The Pratt & Whitney PurePower® Geared Turbofan™ Engine

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Pratt & Whitney

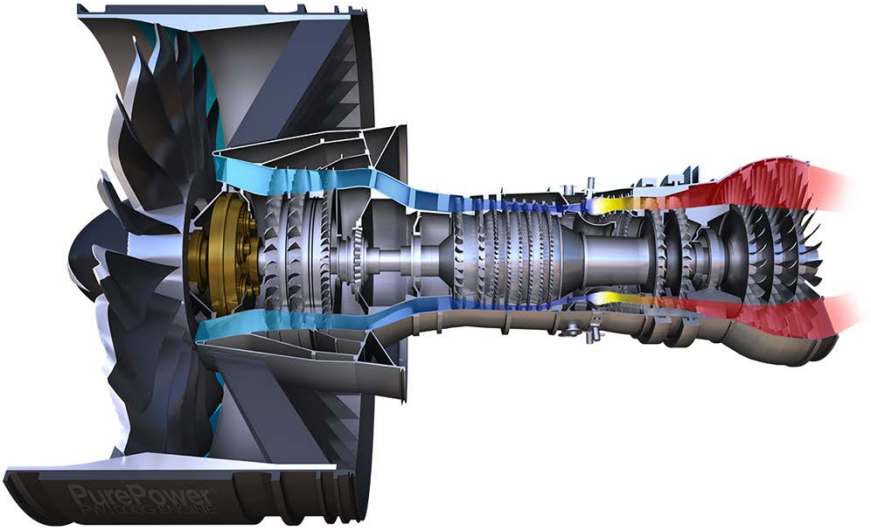
Academie de l'Air et de l'Espace
Paris, September 2015

Overview

The Development of the Geared Turbofan™ Engine

- Some historical perspective
- A recurrent theme - conventional wisdom vs. reality
- The roles of architecture, design, and technology
- Speculation on the future

PurePower® Geared Turbofan™ Engine



Why History?

"There is nothing new in the world except the history you do not know."

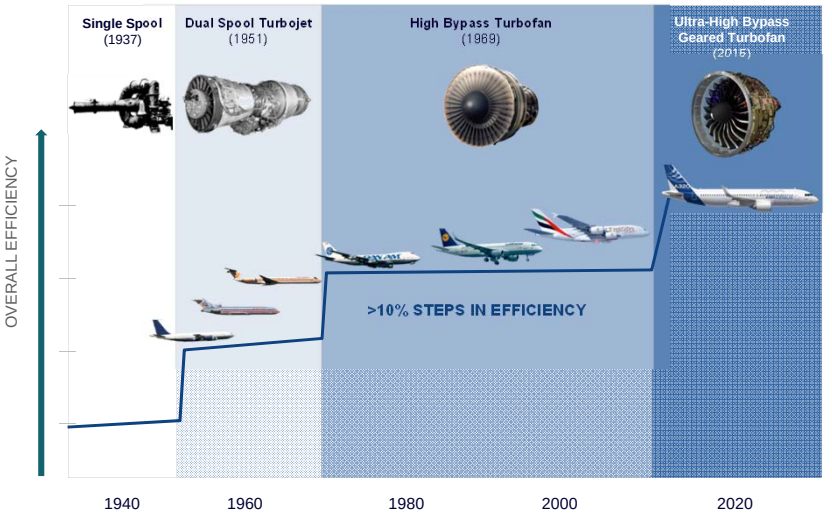
Harry S. Truman

Pratt & Whitney – Dependable Engines

Wasp Engine
1925

Turbofan Engine
2015

Eras of Engine Architecture



Geared Turbofan Technology Demonstrators

Over 50 years of interest

Pratt & Whitney PW304, 1957

Hamilton Standard Q-Fan, 1972[2]

General Electric QCSEE, 1977[4]

Lycoming ALF502 1980[5]

1960 1970 1980 1990

Turbomeca Astafan Variable Pitch Fan, 1969[1]

Garrett TFE731 1970[5]

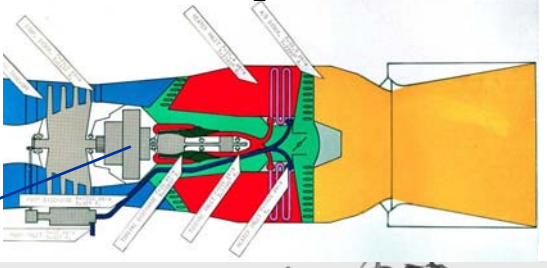
Rolls Royce Dowty M45SD-02, 1975[3]

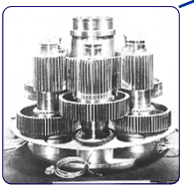
Pratt & Whitney ADP X-Engine, 1992

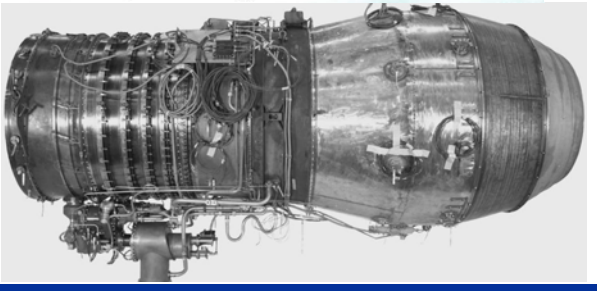
Image Credits
[1] Johan Visschedijk Collection
[2] Schaefer, et al, NASA, 1977
[3] Simon JP O'Riordan
[4] NASA
[5] Wikimedia Commons

P&W Hydrogen Fueled Aircraft Engine

Project Suntan – Liquid H_2 engine circa 1957-58







Geared Turbofan Technology Demonstrators

Variable pitch fans

Hamilton Standard
Q-Fan, 1972[2]

General Electric
QCSEE, 1977[4]

1960 1970 1980 1990

Turbomeca Astafan Variable
Pitch Fan, 1969[1]

Rolls Royce Dowty
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Pratt & Whitney
ADP X-Engine, 1992

Image Credits
[1] Johan Visschedijk Collection
[2] Schaefer, et al, NASA, 1977
[3] Simon JP O'Riordan
[4] NASA

Turbofan Conversion Geared Engines

Turboprops/shaft transformed into high FPR turbofans

Garrett TFE731
1970

1960 1970 1980 1990

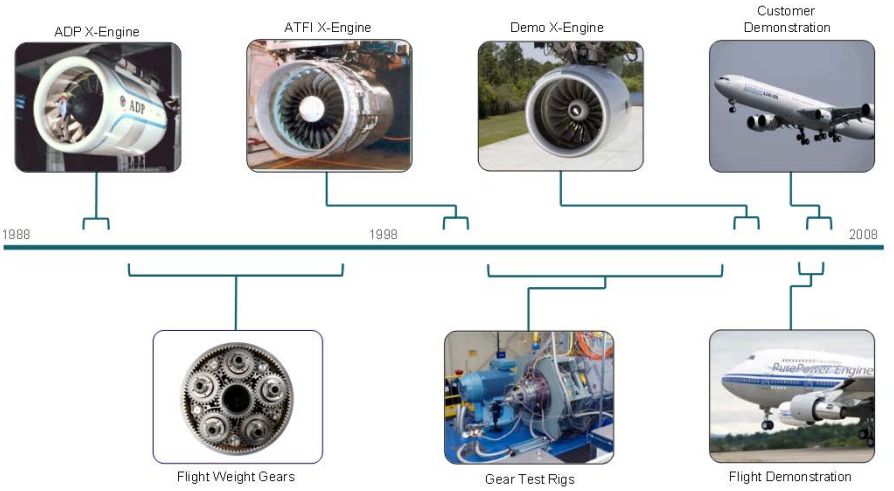
Lycoming ALF502
1980

Image Credits
Wikipedia commons

FPR = fan pressure ratio

$1B Technology Investment

25 years of research prior to product launch



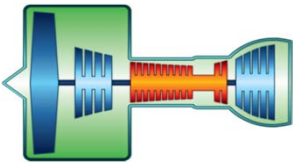
Challenging Conventional Wisdom

Conventional wisdom - areas of general consensus

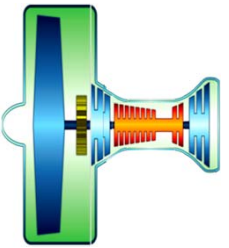
- Gears – too heavy, too much heat to reject, short-lived

GTF™ Engine

Architecture for the 21st Century



Conventional Engine

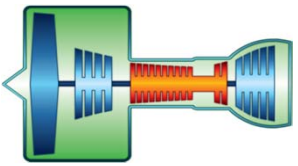


Higher Efficiency, Lower Noise

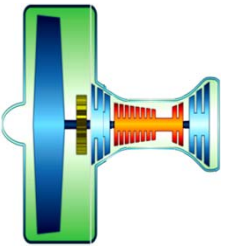
GTF™ Engine

Architecture for the 21st Century

Turning Vision



Conventional Engine

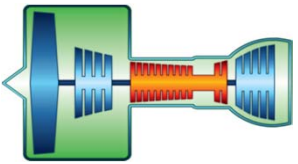


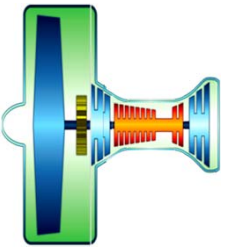
Higher Efficiency, Lower Noise

GTF™ Engine

Architecture for the 21st Century

Into Reality





Conventional Engine

Higher Efficiency, Lower Noise

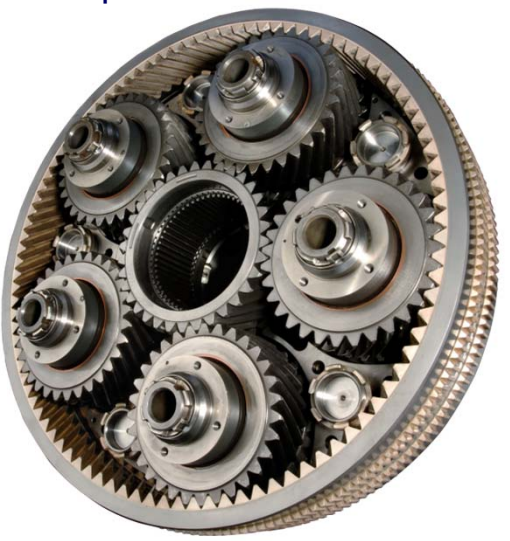
Fan Drive Gear System

25 years of technology development

Efficient: >99.5%

Simple: 13 major parts

Reliable: 20 years before maintenance



Three Interlocking Enabling Technologies

Enable step change in propulsor performance

Very Light Weight
Reliable Gear

Light Weight
Extra Efficient Fan

Advanced
Nacelle

2 + 2 + 2 = 16% Improvement in Fuel Burn

Challenging Conventional Wisdom

Conventional wisdom - areas of general consensus

- Gears – too heavy, too much heat to reject, short lived
- **Low FPR Fans – need variable pitch or variable nozzle**

Low Fan Pressure Ratio Needs a Variable Area Nozzle

A widely accepted view

"Fan pressure ratios at cruise significantly lower than, say, 1.45 will probably have to wait until variable nozzles for the bypass stream become available or acceptable, a point that has been recognized in the industry for some time.

In other words, the variable area nozzle is an enabling technology for lower fan pressure ratio." *

*Cumpsty, N.A., *Journal of Turbomachinery*, Oct 2010

Low Fan Pressure Ratio Needs a Variable Area Nozzle

PW1100G-JM / A320neo Nacelle

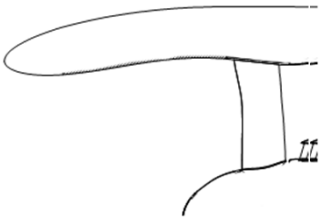
Challenging Conventional Wisdom

Conventional wisdom - areas of general consensus

- Gears – too heavy, too much heat to reject, short lived
- Low FPR Fans – need variable pitch or variable nozzle
- **Nacelles – too large in diameter, too much drag**

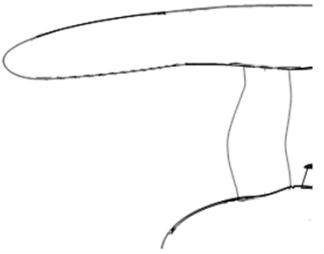
Low Noise Fans Enable Short Inlets

Less noise produced ➡ less acoustic treatment needed



Legacy

Inlet L/D~1



GTF

Inlet L/D ~0.5-0.6

Engine Diameter Grows as Length Shrinks

35,000 lbs thrust (today) versus 47,000 lbs (1976)

A Challenge to Retrofit a Much Larger Engine

Image courtesy of JetBlue

Challenging Conventional Wisdom

Conventional wisdom - areas of general consensus

- Gears – too heavy, too much heat to reject, short lived
- Low FPR Fans – need variable pitch or variable nozzle
- Nacelles – too large in diameter, too much drag
- **Composite blades are a superior, lighter solution**

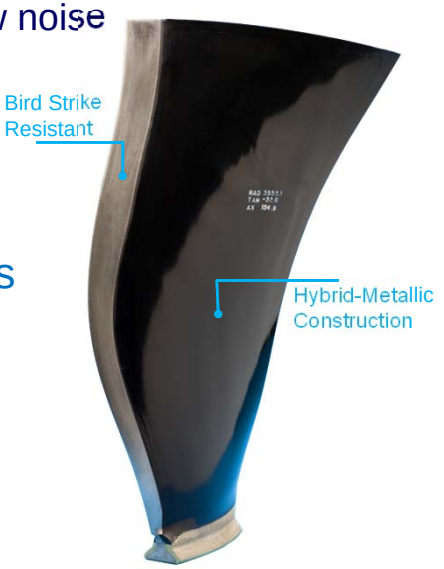
Hybrid Metallic Fan Blade

Disciplined approach surprised conventional wisdom

Advanced Fan Blade

Very high efficiency, very low noise

Superior Aerodynamics
1% Better Fuel Burn



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Conventional wisdom - areas of general consensus

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- Low FPR Fans – need variable pitch or variable nozzle
- Nacelles – too large in diameter, too much drag
- Composite blades are a superior solution
- **Low emissions requires lean burn combustors**

TALON™ X Rich Burn Quick Quench Combustor

Best in class emissions and performance

Blow out free 3rd Generation RQL aero

World-class emissions and smoke levels

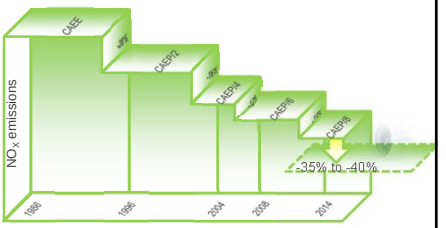
Highly durable float wall construction

3rd Gen combustor alloys for oxidation

Compact, lightweight configuration

No complicated fuel nozzles or staging

Optimized exit profile temperatures



>40% Margin to CAEP/8

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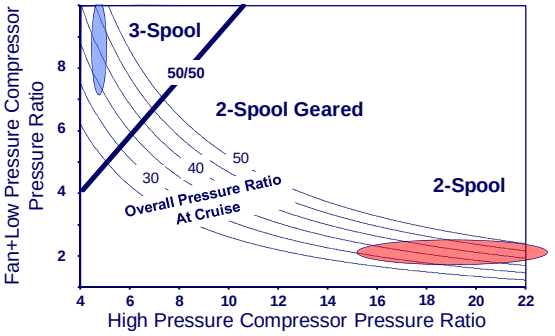
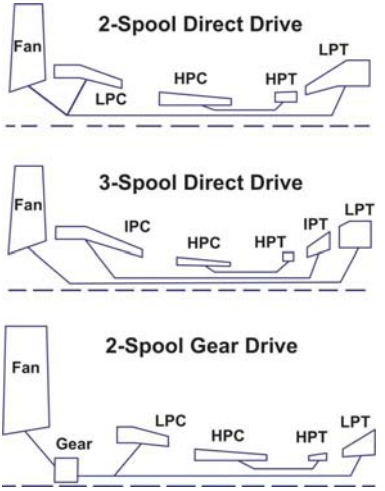
- Low FPR Fans – need variable pitch or variable nozzle
- Nacelles – too large in diameter, too much drag
- Modern fans must use composite blades
- Low emissions requires lean burn combustors
- **Higher pressure ratio core compressors are superior**

Architecture and Spool Pressure Ratio

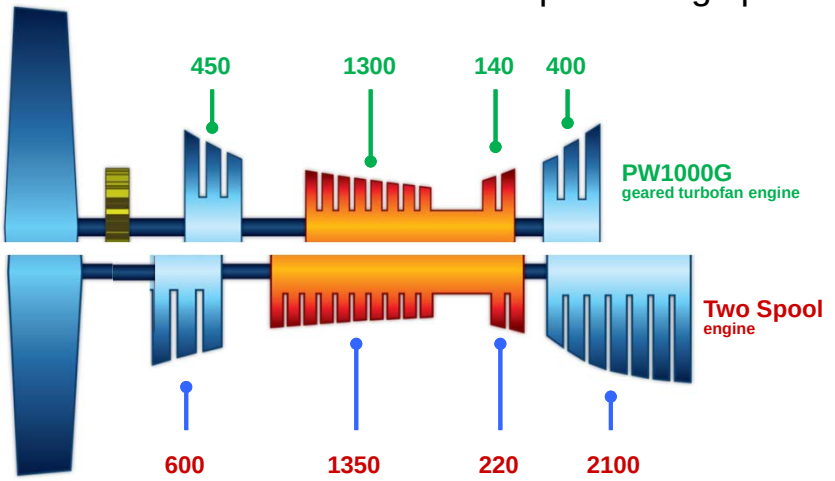
Engine architecture sets optimum low-high split





Same Overall Pressure Ratio (OPR)

Geared vs. direct drive different split among spools



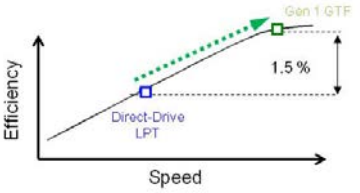
45% fewer airfoils – 6 fewer stages

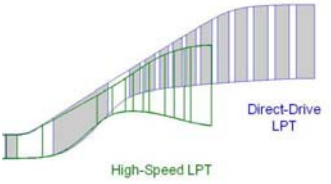
High Speed Low Pressure Turbine

Higher speed improves efficiency and drops weights

Gear Enables High Speed LPT

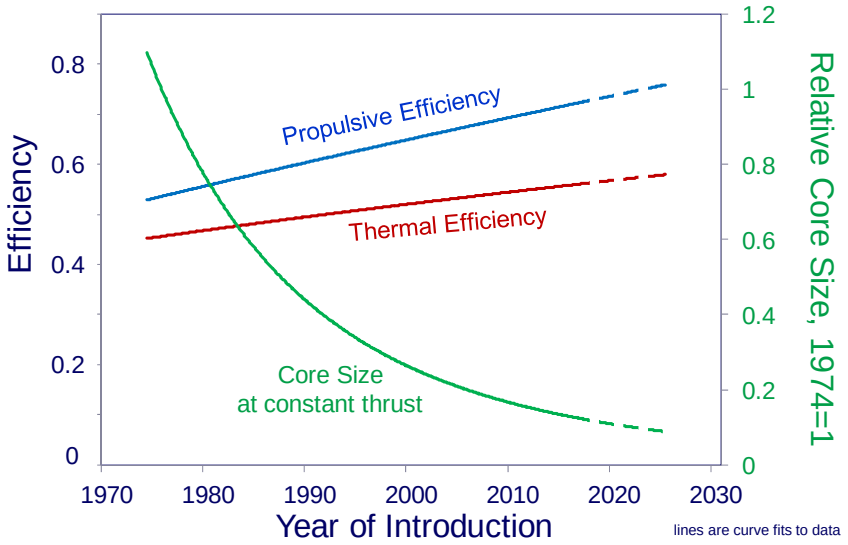
- Higher Efficiency
- Lower Stage Count
- >1700 fewer Airfoils
- Lower Weight
- Smaller Diameter and Length
- Better installation, lower airframe weight
- Lower Maintenance Cost





LPT efficiency trades 1:1 for fuel efficiency (fuel burn)

Cores Shrink as Efficiency Improves

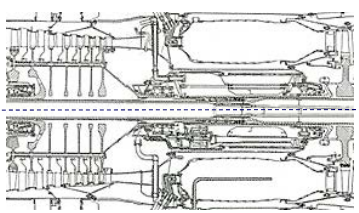


lines are curve fits to data

Cores Shrink as Efficiency Improves

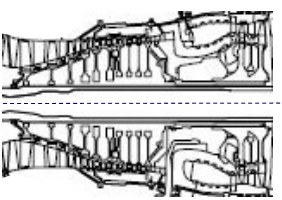
For similar missions

JT8D



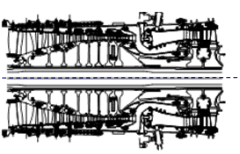
1964/1980
14,000/21,700 lbf

V2524



1995
24,800 lbf

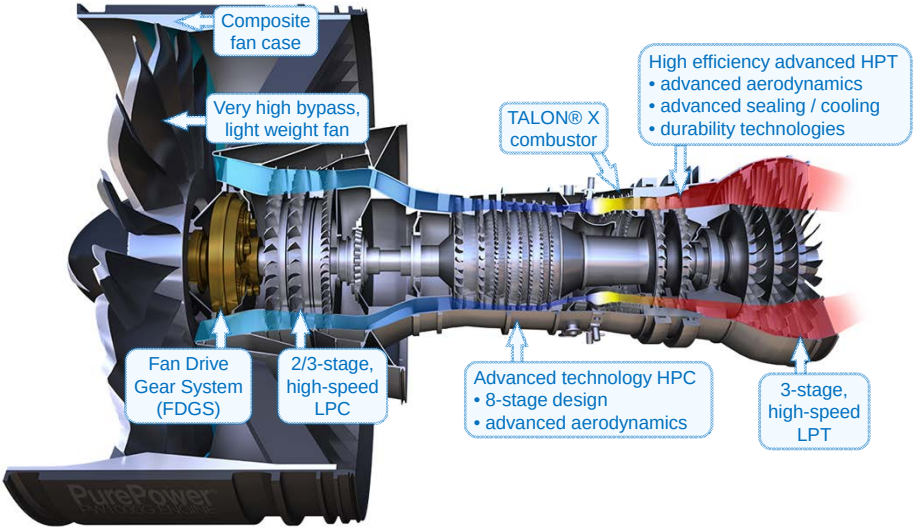
PW1524G



2016
24,000 lbf

PurePower® Geared Turbofan™ Engine

New technologies realized



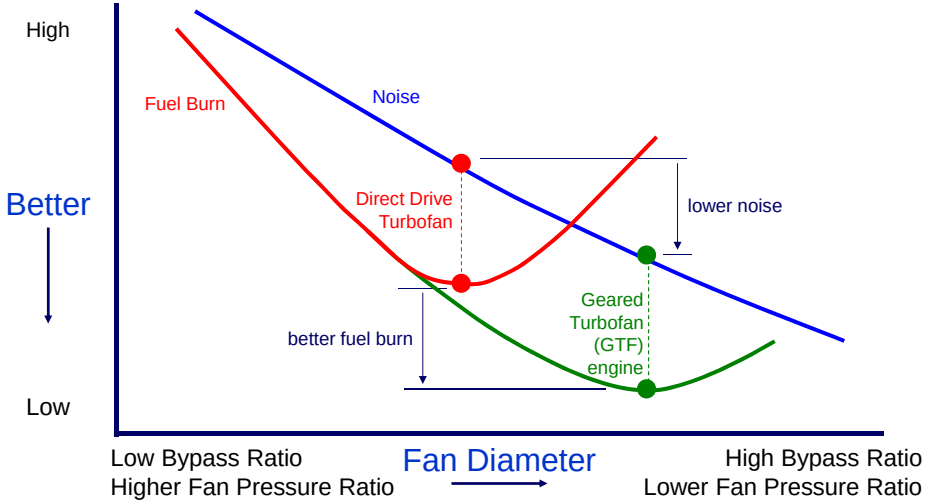
Challenging Conventional Wisdom

Conventional wisdom - areas of general consensus

- Gears – too heavy, too much heat to reject, short lived
- Low FPR Fans – need variable pitch or variable nozzle
- Nacelles – too large in diameter, too much drag
- Modern fans must use composite blades
- Low emissions requires lean burn combustors
- Higher pressure ratio core compressors are superior
- **Larger diameter, low FPR geared engines may have lower TSFC but will have higher fuel burn due to weight & drag penalties**

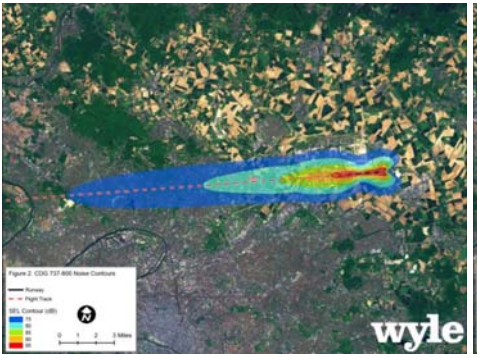
Conventional Propulsion System Fundamentals

Trading fuel burn against noise

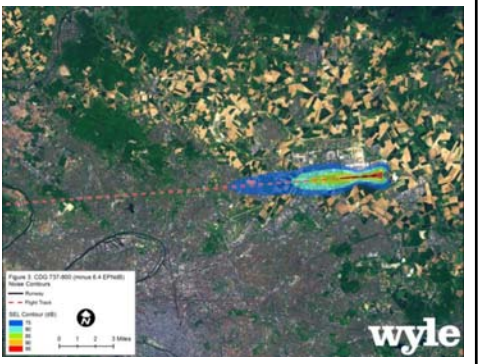


Dramatic Reduction in Community Noise

73% reduction in noise footprint – Paris CDG



Existing turbofan

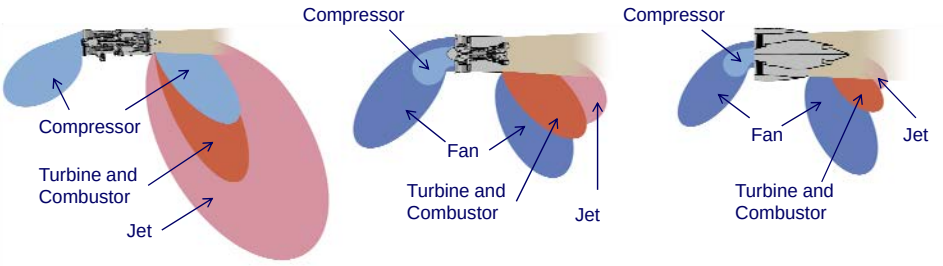


PurePower® PW1000G Engine

Source: Wyle Labs
Existing turbofan: 75 dB contour = 104.4 sq km
PW1000G engine: 75 dB contour = 28.7 sq km

Evolution of Turbofan Engine Noise

Jet noise no longer predominates



1960's engine	1990's engine	2015 engine
1:1 BPR	6~8:1 BPR	12:1 BPR

Engine Models

Airbus A320neo

PW1100G-JM

A319neo	A320neo	A321neo
PW1124G-JM	PW1127G-JM	PW1133G-JM
24,000 lbs	27,000 lbs	33,000 lbs

Mitsubishi Regional Jet

PW1200G

MRJ70	MRJ90
PW1215G	PW1217G
15,000 lbs	17,000 lbs

Irkut MC-21

PW1400G

MC-21-200	MC-21-300
PW1428G	PW1431G
28,000 lbs	31,000 lbs

Bombardier CSeries

PW1500G

CS100	CS100	CS300
PW1519G	PW1521G	PW1524G
19,000 lbs	21,000 lbs	24,000 lbs

Embraer E-Jets E2

PW1700G / PW1900G

E175-E2	E190/195-E2
PW1700G	PW1900G
up to 17,000 lbs	up to 22,000 lbs

7,000 Orders & Commitments

Embraer E-Jets E2

SKYWEST, INC. · AIRCASTLE · TRANS STATES HOLDINGS · HNA Tianjin Airlines · ICBC · air costa · AerCap · Azul

Mitsubishi Regional Jet

ANA · SKYWEST, INC. · TRANS STATES HOLDINGS · JAL JAPAN AIRLINES · EASTERN · AirMandalay

Irkut MC-21

CRECOM · LEASING · nordwind airlines · Ир Аэро · Ilyushin Finance Co. · СБЕРБАНК

Rostekhnologii

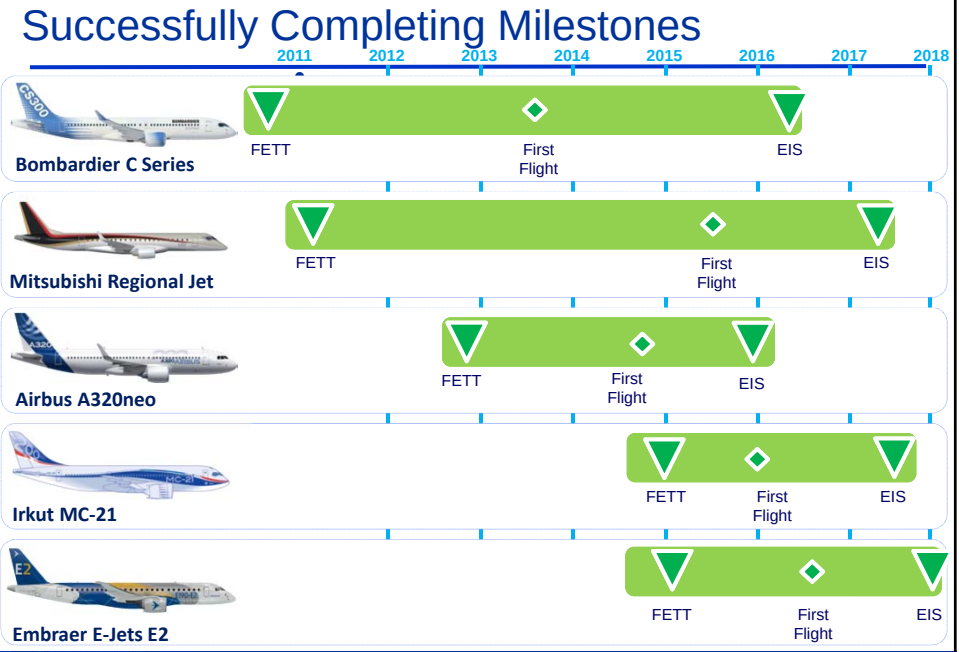
Bombardier C Series

Lufthansa · swiss · MALMÖ AVIATION · CLC · porter · KOREAN AIR · flymojo · REPUBLIC AIRWAYS · Gulf Air · airBaltic · FALKO · **Odyssey Airlines** · SaudiGulf · Ilyushin Finance Co. · PrivatAir · EAS · atlasjet · PETRA AIRLINES

Airbus A320neo

TURKISH AIRLINES · LAN · TAM · SMBC · norwegian.com · ANA · SICHUAN AIRLINES · CEBU PACIFIC AIR.COM · AIR LEASE · KOREAN AIR · CHINA SOUTHERN · AerCap · AVIATION CAPITAL GROUP · spirit airlines · HAWAIIAN · CIT · QATAR · jetBlue AIRWAYS · AIR NEW ZEALAND · vivaaerobus.com · IndiGo · Lufthansa · BOC AVIATION · ROYAL BRUNEI · volaris · TransAsia · tigerair · Philippine Airlines · CALC

Successfully Completing Milestones

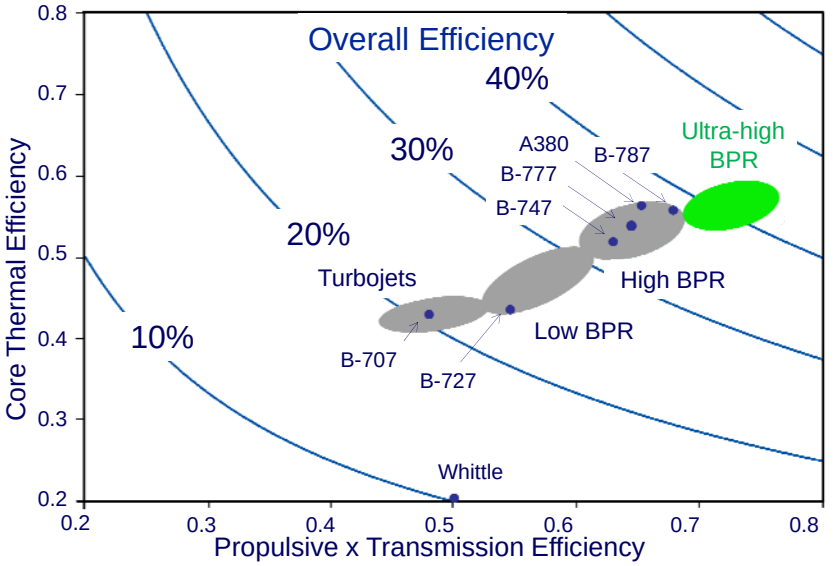


The Future

Semi-informed speculation

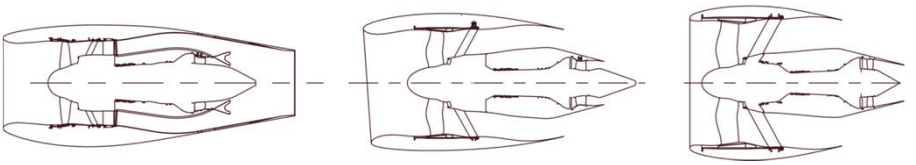
- What will be future engine requirements?
- What will the engines of the future look like?
- What technologies are needed?

Evolution of Jet Engine Efficiency



Change in Bypass Ratio, Efficiency

In Service	2013-16	Longer Term
BPR 5	BPR ~12	BPR 15~18
Fuel Burn Reference	-15%	-20~30%



Fan Pressure Ratios Must Drop

So inlets must shorten

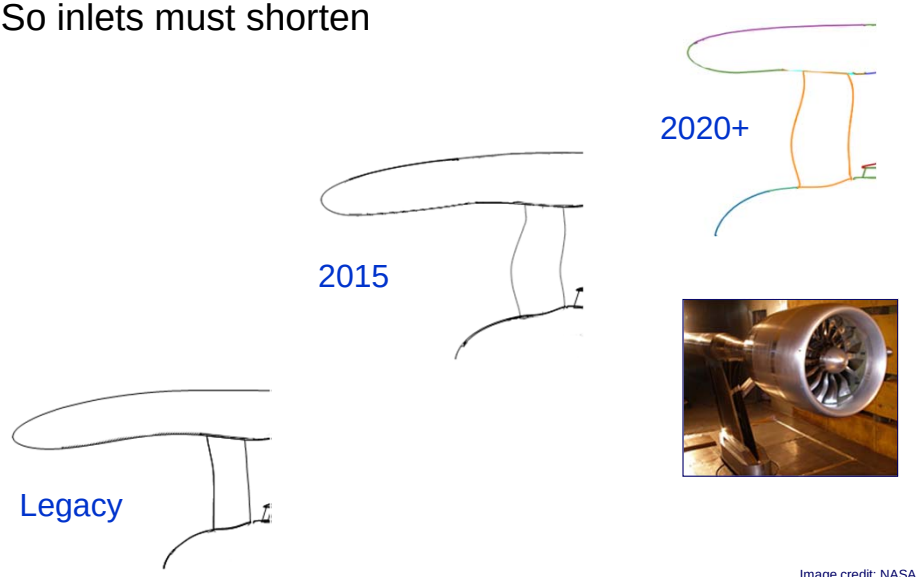
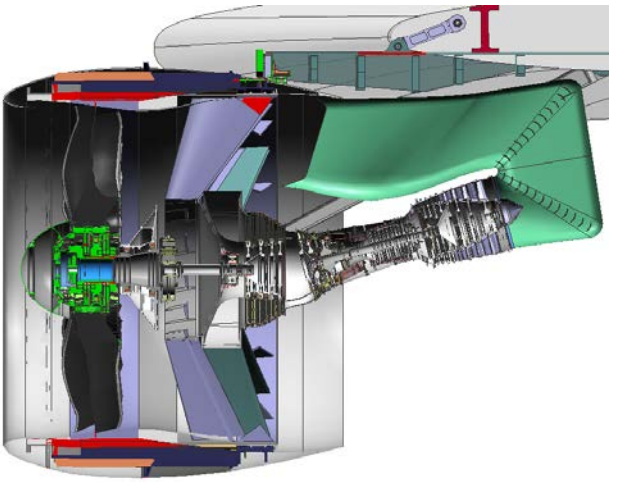


Image credit: NASA

One Advanced Concept, the LRU Core

Solving design challenges, reducing maintenance



Airplanes of the Future?

Future airplane is unclear, future motor is not

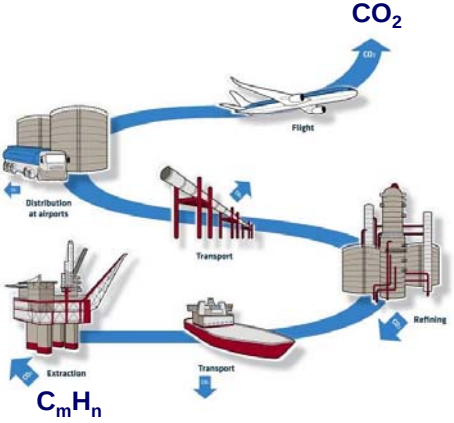
Source: ATAG

1:11 Scale D8 Aircraft

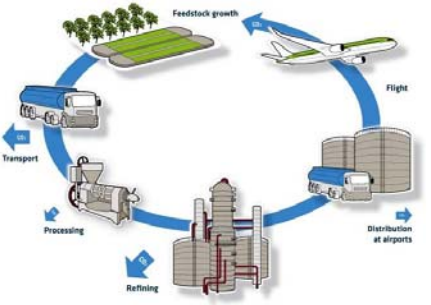
Source: E. Greitzer MIT

Innovation in Energy – Solar Powered Airplanes

Sustainable Drop-In Biofuels for Reduced CO_2



Conventional Fuel

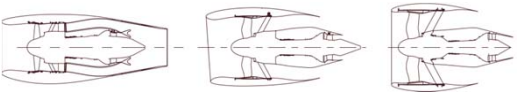


Bio Fuel

Summary

The future of commercial aviation

- Gas turbines are the future of commercial aviation
  - Most efficient engines on the planet
  - Most reliable
  - Lowest emissions
  - Lowest cost of ownership



- Geared, Ultra-high bypass ratio will dominate
- Conventional wisdom vs. technical reality
  - Conventional wisdom based on “all else being equal”
  - History suggests that it rarely is

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