CORE NOISE: Implications of Emerging N+3 Designs and Acoustic Technology Needs

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Summary

This presentation is a summary of the core-noise implications of NASA's primary N+3 aircraft concepts. These concepts are the MIT/P&W D8.5 Double Bubble design, the Boeing/GE SUGAR Volt hybrid gas-turbine/electric engine concept, the NASA N3-X Turboelectric Distributed Propulsion aircraft, and the NASA TBW-XN Truss-Braced Wing concept. The first two are future concepts for the Boeing 737/Airbus A320 US transcontinental mission of 180 passengers and a maximum range of 3000 nm. The last two are future concepts for the Boeing 777 transpacific mission of 350 passengers and a 7500 nm range. Sections of the presentation cover: turbofan design trends on the N+1.5 time frame and the already emerging importance of core noise; the NASA N+3 concepts and associated core-noise challenges; the historical trends for the engine bypass ratio (BPR), overall pressure ratio (OPR), and combustor exit temperature; and brief discussion of a noise-research roadmap being developed to address the core-noise challenges identified for the N+3 concepts. The N+3 conceptual aircraft have (i) ultra-high bypass ratios, in the rage of 18 – 30, accomplished by either having a small-size, high-power-density core, an hybrid design which allows for an increased fan size, or by utilizing a turboelectric distributed-propulsion design; and (ii) very high OPR in the 50 – 70 range. These trends will elevate the overall importance of turbomachinery core noise. The N+3 conceptual designs specify the need for the development and application of advanced liners and passive and active control strategies to reduce the core noise. Current engineering prediction of core noise uses semi-empirical methods based on older turbofan engines, with (at best) updates for more recent designs. The models have not seen the same level of development and maturity as those for fan and jet noise and are grossly inadequate for the designs considered for the N+3 time frame. An aggressive program for the development of updated noise prediction tools for integrated core assemblies as well as and strategies for noise reduction and control is needed in order to meet the NASA N+3 noise goals.

The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The SFW Reduced-Perceived-Noise Technical Challenge aims to develop concepts and technologies to dramatically reduce the perceived aircraft noise outside of airport boundaries. This reduction of aircraft noise is critical to enabling the anticipated large increase in future air traffic.

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Subsonic Fixed Wing Project

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www.nasa.gov

Outline

- Current trends
  - N+1.5 time frame
- NASA N+3 concepts
  - implications for core noise
- Core-noise roadmap
  - under development, early days yet

Current Trends (N+1.5)

- Overall cycle changes:

BPR ↑ FPR ↓ N1 ↓

Non-core propulsion noise components will be reduced at all power levels

- High-power-density, low-emission cores:

COMBUSTOR

OPR ↑ T_4 ↑

TURBINE (LPT)

Blade Loading & Temperature ↑

Blade Counts, Stages & Stage Spacing ↓

Core-noise components will be increased at all power levels

NASA N+3 Aircraft Concepts

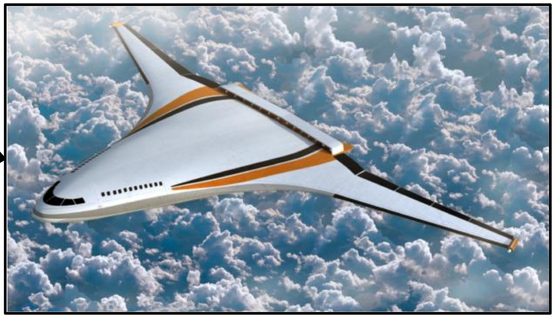
★ = SFW primary concepts

Advanced Tube and Wing

- ★ MIT Double Bubble D8.5
- ★ Boeing/GE SUGAR Volt
- Northrop Grumman SELECT
- ★ NASA Truss-Braced Wing

Evolution of Hybrid Wing Body

- MIT HWB
- Boeing/GE SUGAR Ray
- ★ NASA Turbo Electric



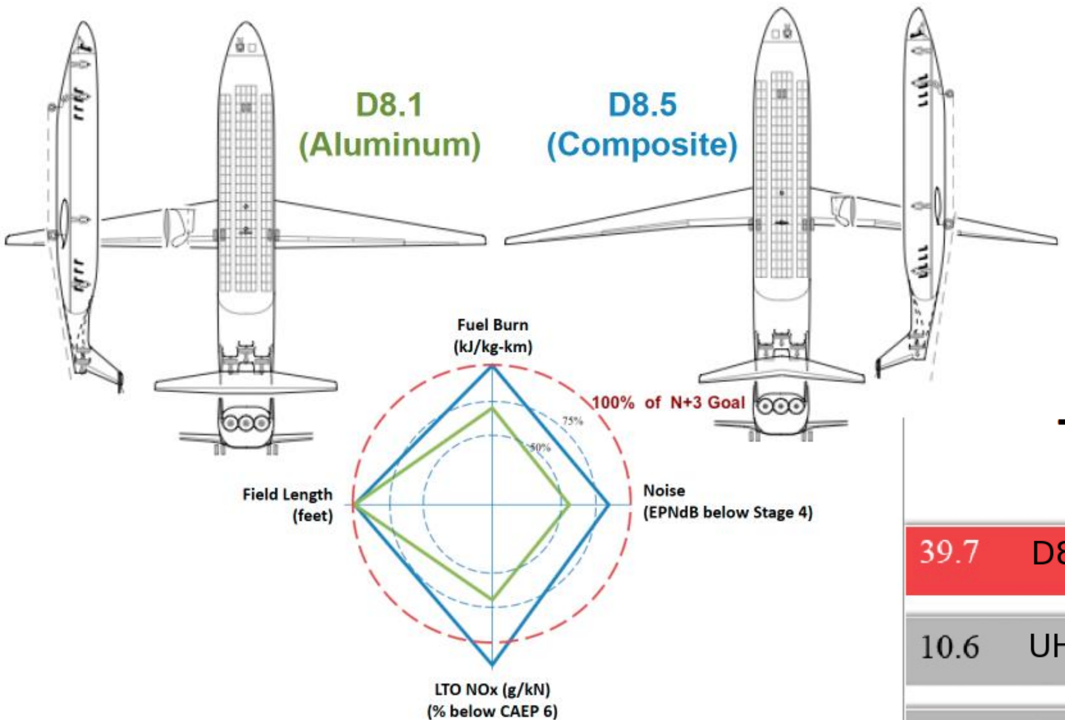
Emerging core designs appear game changing

MIT/P&W Double Bubble D8.5

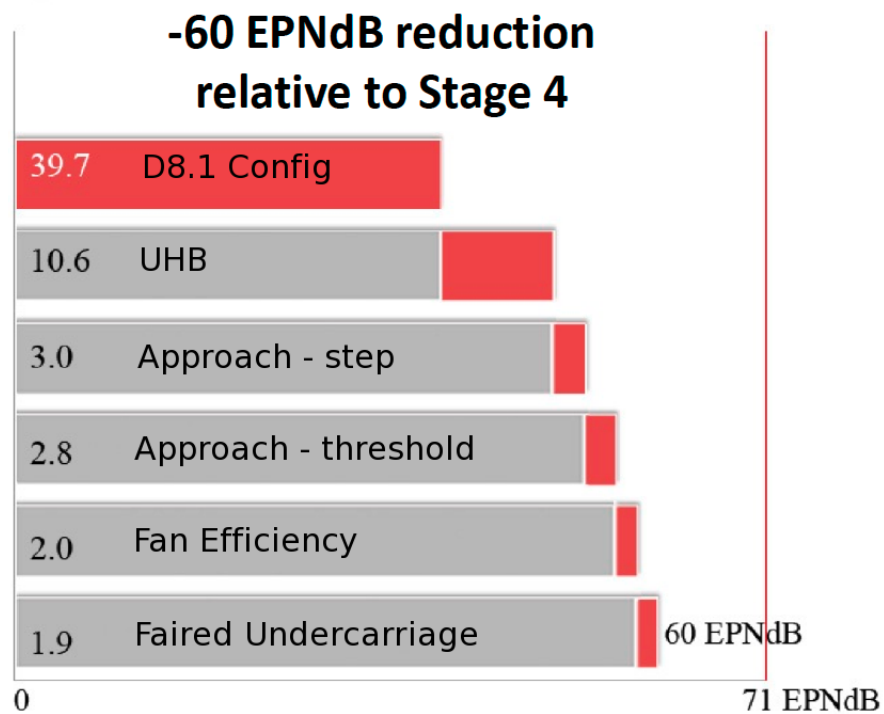
- Natural progression for B737/A320 mission
  - three rear-mounted, UHB, geared turbofans – BPR = 20
  - small high-power-density cores – OPR = 50
  - advanced lean direct injection (LDI) combustor
  - multi-segment rearward acoustic liners

Noise from high-power-density, low-emissions core ignored!

MIT D8 Noise Assessment



- D8.1: CFM56 class
  - 12,000 lbf/engine
- D8.5: UHB geared
  - 8,500 lbf/engine



- D8 shielding & treatment
- UHB reduces fan & jet
- Observer further away

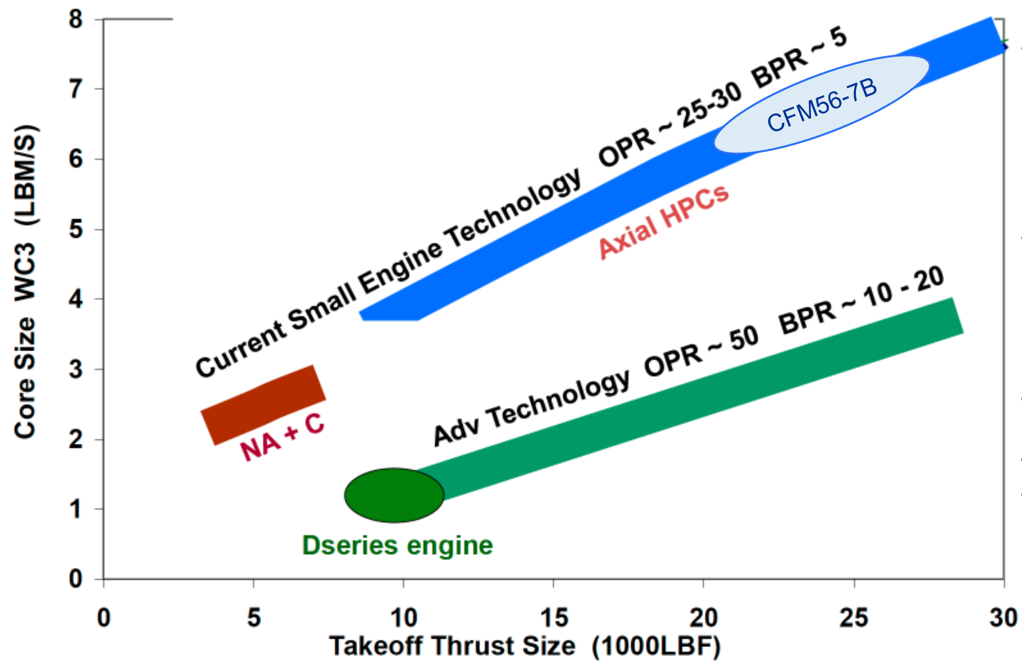
MIT D8 Series Challenges

NRA Conclusions:

- Small-core-size engine technology
- Boundary-layer-ingesting (BLI) propulsion
- Propulsion-airframe integration/exhaust system

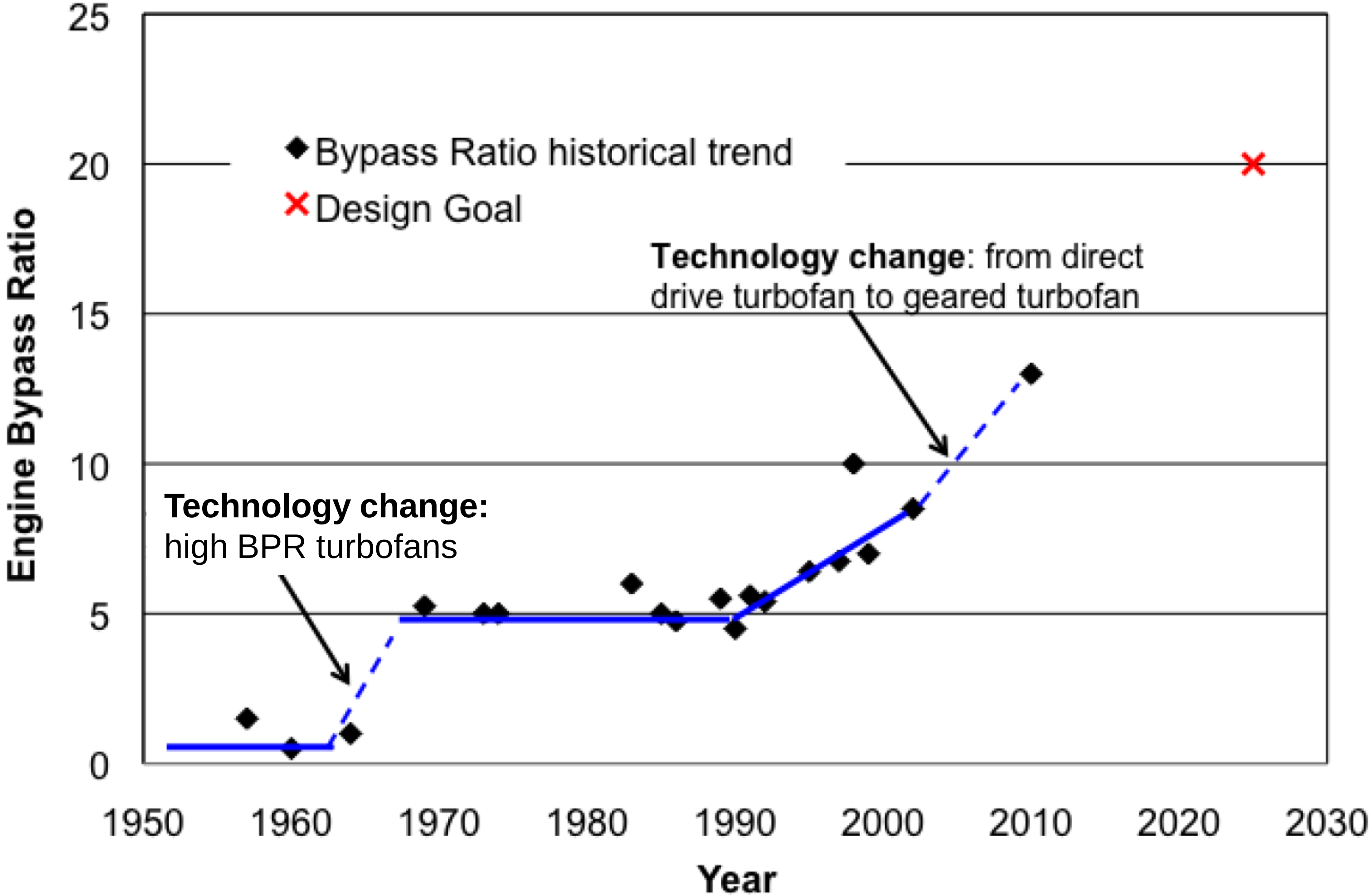
- BPR = w_F/w_c
  - BPR ↑ by w_F ↑
  - BPR ↑ by w_c ↓
- w_c ↓ means radial size ↓ possible
- Traditionally, high-power-density implied reduced axial size

Axial, Mixed NA+C, or Centrifugal HPC



MIT Team Final Review Presentation 2010-04-23 (modified)

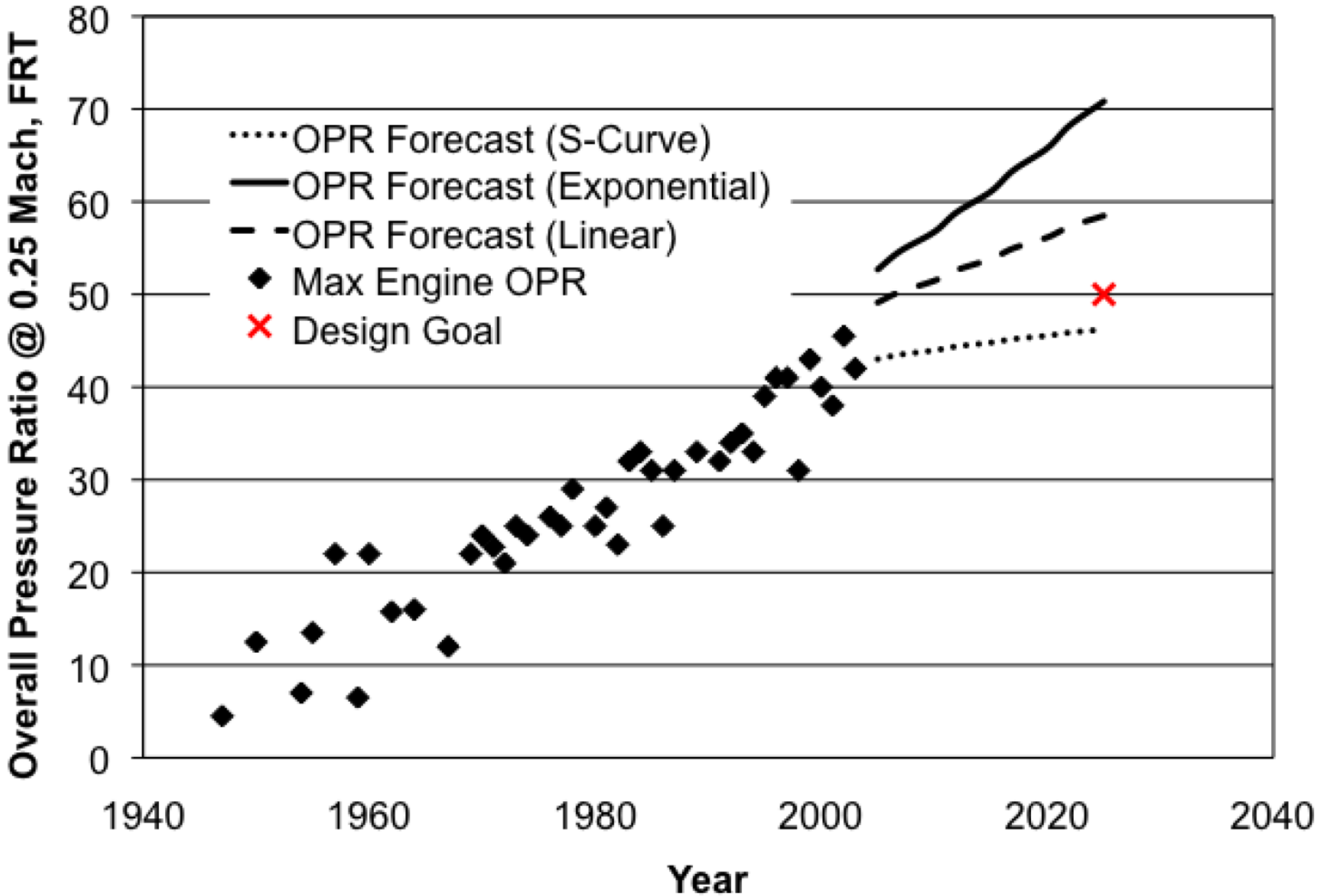
BPR Historical Trend (MIT)



MIT Team Final Review Presentation 2010-04-23 & NASA CR-2010-216794/VOL I (2010)

Historical Data Source:
Ballal, Dilip R, and Joseph Zelina. "Progress in Aeroengine Technology (1939-2003)," *Journal of Aircraft*, 41 (1) (2004)

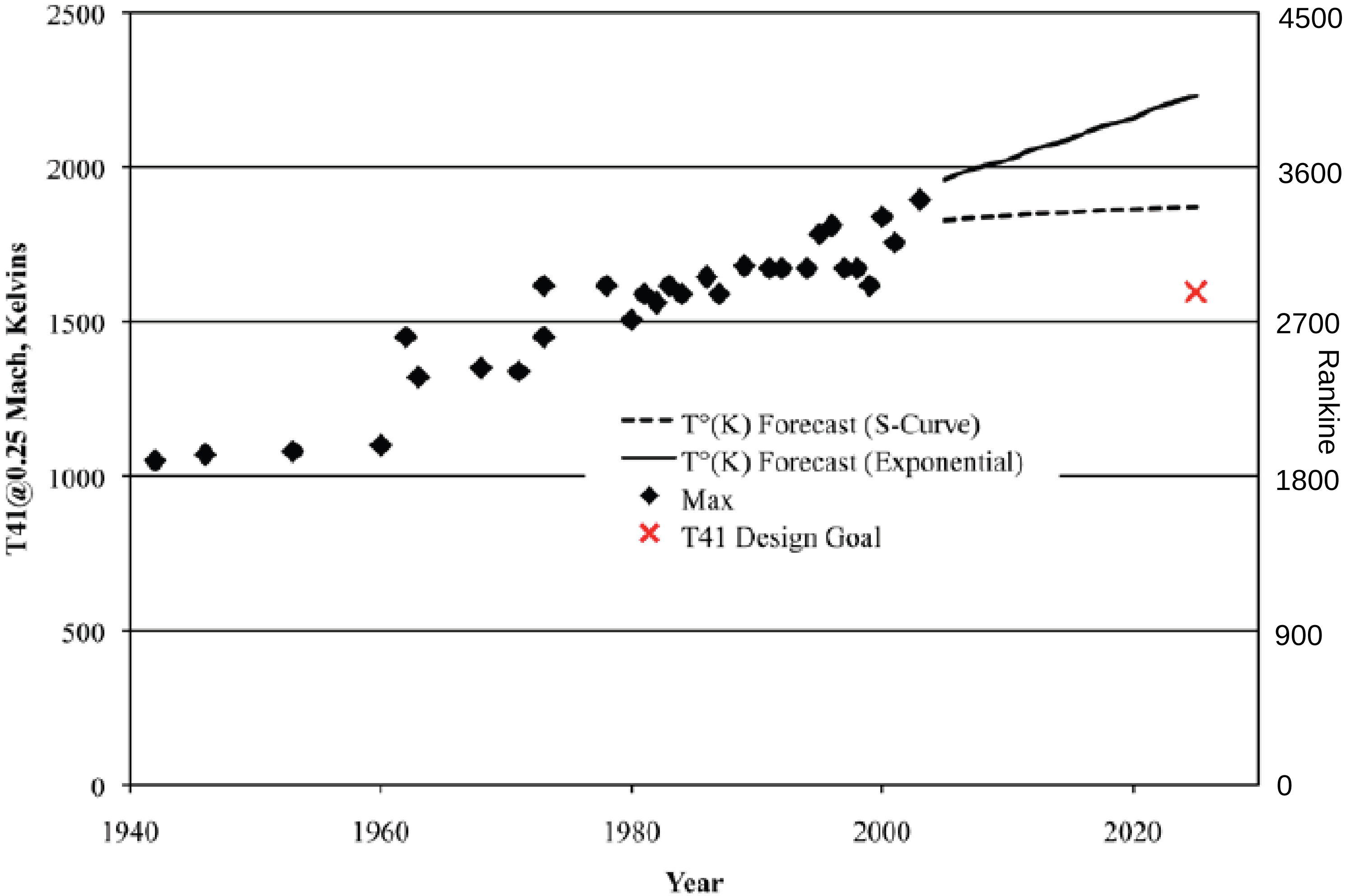
OPR Historical Trend (MIT)



MIT Team Final Review Presentation 2010-04-23 & NASA CR-2010-216794/VOL I (2010)

Sources:
Ballal, Dilip R, and Joseph Zelina. "Progress in Aeroengine Technology (1939-2003)," *Journal of Aircraft*, 41 (1) (2004)
Benzakein, MJ. *"Roy Smith and Aircraft Engine of Today and Tomorrow"* IGTI conference. June, 2009.

T_{41} Historical Trend (MIT)

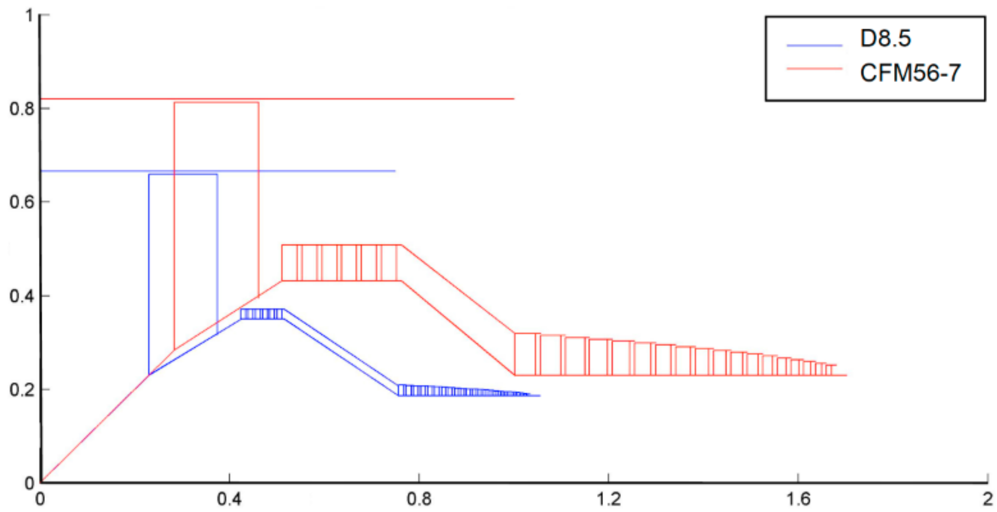


NASA CR-2010-216794/VOL I (2010)

Source: Cumpsty, N. “Jet Propulsion - A simple guide to the aerodynamic and thermodynamic design and performance of jet engines.” Cambridge University Press, 2003.

MIT/P&W D8.5 Core-Noise Issues

- Small-core-size engine technology challenge
  - unknown impact on noise from solutions
- Combustor
  - high OPR noise increase
  - advanced LDI combustor



From: MIT Team NASA FAP Technical Conference Presentation 2011-03-15

- Turbine/Compressor
  - axial/radial design implications on noise
    - well outside of empirical data base (small size/high power density)
  - reduced axial length means less real estate for acoustic liners
- Moderate T_{41}
  - improves prospect for using advanced acoustic liners

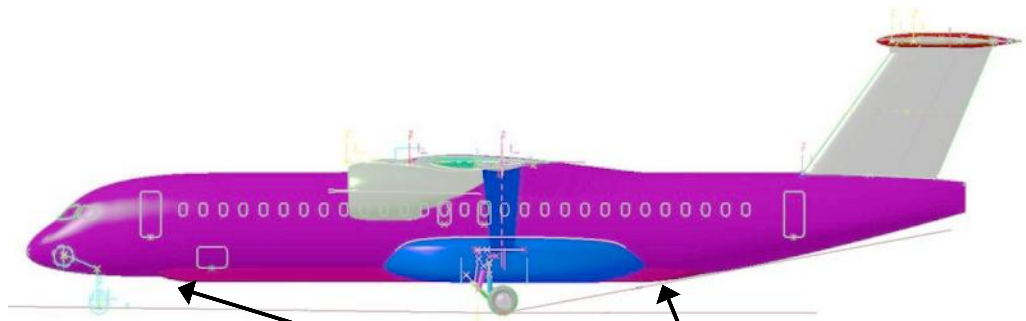
Boeing/GE SUGAR Volt-hFan

- B737/A320 mission
  - two UHB, hybrid gas-turbine/electric engines – BPR = 18
  - high-power-density cores – OPR = 59, with advanced combustor
  - strut-braced, low-weight high wing
  - advanced passive core-nozzle acoustic treatment
  - aggressive active noise suppression in combustor

Lack of information about noise analysis and goal not met!

SUGAR Volt Characteristics

- Laminar-flow maximized
- Larger fan by addition of electric motor
- Removable batteries
  - added battery weight depends on mission
- Noise reduction of -22 EPNdB
  - relative to SUGAR Free
  - SUGAR High based
  - electric-drive effects ignored (pros/cons)



SUGAR Volt is a derivative of SUGAR High Concept

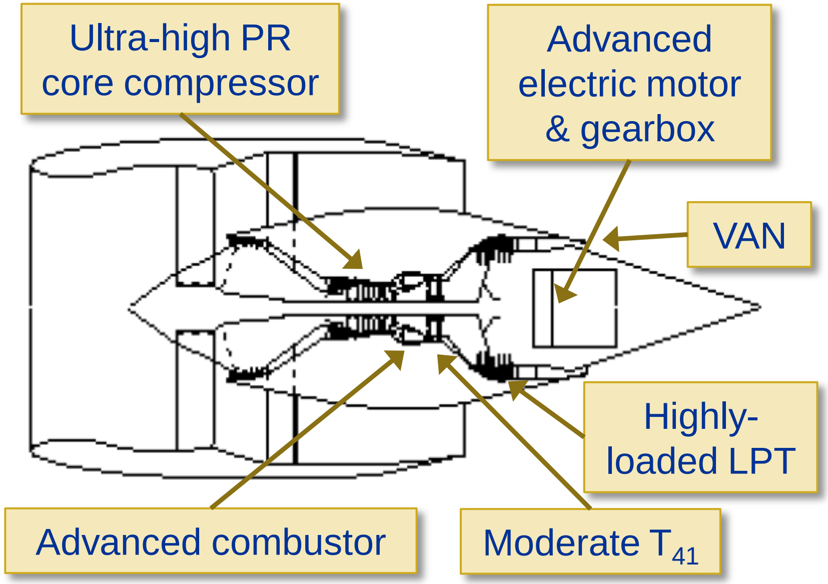
Boeing/GE SUGAR Acoustic Assessment

Configuration	SUGAR Free	Refined SUGAR	Super Refined SUGAR	SUGAR High	SUGAR Volt
Propulsion	CFM56	gFan	gFan+	gFan+	hFan
ΔEPNL (dB)	0*	-16	-22	-22	Potentially lower than gFan+

*reference case – proprietary value (B737NG Certification: -8 dB)

<u>Engine Core Acoustic Tech</u>.

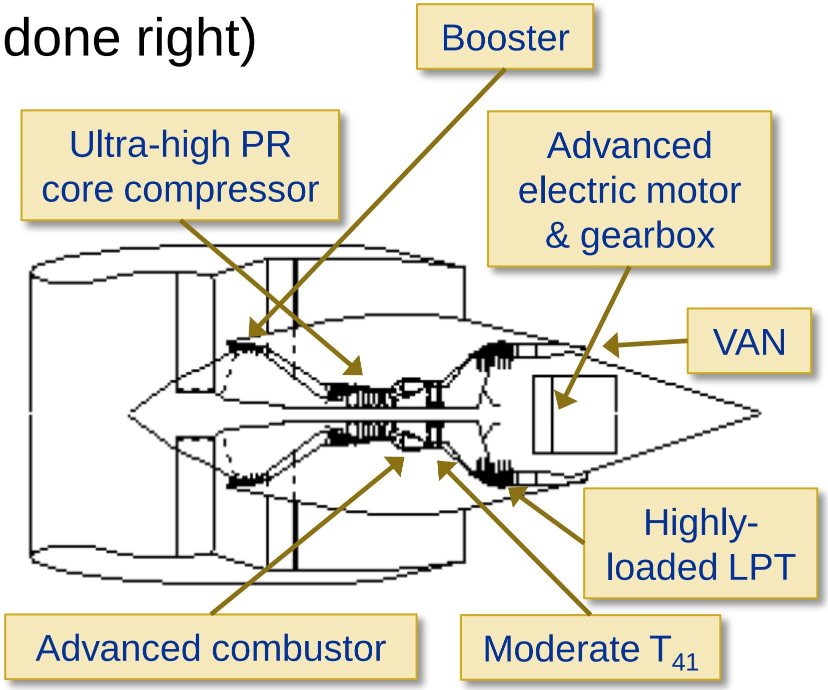
- adv. passive noise suppression
  - acoustic treatments
  - blade and OGV optimization
- adv. active noise suppression
  - low-noise combustor
  - flow control



GT/Electric Hybrid GE hFan

GE hFan Core-Noise Issues

- Turbine noise likely increased
  - highly loaded LPT blades and reduced stage spacing increases tone-noise source strength and complexity
  - reduced stage solidity reduces turbine-tone attenuation
- Combustor noise likely increased
  - advanced combustor design (if not done right)
  - high OPR
- Hybrid electric-drive effects unchartered
  - electric motor likely quieter than combustor
  - GT off-design issues?
- Detailed noise study yet to be carried out for SUGAR Volt



GT/Electric Hybrid GE hFan

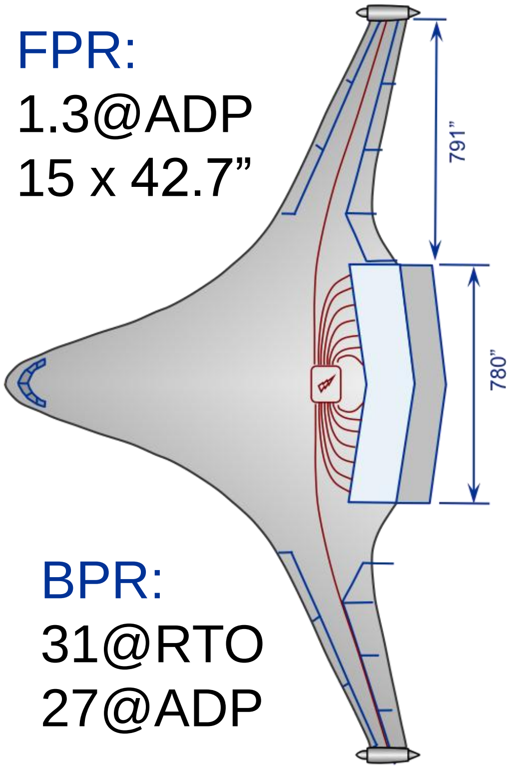
NASA N3-X Distributed Turboelectric

- Distributed-propulsion concept for B777 mission
  - 15 superconducting motor-driven fans in continuous nacelle
    - higher propulsive efficiency through spanwise BLI and wake fill-in
  - two wing-tip mounted superconducting turbogenerators
    - may give performance benefit through tip-vortex interference
    - two large cores more thermally efficient then many small cores

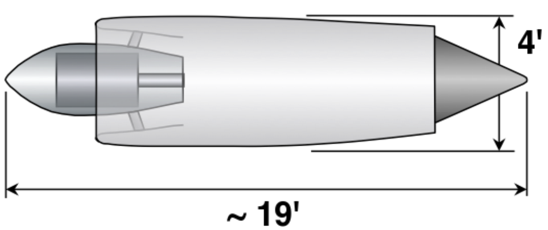
Detailed noise analysis yet to be carried out

NASA N3-X Engine Parameters

FPR:
1.3@ADP
15 x 42.7”



BPR:
31@RTO
27@ADP



Dual-spool core and separate power turbine driving generator

	SLS	RTO	TOC*
V_{amb} (fps)	0	286	836
Thrust (lbf)	124,100	67,760	27,750
BPR	28.9	30.8	26.9
FPR	1.26	1.22	1.3
V_{fn} (fps)	653	648	1007
OPR	69.9	58.1	74.8
T_4 (R)	3460	3412	3260
V_{cn} (fps)	1191	1058	1614

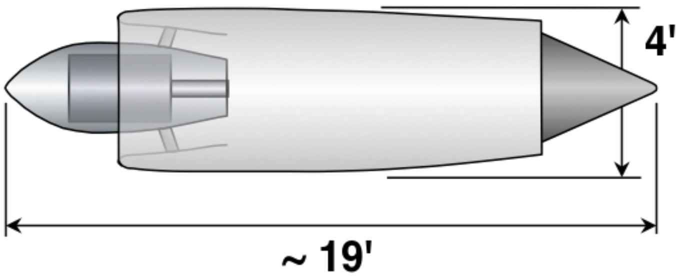
*ADP

Conditions & thrust requirements

SLS	SL/MN0.00/ISA	90,000 lbf
RTO	SL/MN0.25/ISA+27	65,000 lbf
TOC	30kft/MN0.84/ISA	27,750 lbf

N3-X TeDP Core-Noise Issues

- No shielding possible because of wing tip location
- Compressor inlet tone noise
  - high-OPR design consequences – likely outside of experience base
  - good potential for liner treatment with forward mounted generator
- Combustor noise – due to very high OPR
- Turbine noise
  - high T_4 makes acoustic treatment more of a challenge
  - electric gear box to distributed-propulsion allows high shaft speed
- Core jet noise
  - exhaust velocity > 1000 fps @ RTO
- Noise study yet to be carried out



NASA TBW-XN Truss-Braced Wing

- B777 mission
  - GE90-like engines assumed for initial design study
  - optimal wing & truss architecture for high L/D
  - large-aspect-ratio, thin and light wing with maximum laminar flow
  - Goldschmeid propulsor device – thrust vectoring and no tail
    - distorted inflow and jet noise issues

Enough details about propulsion system not yet available

Observations

- NASA N+3 Concepts Summary
  - UHB (18 – 30) in three different ways
    - small-size, low-flow-rate, high-power-density core
    - hybrid gas turbine/electric – electric motor allows for larger fan
    - turboelectric distributed propulsion
  - increased OPR (50 – 70)
  - moderate T_4 in some concepts – more real estate for liners
- All imply need for advanced core-noise reduction methods
  - advanced liners
  - passive and active core-noise control

Current Status and Future Goals

- Current engineering prediction of core noise uses semi-empirical methods based on older turbofan engines, with (at best) updates for more recent designs
  - the models have not seen the same level of development and maturity as those for fan and jet noise and will be inadequate for the game-changing designs considered for the N+3 time frame
- Ultimately the goal is to develop design tools that allow for the routine co-design of high-efficiency, low-emission combustors with the compressor and turbine assembly – in near term:
  - develop high-fidelity computational tools and reduced-order models for coupled combustor-turbine assemblies
  - obtain benchmark data for validation from rigs and real engines
- Initiate work on treatment and control strategies

Roadmap

- Currently under development and internal NASA discussion
- Being designed to account for emerging N+3 concepts
  - current engineering prediction tool modules not up to task
  - high-fidelity simulations needed to understand potential new physics
  - benchmark experiments needed to validate both simulations and reduced-order models
  - ultimately, real-engine tests will be needed
  - acoustic treatment and control strategies
- Work is envisioned to be carried out by multiple NASA organizations and potential external partners
- Again, the following material is preliminary

Noise Prediction & Modeling Approach

Develop Tools Allowing Routine Direct Design of N+3 Integrated Core Assemblies

High-Fidelity Simulation of Integrated Core Components

High-Fidelity Combustor Simulation Using Compressible & Reactive-Flow LES

High-Fidelity Turbine Simulation Using:
1) LES Methods for Pressure & Entropy Interaction with Turbine Stages
2) URANS for multi-stage tone noise

Include Effects of Rig Tailpipe or Combustor-Turbine Interface

Consider Combustor, HPT, LPT and Tailpipe as Loosely Coupled

Coupled Simulation

Develop Integrated-Combustor-Turbine Models Suitable for Incorporation into Engineering Noise Prediction Tools (Multiple Fidelity)

Obtain High-Quality Data for Validation and Support of Modeling Efforts

Increasing Complexity – Canonical – Rigs @ Near-Engine Conditions – Real Engines

roadmap under development

Noise Reduction Approach

Develop Effective Strategies and Technologies for N+3 Integrated-Core-Assembly Passive Noise Reduction

Fan-noise acoustic-liner technologies

Emerging high-temperature materials

Emerging strategies for broadband suppression

Leverage

Assess and Develop Strategies

Test and develop promising technologies

Test in GFIT, or similar facilities

Down select

Rig-test @ near-engine conditions

Down select

Test under realistic engine conditions in rigs and real engines

Product

N+3 treatment technologies

Multiple organizations at GRC, LaRC, and potential external partners

roadmap under development

Noise Reduction Approach

Develop Novel Concepts for Passive and Active N+3 Core-Noise Control

Nascent research areas

- Passive combustion-instability control
- Active combustion-instability control
- Active suppression of multi-tonal and broadband turbine noise

Leverage

Assess and Develop Strategies

Test and develop promising technologies

Canonical experiments

Down select

Adapt for engine control systems

Rig-test @ near-engine conditions

Down select

Test under realistic engine conditions in rigs and real engines;
ultimately tied into real control system

Product

N+3 passive/active control technologies

Multiple organizations at NASA and potential external partners

roadmap under development

Extra Slides

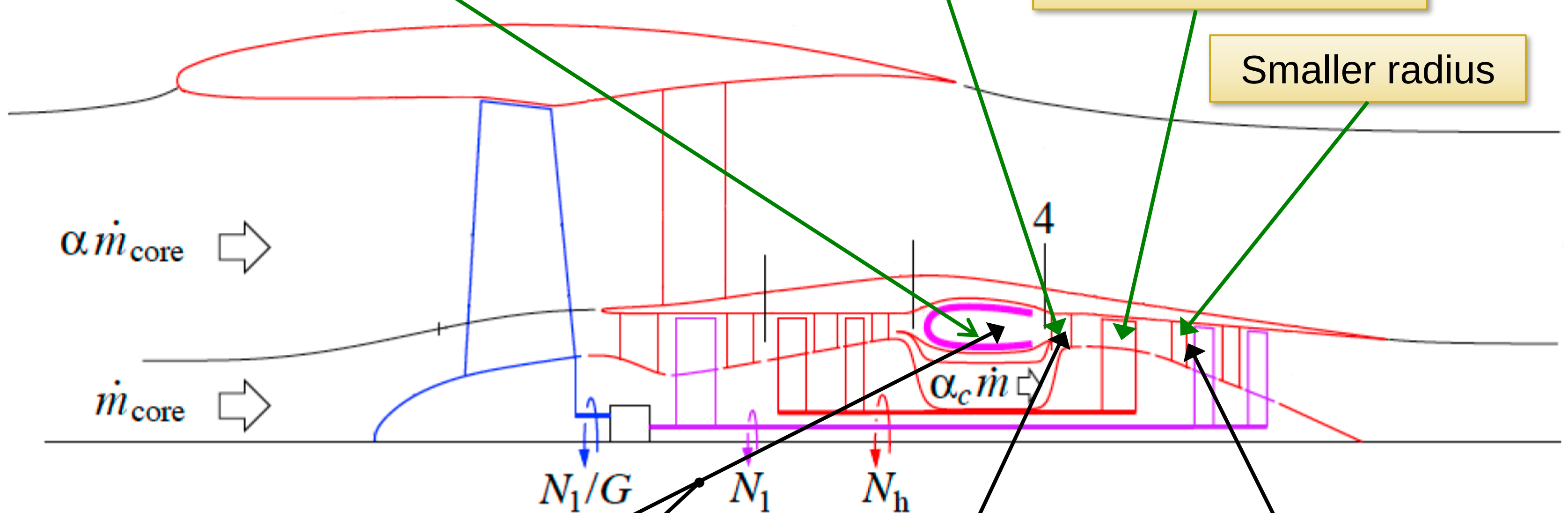
High-Power-Density, Low-Emission, Small-Core Combustor-Noise Issues

N+1.5 BPR & OPR trend continued

N+1.5 T_4 trend reversed

CMC & less cooling

Smaller radius



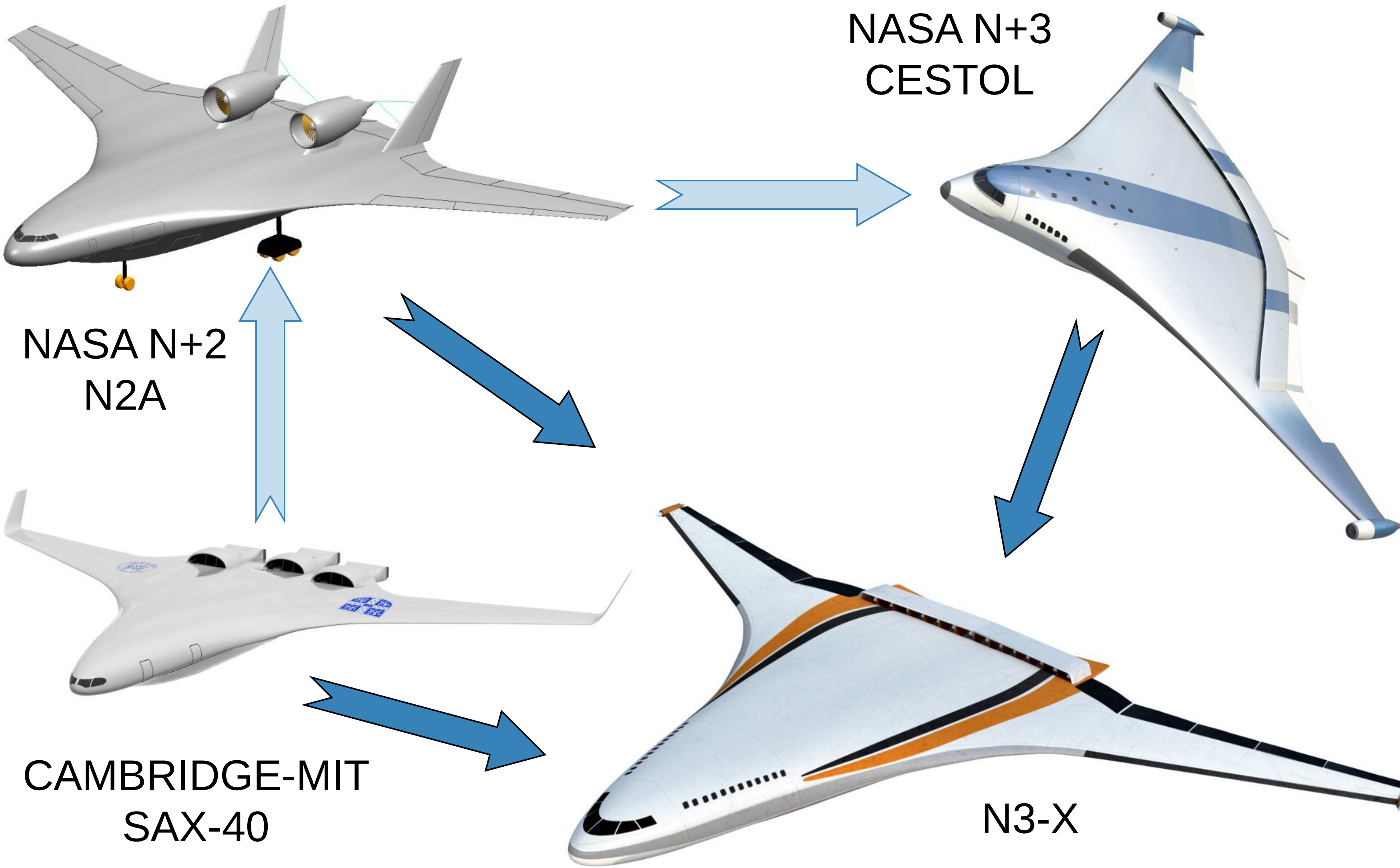
Higher OPR increases noise

Lower T_4: more acoustic liners

Low-emission design may increase noise

Implications for turbine attenuation unknown

NASA N3-X TeDP HWB Concept Lineage



Engine Summary

	CFM56-7B	D8.5 UHB	GE hFan	N3-X	GE90-115B
Number of engines	2	3	2	15/2	N/A
SLS Thrust (lbf)	26,300	8,500	18,800 (GT) 25,600	124,100 (total)	115,300
Fan diameter (in)	61	52	89.4	15 x 42.7	128
BPR	5.1	20	18	29	9
FPR	1.65	1.42	1.35	1.26	1.5
OPR	32.8	50	59	69.9	42
T_{41} (R)	?	2,880	Moderate	< 3,460	3,215*
Combustor	SAC/DAC	LDI	Advanced	N+3	DAC

*Non-proprietary NPSS result

Noise Prediction & Modeling Approach

- Integrated Combustor-Turbine Assembly
  - High-Fidelity Combustor Simulation – *direct computation of combustor noise using compressible and reactive-flow LES methods; include effects of combustor-turbine interface or rig tailpipe; obtain benchmark data for validation and additional support of modeling*
  - High-Fidelity Turbine Simulation – *direct computation of pressure and entropy interaction with turbine stages using compressible LES methods; consider the combustor, HPT, LPT, and exit nozzle as loosely coupled; URANS for tone noise; obtain benchmark data for validation and additional support of modeling work*
  - Reduced-Order Modeling of Integrated Combustor-Turbine Assembly – *develop models suitable for for incorporation into engineering-prediction tools such as ANOPP2; allow for variable-fidelity modeling of core components; validate with real-engine data*

roadmap under development

Noise Reduction Approach

- Assess/develop emerging novel concepts and advanced materials for combustor-turbine-assembly noise reduction
  - Assess and Develop Strategies – *leverage acoustic-liner technologies developed for fan-noise reduction using emerging high-temperature materials and strategies for broadband suppression; work involves multiple organizations at GRC, LaRC, and potential external partners*
  - Passive Acoustic-Liner Technology – *test and develop promising technologies in GFIT, or similar facilities; down-select concepts and rig-test at near-engine conditions; test successful concepts under realistic engine conditions in rigs and real engines; work is performed in-house and/or with external partners*

roadmap under development

Noise Reduction Approach

- Assess/develop novel concepts for passive and active core-noise control
  - Assess and Develop Strategies – *leverage technologies being developed for passive and/or active combustion-instability control to also reduce incoherent combustor broadband noise; develop novel concepts for active reduction of combustor noise and multi-tonal and broadband turbine noise; work involves multiple organizations at NASA and potential external partners*
  - Passive/Active Core-Noise-Reduction Technology – *test and develop passive- and active-control strategies in canonical experiments; adapt active strategies for incorporation into engine-control systems; test in rigs at near-engine conditions; test and validate in real engines, ultimately tied into a real engine-control system; work is performed in-house and/or with external partners*

roadmap under development