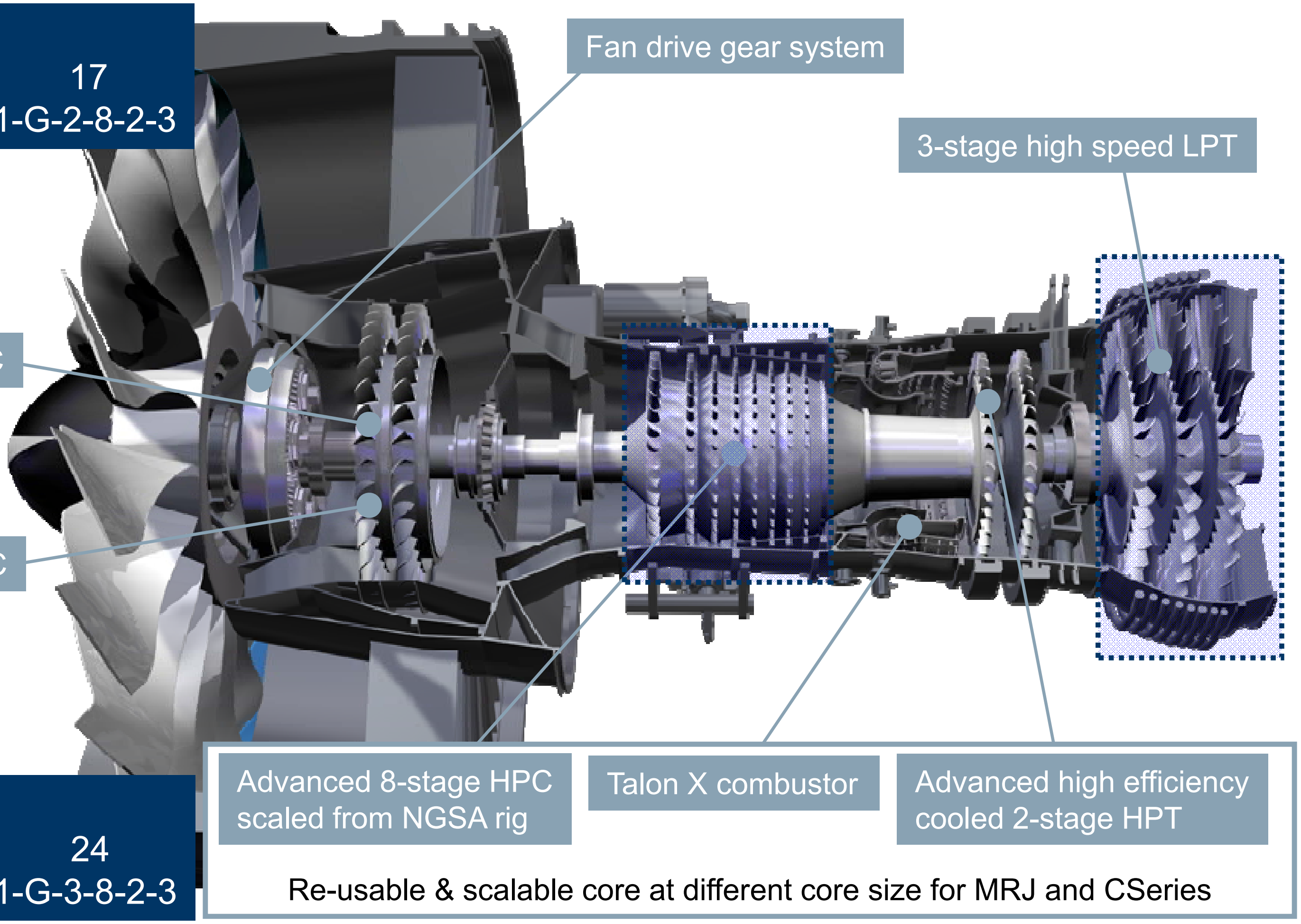
Order book (#engines)

Total contracts: 180 / 180

Lease Corporation International (LCI)
Lufthansa
Republic Airways

The first GTF^{TM} products

PW1217G
Thrust class [k lbs] 17
Configuration 1-G-2-8-2-3

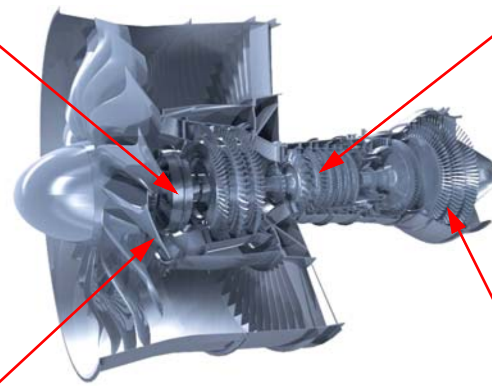


PW1524G
Thrust class [k lbs] 24
Configuration 1-G-3-8-2-3

GTF^{TM} Technology Development & Validation

Gear System Test Facility (P&W)

HPC Technology (MTU)



LPC Rig (P&W)

LPT Demo (MTU)

Excellent P&W Reduction Gearbox Experience

29,338 PT6A series engine in service
over 235 Million operating hours

8,169 PT6T turboshaft engines in service
over 33 Million operating hours

> 42,000 engines
> 460 Mio Op. hrs

4,845 PW100 series engines in service
over 70 Million operating hours

Sikorsky Helicopters Gear Reduction
Units to 10,000 SHP

		GTF (Estimate)	Turboprop (Typical)
Gearbox	Reduction Ratio	3:1	10:1
	IFSD (1,000 Hours)	0.0004	0.0008
	MTBUR (Hours)	250,000	128,000+
Variable Pitch Mechanism	IFSD (1,000 Hours)	No Variable Pitch Mechanism	0.0090
	MTBUR (Hours)		2,500

Fan Drive Gear System Development

20+ Years Technology Maturation, +3500 Hours of Testing

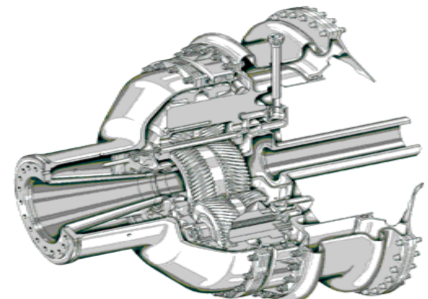
High

Risk

Low

PropFan Demo Engine 13K SHP
Counter Rotating System
Ground and MD80 Tested

’87 – ‘89



ADP Demo Engine 40K SHP
Planetary System
Ground, Wind Tunnel and Rig Testing - 600 Hours

’92 – ‘93

Flight Weight Design 32K SHP
Planetary & Star Systems
4 Builds - 1000 Hours Testing

’94 – ‘98

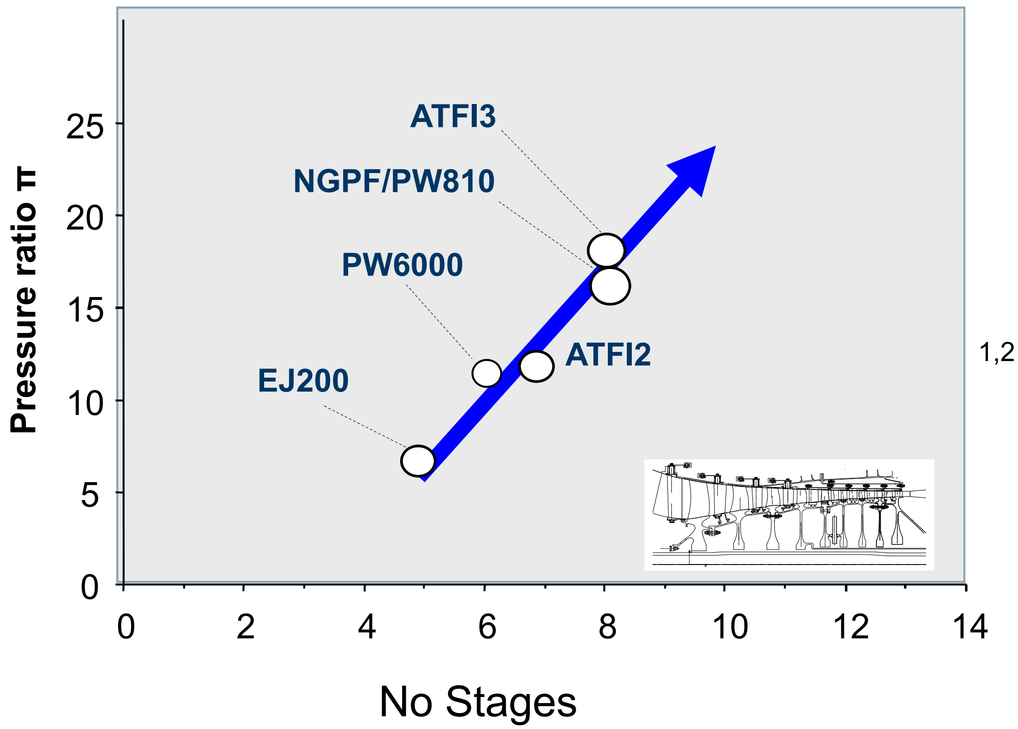
PWC ATFI Demo 11K SHP
Star System 276 Hours

’01-’02

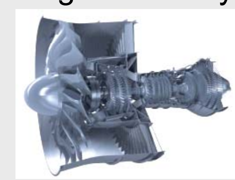
GTF Demo 28K SHP Star System
1762 Hours

1987 **1992** **1994** **2001** **2007** **2009**

MTU HPC Systematic Technology Development



NGPF/ PW810 ‘2006-08 — High Pressure Ratio/High efficiency, Low weight, Low cost

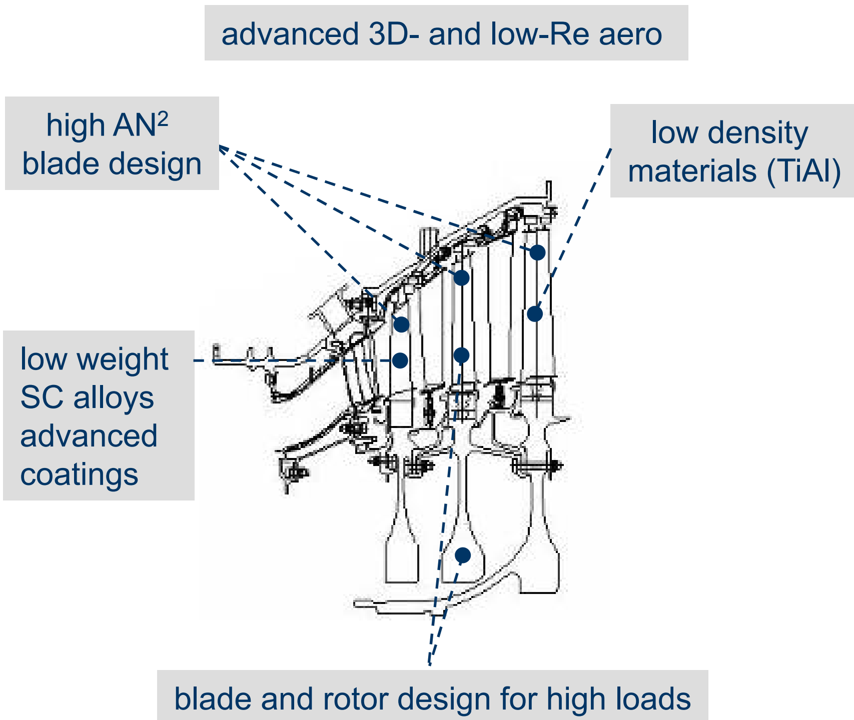


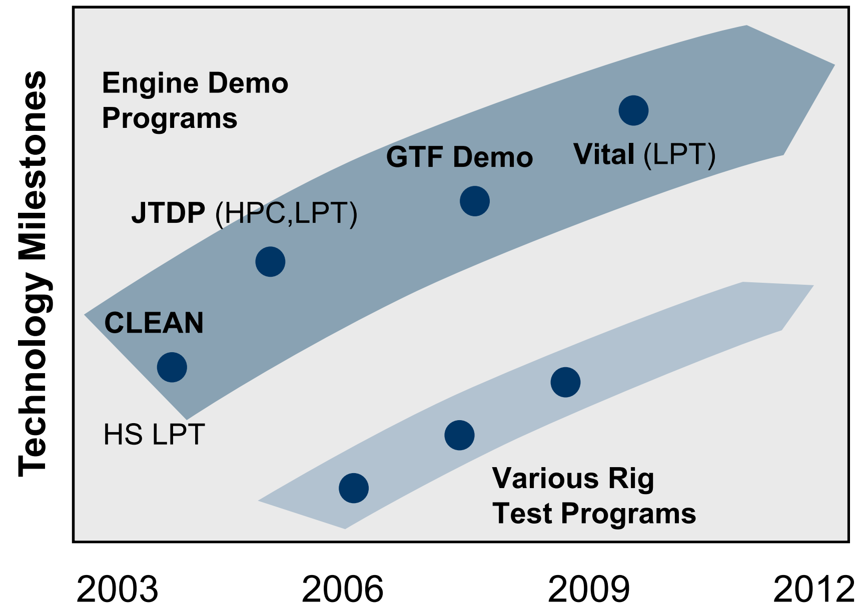
ATFI2 ‘2004 — High efficiency

PW6000 ‘2000 — Low Stage Count

EJ200 ‘1990 — Military High Performance

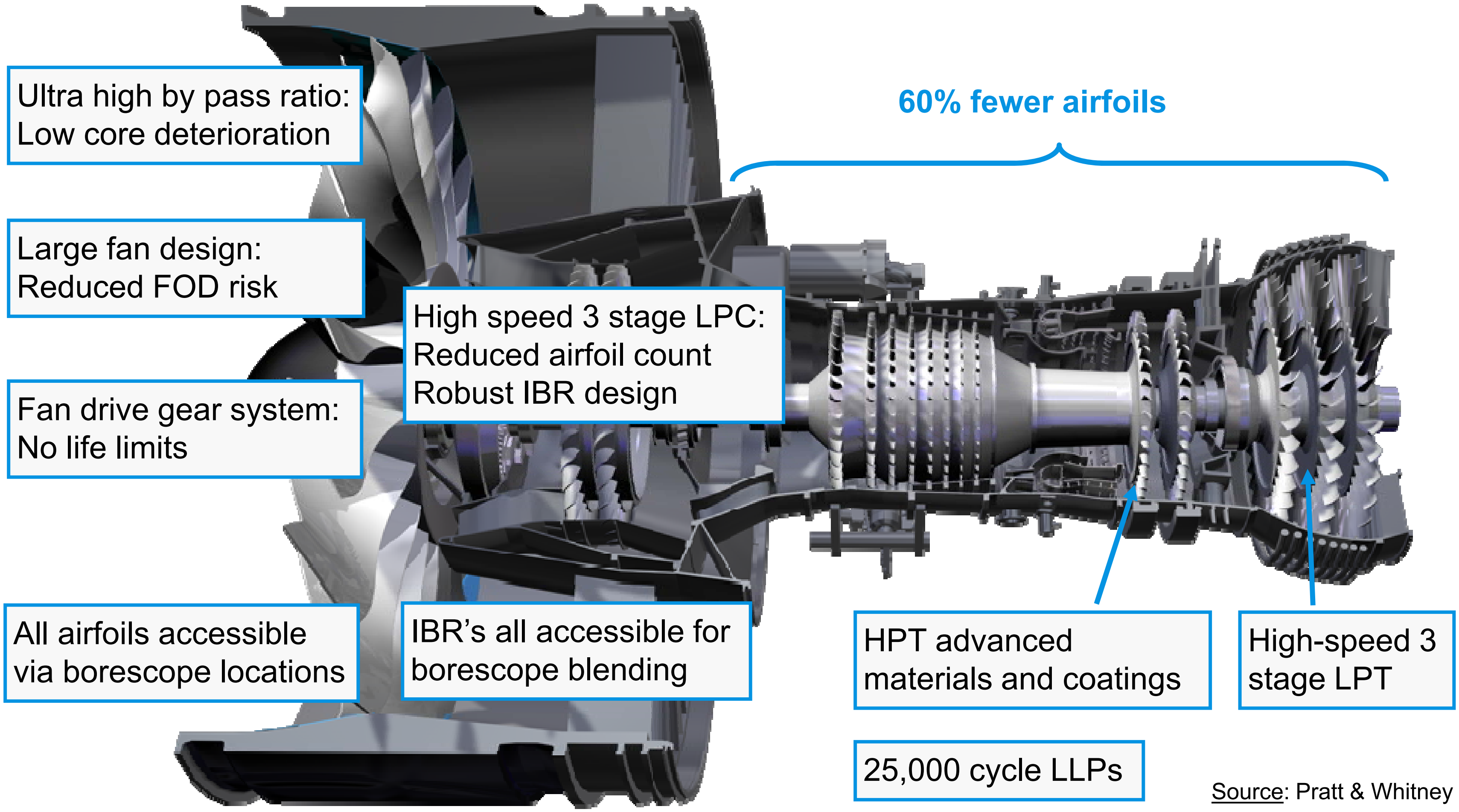
High Speed LPT Technology Development





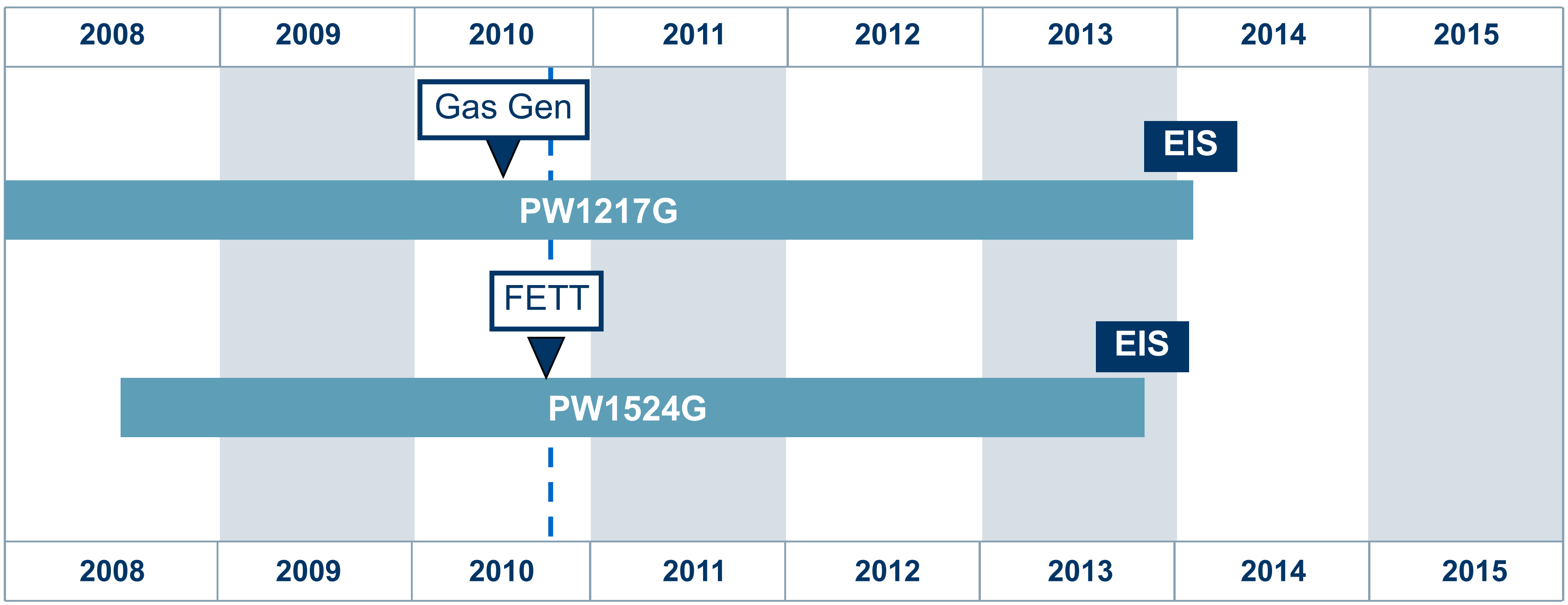
- Technology development addressing high speed LPT challenges
- Maturation plans to protect product EIS end of 2012

PW1000G – GTF™ design for low maintenance cost



Source: Pratt & Whitney

PW1000G level 1 plan



- Gas Generator testing completed in June 2010 exceeding expectations
- PW1524G FETT @ test, first light-up to idle on 09/25/2010

PW1217G & PW1524G on track for EIS

1 December 2010

Core engine testing

Test highlights

- Very successful test campaign
- Accumulated > 260 hrs run time
- HPC & HPT aero test plan completed
- Combustor performance confirmed

HPC results

- **Efficiency:** Pre-test prediction & efficiency projection confirmed
- **Stability:** SVS schedule optimization demonstrated and SM slightly exceeding pre-test

Testing successfully completed in June 2010 exceeding expectations

PW1524G FETT @ test

All HPC H/W delivered to PWA

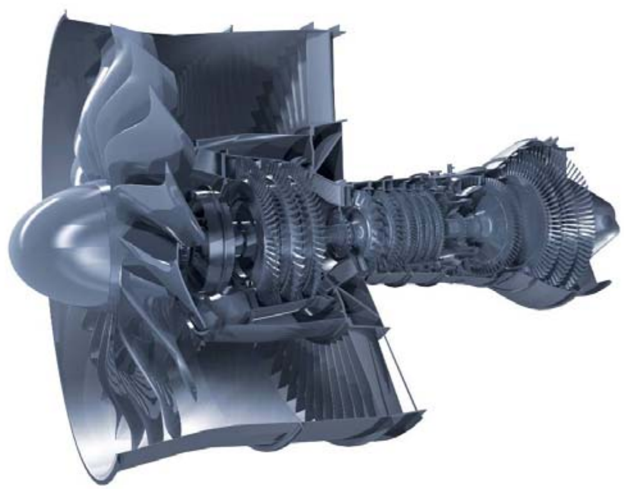
LPT module delivered to PWA after last bolt ceremony

Core assy complete

Men at work

1 December 2010

Geared Turbofan proven potential



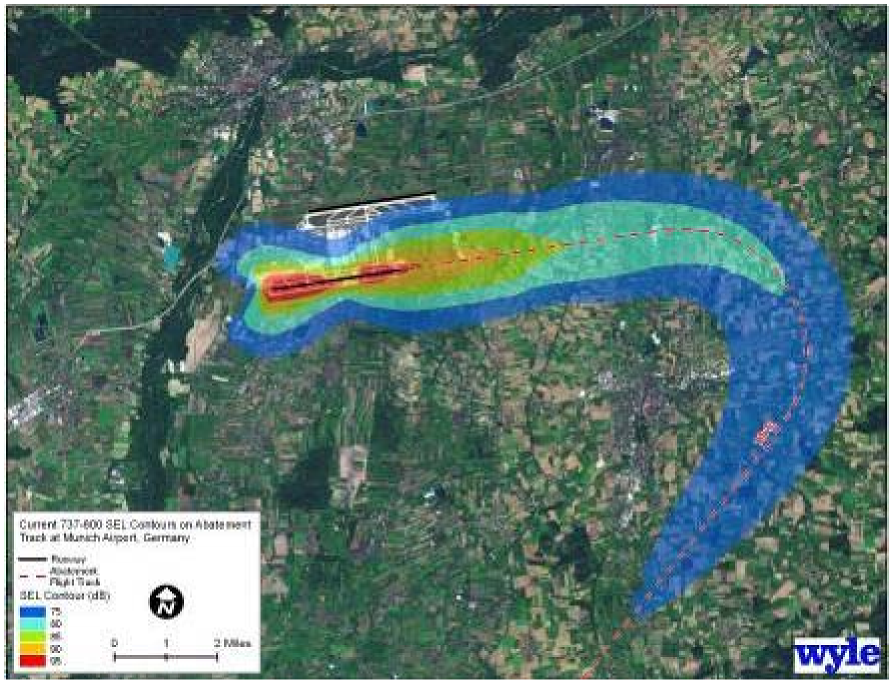
Geared Turbofan

- - 15%+ Fuel Burn rel. to year 2000 engine
- Further Fuel Burn improvement via technology insertion
- - 20 dB Noise (cum.) Emission rel. to ICAO stage 4
- Technology Readiness end of 2008

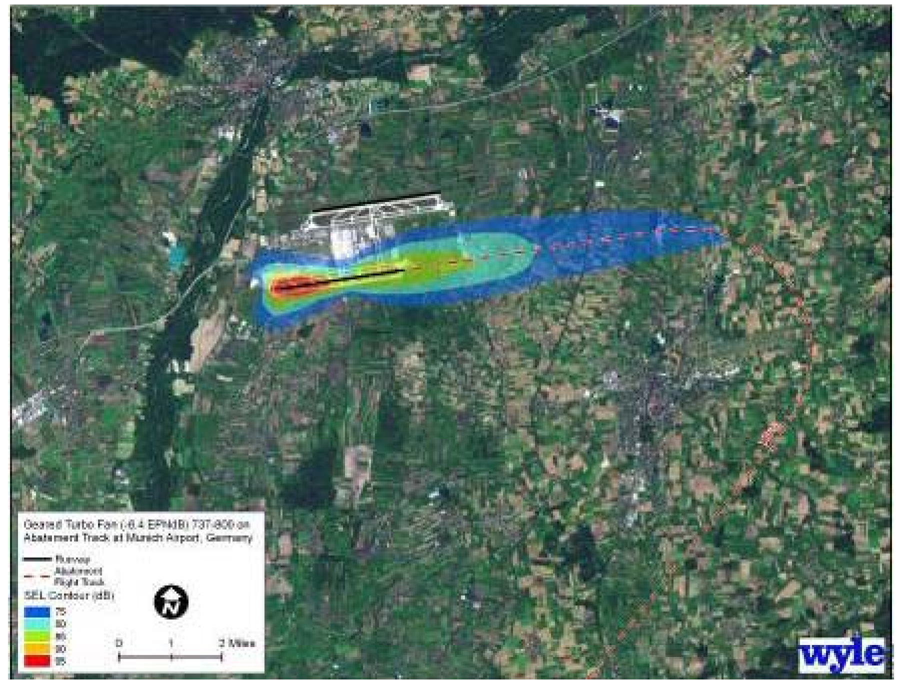
The Geared Turbofan is the only concept which allows both significant reduction in fuel burn and noise

Significant Reduced Noise Emission

Munich International Airport (MUC)



Today's Aircraft



Geared Turbofan Powered Next Generation Aircraft

Noise Simulation: Pratt & Whitney
SEL Contour Source: Wyle Laboratories

72% Reduction in 75dB Single Event Noise Contour