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.
Large-Scale Low-Boom Inlet Test Overview
Stefanie Hirt
NASA Glenn Research Center
Large-Scale Low-Boom Inlet Test

Fundamental Aeronautics Program - Supersonics Project
**Technical Challenge:** Supersonics Cruise Efficiency – Propulsion; Advanced Inlet Concepts

**Objectives:**

- 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

**Accomplishments:**

- 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
  - Release Hardware Solicitation: 12/2009
  - Hardware Contract Awarded: 02/2010
  - Model Delivered: 06/2010
  - Test Entry: 10/04/2010 – 11/17/2010
Axisymmetric Isentropic Inlet

Relaxed Compression:
- Decreases the flow angle at cowl lip
- Increases shoulder turning and hub boundary layer thickness
- Increases terminal shock Mach number and strength near the cowl

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.

Cowl lip radius consistent between single and dual stream configurations

Centerbody geometry consistent between single and dual stream configurations
Impact of Inlet Shaping on Near-Field Pressure

Both inlets sized for Rolls-Royce Tay engine

- **Inlet with baseline relaxed compression shaping**
- **Inlet with zero degree cowl angle and conic shock capture**

**Color cut-off < 0.01 ∆M from freestream**

- Cowl shock disturbance regions
- Conic shock capture

CFD analysis by T. Conners, Gulfstream
Design by CFD Analysis

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

- Axisymmetric inlet installed in 8x6
- Method of Characteristics (MOC)
- Full 3D with vortex generators
- 3D segment with vortex generators
- Full 3D with bypass channels
- Axisymmetric inlet with R-R fan
- Axisymmetric inlet only

Increasing Fidelity in Simulation
Test Facility

Facility

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

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.
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

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”
List of Publications:


