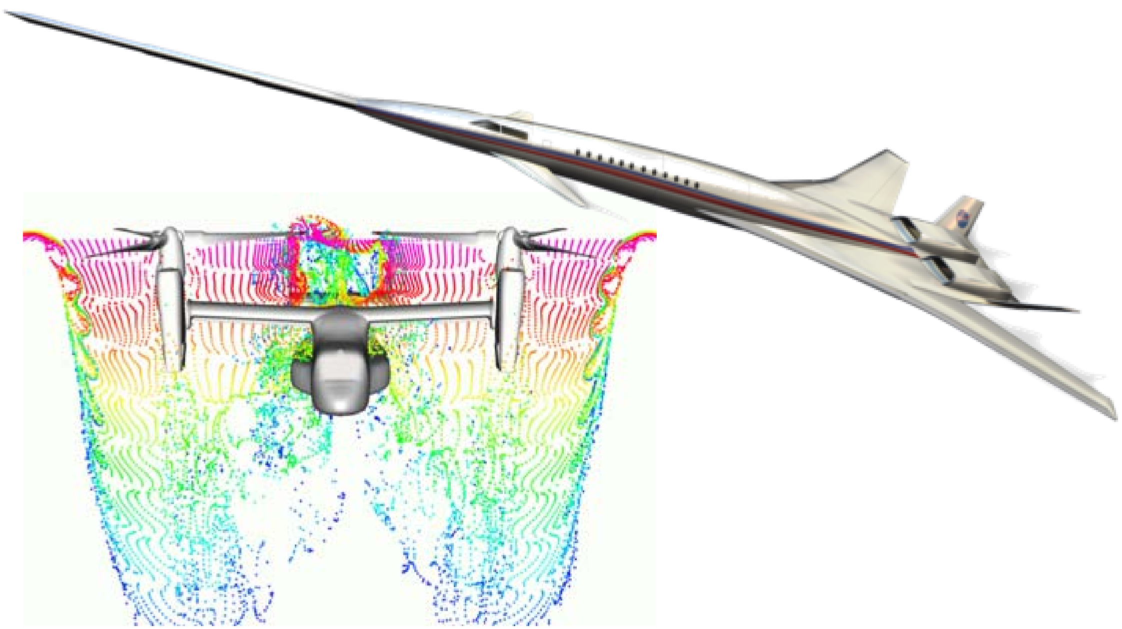
Computational Engineering and Science in the NASA Fundamental Aeronautics Program

AIAA 46th Aerospace Sciences Meeting
Grand Sierra Resort
Reno, NV
January 9, 2008



Outline

- Brief overview of the Fundamental Aeronautics Program
- Some ongoing efforts
- Future Computational Engineering and Science Requirements at NASA / FA
- Observations and conclusions

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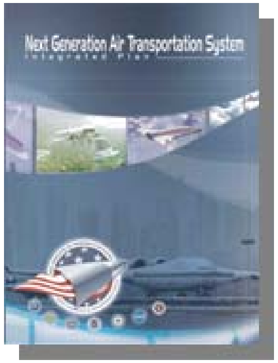
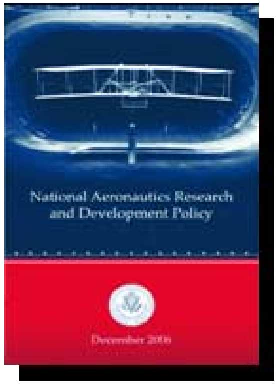
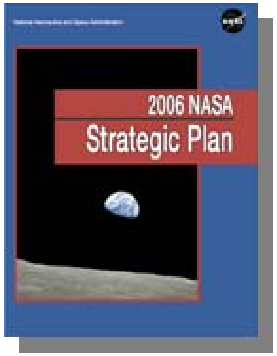
The National and NASA Contexts

- NextGen: The Next Generation Air Transportation System
  - Joint Planning Development Office (JPDO), Vision 100 (2003)
  - Revolutionary transformation of the airspace, the vehicles that fly in it, and their operations, safety, and environmental impact
- National Aeronautics R&D Policy and Implementation Plan (Dec 2006/7)
  - "Mobility through the air is vital…"
  - "Aviation is vital to national security and homeland defense"
  - "Assuring energy availability…" and "The environment must be protected…"
- NASA Strategic Plan
  - Strategic Goal 3: "Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human spaceflight program to focus on exploration."
  - Sub-Goal 3E: "Advance knowledge in the fundamental disciplines of aeronautics, and develop technologies for safer aircraft and higher capacity airspace systems."







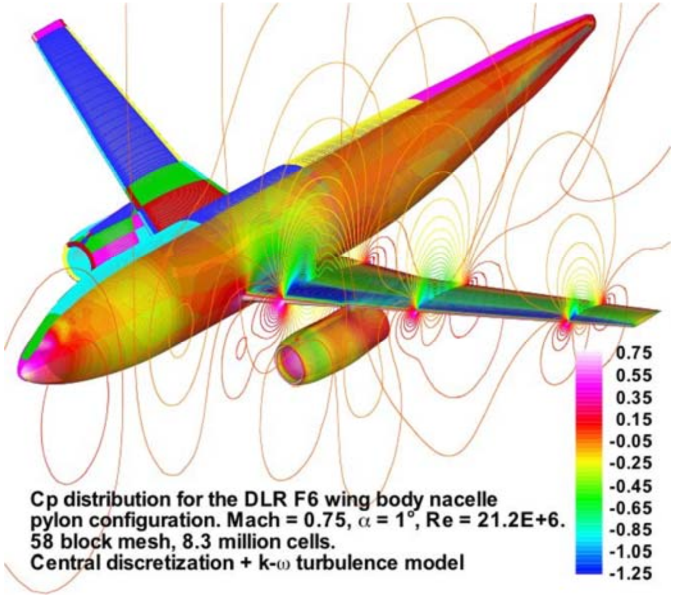
Aeronautics Programs

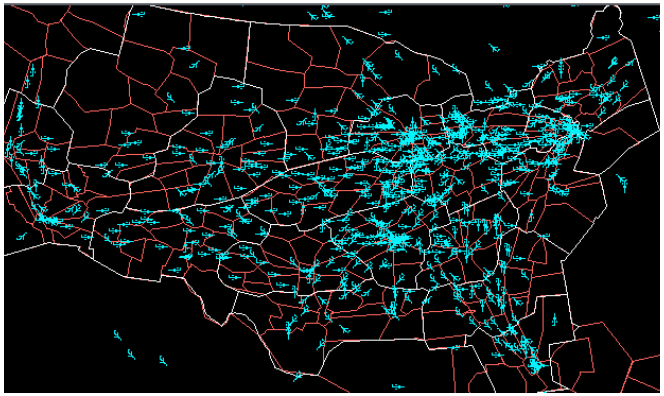
Fundamental Aeronautics Program
- Subsonic Fixed Wing
- Subsonic Rotary Wing
- Supersonics
- Hypersonics

Aviation Safety Program
- Integrated Vehicle Health Management
- Integrated Resilient Aircraft Control
- Integrated Intelligent Flight Deck
- Aircraft Aging & Durability

Airspace Systems Program
- NGATS Air Traffic Management: Airspace
- NGATS Air Traffic Management: Airportal

Aeronautics Test Program
- Ensure the strategic availability and accessibility of a critical suite of aeronautics test facilities that are deemed necessary to meet aeronautics, agency, and national needs.

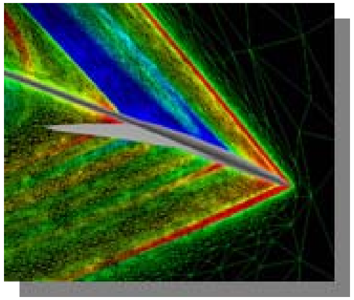




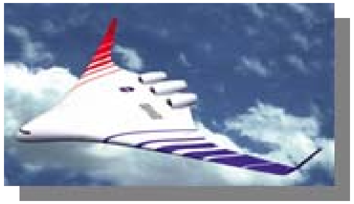
Fundamental Aeronautics Program: Mission Statements

- *Hypersonics*
  - Fundamental research in all disciplines to **enable very-high speed flight** (for launch vehicles) and **re-entry into planetary atmospheres**
  - High-temperature materials, thermal protection systems, advanced propulsion, aero-thermodynamics, multi-disciplinary analysis and design, GNC, advanced experimental capabilities

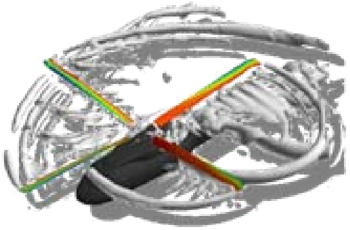
- *Supersonics*
  - **Eliminate environmental and performance barriers** that prevent **practical supersonic vehicles** (cruise efficiency, noise and emissions, vehicle integration and control)
  - Supersonic deceleration technology for **Entry, Descent, and Landing** into Mars



- *Subsonic Fixed Wing (SFW)*
  - Develop revolutionary technologies and aircraft concepts with highly **improved performance** while satisfying **strict noise and emission constraints**
  - Focus on **enabling technologies**: acoustics predictions, propulsion / combustion, system integration, high-lift concepts, lightweight and strong materials, GNC



- *Subsonic Rotary Wing (SRW)*
  - Improve **competitiveness of rotary wing vehicles** (vs fixed wing) while maintaining their unique benefits
  - Key **advances** in multiple areas through **innovation** in materials, aeromechanics, flow control, propulsion

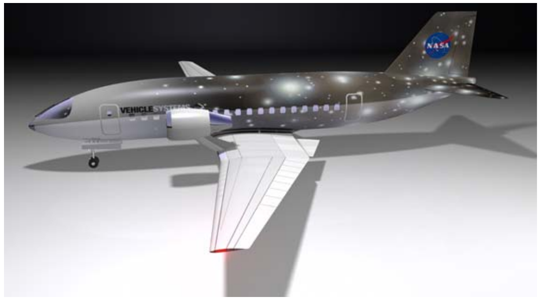


System Level Metrics - Updated

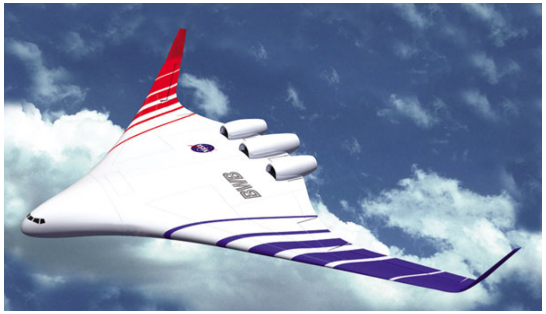
.... technology for dramatically improving noise, emissions, & performance

CORNERS OF THE TRADE SPACE	N+1 Generation Conventional Tube w/Wing (2012-2015)	N+2 Generation Unconventional Hybrid Wing Body (2018-2020)
Noise (cum below Stage 3)	**- 42 dB**	**- 52 dB**
LTO NOx Emissions (below CAEP 2)	**-70%**	**-80%**
Performance: Aircraft Fuel Burn (relative to B737/CFM56)	**-33%**	**-50%*****
Performance: Field Length (relative to B737/CFM56)	**-33%**	**-50%**

N+1 Conventional



N+2 Hybrid Wing/Body



Approach

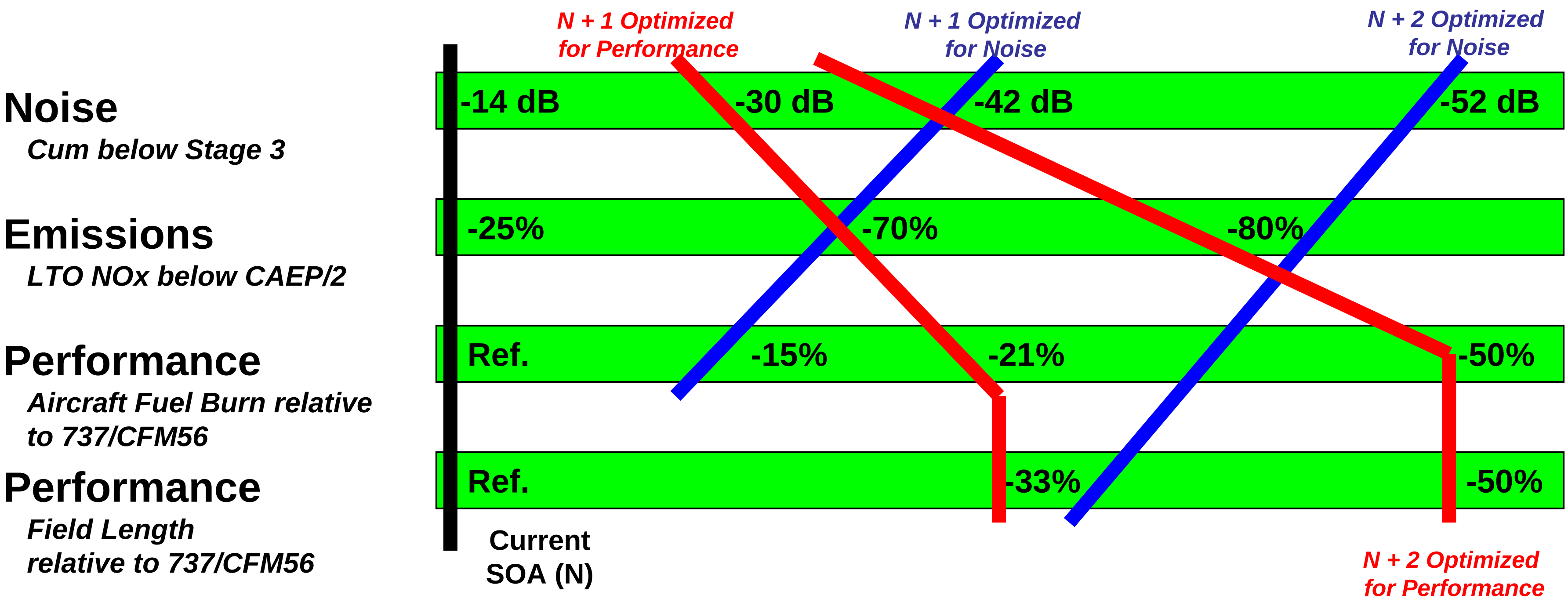
- Enable Major Changes in Engine Cycle/Airframe Configurations

- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes

- Develop/Test/ Analyze Advanced Multi-Discipline Based Concepts and Technologies

- Conduct Discipline-based Foundational Research

Optimization - Performing Trades



"N + 1" Conventional Small Twin

- Technologies available for 2012 – 2015 EIS (market permitting)
- Noise: UHB engines, reduced weight, low-noise fans & landing gear
- Emissions: advanced combustors (TAPS, TALONX, etc.)
- Performance: high power density engine cores, reduced weight, high lift

"N + 2" Hybrid Wing/Body

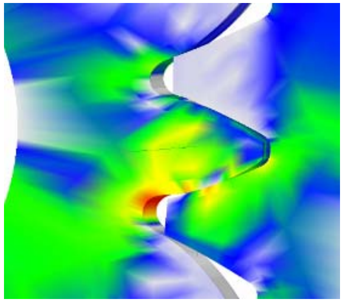
- Technologies available for 2018 – 2020 Initial Operational Capability
- Noise: shielding from above wing engines, low-noise airframe
- Emissions: alternative fuels, alternative combustion concepts
- Performance: embedded engines, morphing structures, low drag
- Balanced Field Length: cruise efficient STOL, high lift

Subsonic Rotary Wing Project

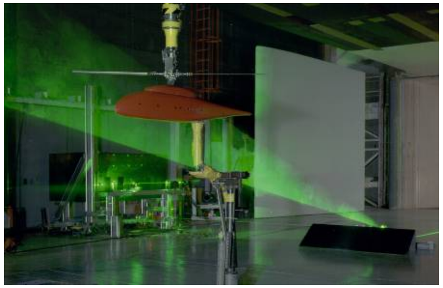
Solving Civil Utility Problems

- Solving problems relevant to civil and military applications
- Close partnership with the Army
- Researchers working side-by-side on fundamental, difficult problems
- Sharing and leveraging experimental and computational expertise

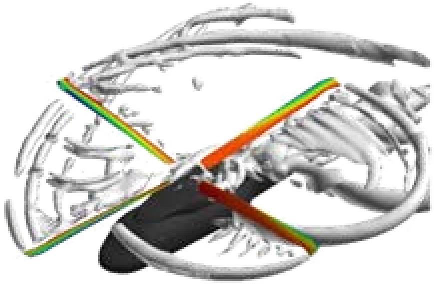
Other partners include: Bell Helicopter, Sikorsky, HeloWerks, AF, DARPA



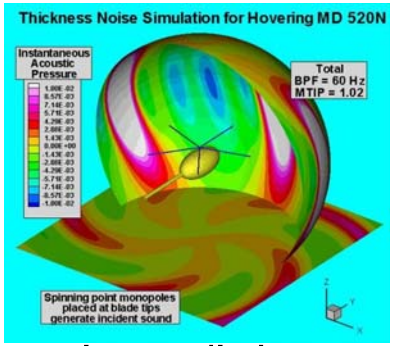
3-D Analysis of Spur / Helical Gears



14- by 22-Foot Subsonic Tunnel



First-Principles Modeling



Noise prediction

Research Areas:

Noise propagation and reduction	➡	Community acceptance
Increase speed and range	➡	Reduce airport congestion
Increase propulsion efficiency	➡	Reduce emissions
Increase payload	➡	Decrease cost, increase utility
Improve control systems	➡	Safe operations for advanced concepts

Supersonics Project Technical Elements

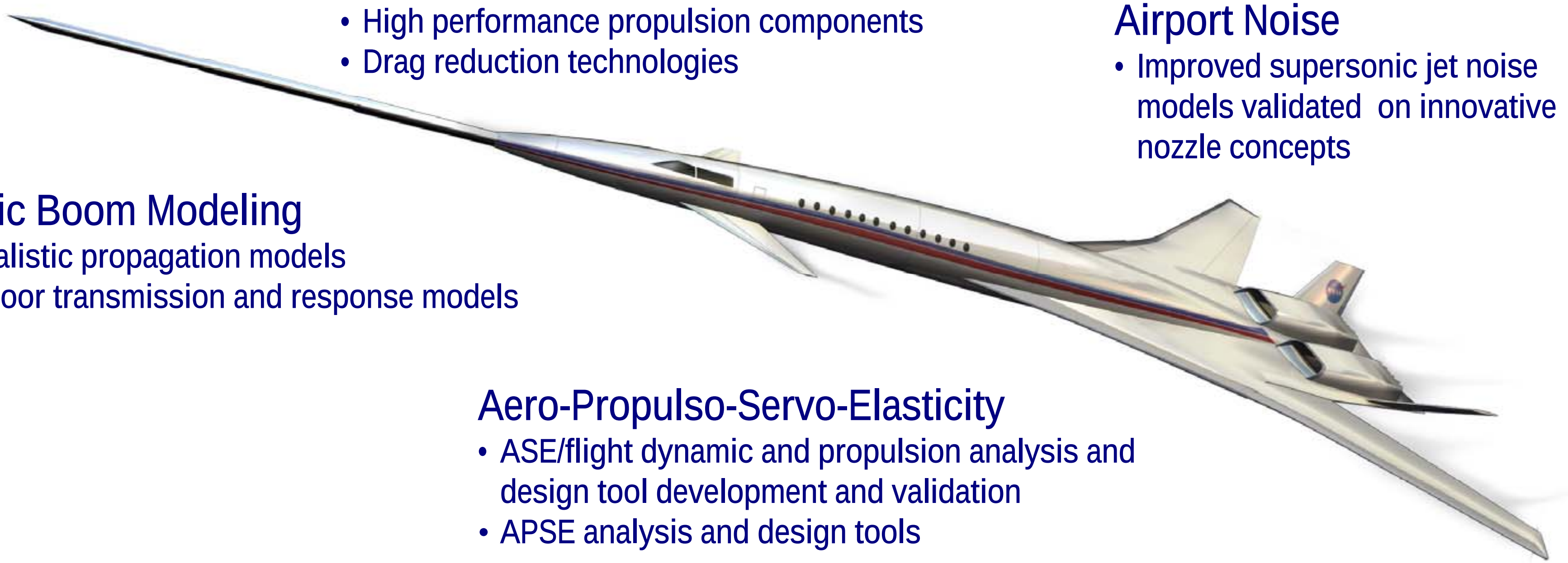
Deliver Knowledge, Capabilities, and Technologies Addressing Supersonics Challenges

Cruise Efficiency

- Tools and technologies for integrated propulsion and vehicle systems level analysis and design
- High performance propulsion components
- Drag reduction technologies

Airport Noise

- Improved supersonic jet noise models validated on innovative nozzle concepts



Sonic Boom Modeling

- Realistic propagation models
- Indoor transmission and response models

Aero-Propulso-Servo-Elasticity

- ASE/flight dynamic and propulsion analysis and design tool development and validation
- APSE analysis and design tools

High Altitude Emissions

- Improved prediction tools
- Low emissions combustors

Light Weight and Durability at High Temperature

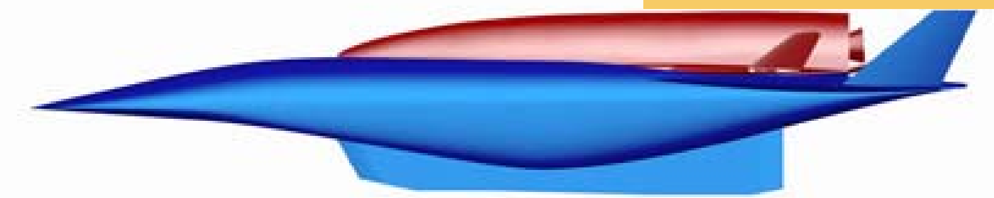
- Materials, test and analysis methods for airframe and engine efficiency, durability and damage tolerance

Hypersonics Project Focus

Highly Reliable Reusable Launch Systems

Materials & Structures
- Thermal Protection Systems
- Hot Structures
- High Temperature Seals

Integrated Systems
- Staging
- Thermal Management
- Power and Actuators
- Intelligent Controls

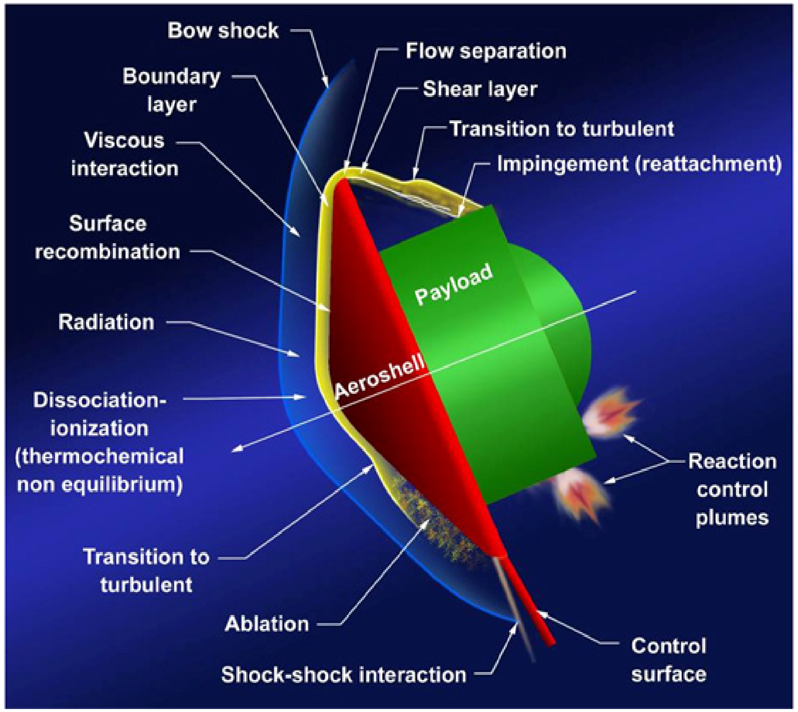


Airframe-Propulsion Integration
- Integrated Vehicle Performance
- Inlet Boundary Layer Ingestion
- Nozzle Performance

Propulsion
- High-Mach Turbojets
- Dual-Mode Scramjets
- Combined Cycle Engines

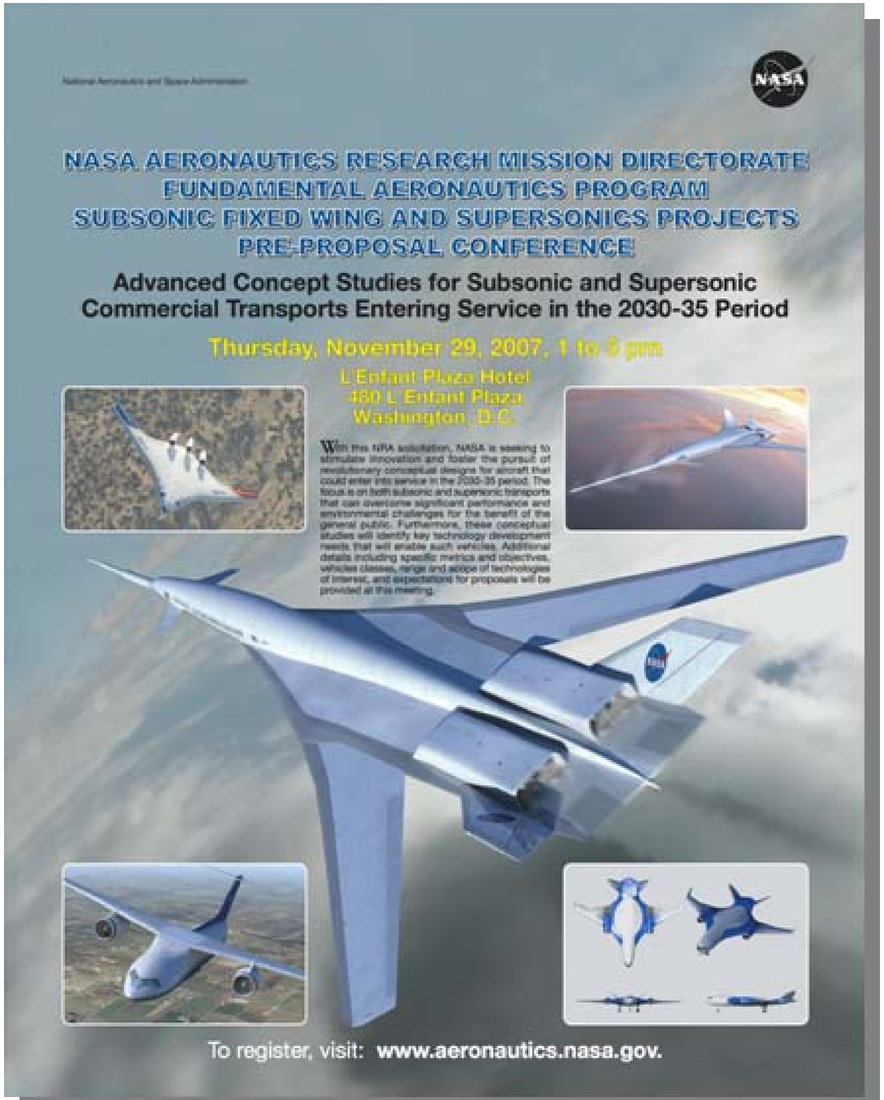
Similar technologies needed for both applications

High Mass Mars Entry Systems



Mission Statement: Conduct fundamental and multidisciplinary research to enable airbreathing access to space and entry into planetary atmospheres

NASA NRA Pre-Proposal Conference, Nov 29



- *Advanced Concept Studies for Subsonic and Supersonic Commercial Transports Entering Service in the 2030-35 Period*
- L'Enfant Plaza Hotel, Washington, DC
- Stimulate innovation and foster the pursuit of revolutionary conceptual designs for aircraft that could enter service in the 2030-35 time period. Overcome significant performance and environmental challenges for the benefit o the public.
- Phase I: 12-Months, Phase II: 18 Months to Two Years, with significant technology demonstration
- Solicitation will be released in the coming weeks

SFW System Level Metrics

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<u>N+1 Conventional</u>

<u>N+2 Hybrid Wing/Body</u>

Supersonics System Level Metrics

CORNERS OF THE TRADE SPACE	N+1 Supersonic Business Jet Aircraft (2015)	N+2 Small Supersonic Airliner (2020)
Cruise Speed	Mach 1.6-1.8	Mach 1.6-1.8
Range (nmi)	4,000	4,000
Payload	6-20 pax	35-70 pax
Sonic Boom	65-70 PLdB	65-70 PLdB
Airport Noise (cum below Stage 3)	10 EPNdB	10-20 EPNdB
Cruise Emissions	?	?
Fuel Efficiency	Baseline	15% Improvement

N+1 "Conventional"

N+2 Small Supersonic Airliner

Outline

- Brief overview of the Fundamental Aeronautics Program
- Some ongoing efforts
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Topics of Current Interest

- Fluid mechanics: applied aero, acoustics, aeromechanics, sonic boom
- Aerothermodynamics: combustion, emissions, fuels
- Materials & Structures: high temperature, multi-functional, lightweight
- Propulsion: propulsion /airframe integration, gas turbines, transmissions and bearings, high-speed, combined cycle
- Aeroelasticity

Subsonic Fixed Wing: X-48B First Flight

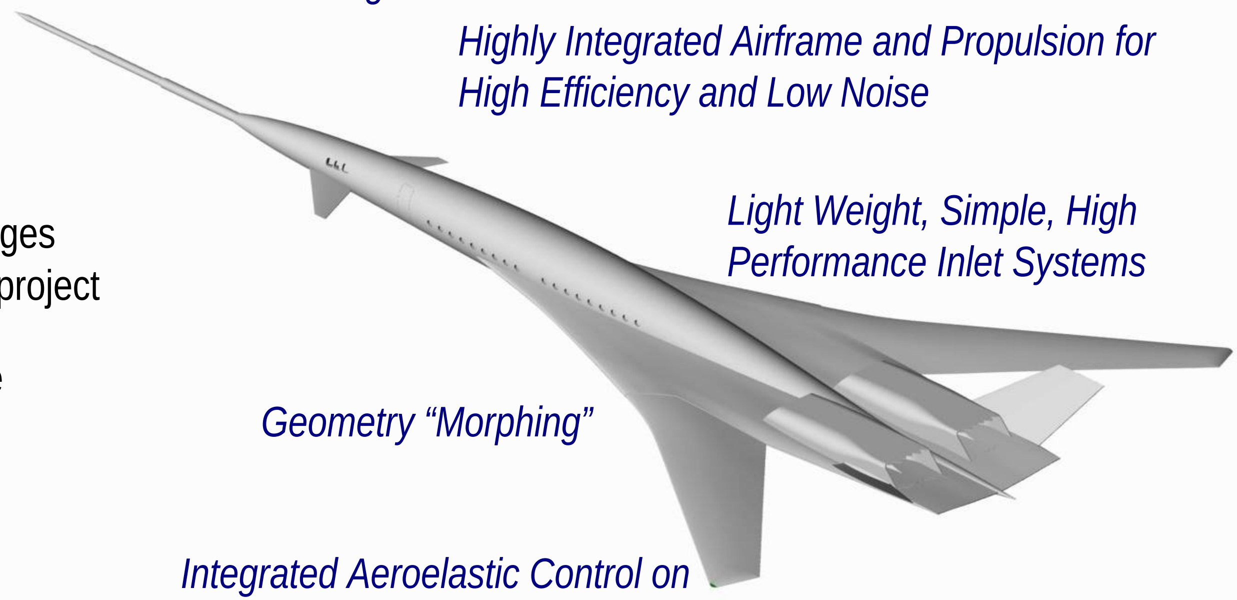
- First flight July 20, 2007
  - X-48B
  - 500 lb, 21 ft wing span
  - 31 minute flight
  - Low-speed flying/handling qualities experiment
  - Potential future use for acoustics tests (ground and flight) and transonic experiments
- 6 Flights Completed

Systems Integration, Assessment and Validation

Icon Concept Development and Systems Level Assessment

Define a stretch vehicle concept

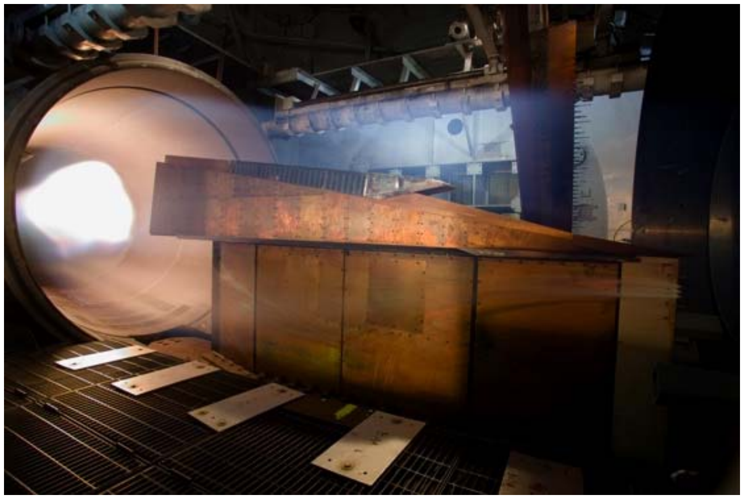
- Illustrate project technical challenges
- Illustrate possibilities enabled by project technologies
- Define requirements for discipline development
- Aid refinement of project goals



Low Speed configuration with unswept wing, retracted spike and deployed SERN Nozzle

- "N+2" Concept - Small Supersonic Airliner
- ~ Mach 1.8
- ~ 70 Passengers

Hypersonics:
X-51A Scramjet Engine Demonstrator



X-1 Engine Undergoes Testing in the 8ft Tunnel

Program Overview

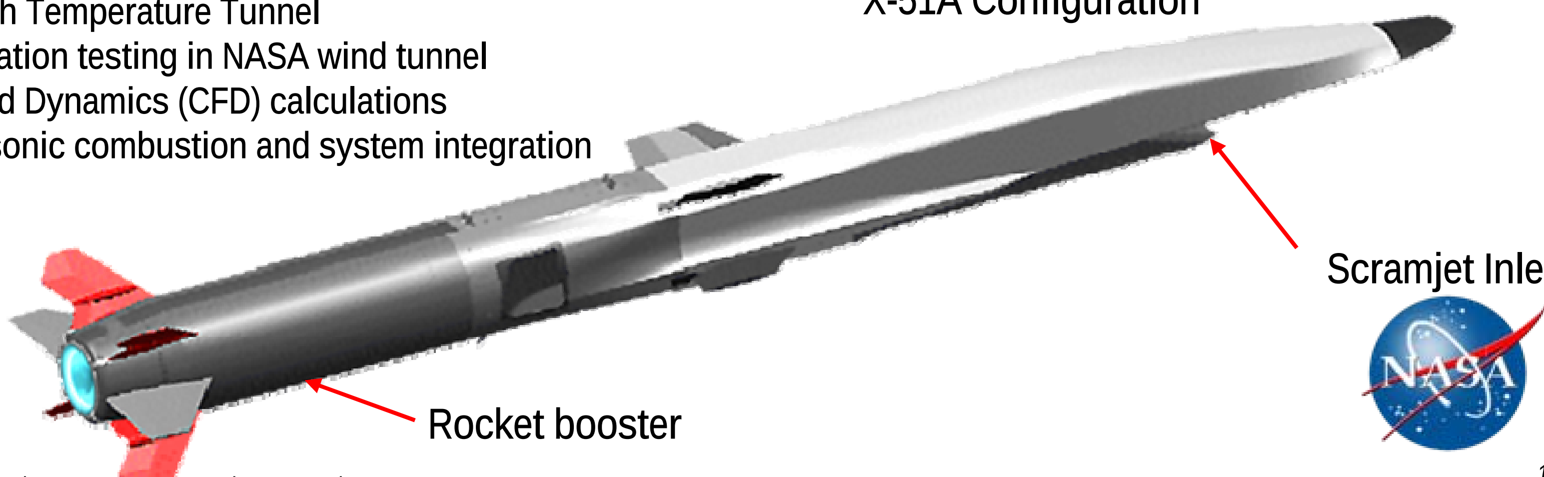
- Joint AFRL/DARPA/NASA flight demo
- Hydrocarbon-fueled and cooled scramjet
- Scramjet flight from Mach 4.5 to 6.5
- 5 minute-plus flight duration
- Four to eight flights (FY09 1st flight)

Major Accomplishment:

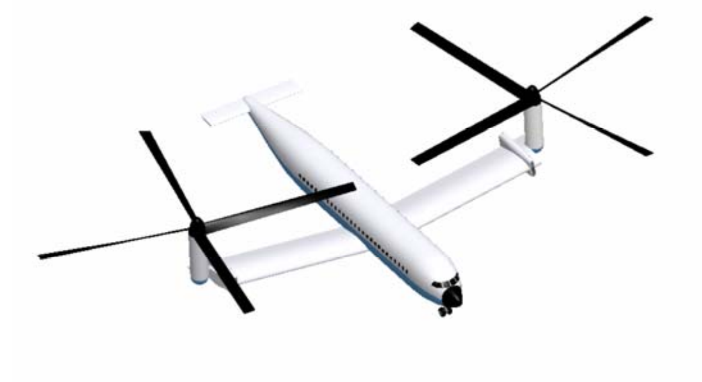
- Demonstrated hydrocarbon-fueled, self-cooling, complete envelope operation of scramjet engine for significant duration.

NASA's Role:
- Full-scale propulsion testing in the NASA 8-Foot High Temperature Tunnel
- Sub-scale configuration testing in NASA wind tunnel
- Computational Fluid Dynamics (CFD) calculations
- Expertise in supersonic combustion and system integration

X-51A Configuration



Subsonic Rotary Wing Project



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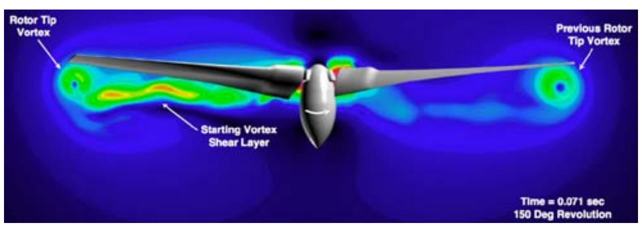
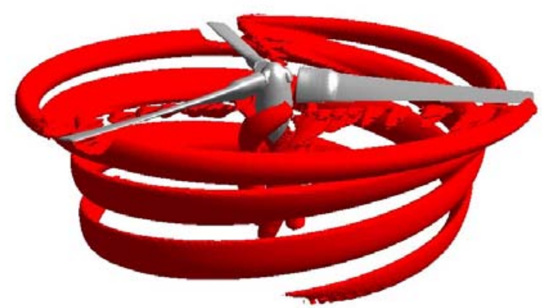
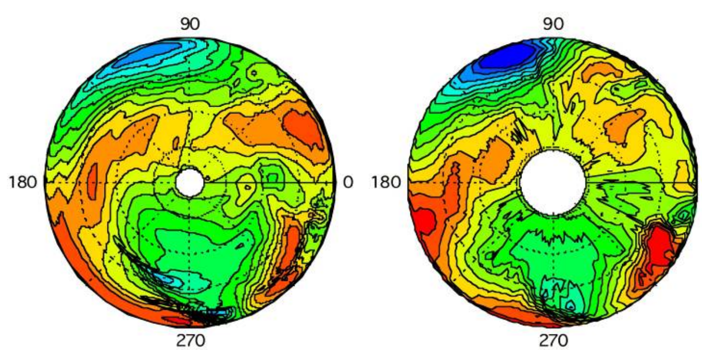




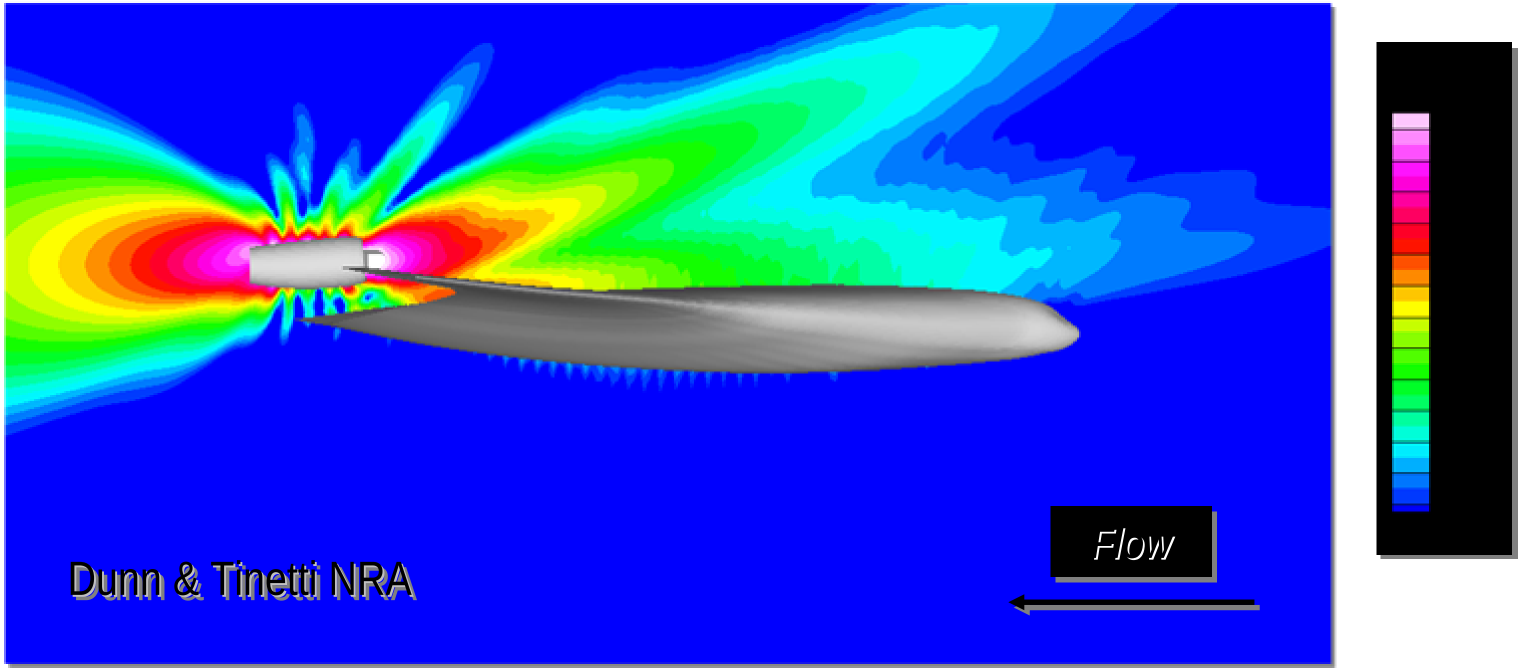
Validation

Coupled Solution

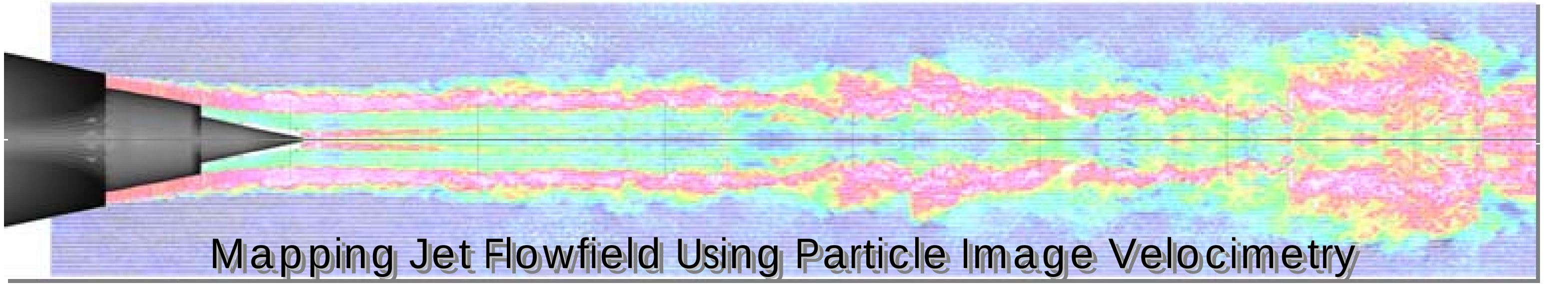


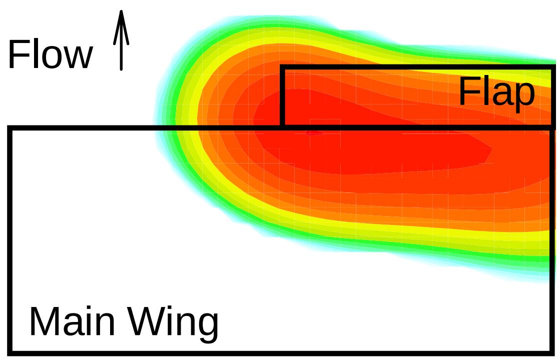
Acoustic Scattering Prediction

Fast Scattering Code is Used to Compute the Scattering of Engine Noise Sources by the Airframe.

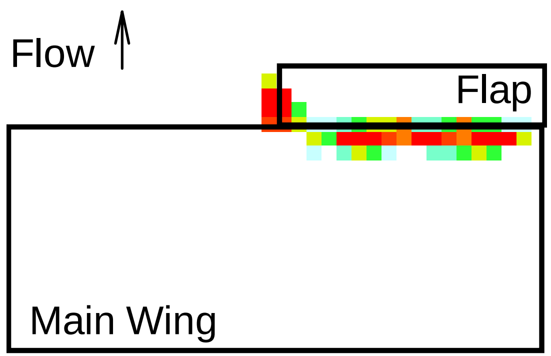


PIV & Phased Arrays





Conventional Beamforming



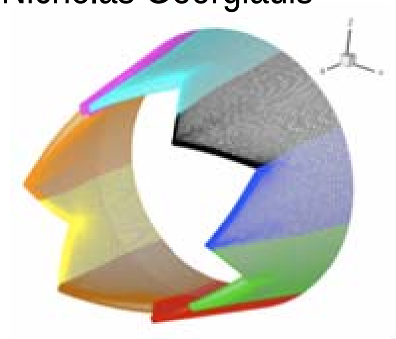
DAMAS Deconvolution

Mapping Noise Sources with Conventional and DAMAS Array Processing Techniques

High-Fidelity Numerical Simulations in Jet Aeroacoustics with Application to Chevron Nozzles

PI: Prof. Yousuff Hussaini, Co-PI: Dr. Ali Uzun Florida State University

NASA TM: Dr. Nicholas Georgiadis



Objective:

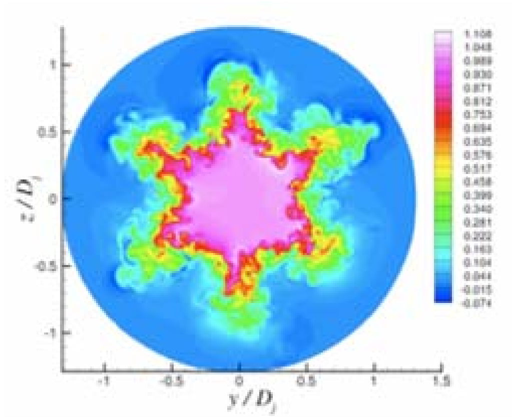
- Develop and utilize state-of-the-art LES method for reference chevron nozzle flow using high-order numerical scheme and as dense grid as possible in jet near-field region

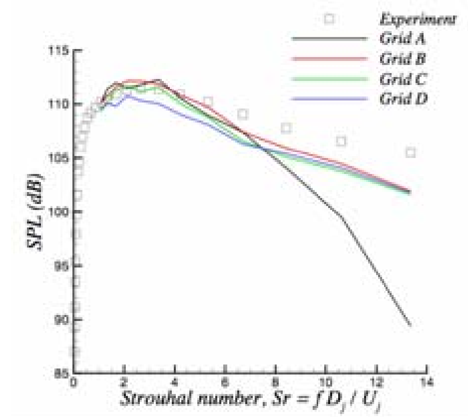
Approach:

- LES Method: 4th order prefactored compact scheme, 4th order Runge-Kutta time integration
- Recycling method used for nozzle internal boundary layers
- Very dense grid in jet near-field region (x/D=4) in order to calculate noise source region
- Jet Re/D = 1.4M, LES run at 100,000

Key Accomplishments to Date:

- Effects of grid density examined (see below) for (A) 50 M, (B) 100 M, (C) 150 M, and (D) 190 M grid points



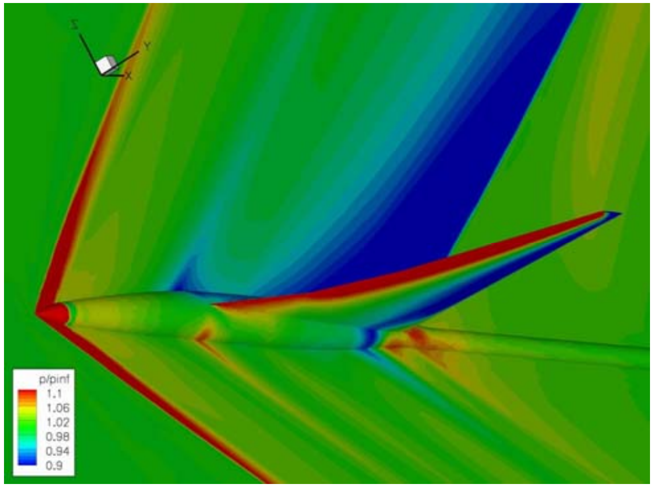


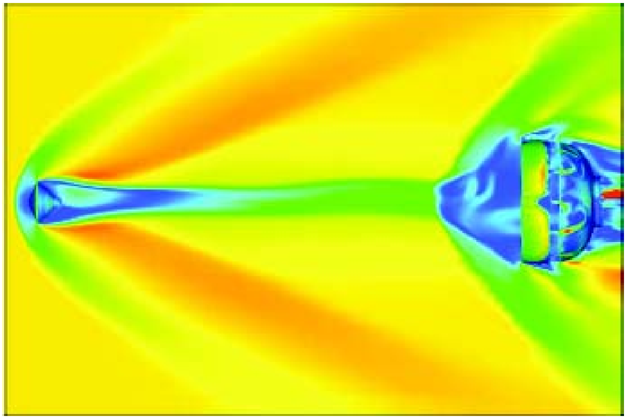
Upcoming Year 1 milestone:

- Examine SMC001, SMC005, and SMC006 nozzle geometries to examine effect of chevron penetration
- Even more dense grid (1 billion) points may be examined, although not required in proposal. These results would give even better information on LES resolution effects on accuracy of noise spectrum results

Supersonics Project Current Efforts

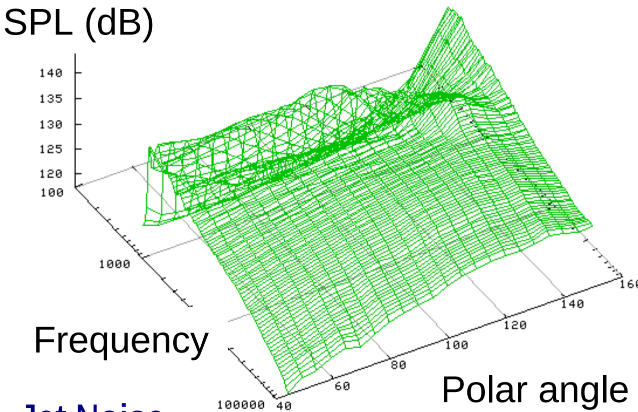
V&V
-Error estimation
-Anisotropic adaption



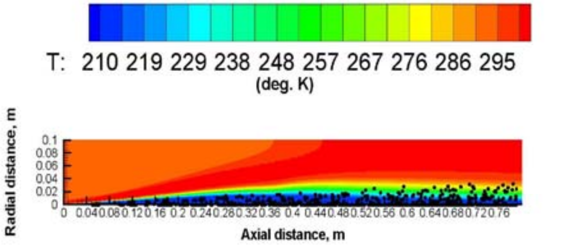


Fluid Dynamics
- Highly Unsteady Flow
- Turbulence

Fluid-Structures Interaction
- Simulation tools for design
- Flexible membrane structures
- High-speed deployment



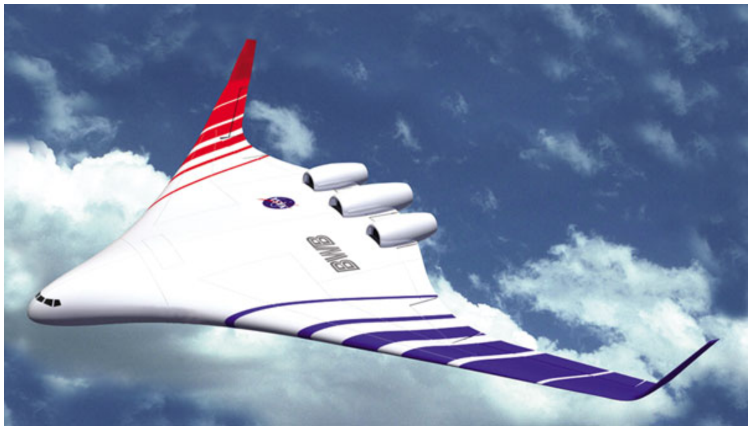
Jet Noise
-Predictions
-Experimental validation



Predicted global structure of a vaporizaring spray for a 1mm VKI nozzle (Combined superheat-normal vaporzation model).

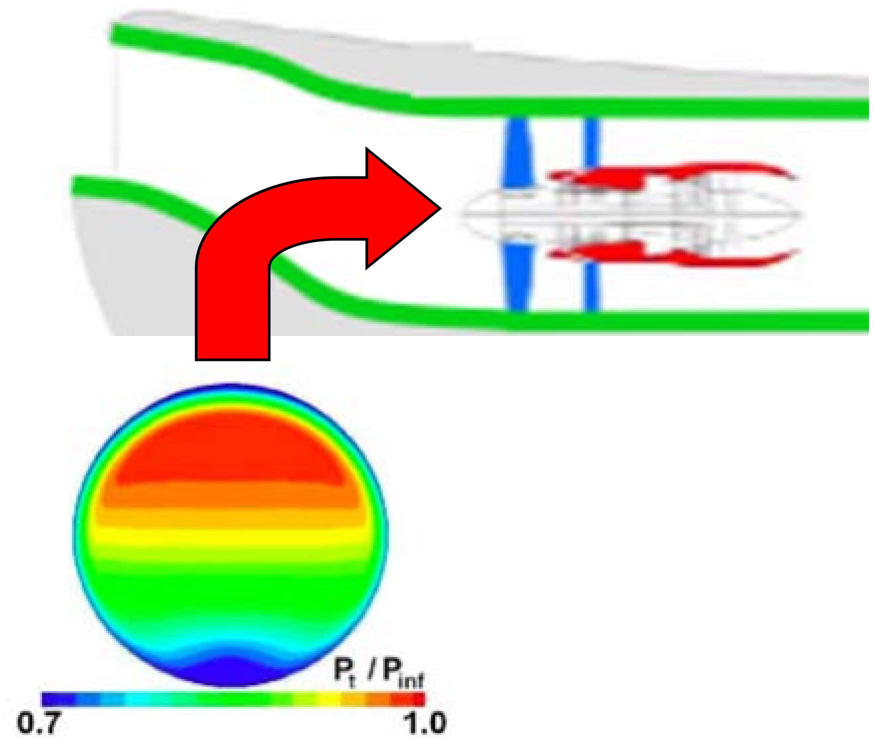
Combustion/Emisions
- Reacting flow
- Multi-phase

Integrated Embedded Propulsion Systems



N+2 Hybrid Wing/Body
with Embedded Engines

Noise and fuel burn
benefits to embedded
engines

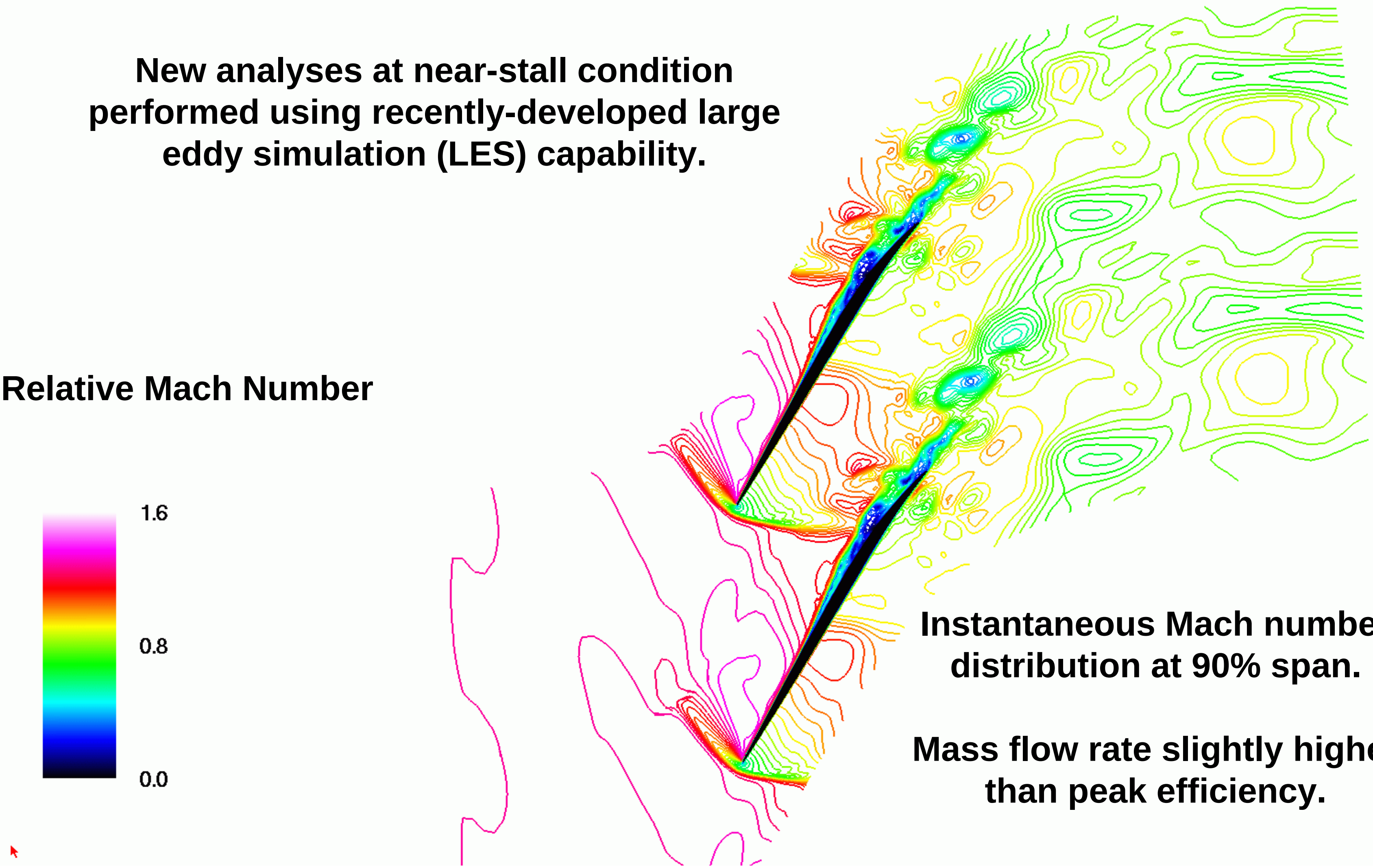


Distorted inlet flow propagated to fan-face for
hybrid wing vehicle embedded engine, highlighting
challenges in fan design and operation.

H3D Analysis for NASA Rotor 37

New analyses at near-stall condition performed using recently-developed large eddy simulation (LES) capability.

Relative Mach Number



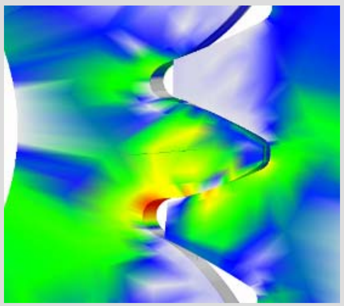
Instantaneous Mach number distribution at 90% span.

Mass flow rate slightly higher than peak efficiency.

SRW Discipline: Propulsion

Advanced modeling tools/concepts essential to allow an engine/drive system to achieve a significantly larger speed range without sacrificing power and efficiency

Physics-Based Modeling & Analysis



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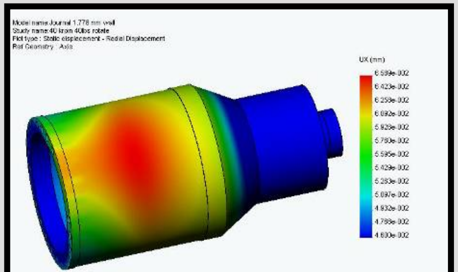
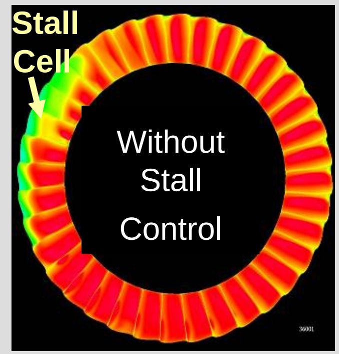
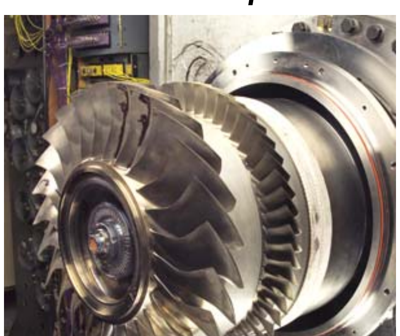


Gas Lubricated Foil Journal Bearing Performance



- High efficiency,multi/variable-speed drive systems
- Oil free engine/optimized gearbox systems
- Wide operability engine systems for rotary wing applications

Validation with Experimental Data



Highly-loaded compressor test facility

Gas Lubricated Foil Journal Bearing Performance

Gear train in test gearbox

Outline

- Brief overview of the Fundamental Aeronautics Program
- Some ongoing efforts
- Future Computational Engineering and Science Requirements at NASA / FA
- Observations and conclusions

Moving Forward…

- Multiple worthwhile efforts in computational science and engineering are currently being pursued in all FA projects

- The question is: do we have a coherent strategy for computational science and engineering?

- Some strategic directions:
  - Physics-based / high-fidelity modeling as appropriate
  - System-level modeling / MDAO / Interactions
  - Managing model and system uncertainties
  - Key interaction with experiments for proper V&V

- Major challenges include strategy, focus, approach, workforce

"Ask what HPC can do for NASA, not what NASA can do for HPC"

Some Basic Observations

- A sizable portion of the Fundamental Aeronautics Program (FAP) relies on modeling and computations. Increased relevance inevitable.
- Similar problems are / will be faced by all four Projects:
  - Subsonics: Rotary Wing (SRW)
  - Subsonics: Fixed Wing (SFW)
  - Supersonics
  - Hypersonics
- Some key outstanding problems remain: can we use our simulations tools with confidence and focus on science and engineering?
- This problem is not specific to ARMD: it is pervasive across the Agency

Workshop Objectives

- Define the key technologies that will be needed to meet the computational infrastructure requirements facing NASA in the coming 10-15 years,
- Discuss alternatives for the overall architecture of such an infrastructure, and
- Setup working groups to define approaches that can help us accomplish our goals.

Key Questions

- What type of computational problems are we working on today?
- What are the fundamental bottlenecks of our current analysis/design processes?
- What type of computational problems should we be working on in 10-15 years?
- What are the key technologies that require attention and advancement?

Key Questions (2)

- How do we quickly incorporate new ideas (NASA, NRA, academe, industry)?
- How do we create a flexible environment where all of the above can be made possible?
- How can we best leverage our capabilities across all Centers and across all projects?

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Some More Observations

- Steady-state calculations will undoubtedly continue to be important but a substantial shift to time-dependent calculations seems inevitable
- Multi-physics coupling will become pervasive (fluid, structures, heat transfer, multi-phase, ablation, etc)
- Must focus on end-to-end computational science and engineering cycle: many issues are important inhibitors to progress (mesh, geometry, information extraction, coupling, etc)
- What will drive specific investments in computational science and engineering? Pay attention to the national agenda…NextGen, environment, fuels, etc.

Some More Observations (2)

- This is a “transition” period: 2-pronged strategy to nurture existing capabilities AND look ahead and begin to develop future capabilities

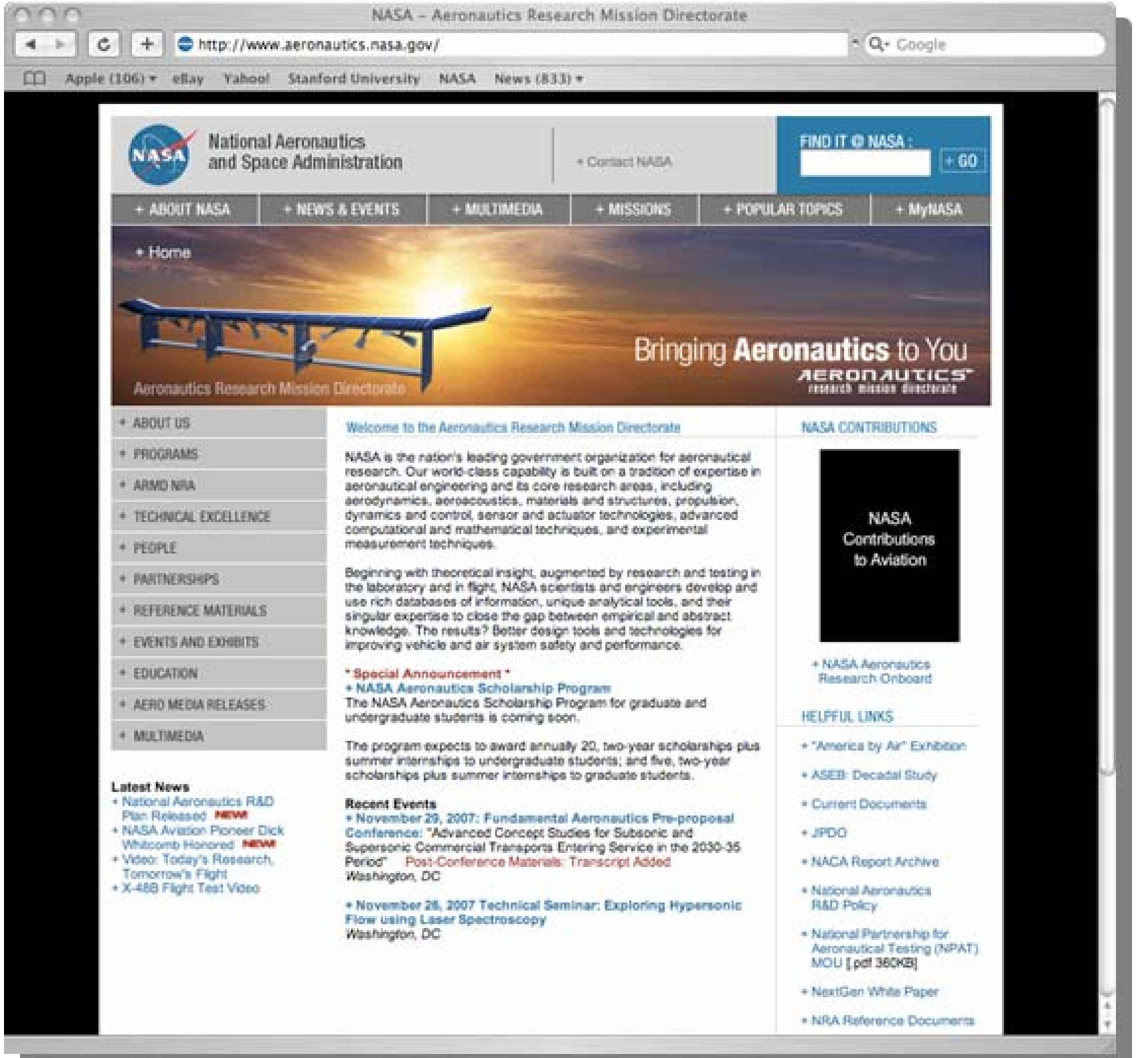
- Long-term focus is needed: revolutionary capabilities can take 7-10 years to develop

- Partnerships (OGAs, academe, industry) are necessary

Conclusions

- FA has significant investments (in-house, out-of-house) in computational science and engineering
- A strategic vision is in the process of being developed. Input from the community is/will be sought
- Strategy must include a long-term view, a solid focus on the requirements, and strong partnerships with the community
- Discussion is specific to FA but several issues are NASA-wide
- Must ensure that we are beginning to develop the capabilities that we know we will need in the future so that those capabilities have a chance to be in place when needed.

For More Information…



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