Propulsion Technology Direction

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on Aviation and Climate Change
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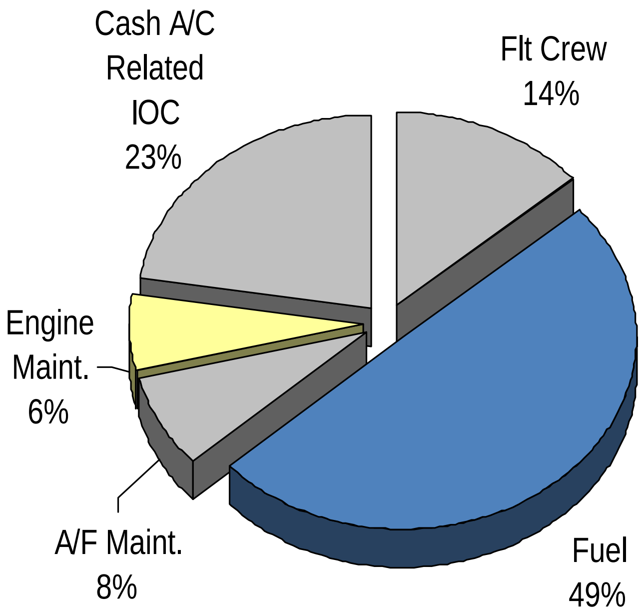
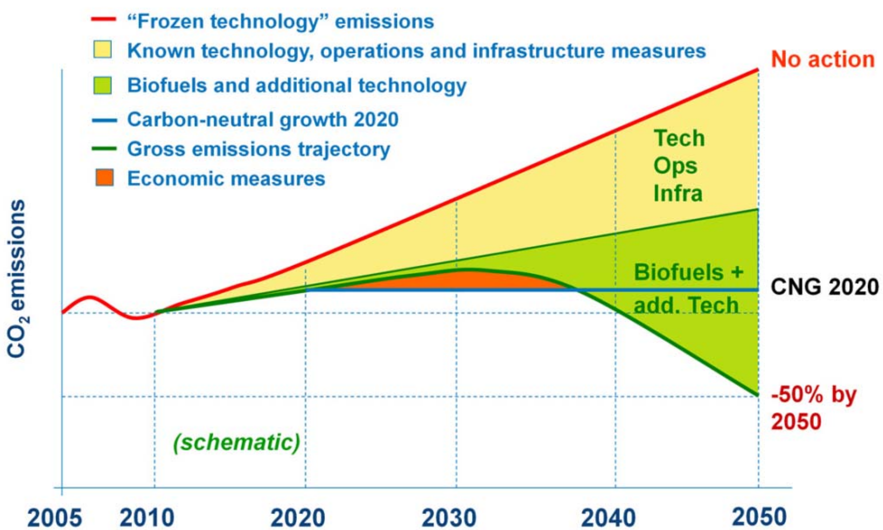
Twofold Pressure to Improve Performance

Medium range aircraft, $3/gal



IATA
Emissions reduction roadmap



$$$

CO2

Aggressive Technology Goals Have Been Defined

Vehicle Level Metrics for Fuel Burn Reduction

	Δ Fuel Burn	Time Frame
NASA N+2 ACARE Vision 2020	-50%	15 yrs
NASA N+3 Flightpath 2050	-60 to -75%	20-40 yrs

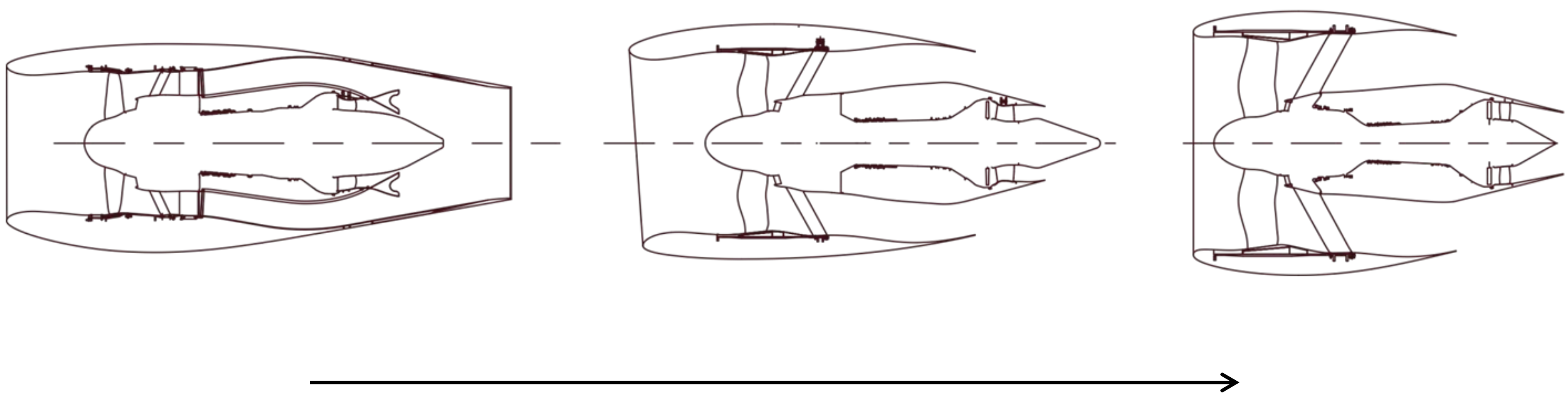
How Much Δ Fuel Burn from the Propulsion System?

Short/Medium Range

In Service
BPR 5
Fuel Burn Reference

2013-16
BPR ~12
-15%

Longer Term
BPR 15~18
-20~30%



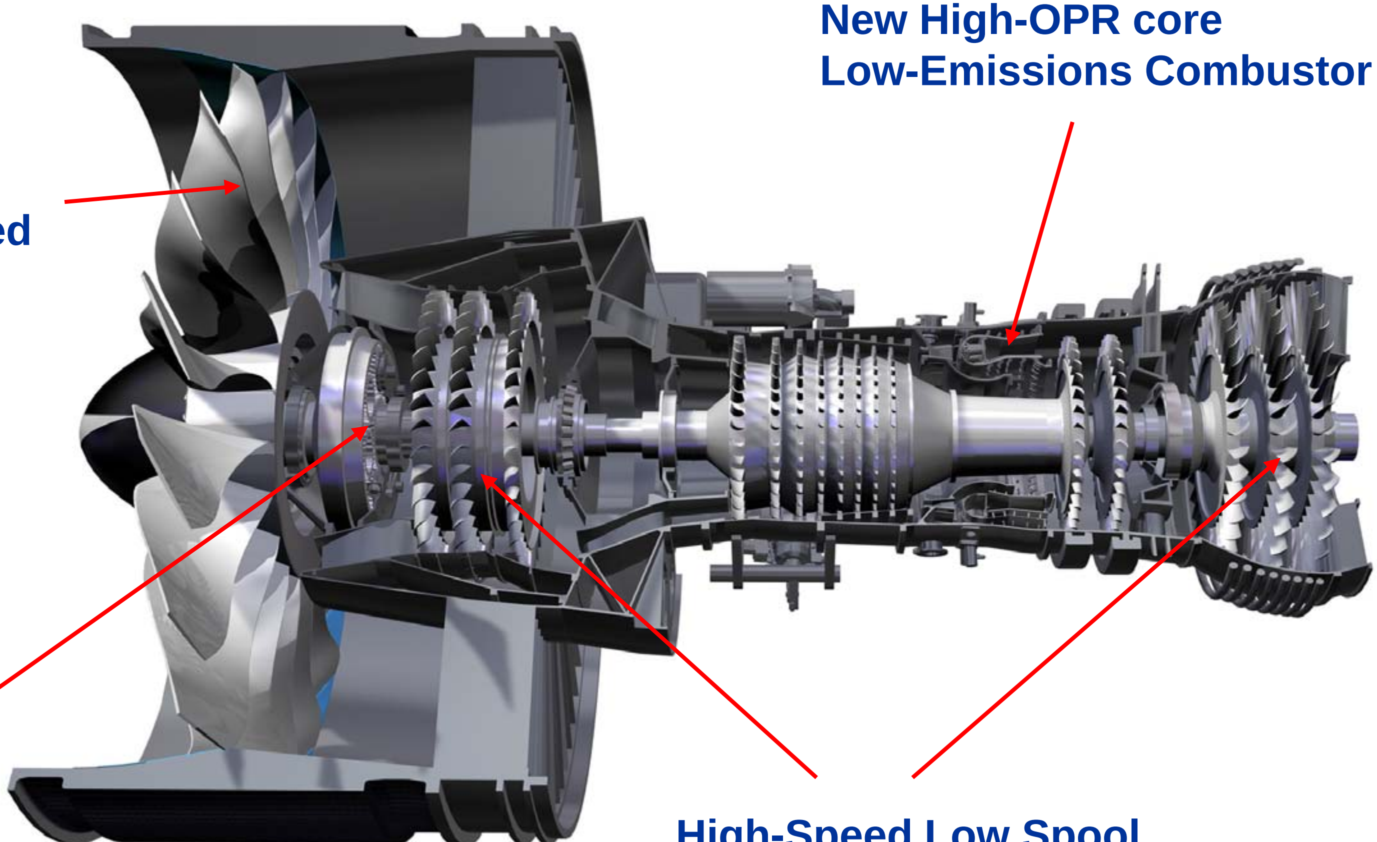
Propulsion Trend to Big Fans/ Small Cores

GTF Engine Architecture – 2013 Configuration

BPR ~ 12

New High-OPR core
Low-Emissions Combustor

Low-PR Fan
Low Tip Speed

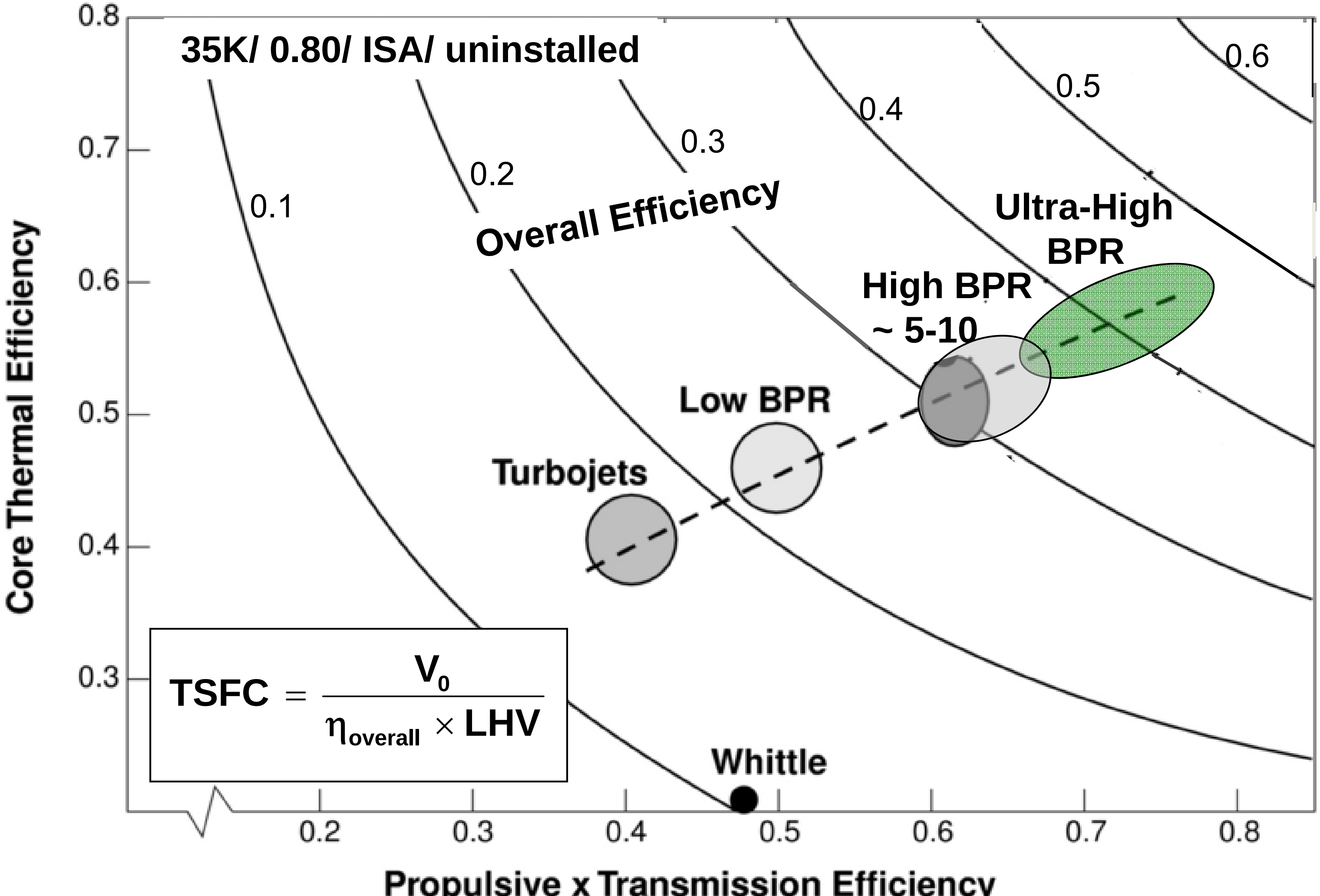


High-Speed Low Spool
Compact 3-stage LPC, LPT

Fan Drive Gear System
Planetary- 5 Planets
Compact High Efficiency Power Transmission

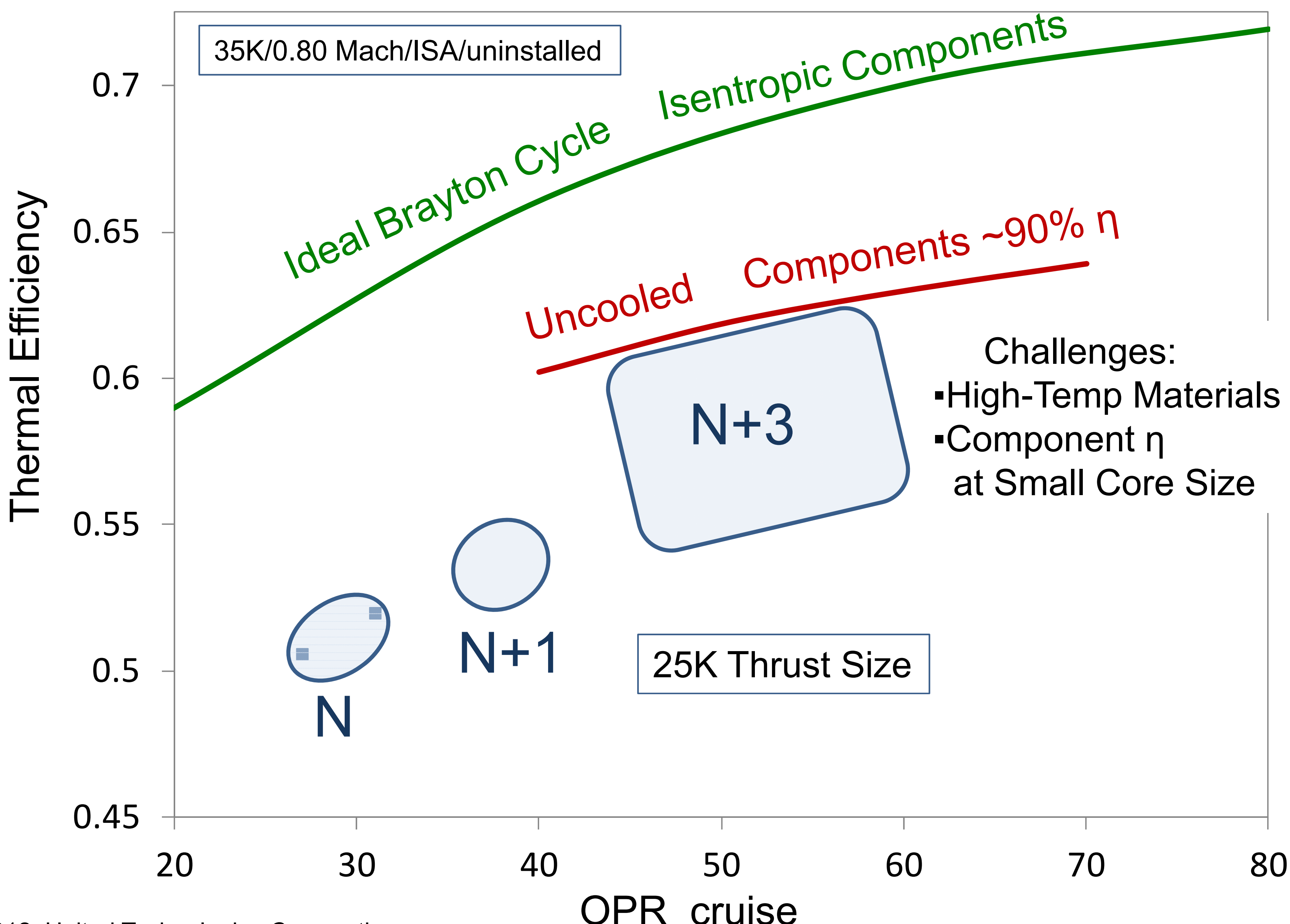
Fuel Efficiency Drives Thermodynamic Cycle

Thermal efficiency- production of power from fuel heat release → higher OPR
Propulsive efficiency- conversion of power to thrust → lower FPR



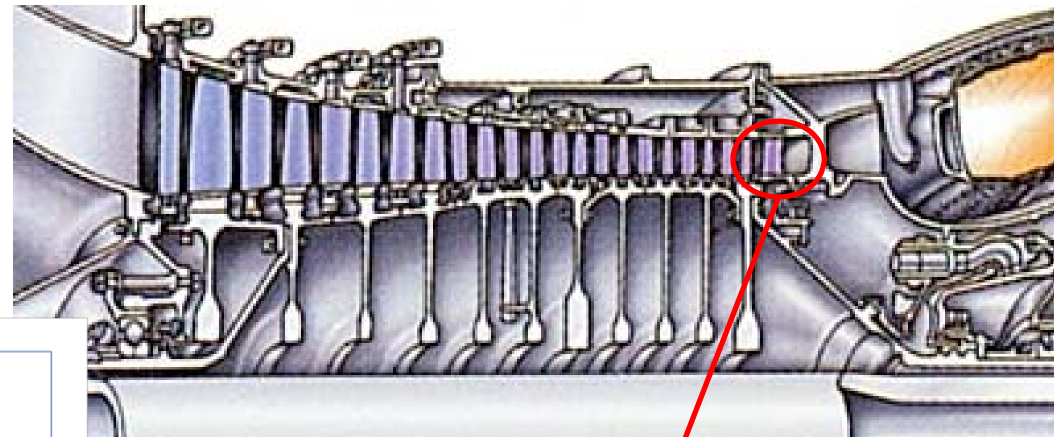
$$\text{TSFC} = \frac{V_0}{\eta_{overall} \times \text{LHV}}$$

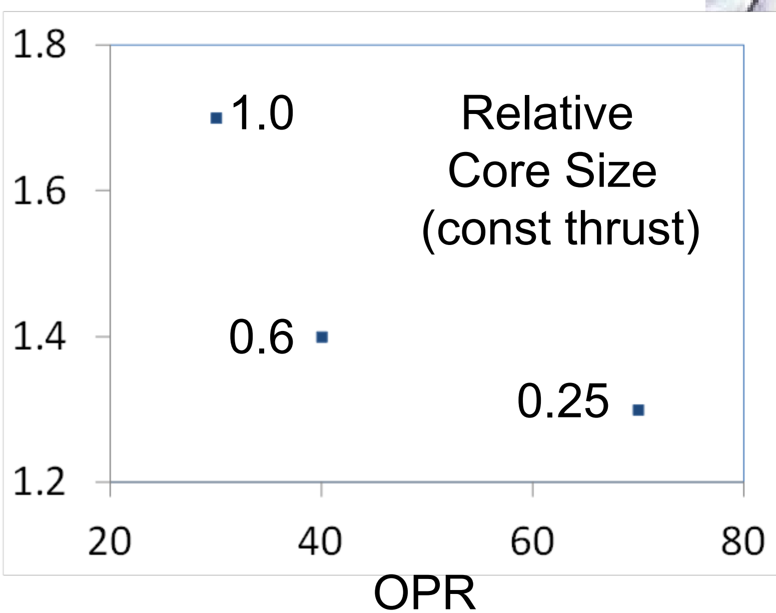
Thermal Efficiency Trend with Overall Pressure Ratio

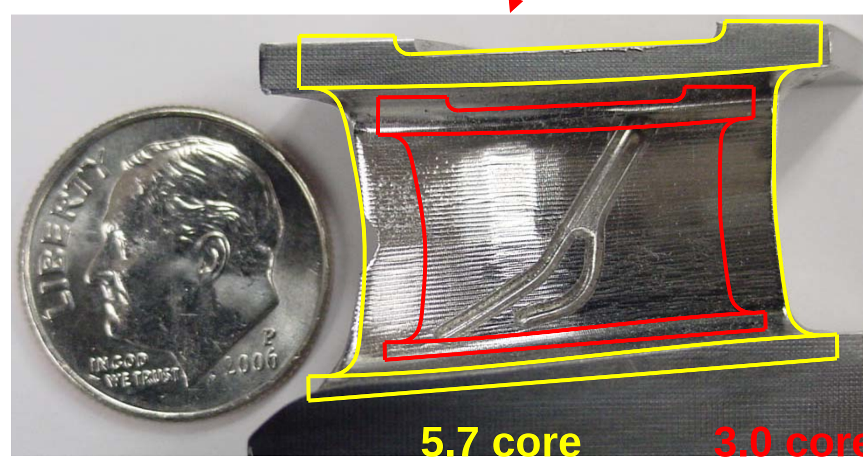


"Core Size" Design Issue for High-OPR Engines

Compressor exit corrected flow $\frac{W\sqrt{\theta}}{\delta}$ ~ "core size"

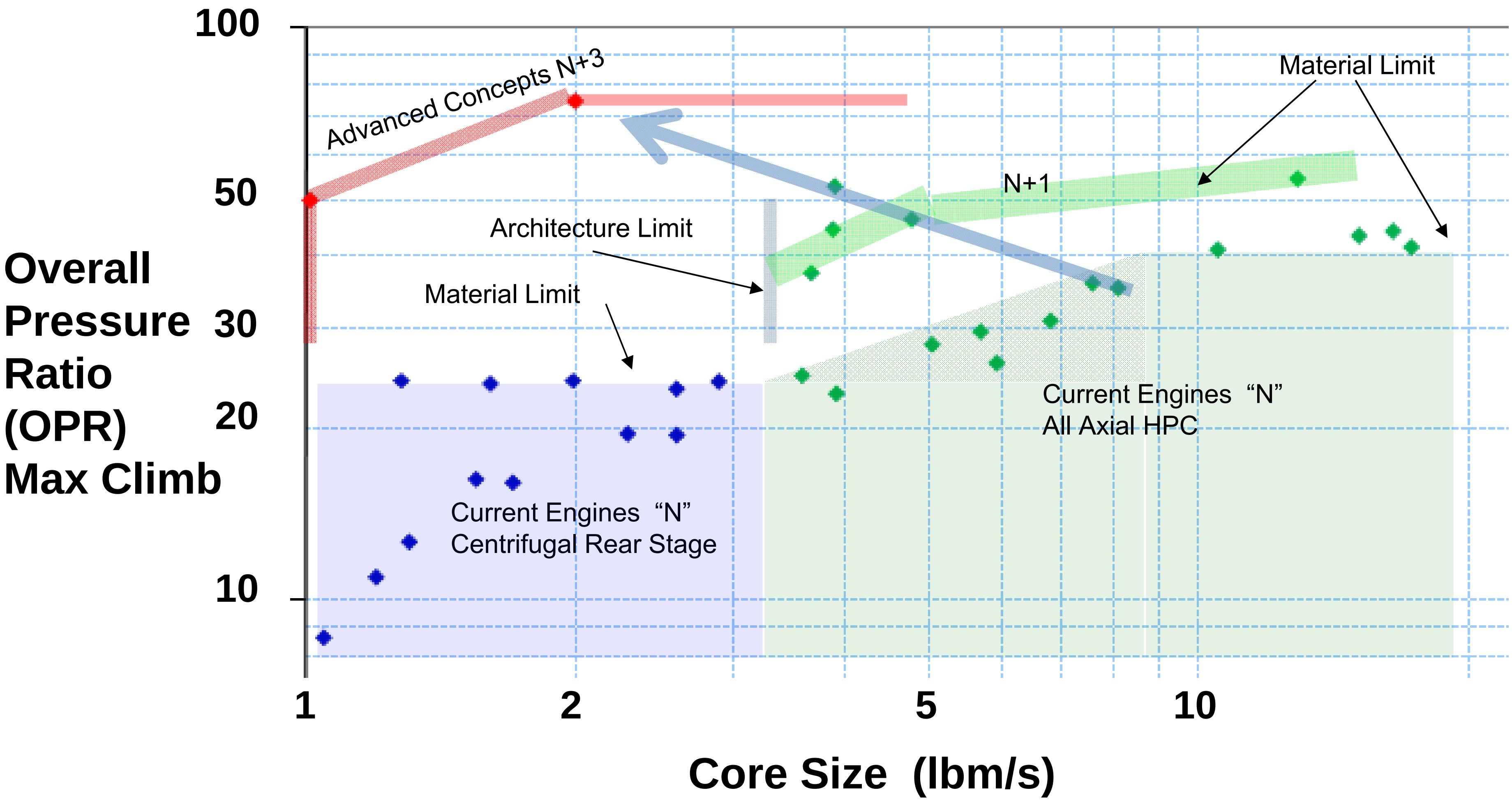






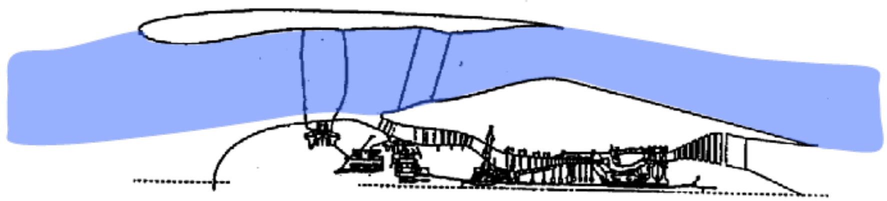
OPR-CS Design Space Chart

Technology trend to higher OPR/ smaller CS challenges material capability and architecture

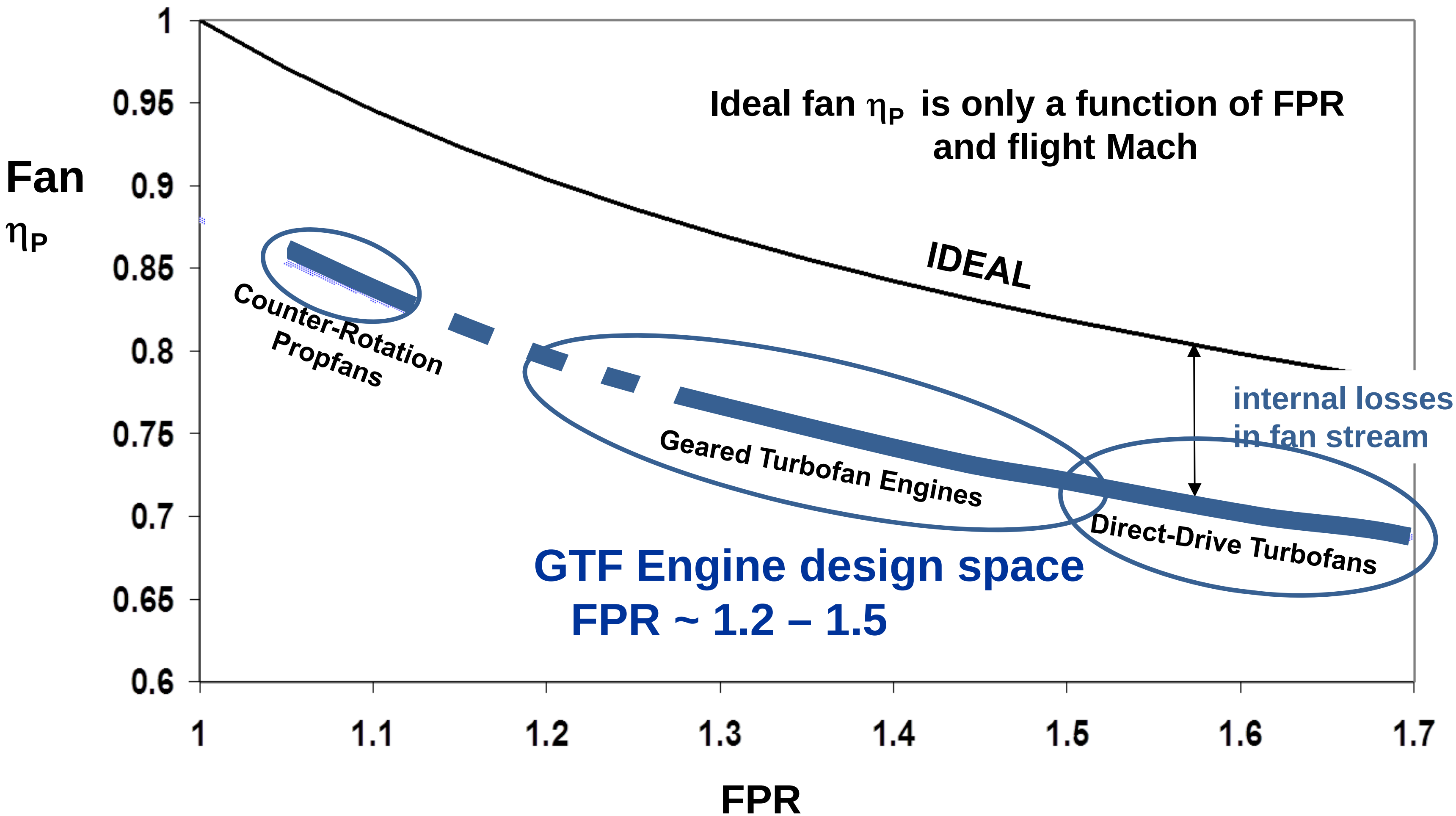


Propulsive Efficiency Trend with Fan Pressure Ratio

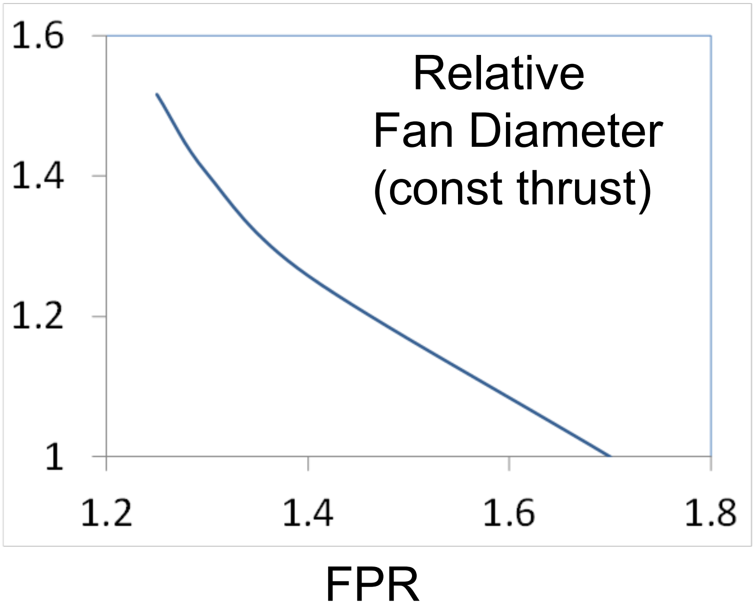
Flight Mach = 0.80

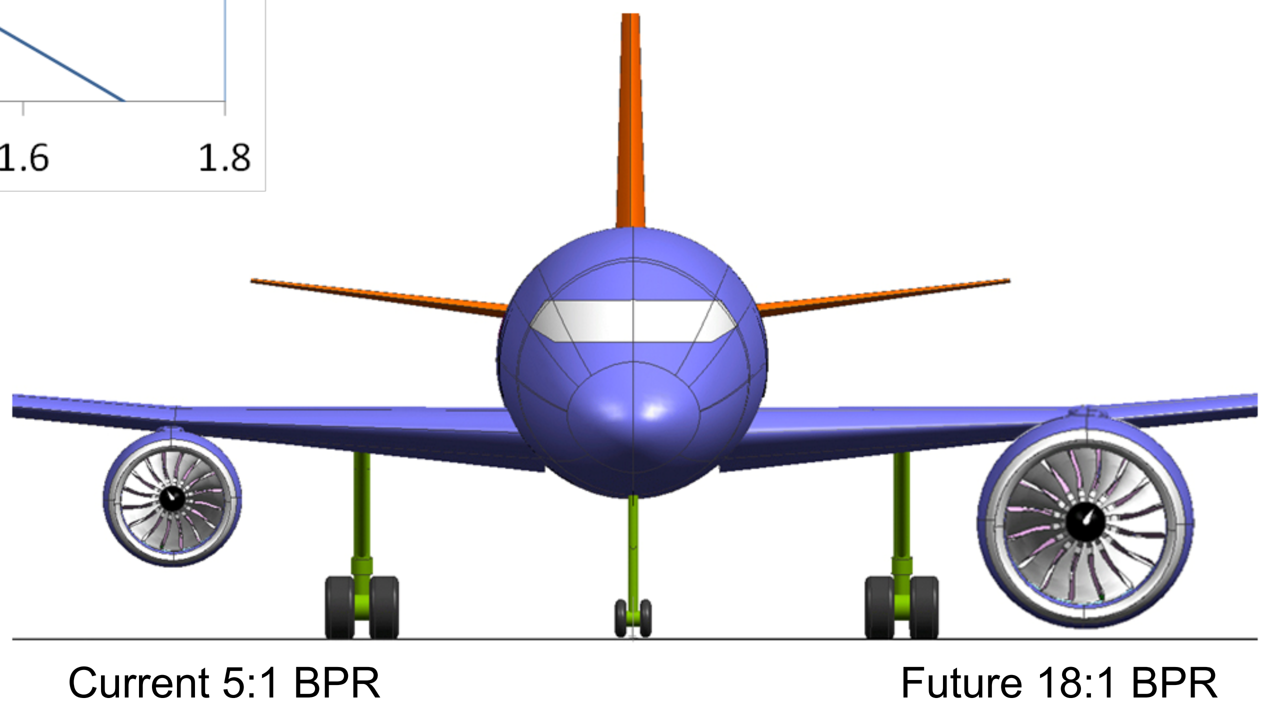


$$\eta_{Pfan} = \frac{F_{Nfan} V_0}{SHP_{fan}}$$



Installation Challenge for Low-FPR/ High-BPR Engines





Unconventional Installations Considered for N+2, N+3

PW1000G GTF™ Engine
+16% Eff
EIS 2013-2015

Reference
V2500
1988 EIS

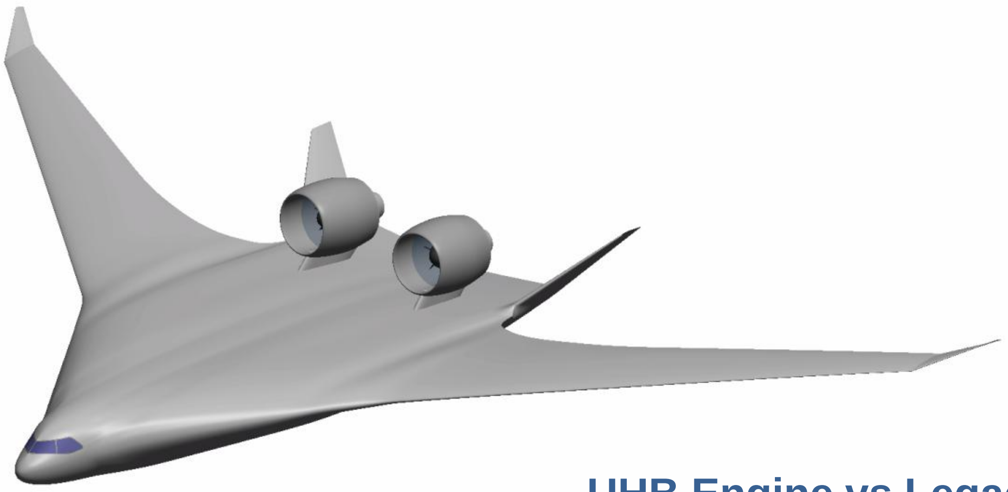
Adv GTF™
Engine
+30% Eff
EIS 2020-2025

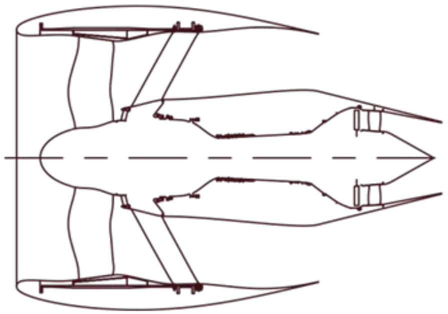
Unconventional
Installations

Gen 3 GTF™ Engine
+45% Eff
EIS 2030-2035

2015 2020 2025 2030

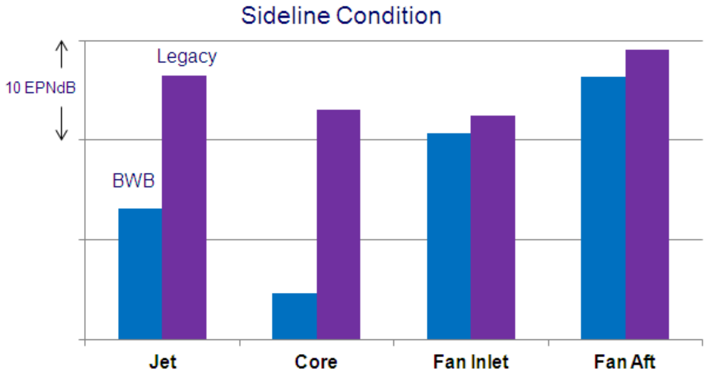
N+2 Boeing BWB Installation UHB Ducted Engine





BPR ~ 18 Engine
∆ Fuel Burn for the Propulsion System estimated at -18% relative to PW4090/777

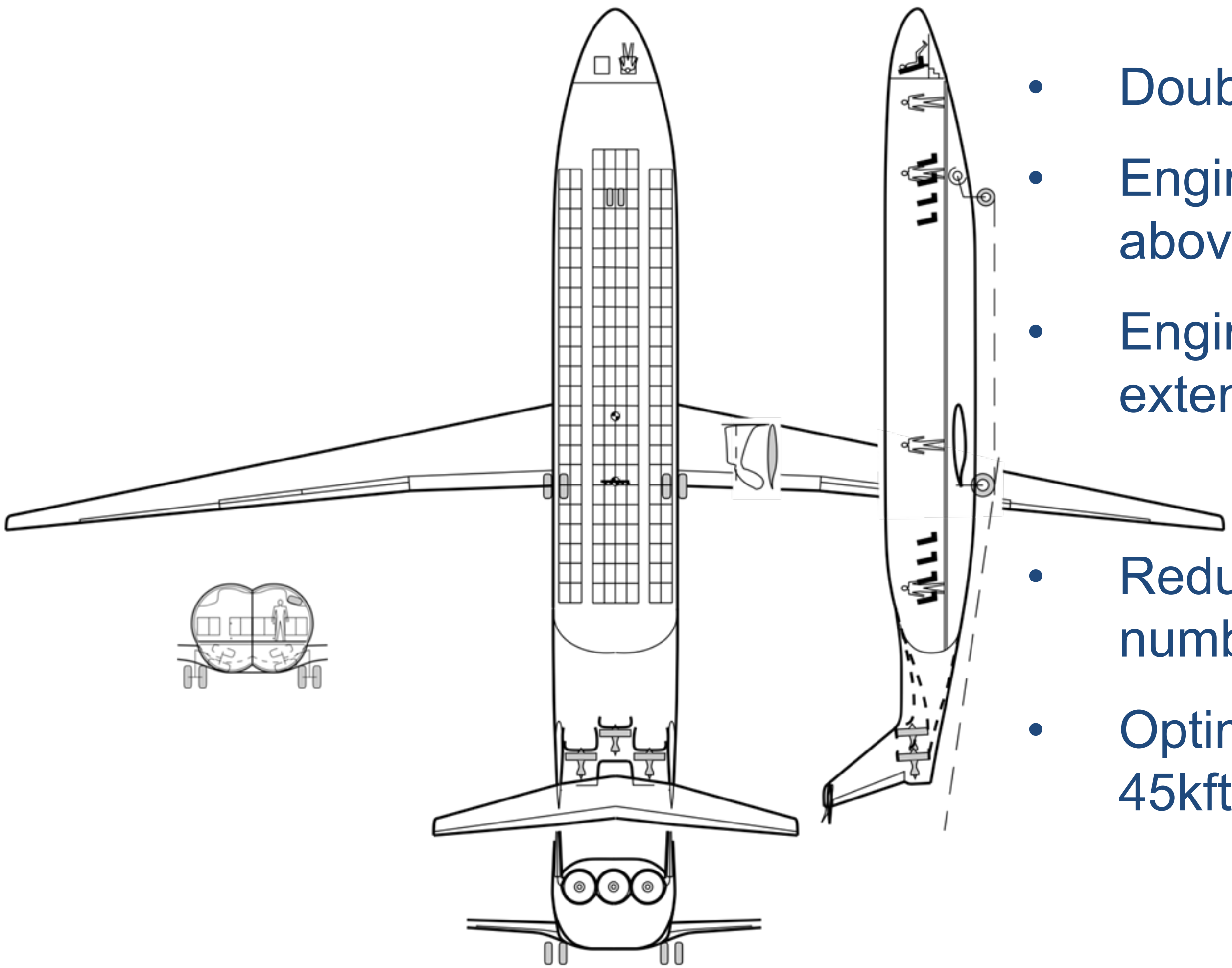
UHB Engine vs Legacy (PW4090) Noise



Significant reduction in jet noise for the low-FPR engine
Combine with airframe shielding of fan noise and airframe noise reduction to meet N+2 noise goals

N+3 D8 (Double-Bubble) Configuration

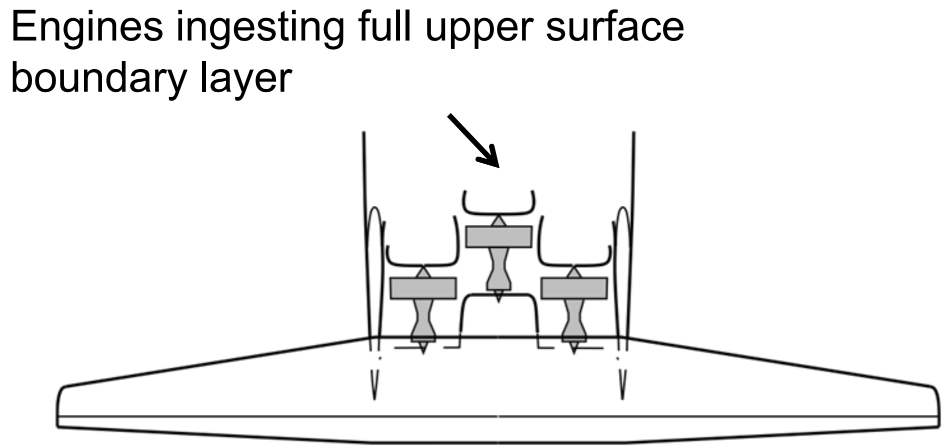
180 Passengers, 3000 nmi Range

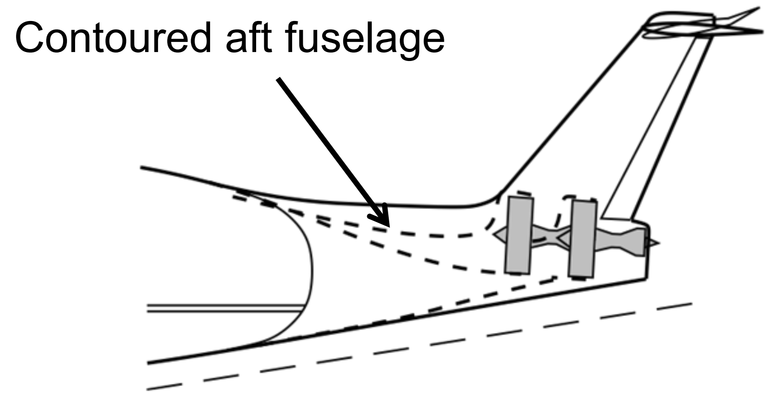


- Double bubble lifting fuselage
- Engines flush-mounted above aft fuselage
- Engine noise shielding and extended rearward liners
- Reduced cruise Mach number with unswept wings,
- Optimized cruise altitude 45kft (13.7 km)

From: M Drela, MIT

Fuselage Boundary Layer Ingestion for Increased Propulsive Efficiency





- Entire upper fuselage BL ingested by propulsor bypass stream
- Exploits aft fuselage static pressure field to condition flow
  - Fuselage's potential flow has local M = 0.6 at fan face
  - No additional required diffusion into fan
  - No generation of streamwise vorticity and secondary flow

From: M Drela, MIT

Reduced Emissions/ Combustor Technology

- For aviation gas turbines, key issues are:
  - Landing and Take-Off (LTO) NOx => impacts on local airport operations
  - Cruise NOx and particulate matter (PM) => man-made pollutants at altitude
- P&W combustor technology
  - World-class TALON rich-quench-lean (RQL) technology
    - Significant reductions in LTO NOx (over 50% reduction compared to CAEP 6 for the TALON X in a GTF)
    - Similar reductions in cruise NOx
    - Swirler technology to reduce smoke and PM
  - Continued exploration of novel combustor concepts
    - Seeking very low NOx and PM
    - Robust configurations
    - Working with NASA, AFRL, Navy

Propulsion Technology Direction - Summary

- -15% fuel burn by mid-decade enabled by new technology engines (PW1524G, PW1133G) on single-aisle aircraft
- Longer term goal -20 to -30% (2025+)
- Future propulsion design challenges involve small cores and big fans
  -alternative architectures at engine and vehicle level may be required