Fundamental Aeronautics Program: Overview of Propulsion Work in the Supersonic Cruise Efficiency Technical Challenge

The Supersonics Project, part of NASA's Fundamental Aeronautics Program, contains a number of technical challenge areas which include sonic boom community response, airport noise, high altitude emissions, cruise efficiency, light weight durable engines/airframes, and integrated multi-discipline system design. This presentation provides an overview of the current (2012) activities in the supersonic cruise efficiency technical challenge, and is focused specifically on propulsion technologies. The intent is to develop and validate high-performance supersonic inlet and nozzle technologies. Additional work is planned for design and analysis tools for highly-integrated low-noise, low-boom applications. If successful, the payoffs include improved technologies and tools for optimized propulsion systems, propulsion technologies for a minimized sonic boom signature, and a balanced approach to meeting efficiency and community noise goals.

In this propulsion area, the work is divided into advanced supersonic inlet concepts, advanced supersonic nozzle concepts, low fidelity computational tool development, high fidelity computational tools, and improved sensors and measurement capability. The current work in each area is summarized.

Fundamental Aeronautics Program
Supersonics Project

Supersonic Cruise Efficiency - Propulsion
Ray Castner, Technical Lead, Propulsion
NASA Glenn Research Center/Inlet and Nozzle Branch

Technical Challenge:
Supersonic Cruise Efficiency

- Develop and validate high-performance supersonic inlet and nozzle technologies and design/analysis tools for highly-integrated, low-noise, low-boom applications

Approach:

- Develop high-performance, highly-integrated, low-boom inlet concepts (including inlet-fan interaction effects and consideration for variable cycle engine concepts).
- Develop high-performance, highly-integrated nozzles, including jet plume effects on sonic boom.
- Develop inlet design tools and advanced models for flow control.
- Apply high-fidelity CFD approaches (hybrid RANS/LES, LES) to gain insight into flow physics of shock wave/boundary layer interactions
- Apply CFD to refine high-performance / wide-operability fan and compressor models.

Payoff:

- Improved technologies and tools for optimized propulsion systems.
- Propulsion technologies for a minimized sonic boom signature.
- Balanced propulsion approach to meeting efficiency and community noise goals.

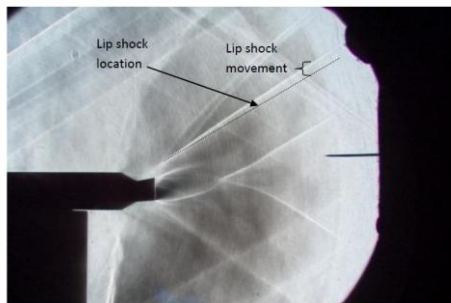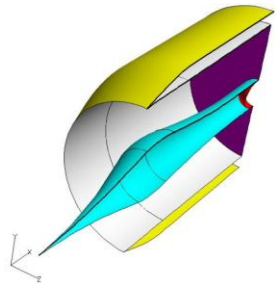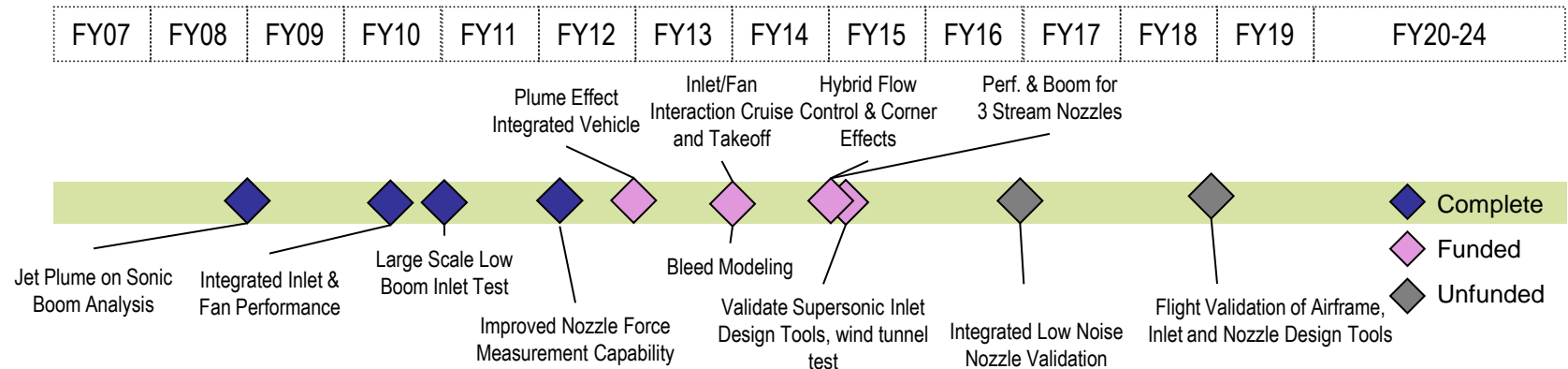# Research Elements - Propulsion

- High Fidelity Computational Tools
  - Micro-Array Flow Control
  - Hybrid Flow Control Actuators
  - Inlet-Fan Interaction
  - High Performance/Wide Operability Fan and Compressor
  - Turbulence Modeling for Propulsion
  - Virtual Topology Editor
  - BAY Vortex Generator Modeling
  - Inlet Bleed Modeling
- Design Tools
  - SUPIN, Supersonic Inlet Design Tools
  - Supersonic Nozzle Design Tools

Research Elements – Propulsion (Cont'd)

- Advanced Inlet Concepts
  - Low Boom/High Performance Inlet Development
- Nozzle Studies
  - Jet Plume Effects on Sonic Boom
  - Low Boom/Low Noise/High Performance Nozzle Analysis
  - Improved Nozzle Force Measurements
- Improved Sensors and Measurement Capability
  - Advanced Schlieren Techniques
  - Improve Optical Diagnostics in Test Facilities

Measuring Progress:
Supersonic Cruise Efficiency - Propulsion

FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20-24

Plume Effect
Integrated Vehicle

Inlet/Fan
Interaction Cruise
and Takeoff

Hybrid Flow
Control & Corner
Effects

Perf. & Boom for
3 Stream Nozzles

◆ Complete
◆ Funded
◆ Unfunded

Jet Plume on Sonic
Boom Analysis

Integrated Inlet &
Fan Performance

Large Scale Low
Boom Inlet Test

Bleed Modeling

Improved Nozzle Force
Measurement Capability

Validate Supersonic Inlet
Design Tools, wind tunnel
test

Integrated Low Noise
Nozzle Validation

Flight Validation of Airframe,
Inlet and Nozzle Design Tools

Milestones:
- Nozzle plume effect on an integrated vehicle (FY12)
- Improved inlet bleed modeling (FY13)
- Inlet/Fan interaction for cruise and takeoff (FY13)
- Validate supersonic nozzle design tools (FY13)
- Performance and sonic boom effect for 3 stream nozzles (FY14)
- Hybrid flow control and corner effects (FY14)
- Validate supersonic inlet design tools (FY14)
- Validate integrated low noise nozzle (FY16)
- Flight validation low boom/drag design, incl. propulsion (FY18)

Progress:
- Predict integrated inlet and fan performance and compare to experimental data (FY10)
- Large-scale low-boom inlet and test in 8x6-ft tunnel (FY10)
- Developed improved nozzle force measurement capability (FY10)
- Developed SUPIN Inlet Design tools (FY11)

Lip shock
location

Lip shock
movement

Research Elements

High Fidelity Computational Tools

Inlet Flow Control

- Study of inlet flow control is needed to eliminate performance bleed and reduce stability bleed requirements in 2D and 3D supersonic inlet designs.

- Computational Fluid Dynamics
  - BAY Vortex Generator Model (Wind-US).
  - Hybrid RANS/LES models of unsteady hybrid micro-ramp with micro-blowing flow control.
  - Models to reduce corner interactions in both 2D inlets and experiments.

- Experiments
  - GRC 15cm x 15cm Oblique shock boundary layer interaction and normal shock boundary layer interaction.
  - Hybrid micro-ramp with micro-blowing flow control.
  - Corner filleting and hybrid micro-ramp flow control experiments planned for 2012.

B. Anderson, J. Dudek, M. Vyas and S. Hirt
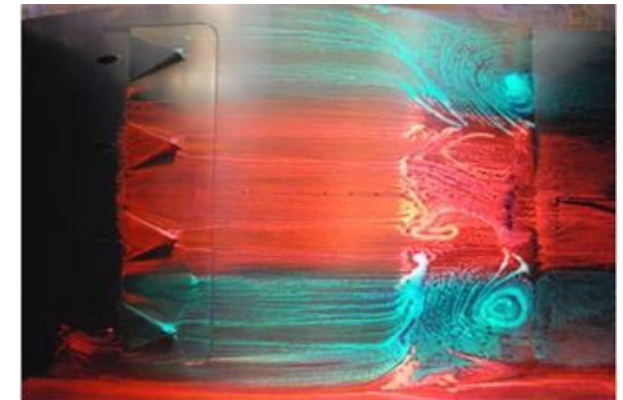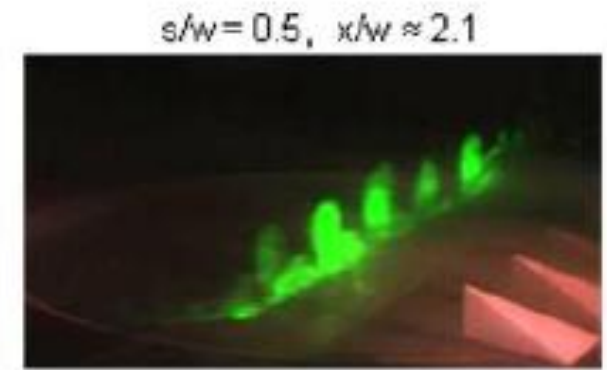
Inlet Bleed Modeling

- Study of inlet bleed is needed to optimize performance and stability bleed in 3D inlet designs
  - Prediction of inlet bleed performance often does not match flight performance.
  - Improvements are desired to the current models.
- Bleed hole simulations, NRA: University of Cincinnati
  - Analysis of single holes.
  - Analysis of single and double rows.
  - Hamed et al, AIAA Paper 2012-0840
- Fundamental experiments
  - Validate models
  - Develop a bleed database
  - 15cm x 15cm wind tunnel at GRC

a) "Thick" bleed plate.

Dr. J. Slater, Dr. D. Davis, and Dr. A. Hamed
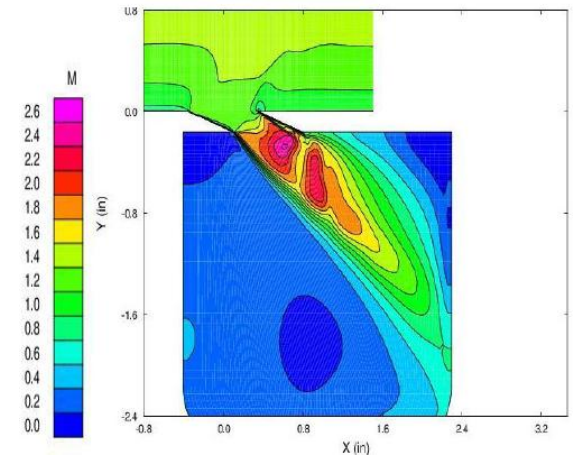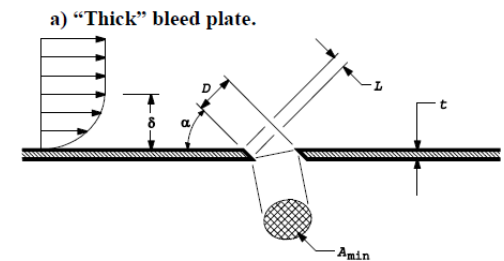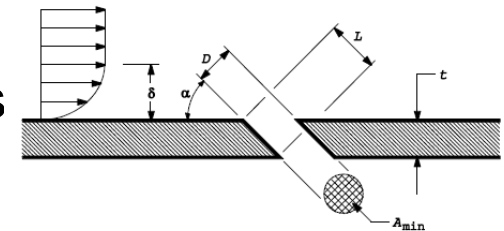
Design Tools

Inlet and Nozzle Design Tools
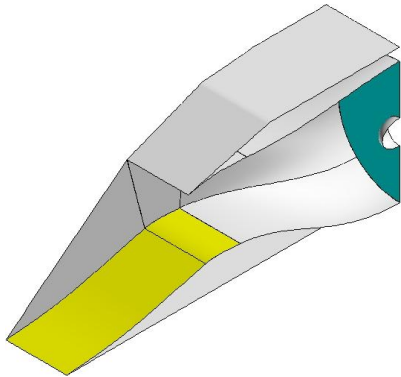
Development of easily available inlet and nozzle tools to assist in both conceptual and detailed design.

SUPIN (Supersonic Inlet Design and Analysis) Code
- Designs external-compression supersonic inlets.
- Computes total pressure recovery, flow rates, and drag.
- Creates surface grids for CFD analysis.
- SUPIN is available as a "Beta" version (Fortran 90 code).
- Future developments will allow off-design analysis and mixed-compression inlets with internal supersonic compression.
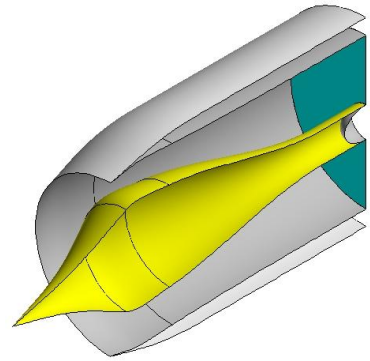
Nozzle MOC Design Code
- Interactive Java Applet.
- Available on the Web.
- 2D or Axisymmetric.
- Provides geometry and flow properties.
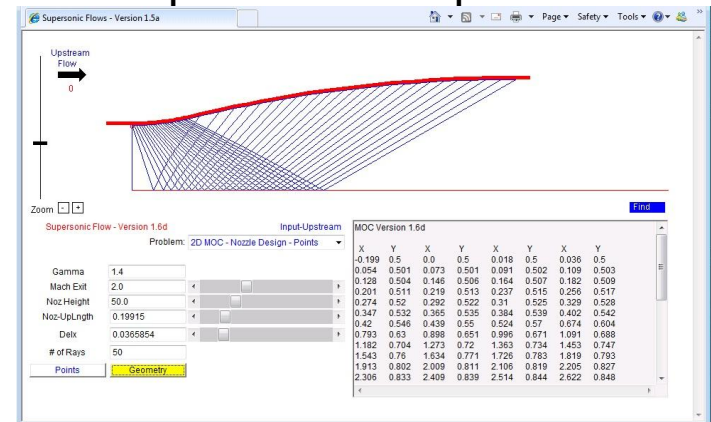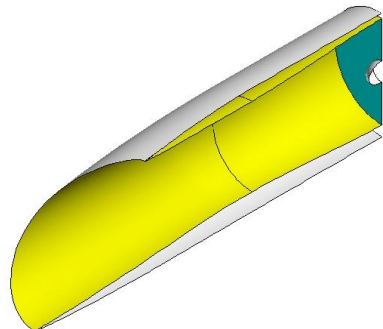
Dr. John Slater / Tom Benson

Research Elements

Advanced Inlet Concepts

Validate Micro-array Flow Control in Low-boom Supersonic Inlets

- This work supported the development of efficient inlet configurations with low sonic boom.

- Met the 2012 annual performance goal.

- Goal to evaluate a large-scale low-boom supersonic inlet concept in the GRC 8'x6' wind tunnel to acquire performance and flowfield validation data.

  - Evaluate inlet stability and operability

  - Conduct CFD analysis to design inlet configurations, evaluate and compare performance and obtain data for CFD code validation

  - Evaluate a zero-cowl-angle configuration

  - Evaluate a high-flow bypass stream

  - Evaluate simple, passive, bleedless inlet boundary layer control options

Dr. Chima, S. Hirt, M. Vyas
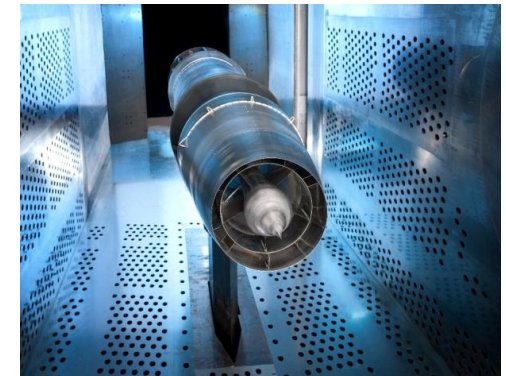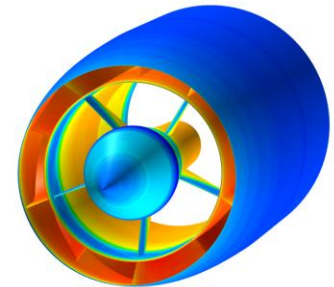
Flight Test of the Channeled Centerbody Inlet

- Patented center-body design allows large throat area variation through simple lightweight system.

- Developed by Techland Research under a NASA SBIR.

- Flight tested on the Dryden F-15 in FY11.

- Results used to validate the inlet concept, and the flight test methodology.
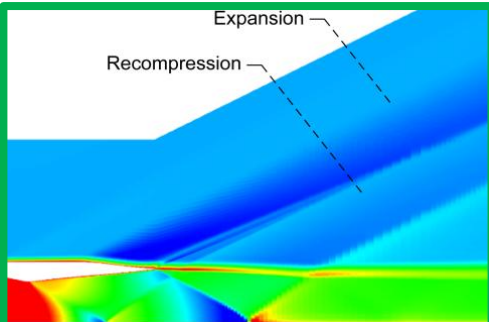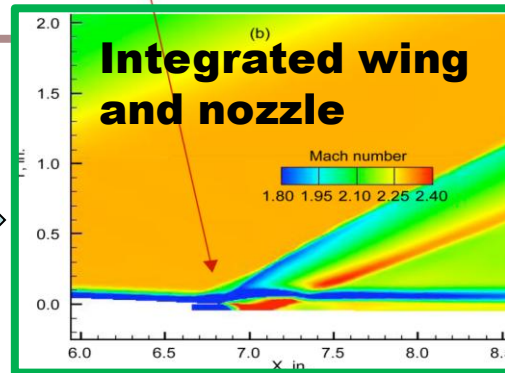
L. Weir and B. Sanders
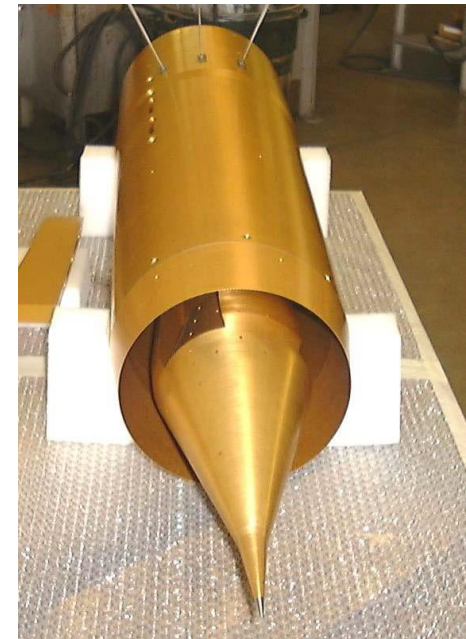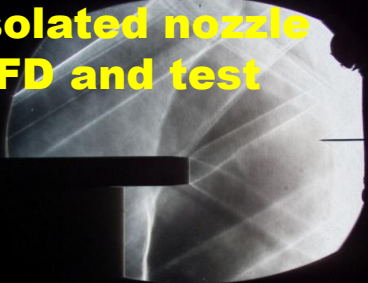
Research Elements

Nozzle Studies

Plume Effects on Sonic Boom

Isolated nozzle CFD and test

Integrated wing and nozzle

Integrated wing-body with plume
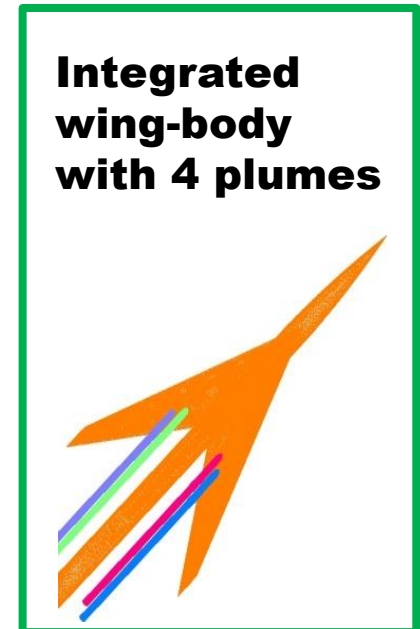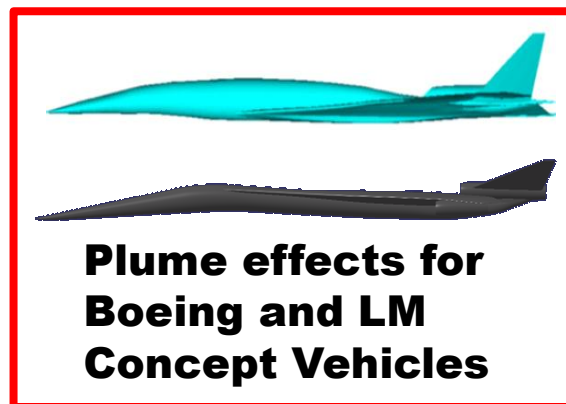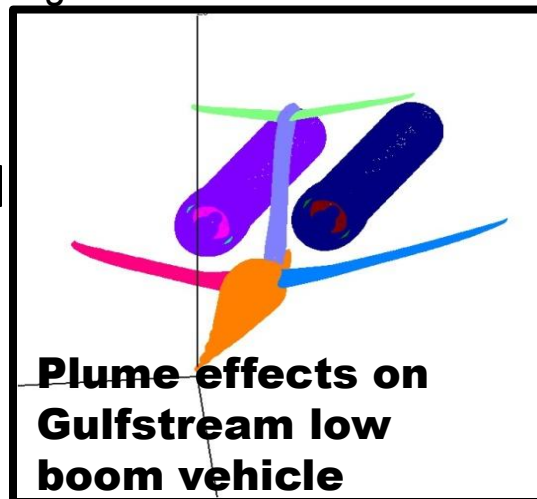
Study of nozzle plume effects on Sonic Boom

• Consistent results show benefit of under-expanded nozzle operation on far field pressure signature in both testing and analysis.

• Current work on both underexpanded plume and improved low boom plume shapes for integrated vehicle configurations.

Integrated wing-body with 4 plumes

Plume effects for Boeing and LM Concept Vehicles

Plume effects on Gulfstream low boom vehicle

Ray Castner

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Low Boom/Low Noise/High Performance Nozzle Analysis

- Validate the integrated low noise nozzles developed under both N+2 and N+3 system studies
  - Evaluation of both steady and unsteady CFD methods using the Rolls Royce Liberty Works 3-stream bi-ejector nozzle concept.
  - Comparison to Phase I results, collected from the Nozzle Acoustic Test Rig at NASA GRC.
  - Goal to develop improved design and analysis methodology for three stream ejector nozzle concepts.
  - Develop methods for prediction of nozzle performance and sonic boom contribution.
 - Coordinated effort with the Airport Noise technical challenge.
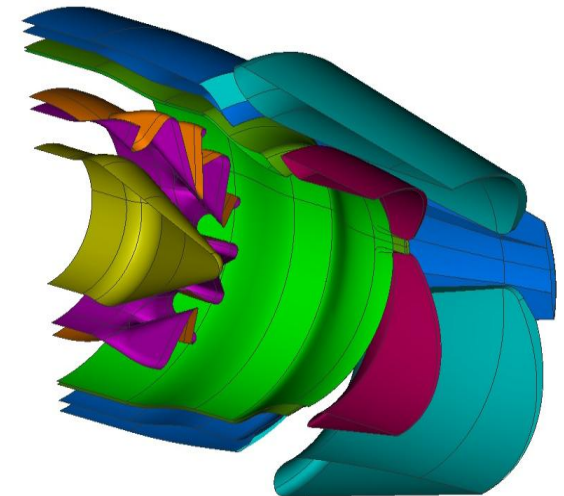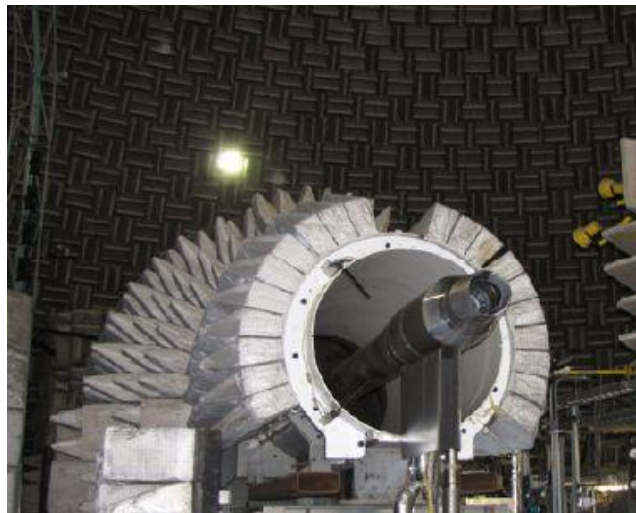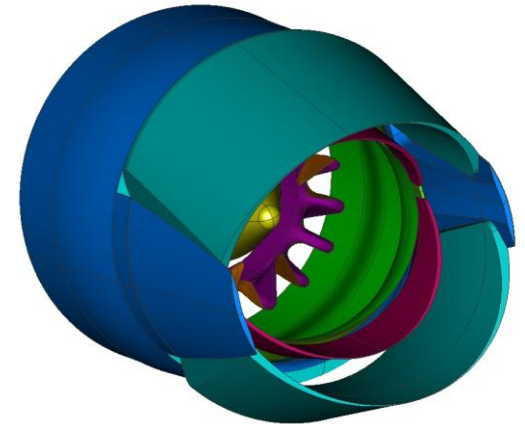
Vance Dippold

Improved Nozzle Force Measurements

- Developed a new 6-component flow-through air balance to support high speed performance measurement, and nozzle plume effects on sonic boom.

    - Jet Exit Rig used for tests in supersonic wind tunnels.

    - Improved test capability for supersonic nozzles.

    - Repeatability better than +/-0.2%

- Revitalized capability demonstrated in partnership with Aeronautics Test Program
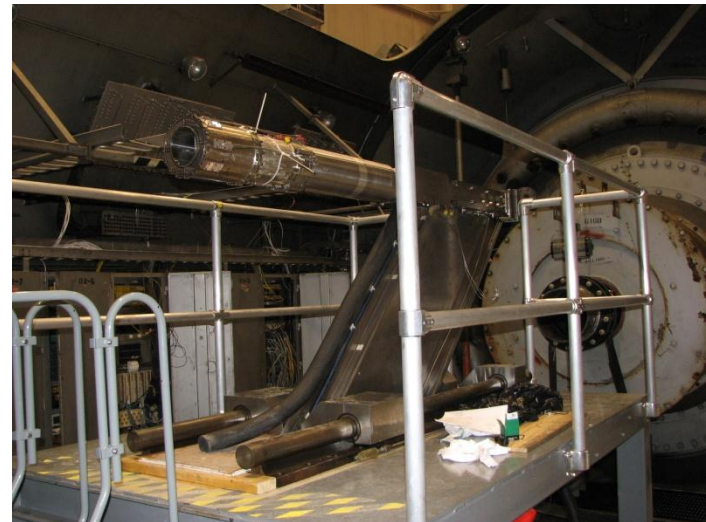
John Wolter and Ray Castner

Research Elements

Improved Sensors and Measurement Capability
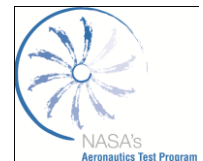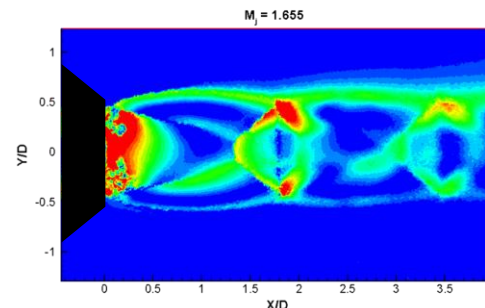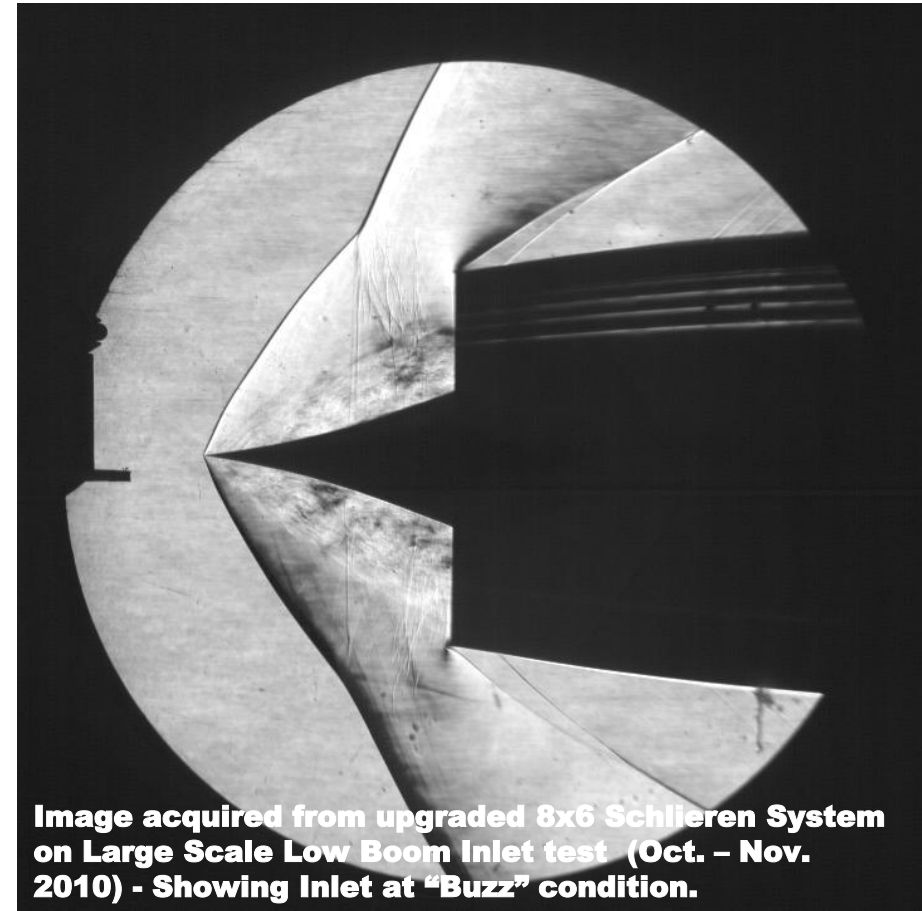
Sensors and Measurement Capability

Developed improved measurement capability to support both high speed inlet and nozzle testing and comparisons to CFD.

Accomplishments:
- Improved Schlieren in the NASA GRC 8'x6' SWT with upgraded optics.

- New high speed digital imaging capability.

- Installing two new Schlieren windows via ATP Test Technology Investment.

- Brighter light source utilizing LED technology.

- Developing optical phase knife edge technology.

Additional Work:
- Background Oriented Schlieren (with Airport Noise challenge).

- PIV for 1x1 SWT and 15cm SWT.

Image acquired from upgraded 8x6 Schlieren System on Large Scale Low Boom Inlet test (Oct. – Nov. 2010) - Showing Inlet at "Buzz" condition.

M. Woike, M. Clem

Key Upcoming Events
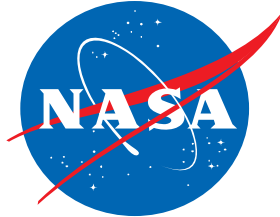
- NRA Partnerships & Space Act Agreements
  - Propulsion effects for N+2 vehicle concept studies with Lockheed Martin and Boeing.
  - Study low boom inlet and nozzle concepts with Gulfstream Aerospace.
  - Study high performance inlet concepts with Aerion Corporation.

- SBIR's
  - Simultaneous Skin Friction and Pressure Sensitive Paint (Innovative Scientific Solutions, Inc.), sponsored through FA ATP.
  - Skin Friction and Pressure Measurements in Supersonic Inlets (Innovative Scientific Solutions, Inc.), sponsored through FA Propulsion Systems.

- Future Plans
  - Validate supersonic inlet design tools on integrated supersonic inlets (FY14)
  - Validate integrated low noise nozzle (FY16)

FAP Meeting Presentations

- Tuesday March 13, 2012:

  - 5:00 "Analysis of Buzz in a Supersonic Inlet." Dr. Rodrick Chima, NASA GRC.

  - 5:30 "Inlet Bleed Modeling and Experimental Results." Dr. David Davis, NASA GRC.

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