CORE-NOISE

Summary

This presentation is a technical progress report and near-term outlook for NASA-internal and NASA-sponsored external work on core (combustor and turbine) noise funded by the Fundamental Aeronautics Program Subsonic Fixed Wing (SFW) Project. Sections of the presentation cover: the SFW system level noise metrics for the 2015, 2020, and 2025 timeframes; the emerging importance of core noise and its relevance to the SFW Reduced-Noise-Aircraft Technical Challenge; the current research activities in the core-noise area, with some additional details given about the development of a high-fidelity combustion-noise prediction capability; the need for a core-noise diagnostic capability to generate benchmark data for validation of both high-fidelity work and improved models, as well as testing of future noise-reduction technologies; relevant existing core-noise tests using real engines and auxiliary power units; and examples of possible scenarios for a future diagnostic facility.

The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The SFW Reduced-Noise-Aircraft Technical Challenge aims to enable concepts and technologies to dramatically reduce the perceived aircraft noise outside of airport boundaries. This reduction of aircraft noise is critical for enabling the anticipated large increase in future air traffic. Noise generated in the jet engine core, by sources such as the compressor, combustor, and turbine, can be a significant contribution to the overall noise signature at low-power conditions, typical of approach flight. At high engine power during takeoff, jet and fan noise have traditionally dominated over core noise. However, current design trends and expected technological advances in engine-cycle design as well as noise-reduction methods are likely to reduce non-core noise even at engine-power points higher than approach. In addition, future low-emission combustor designs could increase the combustion-noise component. The trend towards high-power-density cores also means that the noise generated in the low-pressure turbine will likely increase. Consequently, the combined result from these emerging changes will be to elevate the overall importance of turbomachinery core noise, which will need to be addressed in order to meet future noise goals.

Core-Noise

NASA Fundamental Aeronautics Subsonic Fixed Wing Program

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Acoustics Technical Working Group, October 21-22, 2010

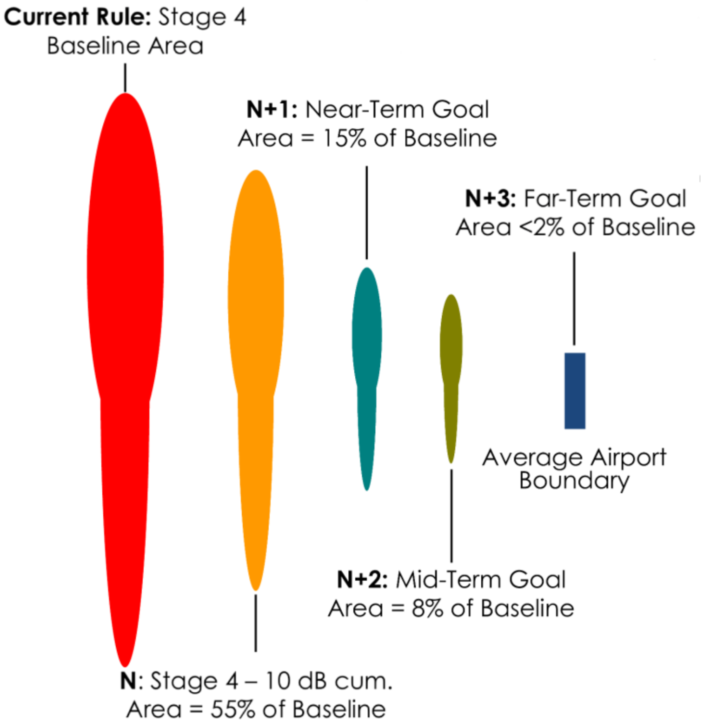
NASA Fundamental Aeronautics SFW

- The NASA Fundamental Aeronautics Program has the principal objective of overcoming today’s national challenges in air transportation.
- Reduction of aircraft noise is critical for enabling the anticipated large increase in future air traffic

CORNERS OF THE TRADE SPACE	N+1 = 2015*** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020*** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025*** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-50%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

***Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for “long-pole” technologies.
** Recently Updated. Additional gains may be possible through operational improvements.
* Concepts that enable optimal use of runways at multiple airports within the metropolitan area.

NASA’s Subsonic Transport System Level Metrics

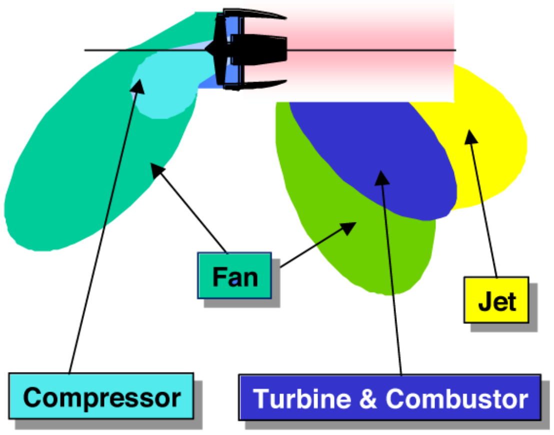


Relative ground contour areas for notional Stage 4, current, and near-, mid-, and far-term goals

SFW Technical Challenge (one of several)

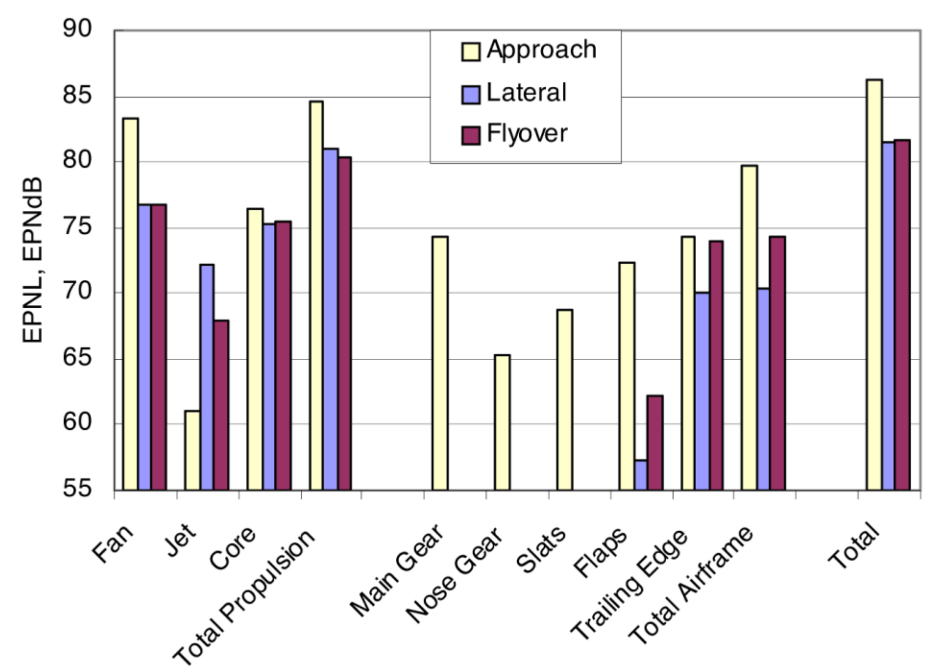
Reduced Noise Aircraft:

Enabling concepts and technologies to dramatically reduce perceived aircraft noise outside of airport boundaries



Engine Noise Sources

- The N+1 predictions by Berton & Envia show that core noise is significant for takeoff and cutback conditions
- At approach:
  - fan-noise EPNL dominating due to tone penalties and duration correction
  - total-airframe then core-noise OASPL peaks are the largest



Predicted N+1 airplane certification levels

From: Jeffrey J Berton & Edmane Envia
“An Analytical Assessment of NASA’s N+1 Subsonic Fixed Wing Project Noise Goal”
AIAA 2009-3144

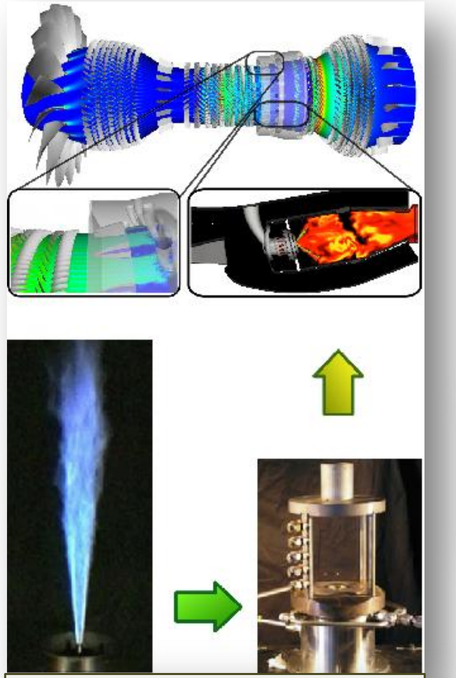
Emerging Importance of Core Noise

- ❑ Core (combustor & turbine) noise traditionally has been a concern only at the approach condition for high-bypass-ratio turbofan engines
- ❑ Increased bypass ratios and expected advances in noise reduction technologies
    - ➢ non-core noise components will be further reduced at all power levels
- ❑ Turbine (LPT) design changes driven by performance, cost, weight and maintainability
    - ➢ reduction in blade counts and stage spacing ➔ increased source strength and complexity
    - ➢ increased operating temperatures ➔ acoustic treatment more difficult
- ❑ Combustor noise more important because
    - ➢ low-emission designs could increase noise levels
    - ➢ turbine design trends could lower transmission losses
    - ➢ airframe shielding may not be effective at low frequencies

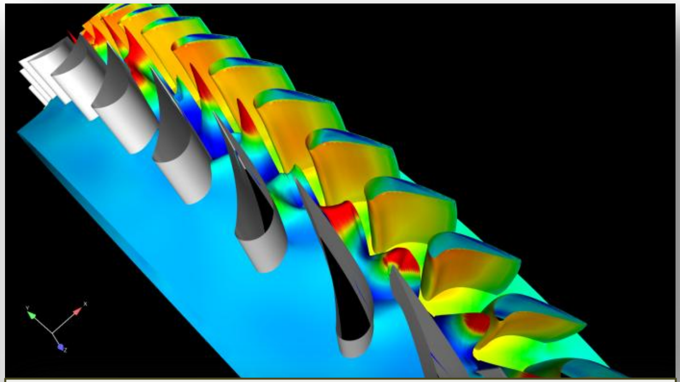
Emerging ultra-high-bypass-ratio engines with advanced high-power-density core components will make core noise a more significant component of the total engine noise signature at all power settings, which will need to be addressed to meet NASA noise goals

NASA FAP SFW Core-Noise Activities

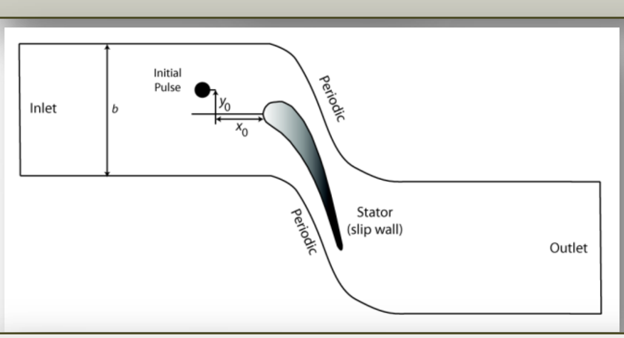
NASA Internal and NASA-Sponsored External Research Efforts Aimed at the Development of Aircraft Noise-Prediction Capability and Tools



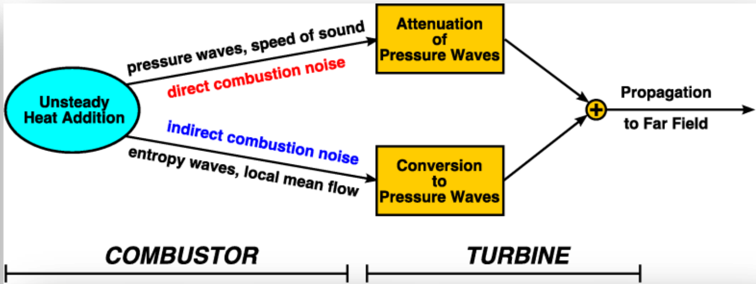
Stanford NRA:
High-Fidelity LES
Combustion Noise
Prediction Capability
4th year of 5



In-House: High-Fidelity URANS (TURBO) Turbine Tone Noise Generation



NRA-sub: Entropy-Cascade Interaction



Unsteady Heat Addition

pressure waves, speed of sound

direct combustion noise

indirect combustion noise

entropy waves, local mean flow

Attenuation of Pressure Waves

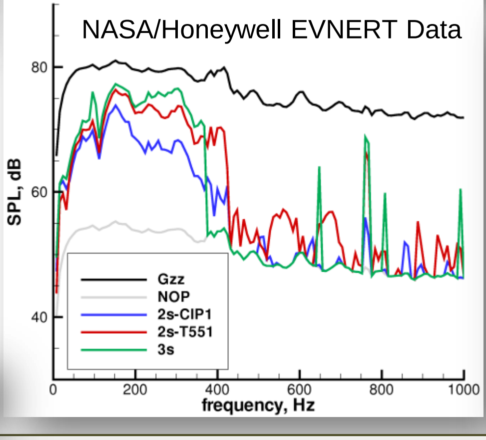
Conversion to Pressure Waves

Propagation to Far Field

COMBUSTOR

TURBINE

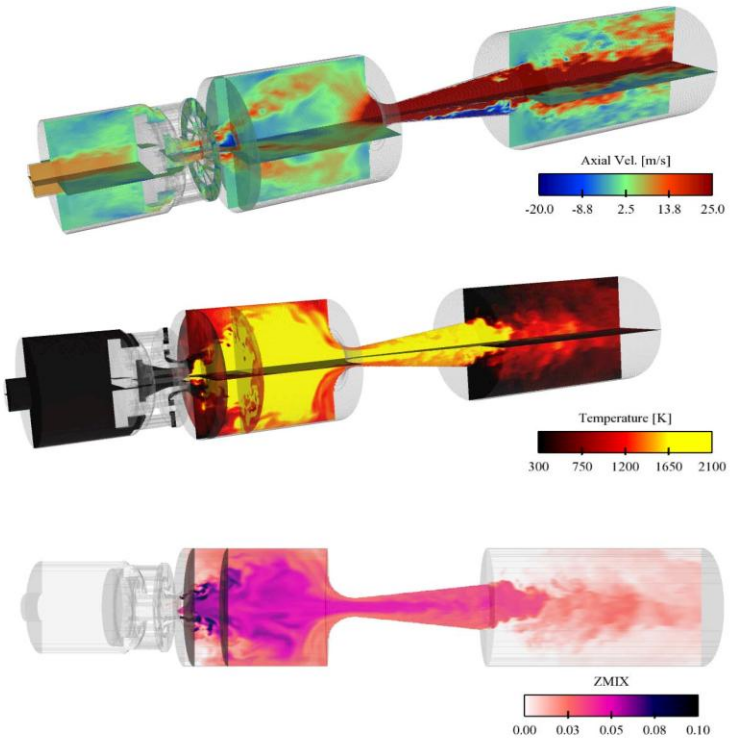
In-House: Multi-Disc Actuator-Theory Modeling of Direct and Indirect Combustion-Noise Generation & Turbine Transmission



In-House:
Source-Separation
Techniques
Applied to
Real Engine
Data to Aid
Modeling
Efforts

High-Fidelity for Physics --- Modeling for Practical/Engineering Prediction

Prel. Simulation of Combustor-Rig Exp.



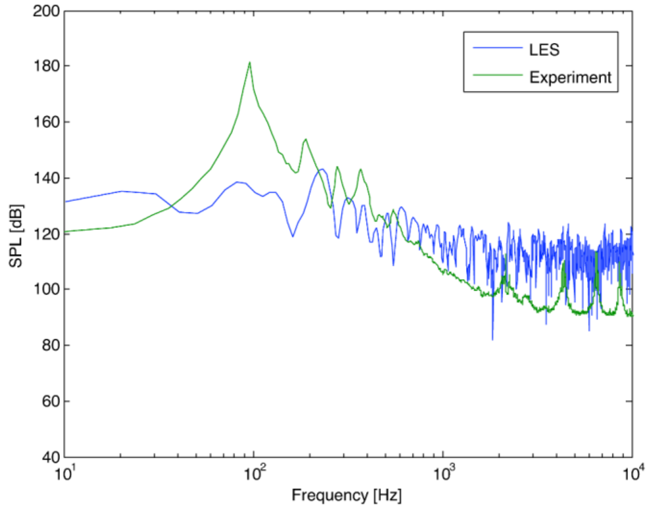
Axial Velocity, Temperature, and Mixing Fraction

- ❑ Combustor-rig experiment at DLR, Germany
- ❑ Preliminary LES simulation at Stanford
- ❑ Over prediction at high freq. might be due to insufficient resolution in chemistry tabulation
- ❑ Results are comparable to existing self-excited URANS simulations by Bake et al
- ❑ Higher-accuracy results not yet available

Reactive-Flow Model (CCLES)

- ❑ Advance Favre-filtered conservative variables $\{\rho, \rho\boldsymbol{u}, \rho z, \rho c, \rho e\}^T$ using LES scheme
- ❑ Chemistry tables provides mass fractions $Y_k(z,c)$
- ❑ Determine temperature from implicit relation

  $e = \Sigma Y_k h_k(T) - RT\Sigma Y_k/W_k + |\boldsymbol{u}|^2/2$
- ❑ Determine pressure from $p = \rho RT\Sigma Y_k/W_k$



SPL at first station in exhaust duct

Need for Core-Noise Diagnostic Capability

Background

- ☐ Existing prediction capability for core (combustor & turbine) noise is based on empiricism
- ☐ Core noise will have to be addressed to meet NASA noise goals

Current SFW Core-Noise Activities

- ☐ High-fidelity work to better understand the physics
- ☐ Development of reduced-order models for improved prediction
- ☐ Source-separation techniques in order to validate new models
- ☐ Lack of benchmark data for validation of both high-fidelity work and improved models

Existing Data with Very Good Engine-Internal Pressure Instrumentation

- ☐ Honeywell RE220 Auxiliary Power Unit (APU) --- Honeywell under NASA RASER Program
- ☐ Honeywell TECH977 Research Turbofan Engine --- Honeywell/NASA EVNERT Program

Core-Noise Diagnostic & Mitigation Capability Needed in Future

- ☐ NASA-internal discussions are ongoing but no decision or funding as of yet (still early days)
- ☐ Several possible scenarios for an in-house capability under consideration

Williams International F112	General Electric TF34	Auxiliary Power Unit	Other Turbofan Engine?

- ☐ Preferable to be able to test in the AeroAcoustic Propulsion Laboratory (AAPL), aka the “Dome”
- ☐ Opportunity for high pressure and temperature instrumentation and measurement development

Honeywell (NASA) APU & EVNERT Tests

Honeywell RE220 APU

☆Schuster & Mendoza, “Auxiliary Power Unit Combustion Noise Measurement,” X3-NOISE/CEAS Combustion Noise Workshop, Portugal, 2007

An array of internal and external sensors was used: circumferential pressure measurements in combustor, axial pressure measurements in tailpipe, and a 25 ft far-field microphone array

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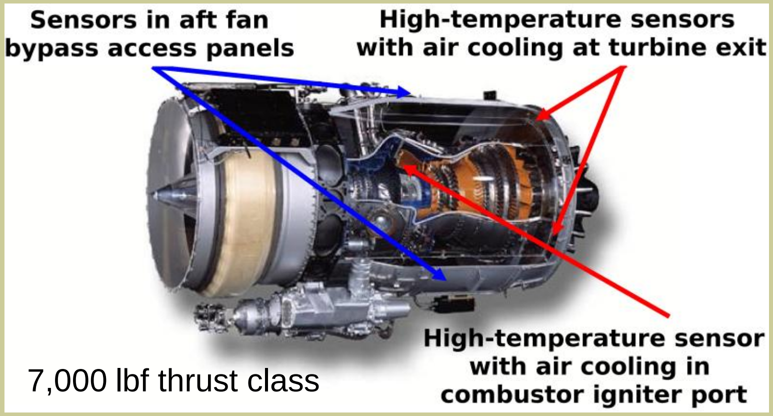
Data from RE220 APU also used to extend ANOPP:

Schuster & Lieber, “Narrowband Model for Gas Turbine Engine Noise Prediction,” AIAA 2006-2677

Tam et al, “Combustion Noise of Auxiliary Power Units,” AIAA 2005-2829

Honeywell TECH977 Turbofan



7,000 lbf thrust class

Weir, “Engine Validation of Noise and Emission Reduction Technology Phase I,” NASA/CR 2008-215225

Mendoza et al, “Source Separation from Multiple Microphone Measurements in the Far Field of a Full Scale Aero Engine,” AIAA 2008-2809

☆Royalty & Schuster, “Noise from a Turbofan Engine Without a Fan from the Engine Validation of Noise and Emission Reduction Technology (EVNERT) Program,” AIAA 2008-2810

16 equally-spaced circumferential probes inside combustor

Miles, “Time Delay Analysis of Turbofan Engine Direct and Indirect Combustion Noise Sources,” J Prop. & Power **25,** p. 218, 2009

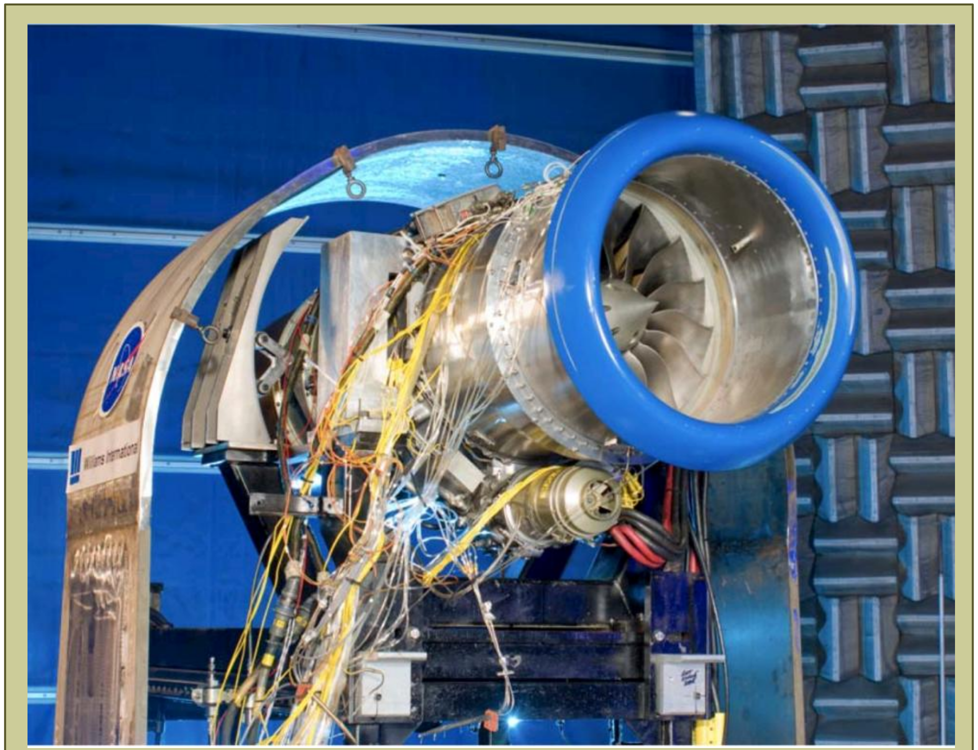
Hultgren & Miles, “Noise-Source Separation Using Internal and Far-Field Sensors for a Full-Scale Turbofan Engine,” AIAA 2009-3220

General Reference - FJ44-3A Test in AAPL

- ❑ Williams International FJ44 tested in "Dome"
- ❑ Noise diagnostics and fan-noise abatement
- ❑ Effects of over-the-rotor foam-metal liners

FJ44-3A

- ❑ 3,000 lbf thrust class --- dual spool
- ❑ 1 fan, 3-stage axial compressor and 2-stage LPT on low spool; 1-stage centrifugal compressor and a 1-stage HPT on high spool
- ❑ BPR: 4.1:1
- ❑ Weight: 582 lb



Lauer et al, "FJ44 Turbofan Engine Test at NASA Glenn Research Center's Aero-Acoustic Propulsion Laboratory," AIAA 2009-0620

Sutliff et al, "Attenuation of FJ44 Turbofan Engine Noise With a Foam-Metal Liner Installed Over-the-Rotor," AIAA 2009-3141

Podboy & Horvath, "Phased Array Noise Source Localization Measurements Made on a Williams International FJ44 Engine," AIAA 2009-3183

Williams International F112-WR-100

General

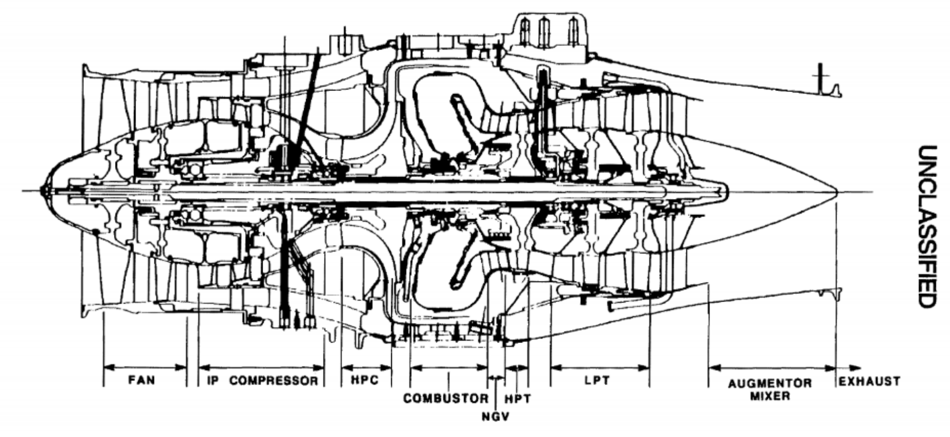
- Small, lightweight and dependable
- Used to power advanced cruise missiles
- Essentially a small version of turbofan engines used in military aircraft

Pros

- Government owns a large number
- Small enough to be tested in the “Dome”
- Interest by other GRC organizations to perform research in control & diagnostics, distributed engine control, optical instrumentation, active flow control, etc.
- VAATE (DOD, NASA & DOE) initiative use

Cons

- BPR and Combustor & LPT design not representative for N+1/N+2/N+3
- Small size (12”) may make instrumentation and concept implementation a challenge



Two-spool, counter rotating turbofan
Maximum thrust: < 1,000 lbf
Weight: 161 lbs
Bypass ratio of 1:1
2-stage fan coupled to 2-stage IP compressor
Centrifugal 1-stage HP compressor
Folded annular combustor, with rotary fuel injection
1-stage HPT and 2-stage LPT
JP-10 Boron-Slurry heavy fuel

General Electric TF34

General

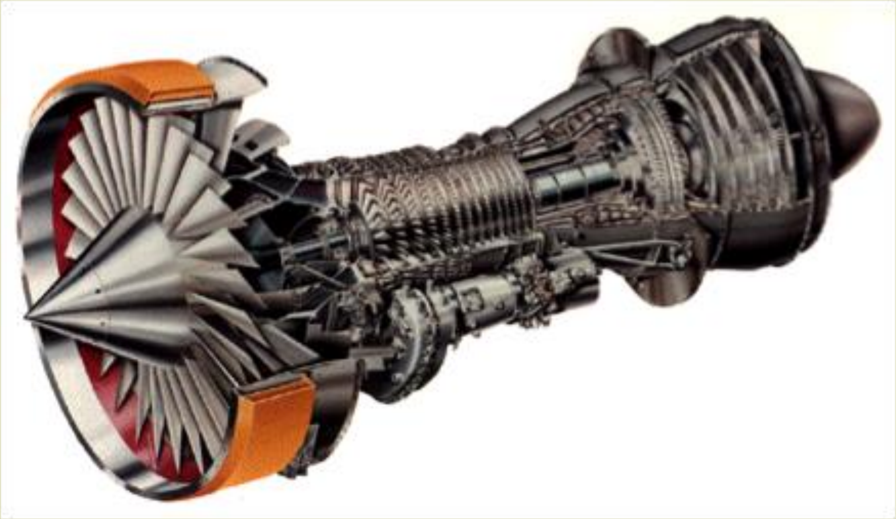
- Military turbofan engine
- S-3 Viking & A-10 Thunderbolt
- Highly reliable and maintainable

Pros

- GRC already has 10+ engines, spare parts, a good relationship with engine depot, and the S-3 Viking flying test bed
- Engine is big enough to be relevant, but small enough to `handle’
- GRC has access to full maintenance manual
- Could do tarmac acoustics measurements to look at installation effects

Cons

- 1970’s engine design – not low-emissions and high-power density core
- Facility requirements more stringent due to size --- testing in the “Dome” maybe difficult



High by-pass, two-spool, counter rotating turbofan
Thrust: 9,000 lbf class
Bypass ratio of 6.4:1
1-stage fan and 14-stage axial HP compressor
Annular combustor
2-stage HPT and 4-stage LPT
FPR = 1.5 and OPR = 20

APU or Other Turbofan Engine - Discussion

APU

- A modern APU could likely be handled in the AAPL
- But would it be useful?
- Questions:
  - Are the core-noise issues and concerns similar enough
  - Are the combustor and turbine designs too different from emerging turbofan cores

Other Turbofan Engine Candidates

- The example engines picked here where chosen because of low hardware costs and there is already in-house familiarity with the engine (GE TF34) or there are other potential in-house activities that could share in engine operation and maintenance costs (Williams F112)
- Questions:
  - Are these engines modern enough to be relevant?
  - Are they “good enough” for the development of instrumentation, techniques and know how?
    - use other engines through cooperative agreements for future research/breakthroughs?
  - Are there any other more modern small engines that should be considered?
    - what thrust class?

Your comments, insights and recommendations are welcome