Large-Scale Low-Boom Inlet Test Overview

This presentation provides a high level overview of the Large-Scale Low-Boom Inlet Test and was presented at the Fundamental Aeronautics 2011 Technical Conference. In October 2010 a low-boom supersonic inlet concept with flow control was tested in the 8'x6' supersonic wind tunnel at NASA Glenn Research Center (GRC). The primary objectives of the test were to evaluate the inlet stability and operability of a large-scale low-boom supersonic inlet concept by acquiring performance and flowfield validation data, as well as evaluate simple, passive, bleedless inlet boundary layer control options. During this effort two models were tested: a dual stream inlet intended to model potential flight hardware and a single stream design to study a zero-degree external cowl angle and to permit surface flow visualization of the vortex generator flow control on the internal centerbody surface. The tests were conducted by a team of researchers from NASA GRC, Gulfstream Aerospace Corporation, University of Illinois at Urbana-Champaign, and the University of Virginia.

National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Large-Scale Low-Boom Inlet Test Overview

Stefanie Hirt

NASA Glenn Research Center

2011 Technical Conference

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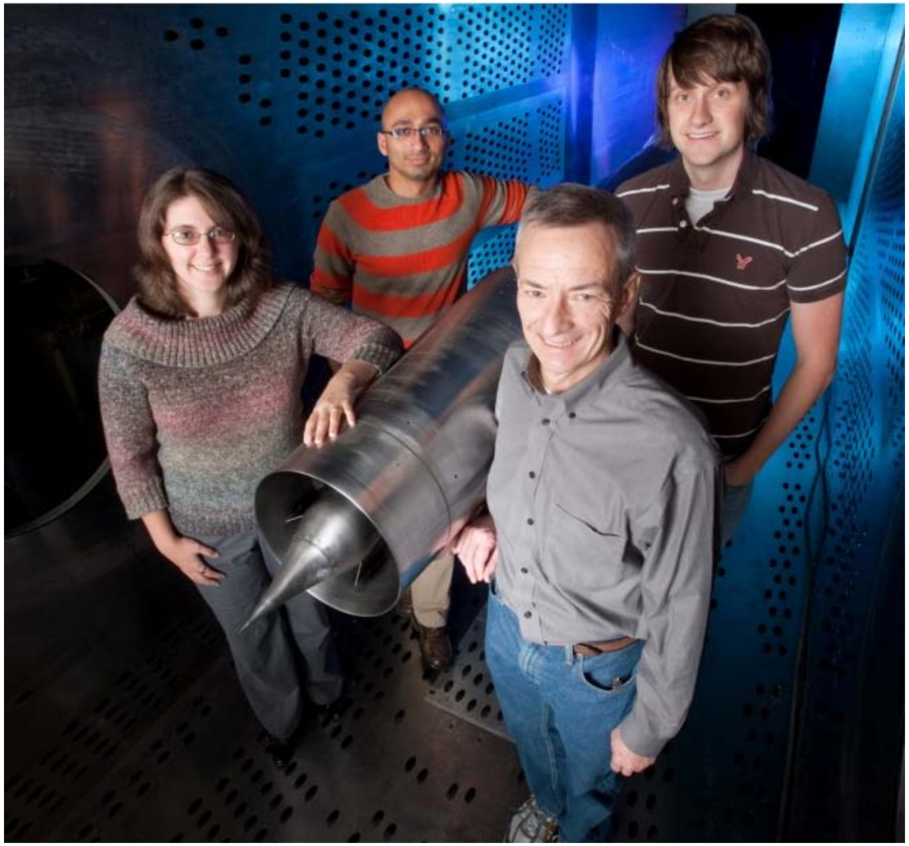
Cleveland, Ohio

Large-Scale Low-Boom Inlet Test



Fundamental Aeronautics Program- Supersonics Project

Large-Scale Low-Boom Inlet

<u>Technical Challenge:</u> Supersonics Cruise Efficiency – Propulsion; Advanced Inlet Concepts

<u>Objectives:</u>

- Evaluate a large-scale low-boom supersonic inlet concept using the GRC 8'x6' wind tunnel to acquire performance and flowfield validation data
- Evaluate practicality of a zero-cowl-angle configuration
- Evaluate the effect of integrating a high-flow bypass stream
- Conduct CFD analysis to design inlet configurations, evaluate and compare performance and obtain data for CFD code validation
- Evaluate simple, passive, bleedless inlet boundary layer control options
- Evaluate inlet stability and operability at various Mach numbers and angles of attack (AOA) for dual and single stream inlet configurations
- Use pressure sensitive paint (PSP) on internal and external surfaces of the model to examine the local effects of the upstream and downstream VGs

<u>Accomplishments:</u>

- Demonstrated a low-boom inlet with high recovery, excellent buzz margin, and high operability. Gained confidence in use of modeling and simulation tools to design inlets of this class with flow control.
- Developed a high quality database of results that can be shared with the community.
- Conducted a high quality test while maintaining a very aggressive schedule.
  - NRA under contract: 03/2008
  - Aerodynamic Design Review: 06/2009
  - Release Hardware Solicitation: 12/2009
  - Hardware Contract Awarded: 02/2010
  - Model Delivered: 06/2010
  - Test Entry: 10/04/2010 – 11/17/2010

Dual stream configuration

Bypass stream w/vanes

Passive flow control devices

Axisymmetric Isentropic Inlet

Relaxed Compression:

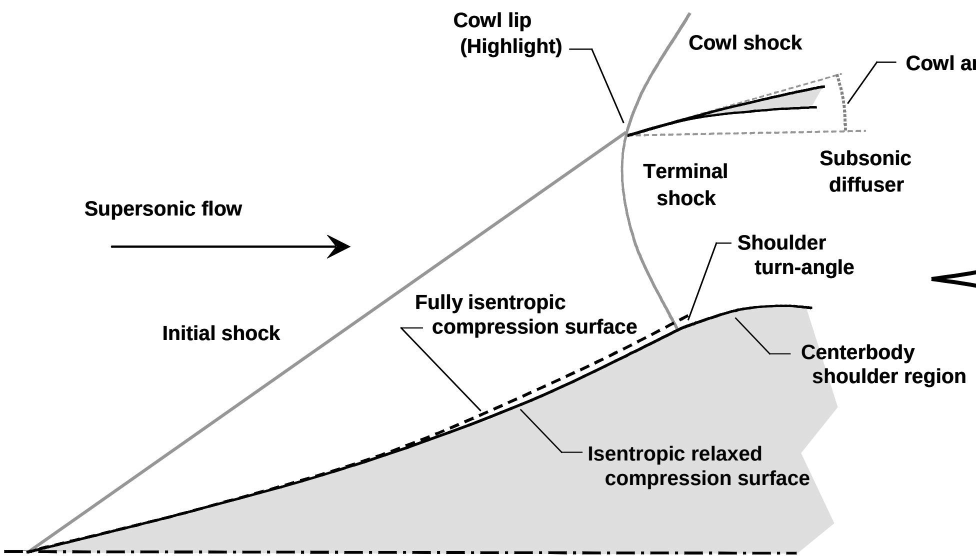
- Decreases the flow angle at cowl lip → Reduce the cowl angle, decreasing inlet influence on sonic boom.
- Increases shoulder turning and hub boundary layer thickness → Investigate vortex generator flow control to mitigate the negative impacts.
- Increases terminal shock Mach number and strength near the cowl → Add an inlet bypass duct which removes the low energy flow from the engine and encloses the gear box.

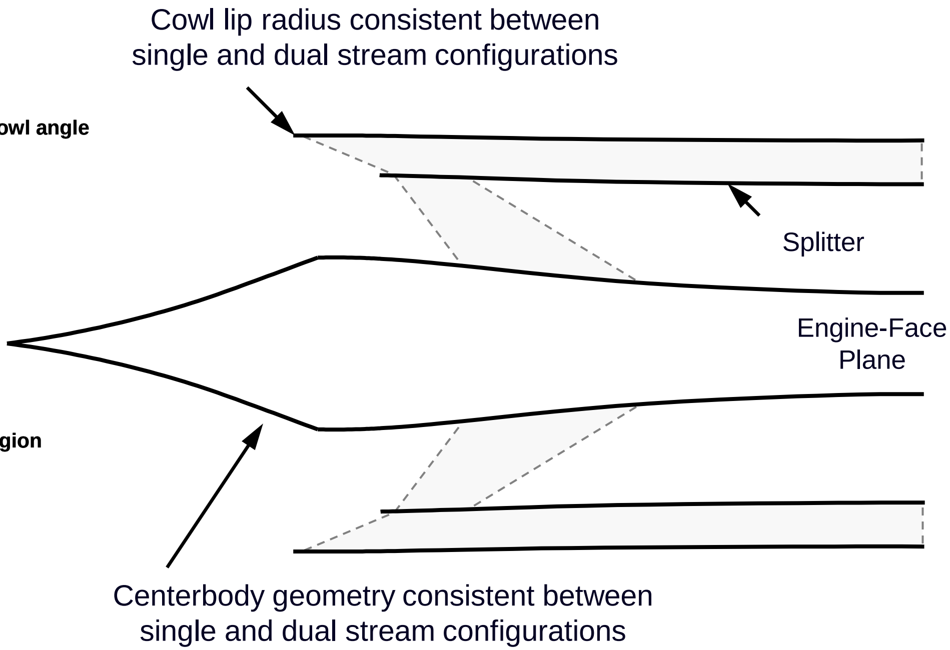
So we:

Reduce the cowl angle, decreasing inlet influence on sonic boom.

Investigate vortex generator flow control to mitigate the negative impacts.

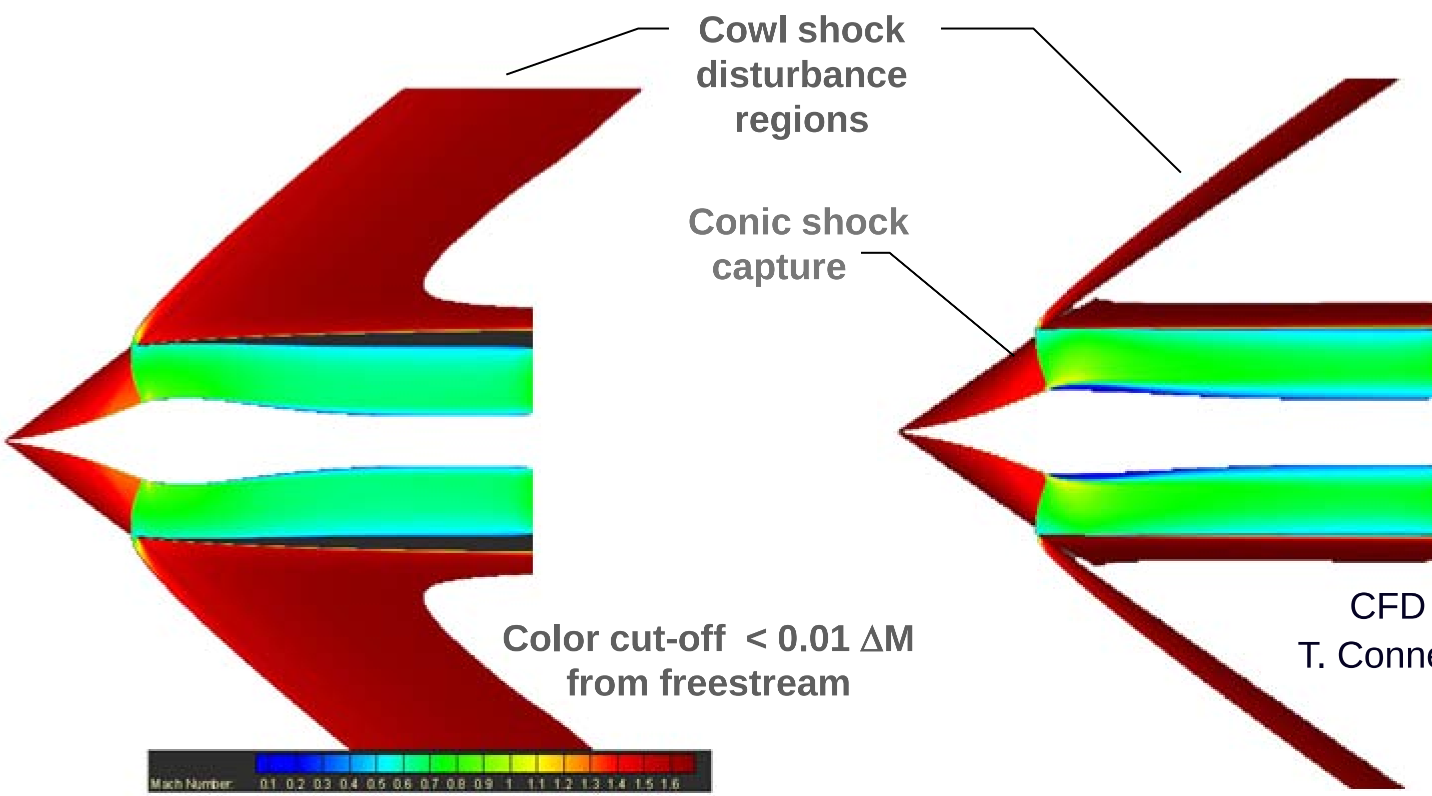
Add an inlet bypass duct which removes the low energy flow from the engine and encloses the gear box.





Impact of Inlet Shaping on Near-Field Pressure

Both inlets sized for Rolls-Royce Tay engine



CFD analysis by
T. Conners, Gulfstream

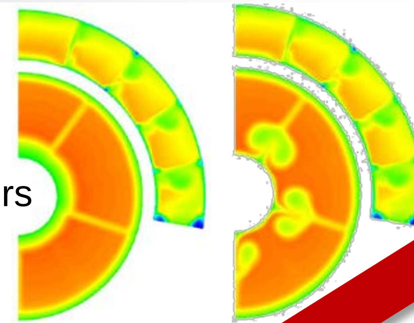
Inlet with baseline relaxed compression shaping

Inlet with zero degree cowl angle and conic shock capture

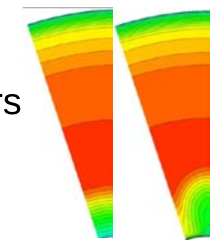
Design by CFD Anaylsis

By: Gulfstream, NASA GRC, UIUC, UVa
Using: MOC, WIND-US, AVCS, USM3D

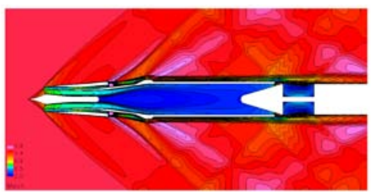
Full 3D with vortex generators



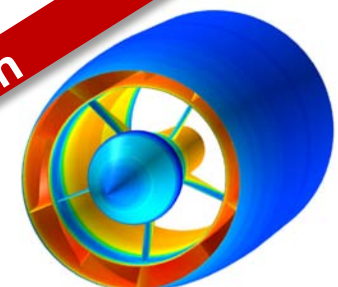
3D segment with vortex generators



Axisymmetric inlet installed in 8x6

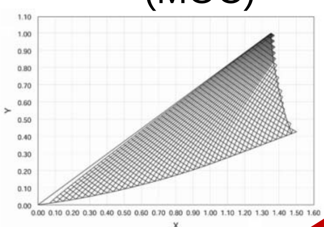


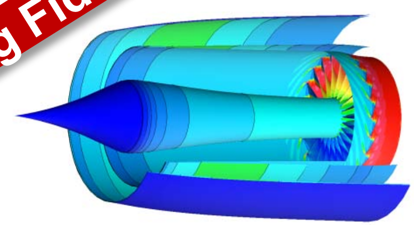
Full 3D with bypass channels



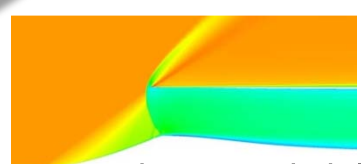
Increasing Fidelity in Simulation

Method of Characteristics (MOC)





Axisymmetric inlet with R-R fan

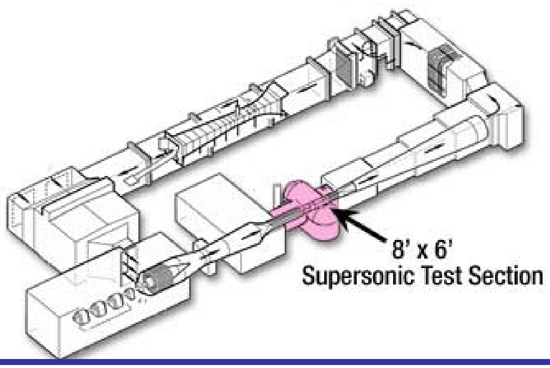


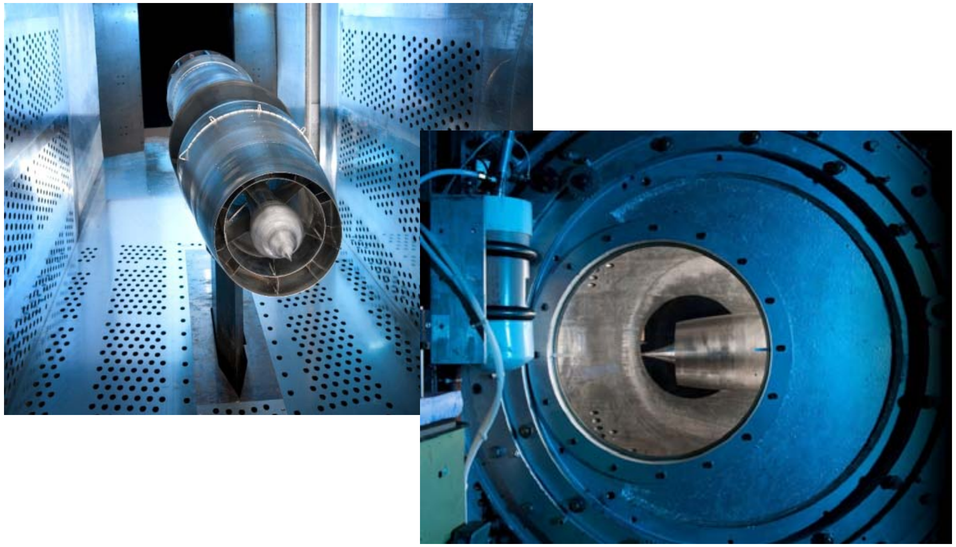
Axisymmetric inlet only

Test Facility

Facility

- GRC 8x6 Supersonic Wind Tunnel
- Mach 0.5 to 1.8 operation





Large Scale Low Boom Inlet in 8x6

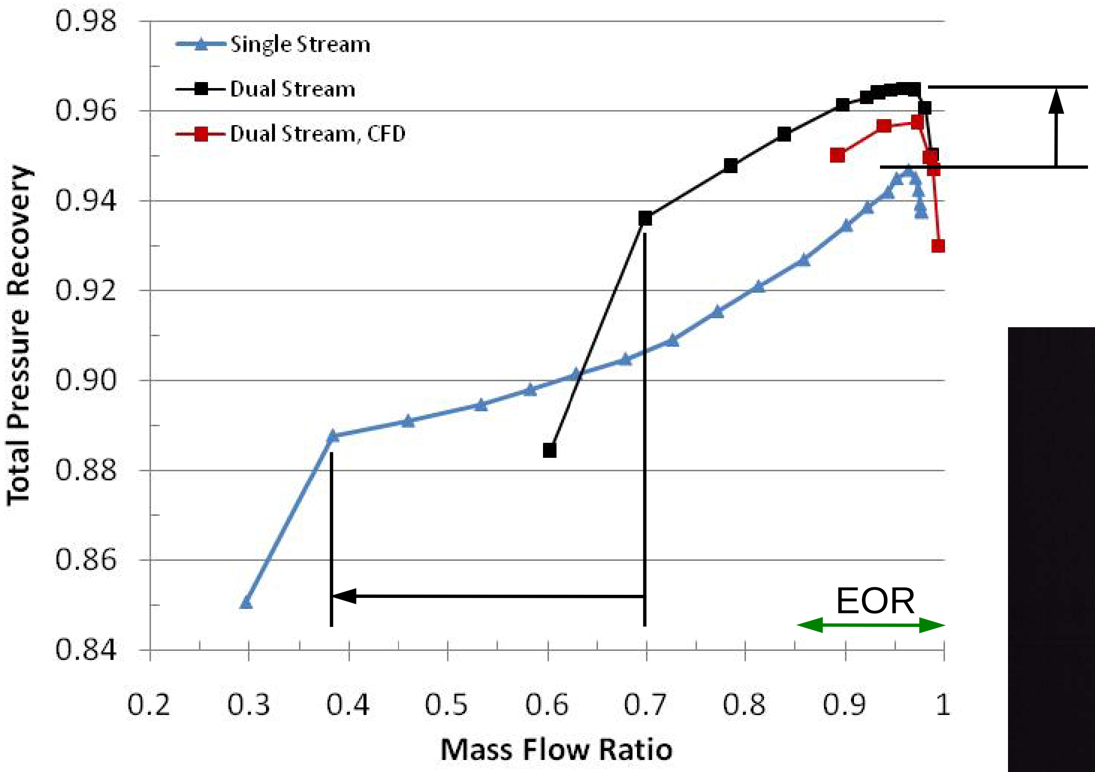
Key Contributions

- ATP Test Technology-funded schlieren receiving optics improvements provided high quality still and high speed video data
- PSP and oil flow viz internal surface pressure contours successfully acquired.

Accomplishments

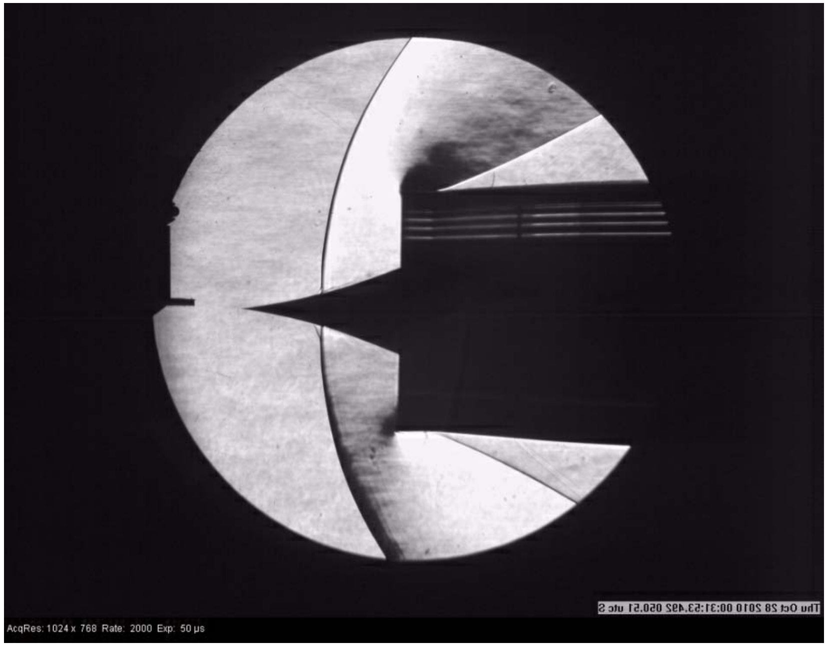
- Aerodynamic performance, pressure sensitive paint, high speed schlieren and oil flow visualization data were collected during the testing.
- A total of 91 hours of run time (21 run days), 5880 steady state data points and 5822 dynamic data points were accumulated during the test.

Preliminary Results-Performance & Buzz Margin



Dual stream inlet provides greater total pressure recovery to the engine than the single stream inlet.

- Dual stream: 96.5 %
- Single stream: 94.7 %
- Mil spec, M1.7: 95.3 %

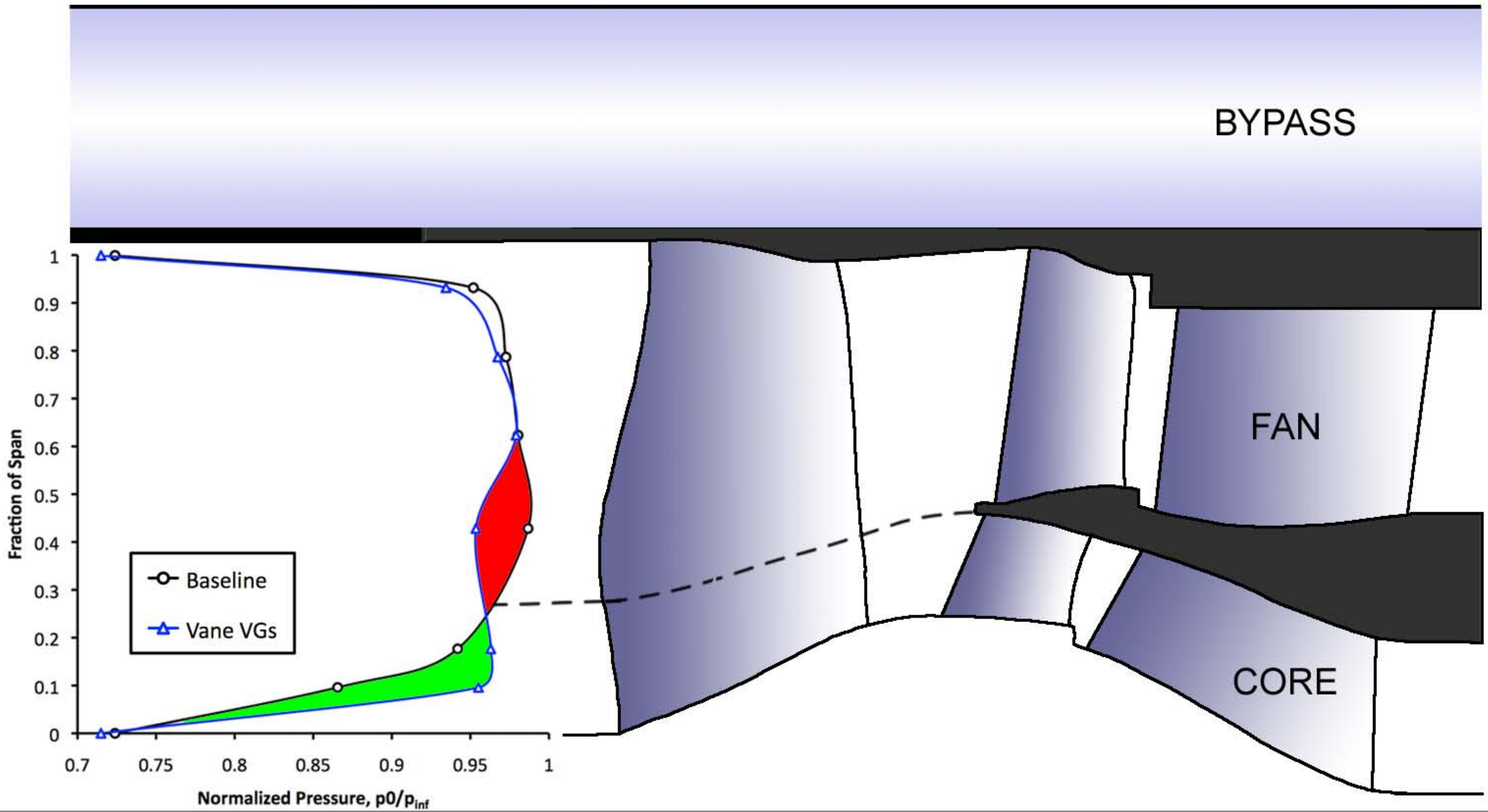


Single stream inlet has more buzz margin than the dual stream inlet.

Both inlets have adequate buzz margin for the engine operating range (EOR).

Demonstrated a low-boom inlet with high recovery, excellent buzz margin, and high operability.

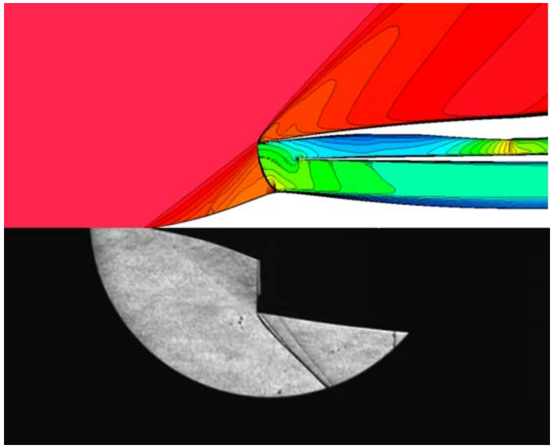
Preliminary Results – Vortex Generators



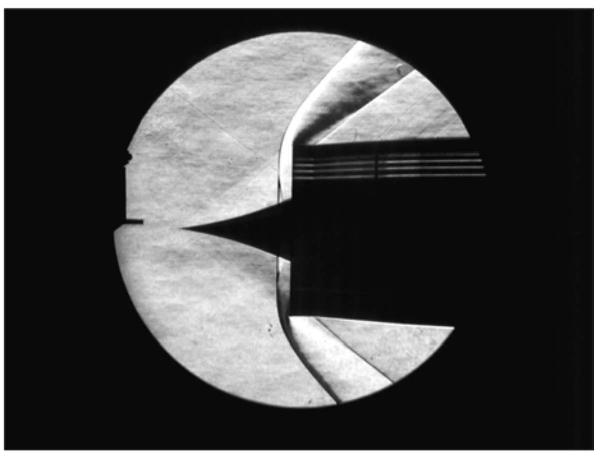
Vortex generators create a more uniform profile across the span by mixing to more closely match engine design flow.

- **Green: increased pressure recovery to the engine core**
- **Red: decreased pressure recovery to the fan, which can tolerate the deficit**

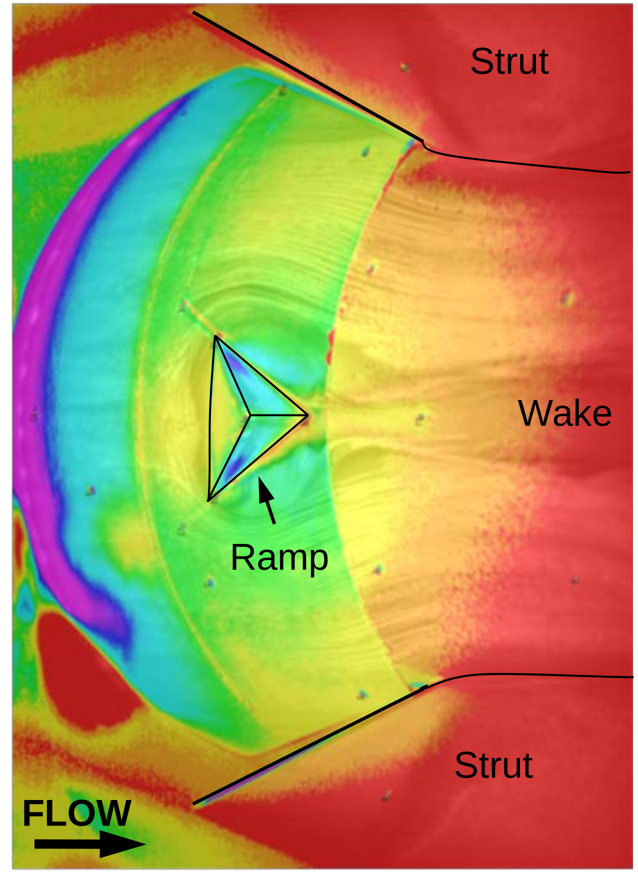
Preliminary Results – Flow Visualization



Schlieren with CFD near design point



Schlieren off design



Oil flow and pressure sensitive paint
Internal view of subsonic diffuser centerbody
Large Aft Ramp, Mach 1.7

Developed a high quality database of flow visualization results that can be shared with the community.

Partner Responsibilities

NASA Fundamental Aeronautics Program- Supersonics Project

- Managed and directed overall effort
- Funded inlet model fabrication and testing
- Co-designed instrumentation system
- Led fabrication coordination
- Ran CFD for test model and installation to assist with test planning and data reduction
- Leading post-test data analysis and reporting

Gulfstream – NRA Year 1 & Non-Reimbursable Space Act Agrmt

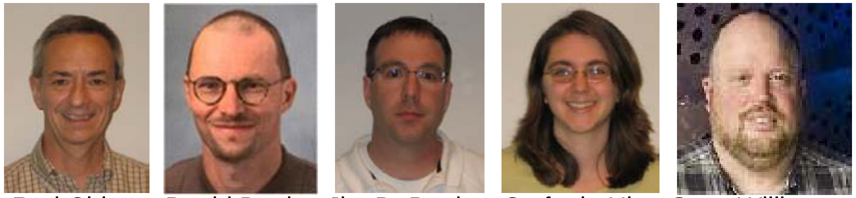
- Designed relaxed compression flowpaths for both inlet models
- Produced baseline CAD packages supplied to TriModels
- Co-designed instrumentation system
- Assisted with fabrication coordination
- Provided on-site test support
- Assisting with post-test data analysis and reporting

University of Illinois & University of Virginia – NRA Years 1 & 2

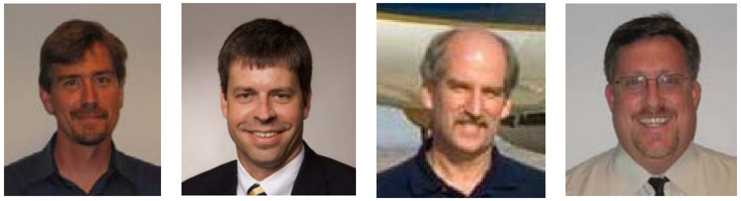
- Ran CFD to evaluate and rank VG configurations for testing
- Co-designed instrumentation system and led design of pressure-sensitive paint system
- Provided on-site test support
- Assisting with post-test data analysis and reporting

TriModels, Inc.

- Detail model design and fabrication



Rod Chima David Davis Jim DeBonis Stefanie Hirt Scott Williamson



Tim Conners Robbie Cowart Don Howe Tom Wayman

Craig Dutton Greg Elliott Joe Koncsek Eric Loth

Wilbur Chang Terry Coyne Tyler Gillen Tommy Herges

Erik Kroeker Mike Rybalko Nirav Shah

A dedicated team of people from government, industry and academia producing results on schedule and on budget!

Conclusions & Next Steps

Conclusions:

- Achieved several firsts in the history of supersonic inlet development :
  - On-design zero-spillage can be achieved for a simple, fixed-geometry relaxed external compression inlet system featuring high inlet-bypass flow
  - Massive amounts of tertiary bypass flow can be fully and predictably controlled in a stable manner across a wide Mach, flow, and AOA operational space
  - Excellent core stream performance can be maintained across the supersonic speed range, even to high AOA, when relaxed compression and high-bypass geometry are combined
  - Very large margins against buzz are possible with a shock-on-lip relaxed external compression inlet operating at an over-speed condition and at angle-of-attack
- A new standard in high-speed Schlieren imagery was achieved
- A non-restricted database was produced that can be used as a basis for subsequent 3-D tailoring for flight-type applications and for additional verification of CFD modeling fidelity, including time-accurate solving

Next Steps:

- Continue detailed data analysis and preparation of technical papers for special session at AIAA Applied Aero Conference in Honolulu in June 2011
- Support completion of FY12 APG Milestone (03/2012) “Validate effectiveness of Micro-array Flow Control devices for improving performance and flow quality in low-boom supersonic inlets”

NASA

BACKUP Slides

List of Publications:

1. Gillen, T., Rybalko, M., Loth, E., "Vortex Generators for Diffuser of Axisymmetric Supersonic Inlets", AIAA-2010-4253 , 5th Flow Control Conference, Chicago, Illinois, June 28-1, 2010.
2. Coyne, T., Koncsek, J., Loth, E., Davis, D., Conners, T., Howe, D., “Simulations of a Low-Boom, Axisymmetric, External Compression Inlet", AIAA-2009-4210, 39th AIAA Fluid Dynamics Conference, San Antonio, Texas, June 22-25, 2009.
3. Rybalko, M., Loth, E., Chima, R., Hirt, S., DeBonis, J., "Micro-Ramps for External-Compression Low-Boom Inlets", AIAA-2009-4206, 39th AIAA Fluid Dynamics Conference, San Antonio, Texas, June 22-25, 2009.
4. Chima, R., Conners, T., Wayman, T., "Coupled Analysis of an Inlet and Fan for a Quiet Supersonic Jet", AIAA-2010-479, 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 4-7, 2010.
5. Herges, T., Kroeker, E., Elliott, G., Dutton, C., "Microramp Flow Control of Normal Shock/Boundary-Layer Interactions", AIAA Journal 2010, 0001-1452 vol.48 no.11 (2529-2542), doi: 10.2514/1.52434.
6. Herges, T., Elliott, G., Dutton, C., Lee, Y., "Micro-Vortex Generators and Recirculating Flow Control of Normal Shock Stability and Position Sensitivity", AIAA-2010-1097, 48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 4-7, 201.0
7. Herges, T., Kroeker, E., Elliott, G., Dutton, J., "Micro-Ramp Flow Control of Normal Shock/Boundary Layer Interactions", AIAA-2009-920, 47th AIAA Aerospace Sciences Meeting including The New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 5-8, 2009.