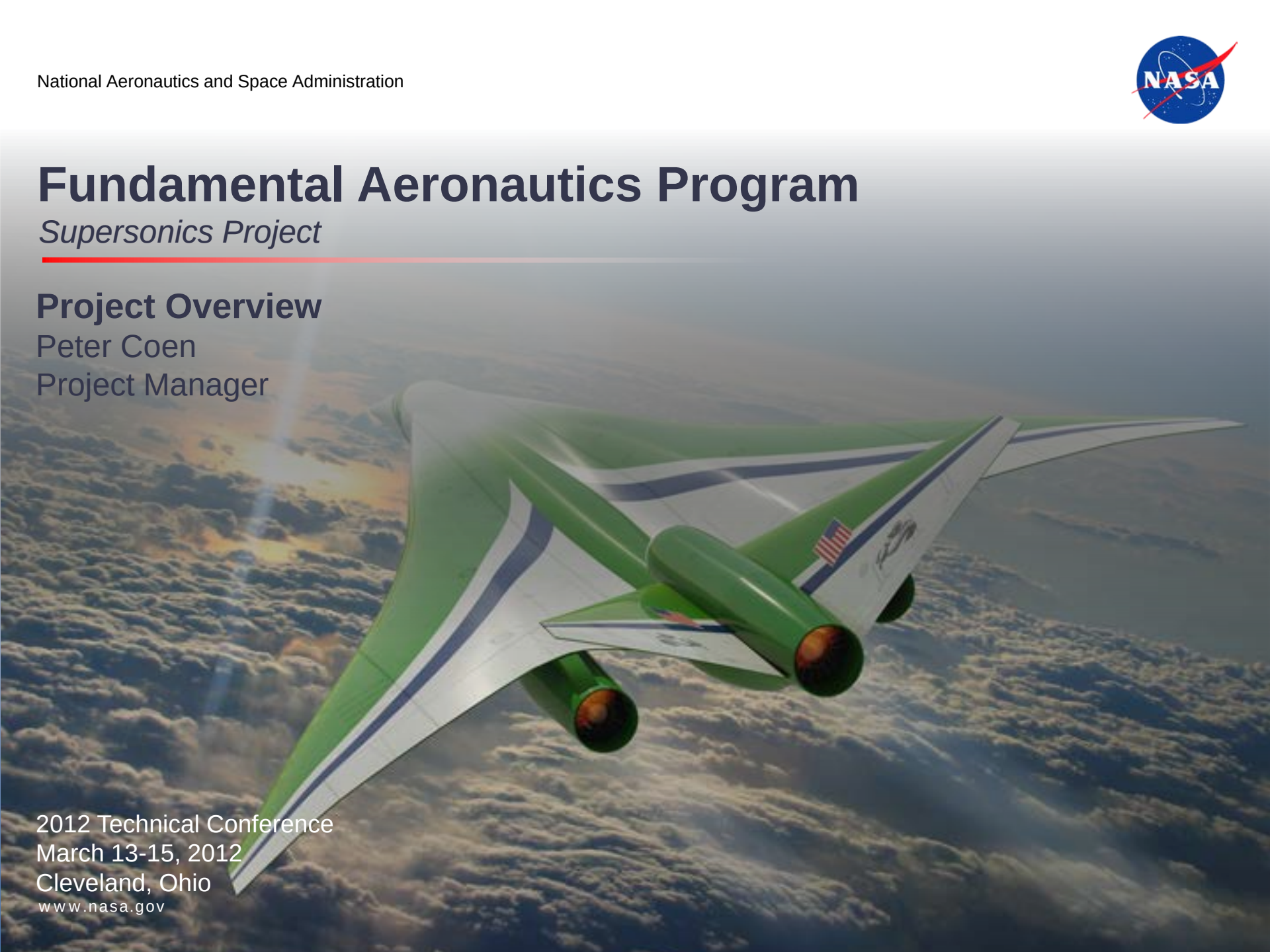
National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Project Overview

Peter Coen
Project Manager



2012 Technical Conference
March 13-15, 2012
Cleveland, Ohio
www.nasa.gov

Presentation Outline

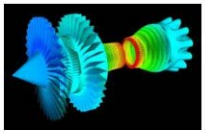
- Overview
  - Project Principles and Strategies
  - Technical Challenges
  - Technical Challenge Goals Status
- **Key Validation Efforts Completed**
- Technical Highlights
- NRAs & Partnerships
- Upcoming Activities
- Summary

Guiding Principles and Motivation

Current Fundamental Aeronautics Overview

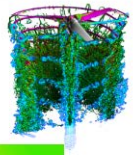
Goal:

To achieve technological capabilities necessary to overcome national challenges in air transportation including reduced noise, emissions, and fuel consumption, increased mobility through a faster means of transportation, and the ability to ascend/descend at very high speeds through atmospheres.



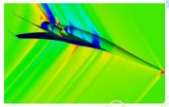
Subsonic Fixed Wing (SFW)

Explore and develop tools, technologies, concepts, and knowledge for improved energy efficiency and environmental compatibility for sustained growth of commercial aviation



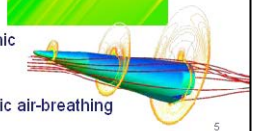
Subsonic Rotary Wing (SRW)

Develop tools, technologies and knowledge to enable radical improvements in the transportation system using rotary wing vehicles by advancing technologies that increase speed, range, and payload and decrease noise, vibration and emissions.



Supersonics (SUP)

Develop tools, technologies and knowledge to overcome the environmental & performance barriers to practical civil supersonic airliners.



Hypersonics (HYP)

Develop tools, technologies and knowledge to enable hypersonic air-breathing vehicles and high-mass entry into planetary atmospheres.

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National Aeronautics Policy & Plan; NASA Strategic Plan

- National Aeronautics R&D Policy (Dec 2006) and Plan (Dec 2007, Feb 2010),
  - "Mobility through the air is vital…"
  - "Aviation is vital to national security and homeland defense"
  - "Assuring energy availability and efficiency is central…" and "The environment must be protected…"
- NASA Strategic Plan
  - Strategic Goal 4: "Advance aeronautics research for societal benefit"
- 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

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National Goals and "Technical Challenges"

Mobility is Vital

Goal 5: Expanded Capabilities

15 related Technical Challenges including:
- Reduced drag, weight, noise, emissions, specific energy consumption (SFW)
- Supersonic aircraft in NexGen (SUP)
- NexGen rotorcraft (SRW)
- Multi-disciplinary tools and system design

Energy & Environment

Goal 1: Alternative Fuels
Goal 2: Increased Energy Efficiency
Goal 3: Reduced Environmental Impact

18 related Technical Challenges including:
- Reduced drag, weight, noise, emissions, specific energy consumption (SFW)
- Supersonic boom & supersonic cruise (SUP)
- Light weight engines/airframes (SUP)
- Actively-controlled, efficient rotorcraft (SRW)
- Multi-disciplinary tools and system design

National Defense

Goal 1: Increase Cruise Lift to Drag
Goal 2: Improved Rotorcraft
Goal 3: Reduced Engine SFC
Goal 5: Sustained Hypersonic Flight

19 related Technical Challenges including:
- Reduced drag, weight, specific energy consumption (SFW)
- Light weight engines/airframes (SUP)
- Integrated Aero/Propulsion System (SRW)
- Airbreathing propulsion (HYP)
- Multi-disciplinary tools and system design

Safety

Goal 1: Enhanced Vehicle Design
Goal 3: Improved Crashworthiness

1 related Technical Challenge:
- NextGen Rotorcraft (SRW)

Supersonic Project Technical Challenges

Overarching Goal:

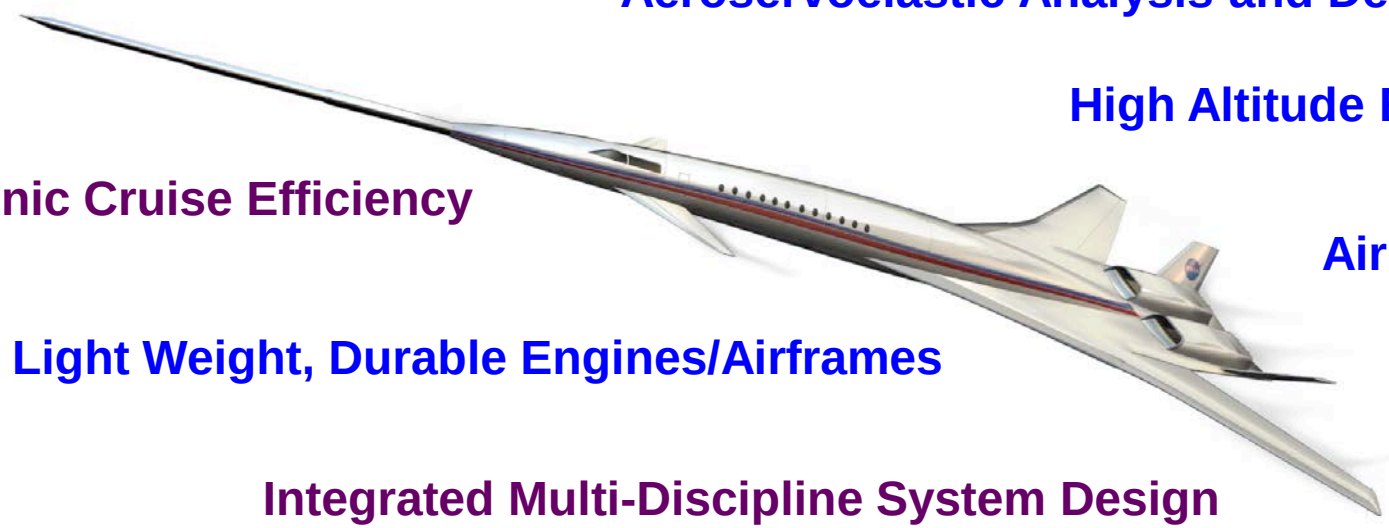
Tool and technology development addressing the challenges of supersonic flight

Focus Area

Overcoming the technology barriers to practical civil supersonic airliners

Sonic Boom Community Response

Aeroservoelastic Analysis and Design



High Altitude Emissions

Supersonic Cruise Efficiency

Airport Noise

Light Weight, Durable Engines/Airframes

Integrated Multi-Discipline System Design

Near Term Focus:
Supersonic overland flight

Integration of Supersonic Aircraft in NextGen System (with Airspace Program)

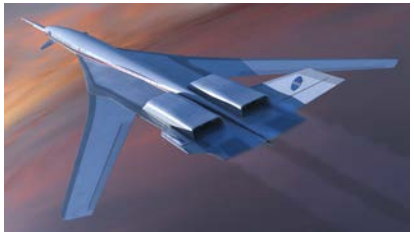
Technology Challenge Goals

Balanced Goals for Practical Civil Supersonic Aircraft (Technology Available)	N+1 Supersonic Business Class Aircraft (2015)	N+2 Small Supersonic Airliner (2020)	N+3 Efficient Multi-Mach Aircraft (Beyond 2030)
Design Goals			
Cruise Speed	Mach 1.6-1.8	Mach 1.6 -1.8	Mach 1.3 - 2.0
Range (n.mi.)	4000	4000	4000 - 5500
Payload (passengers)	6-20	35-70	100 - 200
Environmental Goals			
Sonic Boom	65-70 PLdB	85 PldB (Revised)	65-70 PLdB Low Boom flight 75-80 PldB Overwater flight
Airport Noise (cum below stage 4)	Meet with Margin	10 EPNdB	10-20 EPNdB
Cruise Emissions (Cruise NOx g/kg of fuel)	Equivalent to current Subsonic	< 10	< 5 & particulate and water vapor mitigation
Efficiency Goals			
Fuel Efficiency (pass-miles per lb of fuel)	1.0	3.0	3.5 – 4.5

- NASA defined an initial set of design parameters and performance levels for practical supersonic airliners in the near, mid and far term time frames
- Systems Studies have been used to determine if these goals are valid and achievable

N+1 Business Class

N+2 Small Supersonic Airliner



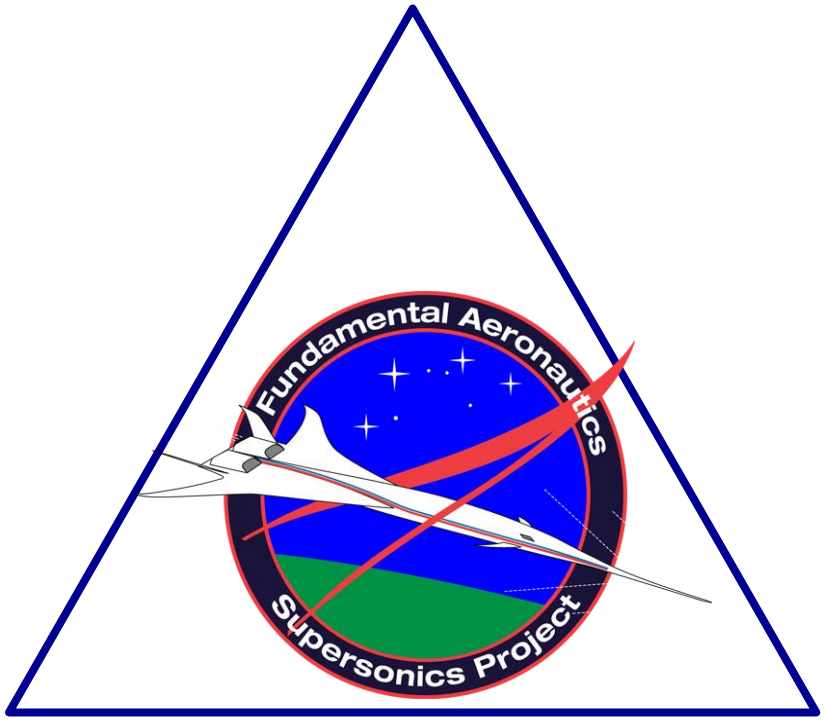
N+3 Efficient, Multi Mach Aircraft

Investment Strategy

- Primary focus on Technical Challenges
  - Foundational, Discipline and Multidiscipline Level activities
  - Identify and address solutions “at the seams” between conventional disciplines
  - Near term focus:
    - Integrated solutions for low boom design
    - Understand community reaction to low boom
- Pursue multidiscipline and flight validation where resources permit
- Majority of effort is supersonics unique, overlapping with other projects where strong synergy exists
- Incorporate an element of long term foundational research with potential high payoffs
  - May not align with a particular Tech Challenge
- Develop facilities and measurement capabilities for unique supersonic problems
- Maximize leverage of investment and partnership with external communities
- Maintain technical excellence and workforce stability

Research Strategy

In house research maximizing the use of
NASA's skilled workforce and unique facilities



Sponsored research with the
best minds in the US University
and Industry communities

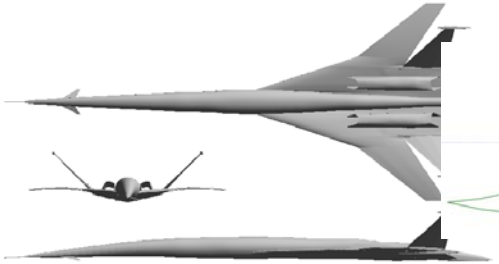
Research Partnerships with
organizations with similar goals
(OGA, US Industry, International)

Meeting Commitments: Key Project Milestones

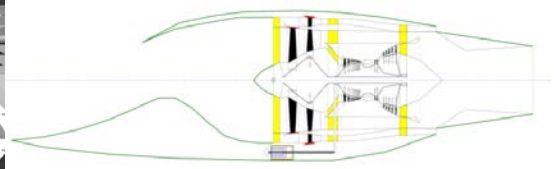
Project met or exceed Annual Performance Goal (APG) Criteria in FY 11 & 12

FY 11 Milestone Objective:

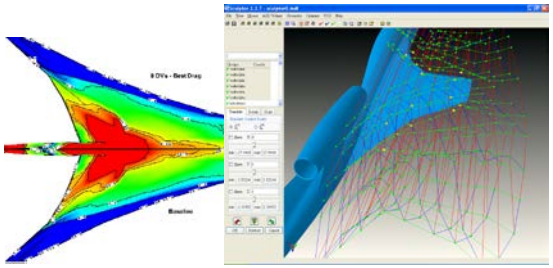
- Develop and demonstrate MDAO for simultaneous design for high cruise efficiency and low sonic boom

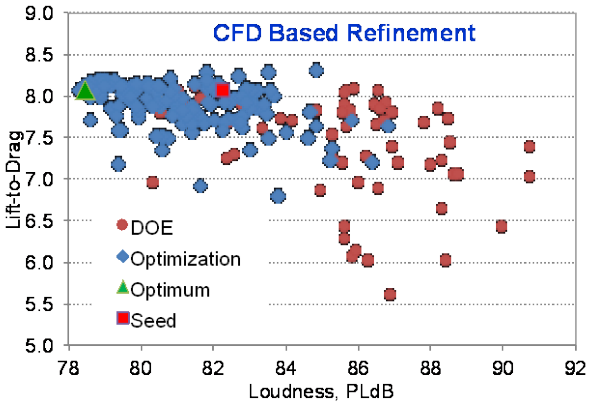


Baseline Concept



VCE Concept



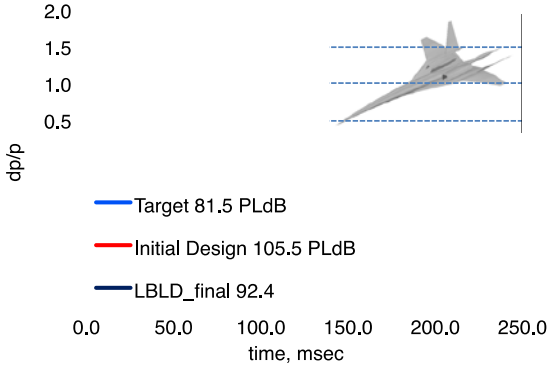


Secondary Objectives:

- Incorporate high fidelity (CFD based) define refinement into MDAO system

Significance:

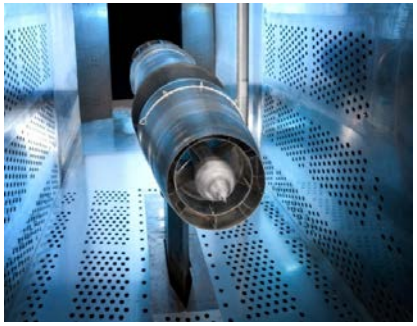
- Multi-discipline, variable fidelity design tools and processes, with more disciplines and higher fidelity than previous attempts have been successfully applied to the difficult problem of simultaneous achieve high efficiency and low sonic boom.

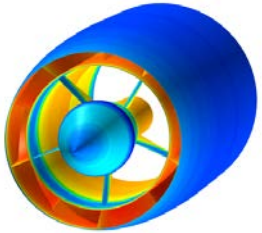


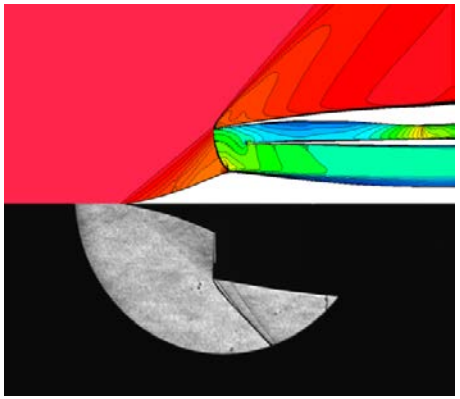
Meeting Commitments: Key Project Milestones

FY 12 Milestone Objective

- Validate effectiveness of Micro-array Flow Control devices for improving performance and flow quality in low-boom supersonic inlets

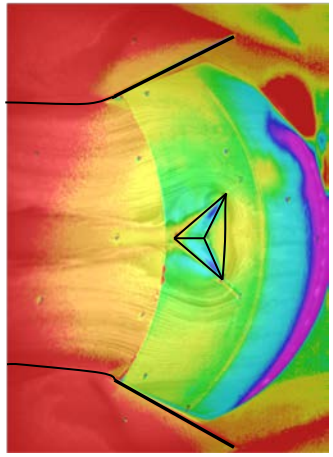






Milestone Accomplishments

- Effective use of NRA, In house and Partner resources to design & fabricate model; conduct efficient test program in GRC 8xt6 Wind Tunnel
  - Evaluate inlet stability and operability at various Mach numbers and angles of attack (AOA)
  - Evaluate simple, passive, bleedless inlet boundary layer control options
  - Conduct CFD validation studies for overall performance and micro array device effectiveness



Significance

- Extensive experiment and computational data collected for a unique low boom compatible inlet design
- Unique and improve test methodologies demonstrated
- Micro Array devices appear to perform as expected. Tested inlet design exhibited robust performance with or without these devices

N+2 Systems Level Validation Progress

Objective

- Validate solutions to key Tech Challenges for N+2 civil aircraft using integrated system level design concepts

Approach

- Two NRA Awards -partially American Recovery & Reinvest. Act (ARRA) funded
  - Boeing R&T supported by BCA
  - Lockheed Martin with subs GE, Liberty Works & Stanford
- Significant in-house research and support
- New, efficient data collection techniques
- Extensive testing at ARC (9x7), & GRC (AAPL)

Status

- Phase 1 testing has successfully validated basic design techniques
- Phase 2 examining propulsion effects in detail

Balanced Goals for Practical Civil Supersonic Aircraft (Technology Available)	NASA N+2 Validation Study Goals	N+2 System Validation Results
Design Goals		
Cruise Speed	Mach 1.6 -1.8	Mach 1.6 - 1.8
Range (n.mi.)	4000	4000 - 5500
Payload (passengers)	35-70	35-80
Environmental Goals		
Sonic Boom	*85 PldB (revised)*	*79 - 81 PLdB*
Airport Noise (cum below stage 4)	10 EPNdB	*12 EPNdB*
Cruise Emissions (Cruise NOx g/kg of fuel)	< 10	*5*
Efficiency Goals		
Fuel Efficiency (pass-miles per lb of fuel)	3.0	1.6 – 3.1

Boeing Concept

Lockheed Concept

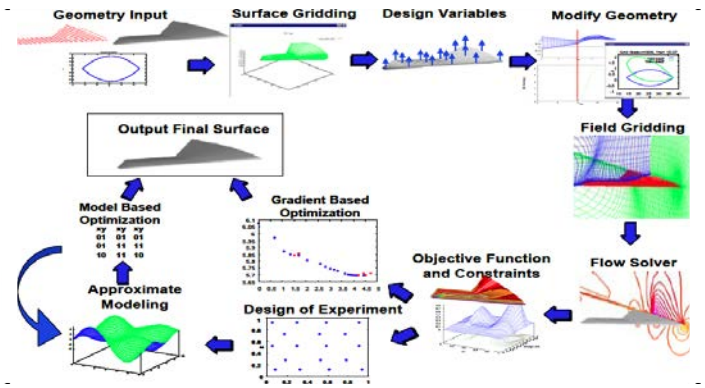
1- Low Boom Design Process Improvements

Low Boom /Low Drag Design Approaches

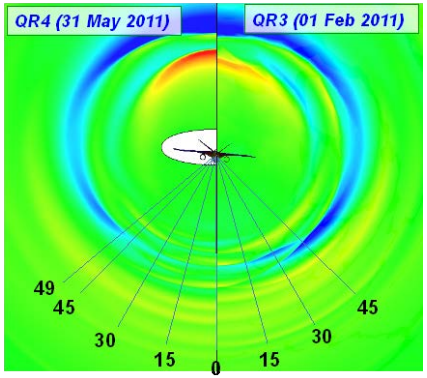
- NASA/Industry developed tools applied in innovative configurations and design processes
  - Variable fidelity aero analysis, including application of viscous CFD
  - Detailed geometric modeling and shape morphing
  - Non-traditional target signatures
  - Simultaneous shape and signature optimization

Significance

- Have achieved robust shaped sonic boom ground signatures with low noise levels
  - On and off track signature shaping
  - Large configurations (35-100 pax)
  - Performance (L/D) optimization included, targets within reach

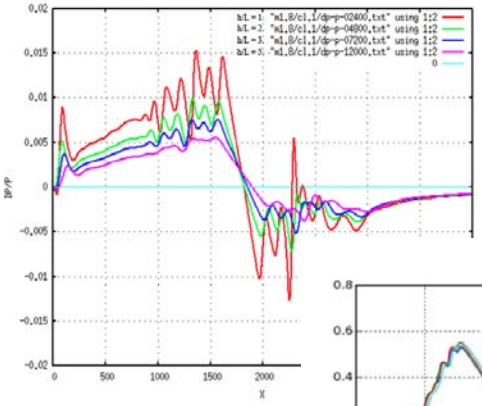


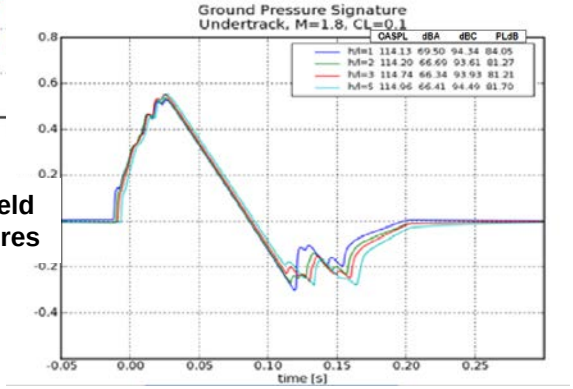
Design Process



Off Track CFD

Mach 1.8 C_L = 0.1





Predicted Near Field & Ground Signatures

2 - Wind Tunnel Testing & Test Techniques

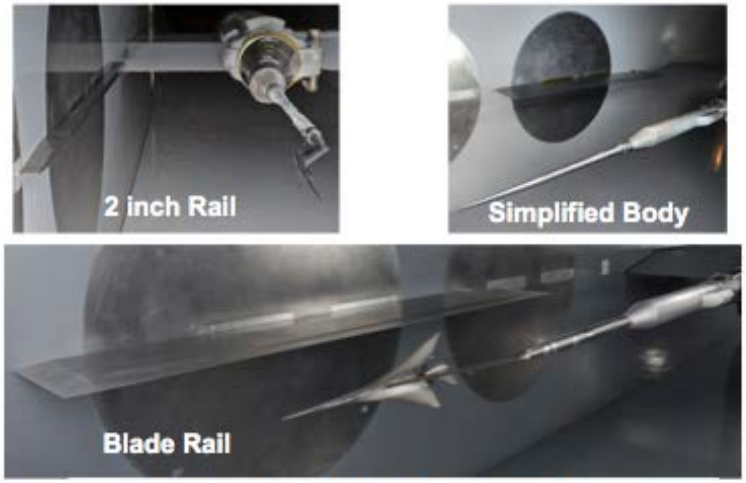
Extensive test campaigns at Ames 9x7 UPWT

- 3 Lockheed entries, 1 Boeing entry
- Numerous parametric variations
  - Model geometry and size
  - Model support to minimize interference with measurement of aft signature
  - Model/sensor separation distance
- Variety of test techniques
  - Tunnel operations for improved data quality
  - Test efficiency
  - Two pressure rail concepts
- Initial significant concerns regarding uncertainty of results
  - Recently identified techniques offer a solution

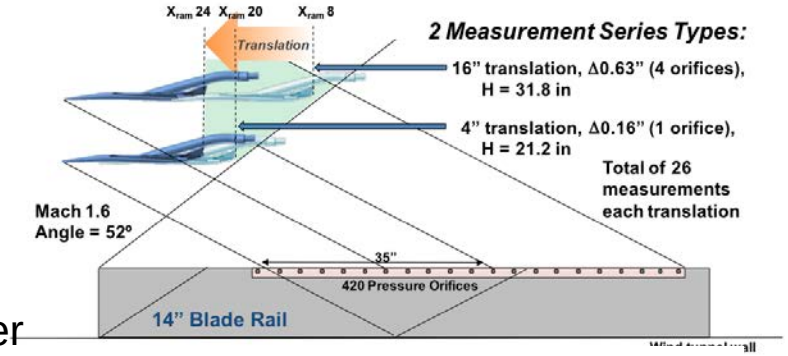
Significance

- Large validation database collected for both boom signature and aerodynamic performance
- Best tunnel operations practices identified
- Test technique for improved accuracy identified
  - Achieves an order of magnitude productivity over single sensor technique

Sophisticated Models and Supports



Wide Variety of Models and Installations

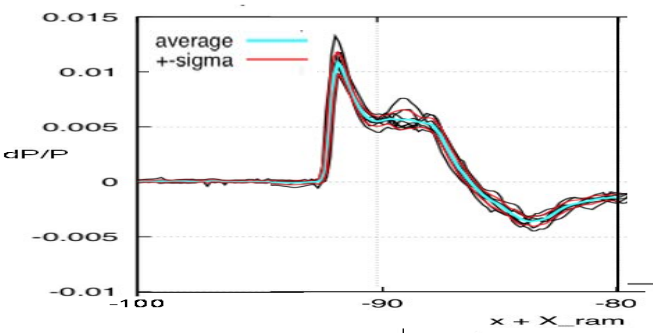


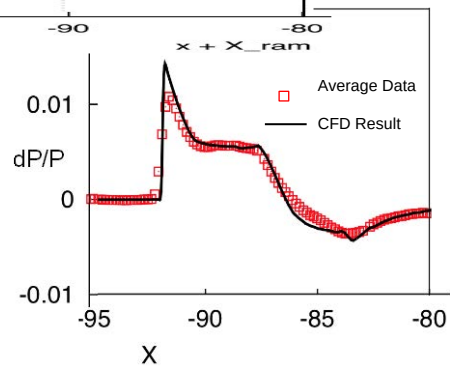
Improved Test Technique

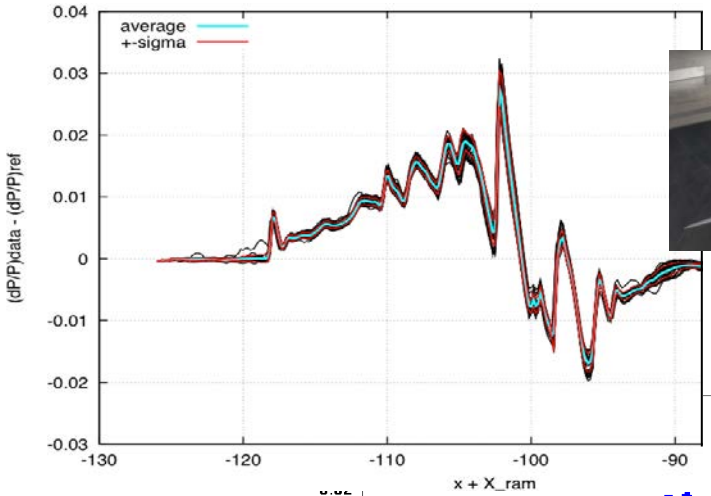
3 - Design Tools Validated with Test

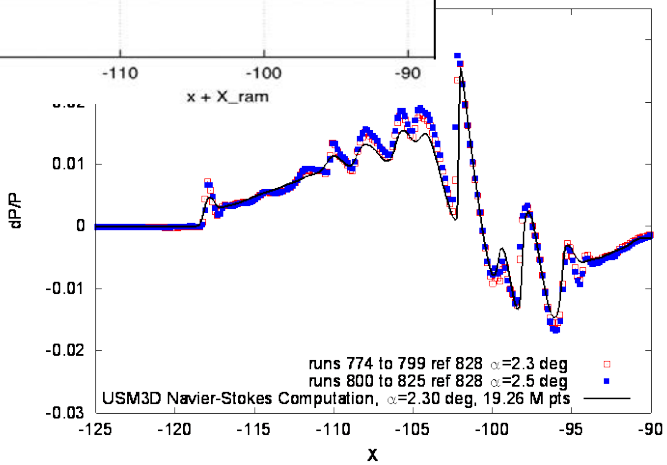
Excellent agreement between data and high fidelity analysis

- New test technique greatly reduces uncertainty in data
- Comparisons completed for a variety of models and test conditions
- Blade mounts appear to provide for nearly interference free measurement
- Remarkable correlations, particularly in aft portion where lift component makes significant contribution to signature
- High quality database for continued fundamental research









4 - Low Noise Nozzle Validation Completed

Objective

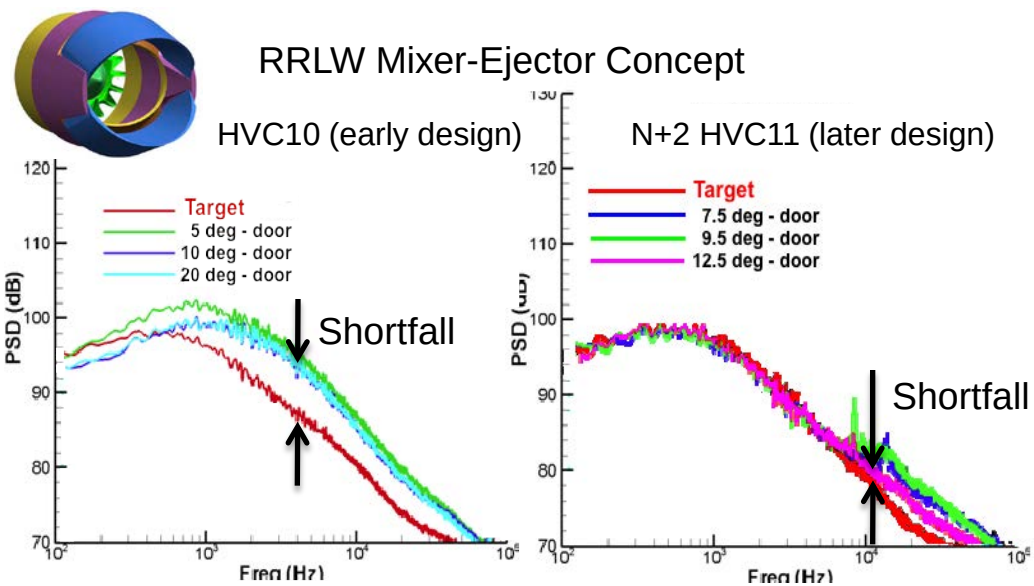
- Validate acoustic performance of N+2 nozzle concepts from GE & Liberty Works

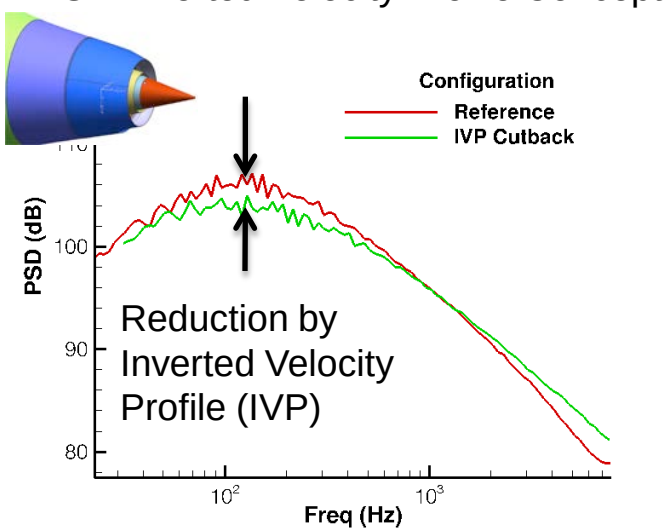
Accomplishment

- Completed major modification of NATR to add capability to simulate 3 stream nozzles
- Tested two concepts for low noise exhausts, applicable to highly variable cycle engines
- Acoustic and PIV flow diagnostic data collected for a variety of nozzle configurations and operating conditions. Baseline conic nozzle data also collected

Significance

- Neither concept directly met acoustic performance goals
- Acoustic diagnostics revealed shortfalls were related to flow separation phenomena
- Further design, particularly incorporating advanced CFD techniques, should result in viable concepts





N+2 Validation Summary

- Successful Team effort
  - Excellent collaboration among NASA team at multiple centers and between NASA and contractors
  - Excellent support from Centers: Facility Operations and Engineering, Fabrication, Contracting, etc.
- Significant progress on Sonic Boom and Airport Noise Technical Challenges
  - Low boom, low drag design methodology
  - Wind tunnel test techniques
  - Low noise nozzles for highly variable cycle engines

Breakthrough Knowledge Advancement

Methodologies for the development of aircraft with shaped sonic boom signatures, particularly in the aft end of the vehicle where complex interaction between lift and volume effects takes place, have been applied to integrated systems level designs and validated through wind tunnel testing. Low boom targets for N+2 configurations have been met; methods are applicable to N+1 and N+3 vehicles as well.

Combustor Validation Completed

Objective

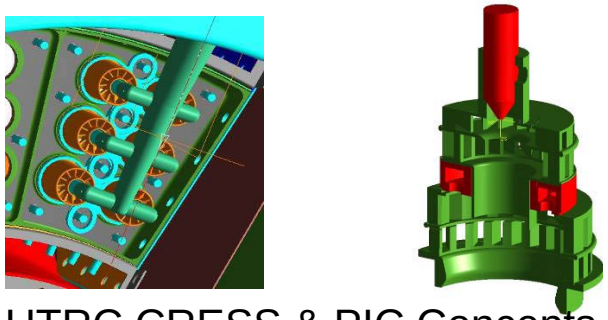
- Explore combustor/mixer concepts to achieve NOX goals for supersonic cruise condition

Approach

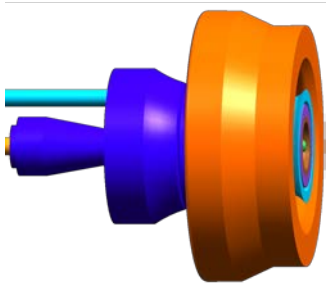
- NRA award to 3 engine manufacturers
- Analytical and small scale testing of multiple concepts
- Hardware fabrication of best concepts
- Test in NASA Flametube Facility (CE-5)

Significance

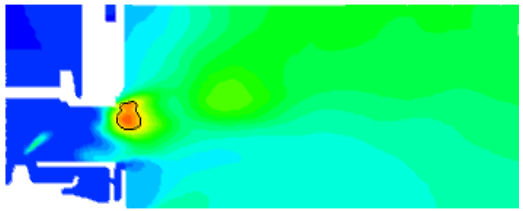
- At least one concept from each company met goal
- Flametube testing to date validated basic performance, some issues identified
- Concepts served as basis for ERA scale up



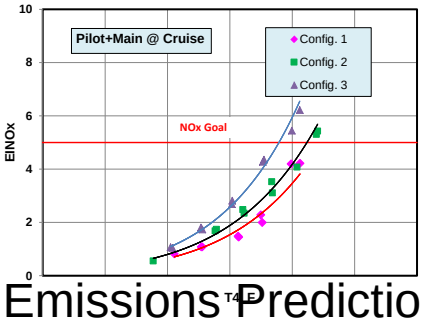
UTRC CRESS & PIC Concepts



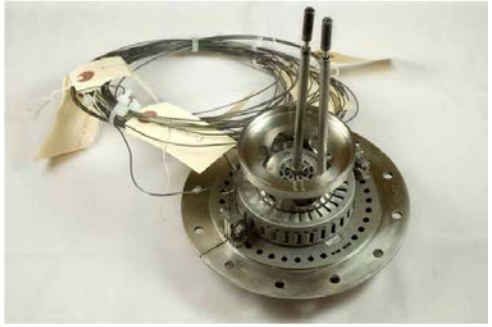
Rolls Royce HiPASS Concept



LES & Rans CFD analysis



Emissions Prediction

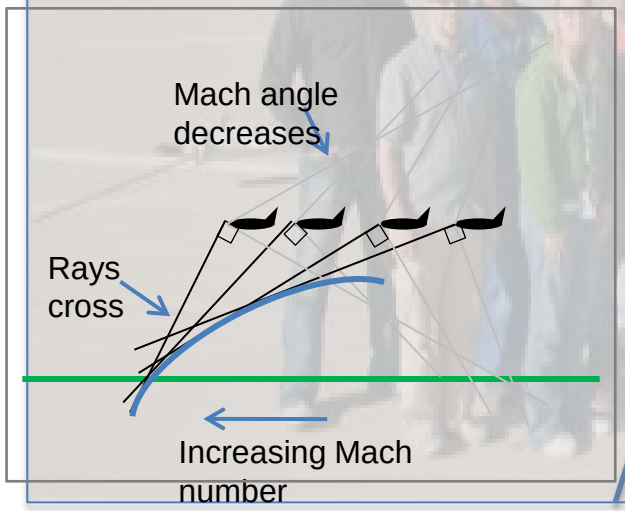


GE XRR Mixer Concept

Intensive Flight Campaigns for Sonic Boom Modeling

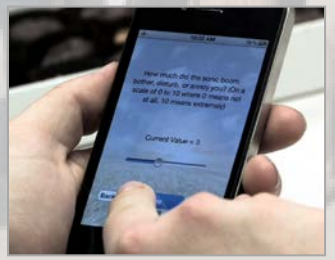
Superboom
Caustic
Analysis and
Measurement
Project

- Focus boom data and analysis tools
  - Primary Interest: acceleration focus
  - Extensive sensor array
  - Remote desert location



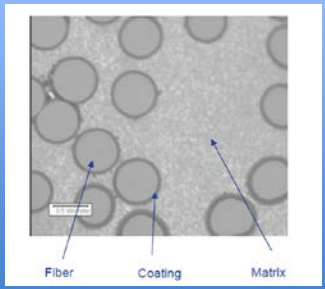
Waveform and
Sonic Boom
Perception and
Response

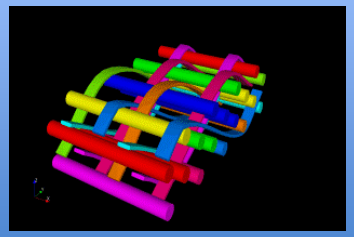
- Pilot study for future sonic boom community studies
  - Boom and subjective response data collection
  - Analysis methodology
- Low boom exposure of EAFB housing
  - F-18 Low boom dive
  - 100 Volunteer residents

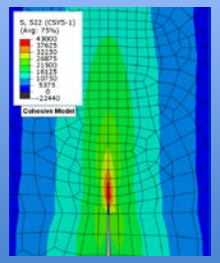


CMC Fundamental Research Consolidated in Supersonics Project

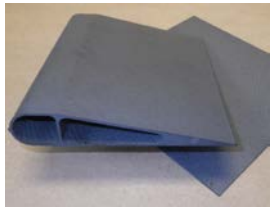
FAP / Supersonics (2011-2020): develop 3000°F CMC/EBC, optimize architecture & validate models, including lifing

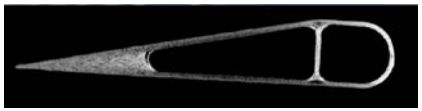




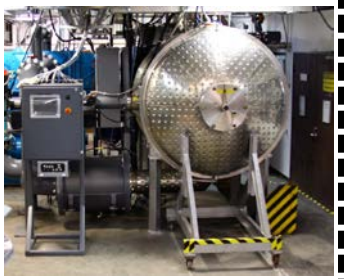


ERA (2010-2012): establish processing approach and baseline properties, evaluate combustor & vane subelement fabrication

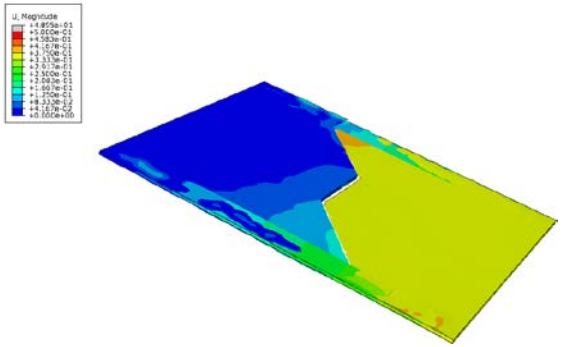




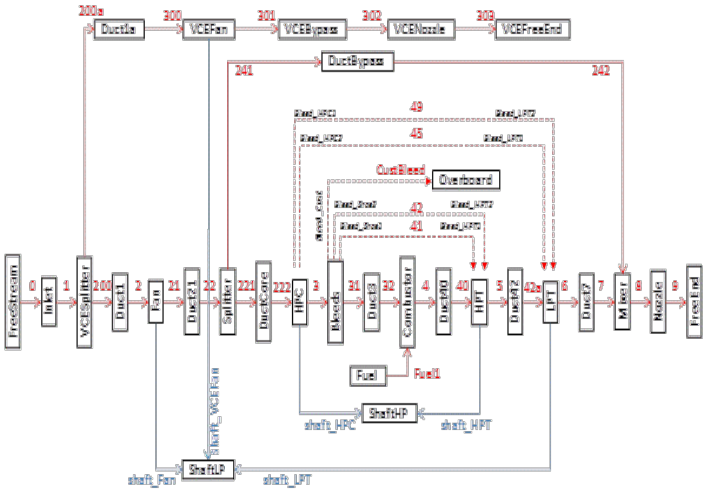
ERA Ph. 2 (2013-2015): design and fabricate components, conduct rig and engine tests to evaluate long-term durability



Highlights of Tech Challenge Progress



Lightweight Durable Airframes
Large Panel Test supporting Progressive Failure Analysis



AeroPropulsoServoElasticity
Dynamics Model for Variable Cycle Engine

Flight Research and Validation
Channeled Centerbody Inlet Experiment flights completed

NRAs & Partners Vital To Research Success

Dryden
Langley
Marshall

Edward A. Haering, Jr.
NASA Dryden Flight Research Center

Upcoming Activities in Supersonics

- FY 12 APG Milestone – “Validate the Effectiveness of Micro-Array Flow Control Devices for Improving Performance and Flow Quality in Low-Boom Supersonic Propulsion Inlets” March 31, 2012 – Completed Early!
- Liquid fuel testing of UTRC PICs combustor March
- Aeroelasticity: S4T session at AIAA SDM Conference, April 23-26, 2012
- N+2 Systems Validation Phase 2 – Propulsion effects incorporated in low boom design
  - 9x7 Parametric testing in ARC 9x7, April 2
  - Exploratory Tests in ARC 11ft and GRC 8x6 tunnels – Summer
  - Configuration testing - Fall
- Workshop: Simulation in Aeroservoelasticity – April 18-19
- Supersonic Boundary Layer Transition Flight Testing – Phase 2: Summer
- Sonic Boom Modeling: SCAMP Focus Boom Special Session: AIAA Aerospace Science Meeting, Jan 2013
- FY13 APG Milestone: Validate high fidelity tools for sonic boom and drag prediction/design applied to N+2 design generation supersonic airliner concepts

Summary

- The Supersonics Project has continued to make progress in developing tools and technologies for the broad spectrum of supersonic flight with a focus on overcoming the barriers to civil aircraft, particularly overland supersonic cruise
- Validation of key advances in low boom design, low noise nozzles & low NO_X combustors completed during FY 11 & 12
  - Large dividends gained from ARRA Investment.
- The project has successfully integrated NRA investments, and leveraged partnerships in many of our research and validation efforts
- FY13 Restructuring presents challenges, but High Speed Project should build on the success of Supersonics and Hypersonics Projects

Supersonics Technical Sessions

- Tuesday PM
  - Technology Challenge Overviews (15 minute presentations)
  - Cruise Efficiency - Propulsion
- Wednesday AM
  - Cruise Efficiency - Airframe
  - Aeroservoelasticity
  - Sonic Boom Modeling
- Wednesday Lunch
  - Special Presentation: Historical Review of Sonic Boom Technology
- Thursday AM
  - Lightweight Durable Airframes
  - Systems Integration and Assessment - Part 1
  - Lightweight Durable Engines
- Thursday AM
  - Systems Integration and Assessment - Part 2
  - Flight Research & Validation
  - High Altitude Emissions
  - Feedback Forum (1/2 hour)
- Thursday PM
  - Airport Noise

Join us in the Ambassador Ballroom one level down

Thank you!

peter.g.coen@nasa.gov

Next Speaker: Dr. Jim Pittman, PM for Hypersonics

Additional Material

Supersonic NRA Investments

Tech Challenge	University		Other Non-Profit		Small Business		Other Industry	
	No.	$M	No.	$M	No.	$M	No.	$M
Sonic Boom Community Response *	3	1.169			1	0.400	5	2.802
Highly Efficient, Low Sonic Boom Design *	11	10.520	1	2.210	1	1.519	3	13.850
Integrated Multi-Discipline System Design	2	1.983			1	1.211	3	5.998
Airport Noise	6	4.491					2	0.730
High Altitude Emissions	4	5.053	1	0.756			4	5.152
Lightweight, Durable Engine/Airframe	10	6.328	1	0.943			3	1.070
Aeroservoelasticity					1	0.600	1	0.418
Flight Research Validation					1	0.306		
Total	36	29.544	3	3.909	5	4.036	21	30.020

* Includes ARRA Funds

An additional $11.2M has funded in-house tests directly related to NRAs. Facilities utilized include: Ames 9x7 WT, Glenn Aeroacoustic Propulsion Lab (AAPL), 8x6 Supersonic WT, and Combustor Test Cell CE-5.

An NRA solicitation is planned in 2012 - the scope will be determined by the outcome of the restructure.

Partnerships

On-Going

- FAA PARTNER Center of Excellence, Cooperatively pursue research supporting sonic boom standards development
- Japan Aerospace eXploration Agency (JAXA) – Sonic Boom Modeling
- Japan Aerospace eXploration Agency (JAXA) – Supersonic Boundary-Layer Transition
- Gulfstream Aerospace Corporation, Low Boom Experimental Vehicle (LBEV) Program, Annexes 8-13
- ONR, Large Eddy Simulation and Jet Noise Reduction Concepts
- NAVAIR, 2009 Lakehurst Engine Test
- Siemens Energy Inc., Thermal Barrier Coatings Testing & Development
- Maverick Corporation, Low-Cost Fabrication of High Temperature Composites
- DOE/National Nuclear Security Administration, SMA-Based Thermal Failsafe Device Development
- Spectre Corporation, Silicon Carbide Pressure Sensors for Commercial, Aerospace and Industrial Applications
- Sulzer Metco (US) Inc, Laser High Heat Flux Rig Evaluation of Sulzer Metco Supplied Thermal Barrier Coating (TBC) Systems
- Rolls-Royce NA Technologies, Materials Selection and Preliminary Component Design
- Rolls-Royce NA Technologies, Application and Testing of Environmental Barrier Coatings for Ceramic Matrix Composite Turbine Engine
- Rolls-Royce Corporation, Durability Testing of Advanced Materials
- USAF AFRL, SiC/SiC Turbine Airfoil Material
- Boeing Company, Damage Prediction
- DOE/Sandia National Laboratories, Peridynamic Theory and Computational Modeling
- Aerion, Supersonic Boundary Layer Transition Prediction and Flight Test

Research Dissemination:
FY11-12 SUP Publications Summary

142 Publications

- 29 Peer-reviewed (17 NASA, 12 NRA)
- 92 Conference (78 NASA, 14 NRA)
- 8 NASA Reports
- 13 Other Publications
  - Contractor Reports
  - SAAs
  - Books
  - Dissertations

Journals

- AIAA Journal (6)
- Acoustical Society of America (4)
- Scripta Materialia (3)
- J. of Aircraft (2)
- Acta Materialia (2)
- Applied Acoustics (2)
- 10 Other Journals (1 each)

45 Presentations

- FAP Annual Conference
- Workshops
- Overviews
- Invited

FY11 -12 Project Bibliography will be included on Meeting DVD