National Aeronautics and Space Administration

TBCC Technical Challenge Overview

Hypersonics Project

Scott R. Thomas
Technical Lead, TBCC Discipline
NASA Glenn Research Center, Cleveland, Ohio

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OUTLINE

- **Turbine Based Combined Cycle Propulsion Technology Challenges**

- **Combined Cycle Engine Large Scale Inlet Mode Transition Experiment (CCE LIMX) in NASA GRC 10X10 SWT**

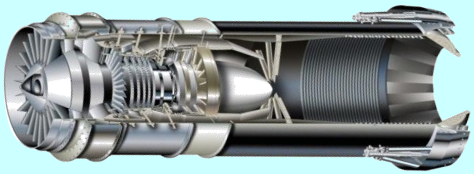
  - **High Mach Turbine Engine Development via Williams International Inc.**

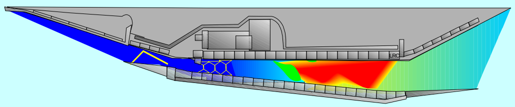
- **TBCC Fan Rig Testing in NASA GRC W8 Compressor Facility**

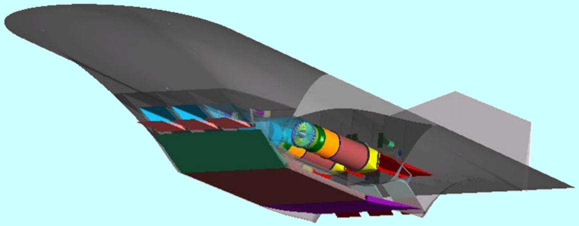
- **Summary and Concluding Remarks**

TBCC Technology Challenges: *Develop Air-Breathing Propulsion Technology for Two-Stage-to-Orbit Vehicles*

Turbine Based propulsion + *Hypersonic Scramjet propulsion* → *Hypersonic TBCC propulsion*







High Mach Turbine Tech Challenges:

- ➢ Increase Maximum Mach from 2+ → 4+
- ➢ Provide thrust margin over entire range (0<M<4+)
- *Light Weight High Temperature Materials*
- *Thermal Management*
- *High Temperature Bearings and Seals*
- *Highly Loaded Turbomachinery*

Scramjet Tech Challenges:

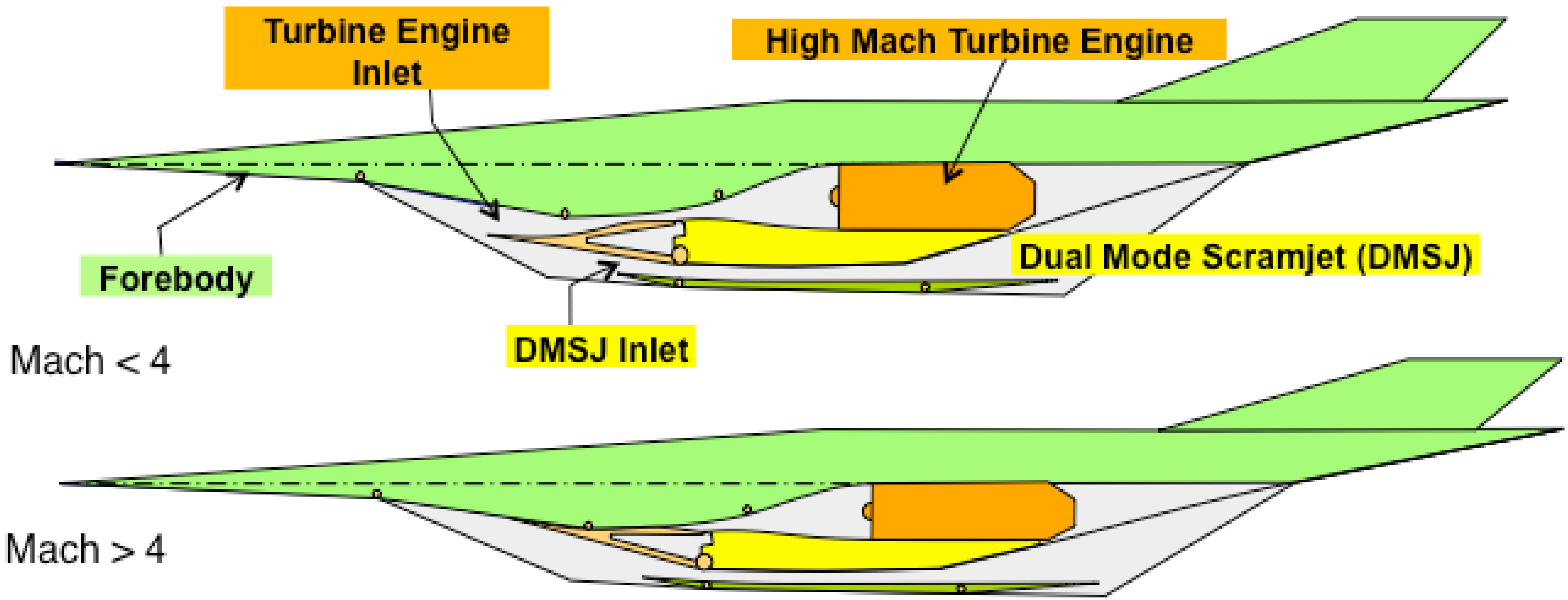
- ➢ Reduce Scramjet Ignition Mach Speed (M5 → M3)
- ➢ Provide transition speed margin (3<M<4)
- *Advanced Combustion Schemes*
- *Light Weight High Temperature Materials*
- *Thermal Management*
- *High Temperature Seals*

Propulsion System Tech Challenges:

- ➢ Propulsion System/ Airframe Integration
- ➢ Inlet(s)/ Engine(s)/ Nozzle(s) Integration
- ➢ Achieve required performance and operability over entire flight range
- ➢ Accomplish stable mode transition

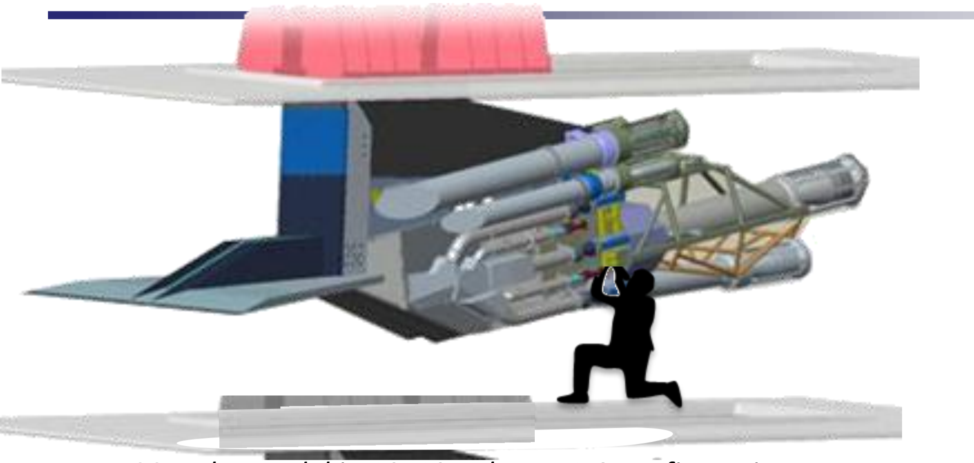
Turbine Based Combined Cycle Concept

- The Turbine-Based Combined Cycle (TBCC) concept involves an over/ under configuration with a split in the propulsion flowpath.
  - From take-off to Mach 4, a turbine engine provides propulsion.
  - Above Mach 4, a dual-mode supersonic combustion ramjet /scramjet (DMSJ) engine provides propulsion.
- Inlet Mode Transition is the procedure by which the flowpath split is achieved and controlled as the turbine engine shuts down and the dual-mode ramjet/ scramjet engine takes over.

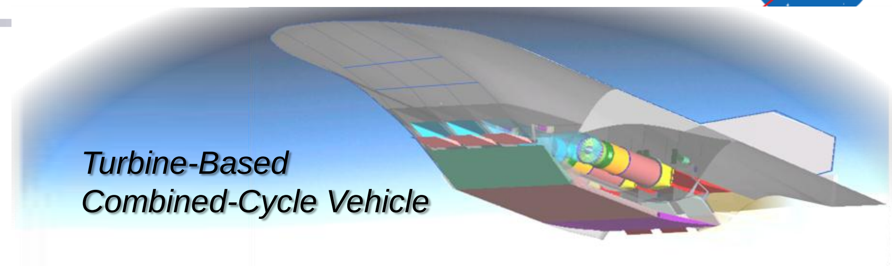


Combined Cycle Engine Large Scale Inlet Mode Transition Testing
NASA GRC 10X10 SWT

CCE Inlet and Controls research in the GRC 10'x10' SWT



CCE Inlet model in 10x10: Phases 1-3 configuration



RESEARCH GOALS

- Proof of concept of over/under split flow inlet
  - Develop performance & operability database for both the turbine and scramjet inlets
  - Demonstrate mode transition and control
- Validate CFD predictions for both flowpaths
- Develop realistic distortion characteristics throughout the mode transition Mach number range
- Testbed for mode transition controls research & for integrated inlet/engine propulsion systems

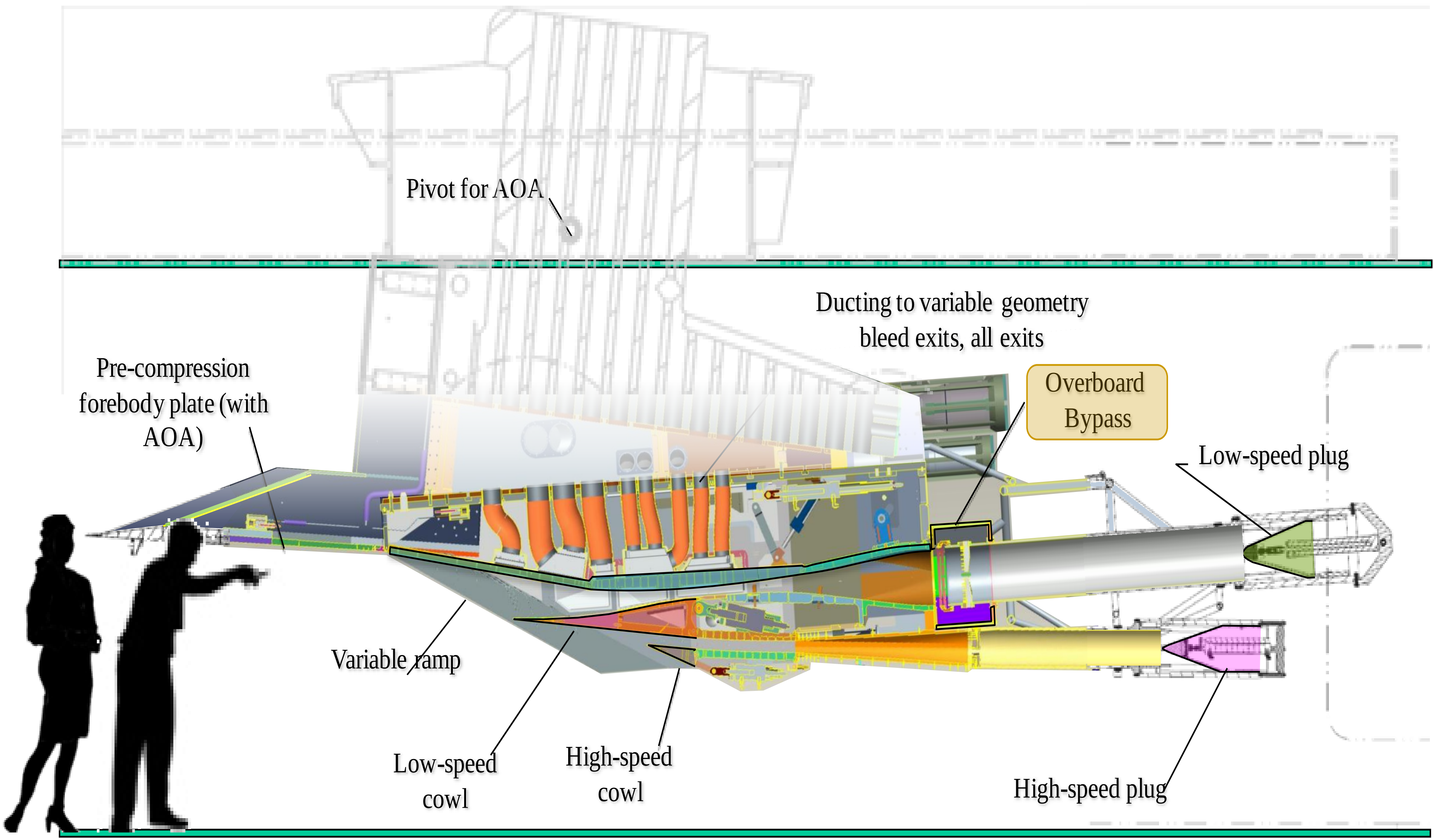
Test Approach - 4 Phases

1. Inlet performance and operability characterization
2. System Identification of inlet dynamics for controls
3. Demonstrate Control strategies for smooth & stable mode transition without inlet unstart
4. Add engines/ nozzle for integrated system test

Seeking Partnerships

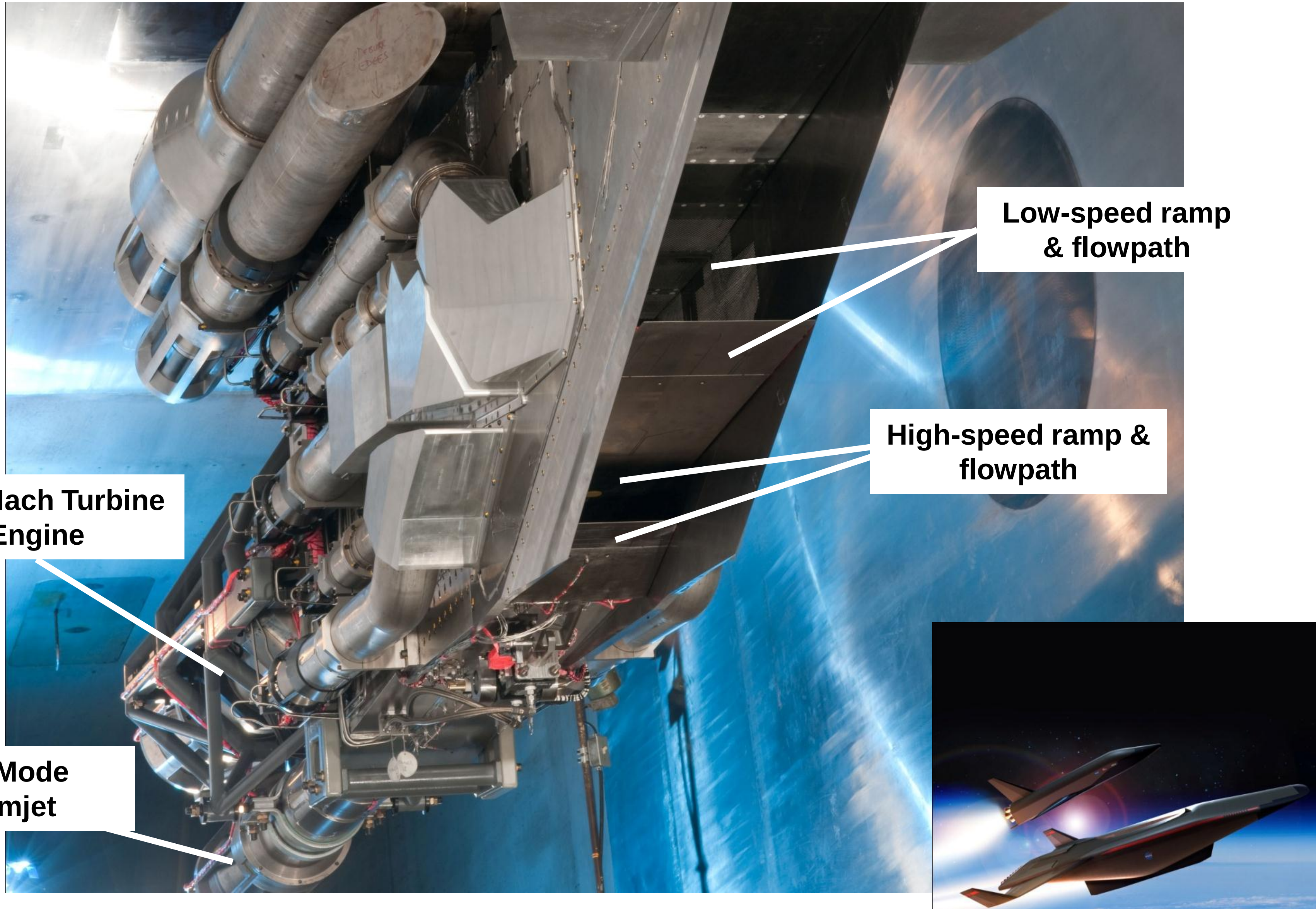
IMPACT: Critical stepping stone to towards practical TBCC-powered aircraft

CCE Large Scale Inlet Model



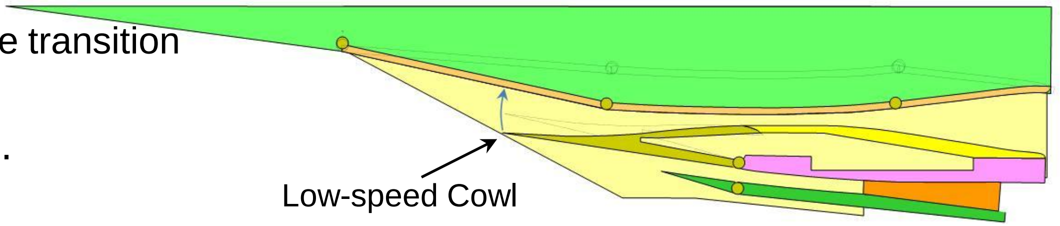
CCE LIMX Installed in NASA 10X10 SWT

CCE LIMX Flowpaths

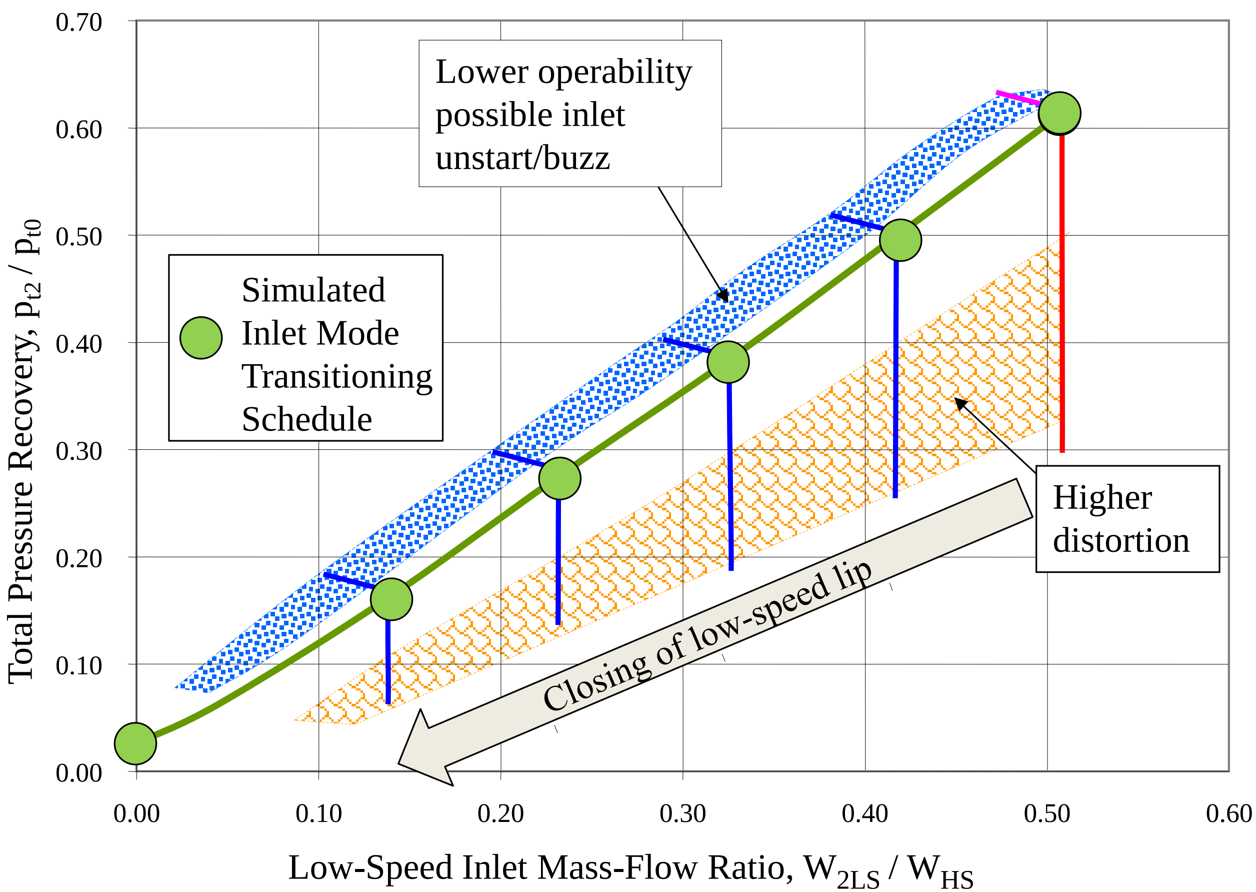


Inlet Mode Transition Sequence

- **Primary Objective:** Demonstrate inlet mode transition at Mach 4.0 within about 5 seconds.
- Low-speed cowl rotates from open to closed.



- Maintain stable operation with high-performance in both flowpaths.
- Total pressure recovery goal is 64% (minimum of 57%).
- Low-speed cowl rotation signals other variable geometry elements to move:
  - ramp
  - high-speed cowl
  - mass flow plugs
- A secondary goal will be to demonstrate inlet mode transition at Mach 3.

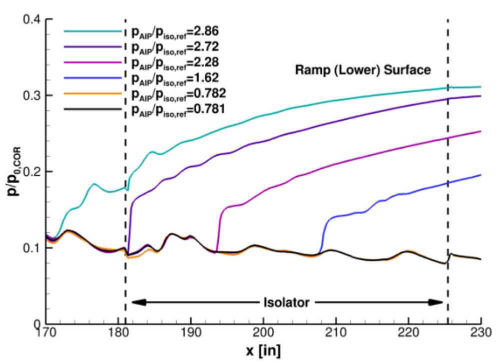


LIMX CFD Effort

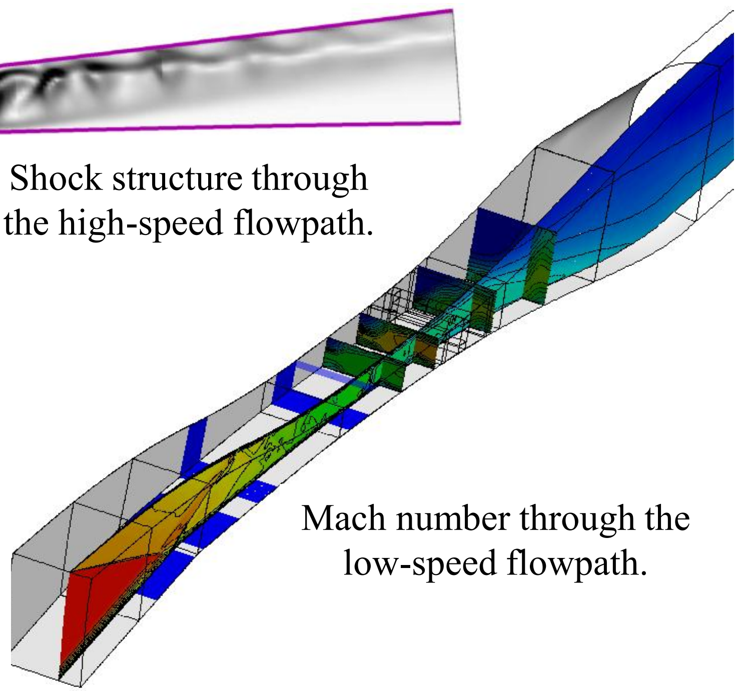
Objectives of CCE LIMX CFD Analyses:

- Characterize the turbulent boundary layers and shock waves within the low and high-speed flowpaths under back-pressure.
- Evaluate performance of the low-speed flowpath as characterized by bleed and engine flow rates and total pressure recovery.
- Evaluate the total pressure distortion at the turbofan face.
- Evaluate the effectiveness of porous bleed and vortex generators.
- Explore sensitivities to variations in low-speed ramp angle and back-pressure for development of inlet controls.

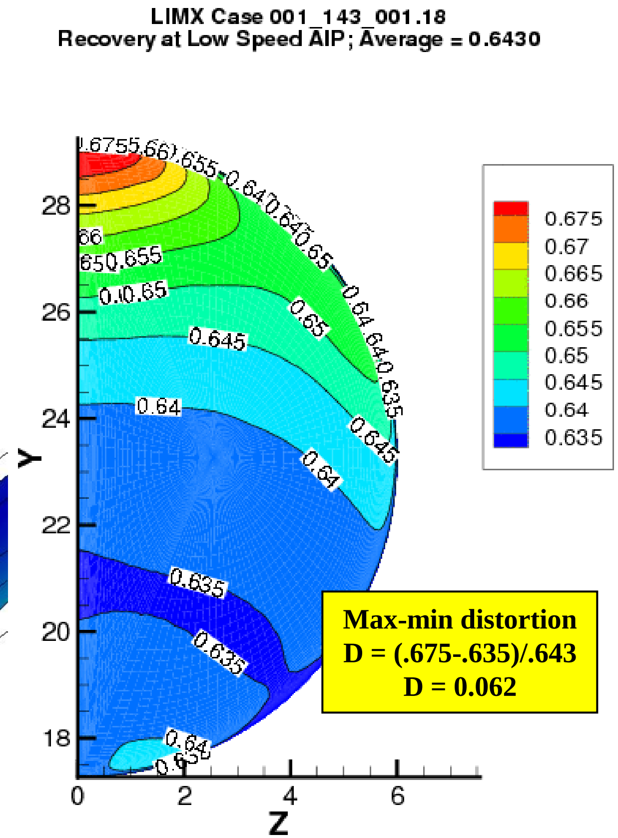
Shock structure through the high-speed flowpath.



Variation in static pressure with back-pressure in the high-speed flowpath.



Mach number through the low-speed flowpath.

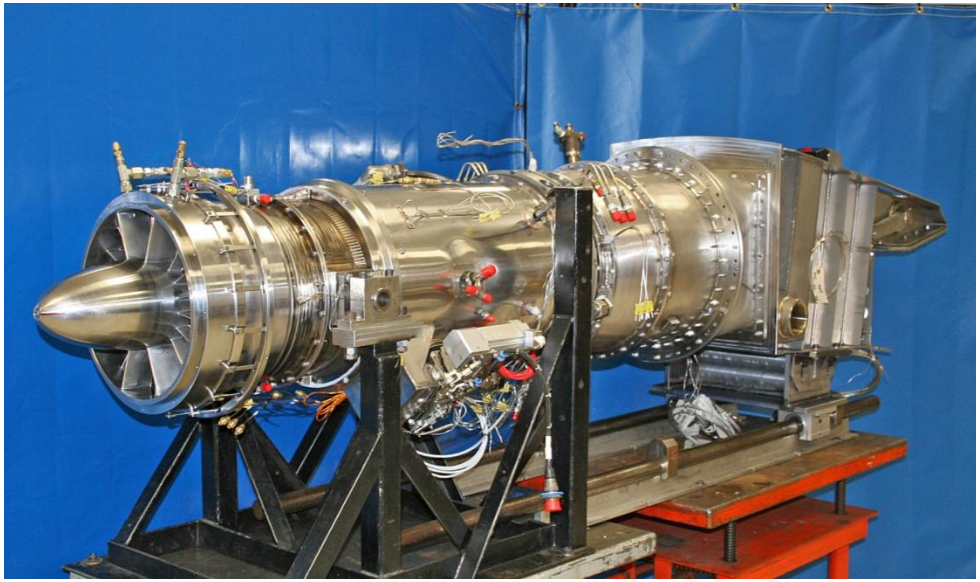


AIP flow field for Basic VG Configuration

Total pressure distortion at the engine face.

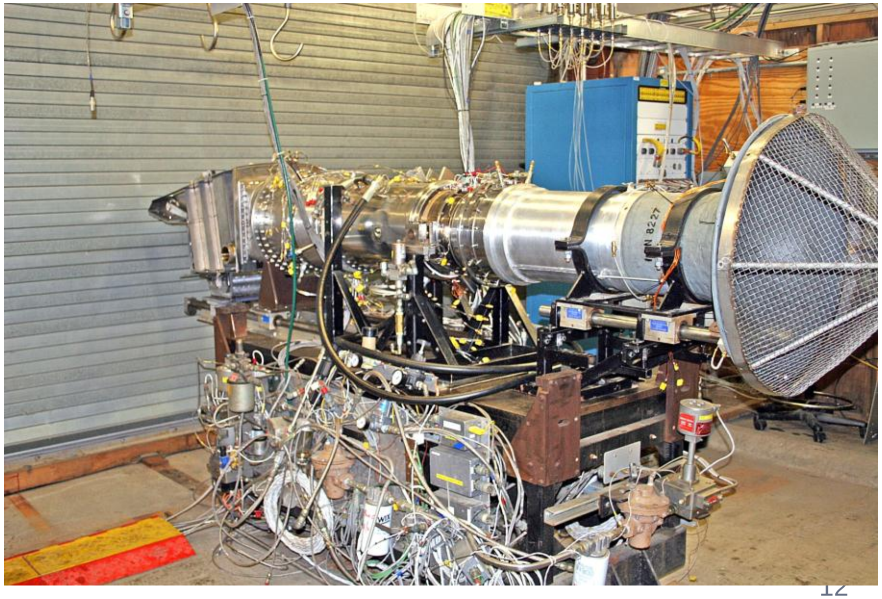
High Mach Turbine Engine Development

- **Expanded operational envelope**
  - ✓ Modified subsonic production engine upgraded for CCE LIMX Test Program
  - ✓ Mach 3 capable (Base engine M 0.9)
  - ✓ New distortion tolerant fan stage, bypass duct, liners, high specific flow fan and IGV
  - ✓ All new hardware downstream of turbine (AB design from IR&D program)

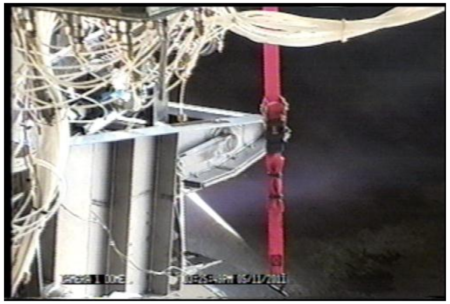


- **Completed Checkout (SLS) testing At WI**
  - ✓ Core engine - June 2010 & May 2011
  - ✓ Full AB, SERN (Nozzle) - May 2011

- **Engine Delivered to NASA August 2, 2011**



- **Phase 4- CCE TBCC integrated inlet / engine Test in FY 2014/15 (Partnership Required)**



TBCC Propulsion System Mode Transition

Phase I testing March 7 – June 17, 2011

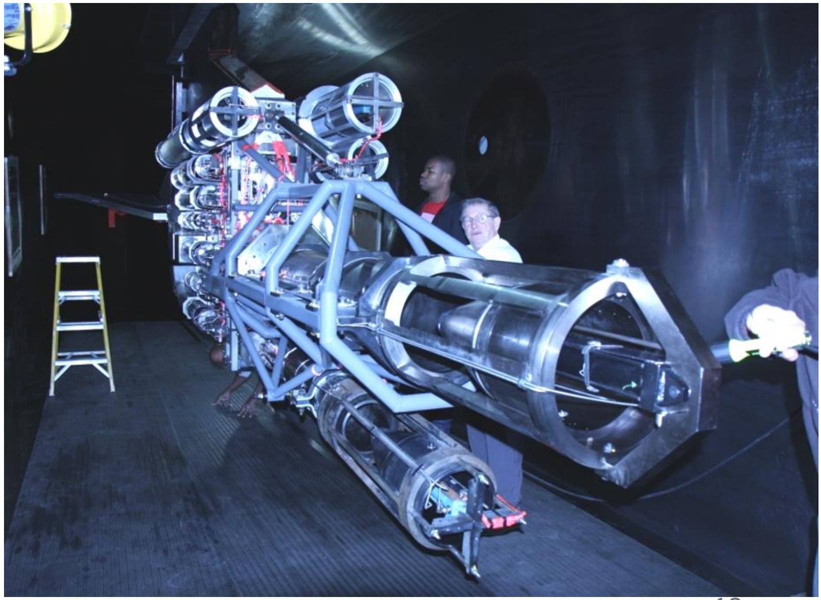
- A series of “cane curves” were generated which serve to outline operating limits and define performance at Mach 4, Mach 3 (abbreviated), and Mach 2 (limited)
- (Open Loop) Mode transition sequences were demonstrated at Mach 4 and 3.
- ***Overall achieved phase 1 critical objectives.***

Phase II testing August 29 – October 19, 2011

- Systems Identification (Dynamics) Study
- 378 Experiments completed in 38.25 hours (11 test nights)
- ***Overall achieved phase 2 critical objectives.***

Testing resumed March 9, 2012 (through May 2012)

- Expanding database for both steady state and dynamic studies.
- Explore model parametrics over expanded operating range



Phases III & IV are planned but currently unfunded

- Controlled Mode transition demonstration FY14
- Controlled Mode transition demonstration with high Mach turbine installed FY15

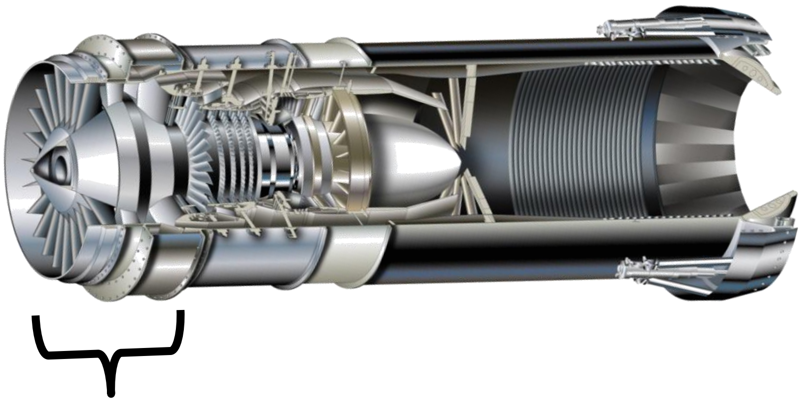
High Mach Fan Rig Testing
NASA W8 Compressor Facility

TBCC Fan Stage Operability and Performance

Fan Rotor Blisk

Inlet Distortion Screens

RTA: GE 57 / NASA Mach 4 capable TBCC Engine

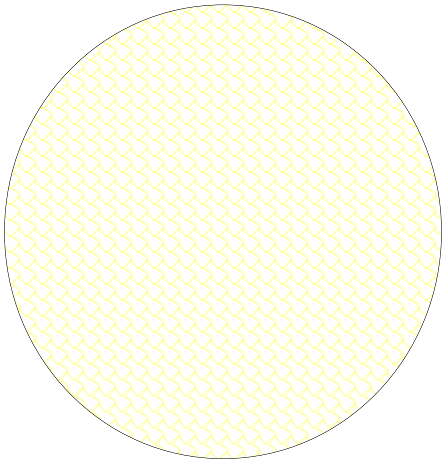


FAN STAGE = Rotor + OGV + Fan Frame Strut

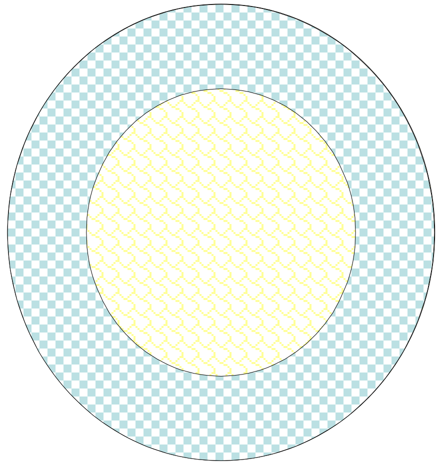
Approach:

- **Perform sub-scale testing of the NASA NGLT Program Mach 4 turbine engine fan stage in the NASA W8 high speed compressor facility.**
- **Predict performance & operability prior to test using SOA analysis tools.**
- **Map fan stage performance and measure stall line stability boundary over wide range of engine operation and compare to pre-test predictions.**
- **Incorporate inlet distortions and quantify performance & operability**
- **Assess the capability of SOA tools to predict results with flow distortions**
- **Utilize test article to understand physics and improve models.**

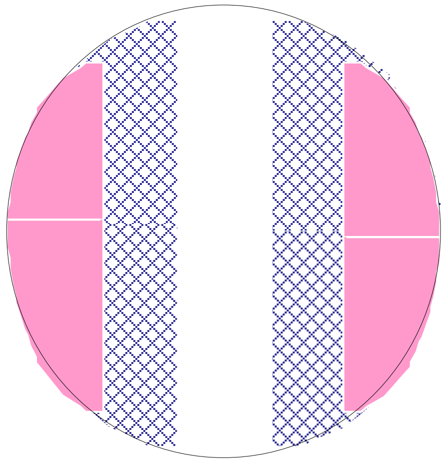
TBCC Fan Rig Test Distortion Screens



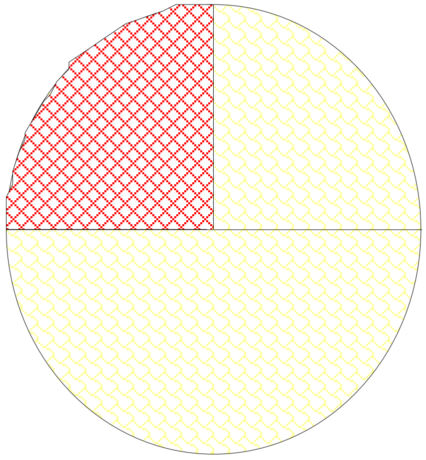
Uniform Flow



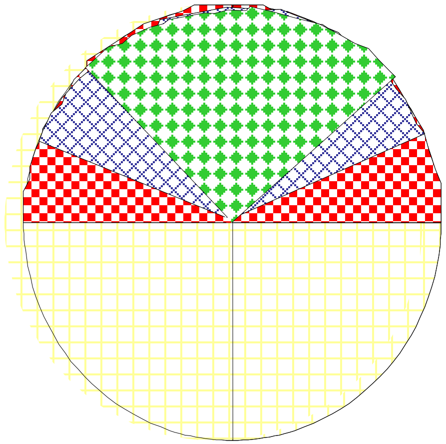
Distortion Screen #2
Circumferential



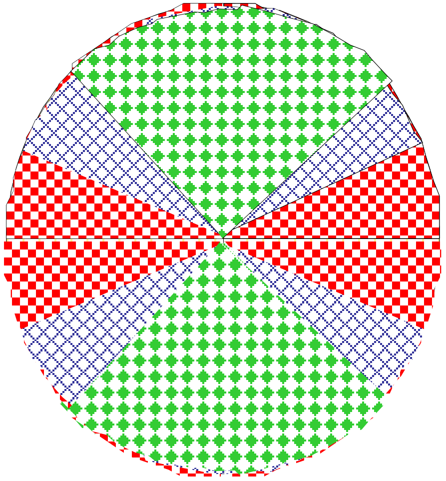
Distortion Screen #4
Based on CCE CFD #1



Distortion Screen #1
Sector



Distortion Screen #3
Sinusoidal

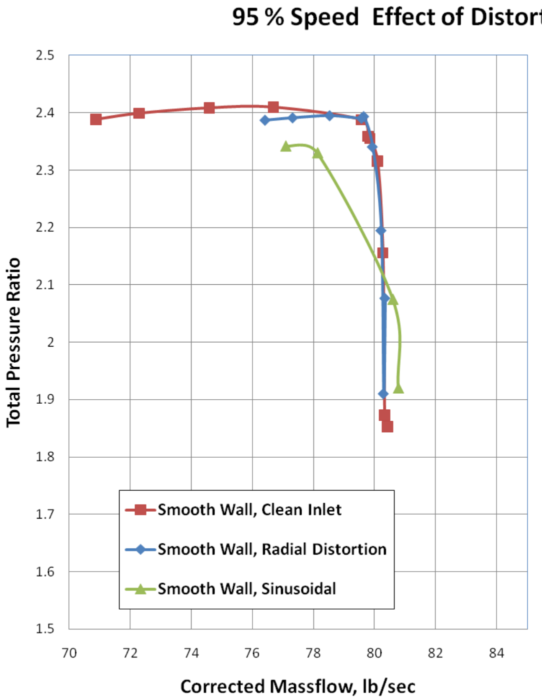


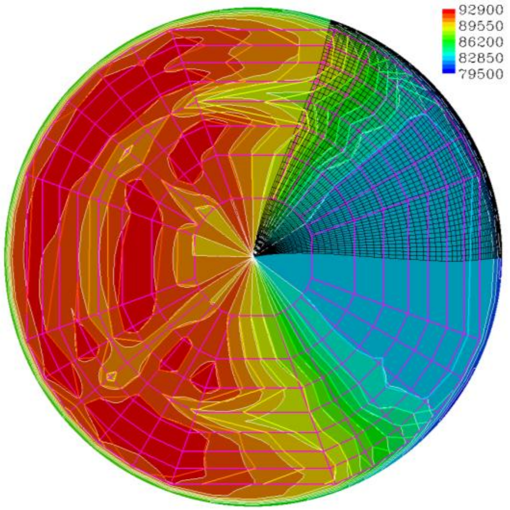
Distortion Screen #5
Based on CCE CFD #2

TBCC Fan Rig Operability and Inlet Distortion

- **Testing Concluded March 2011**
  - Uniform flow and 5 sets of distortion screens were used – average distortion ~10 -15%
  - Speed range: 15%, 37%, 50%, 60%, 70%, 80%, 90%, 95%, 100%
  - Unsteady full annulus stage calculations were done using the TURBO Code with and without distortion
  - Uniform flow or radial distortion calculations were done using the APNASA code

- **Overall Effort completed in FY11 (no FY12 resources)**
  - Initial results reported out at FAP 11
  - Computational analysis is near completion
  - Final post test analysis and reporting is in process
  - RTA fan stage disassembled put into long term storage





10% Deficit in Total Pressure

Concluding Remarks

- **Major Achievements Since Last FAP**

  - **CCE LIMX Phases I & II Testing completed for baseline configuration**
    - Additional testing is currently underway
    - Data processing and post test computational analysis is underway
    - **Mach 3 Capable Turbine Engine Checkout tests were completed and engine was delivered to NASA Glenn (modified WI WJ-38)**
      - Engine and associated hardware/ systems are in protective storage at the NASA 10'X10 SWT for use in future testing

  - **TBCC Fan Rig Testing Completed with Varying Flow Distortion Distributions in the NASA GRC W-8 Facility**
    - Final report being completed
    - Computational results being compared to this test data

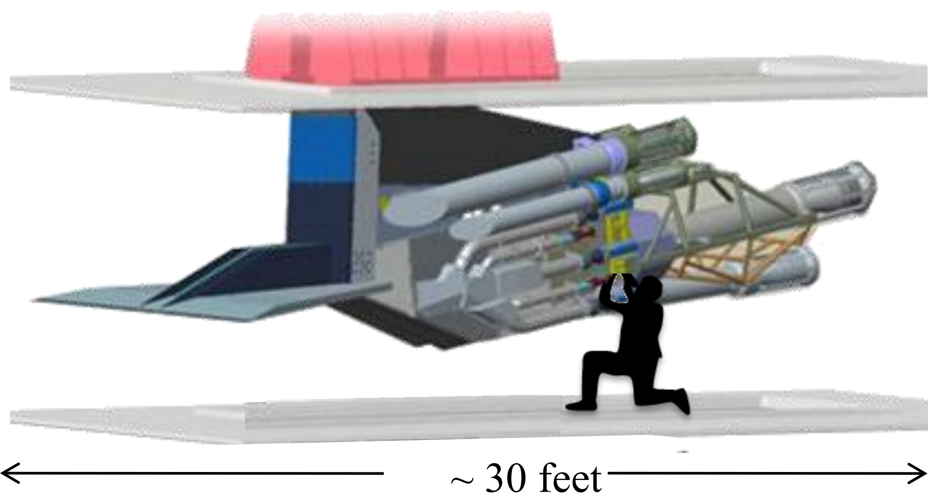
FY12 Key Deliverables and Future Plans

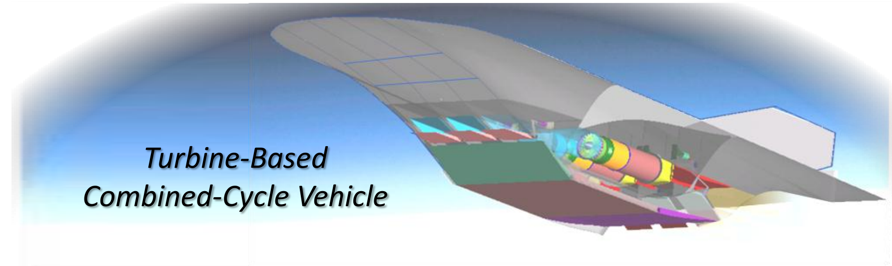
- **Large Scale Inlet Steady State Testing Completed (on and off design)**
- **Large Scale Inlet Dynamics Testing Completed (on and off design)**
- **Reporting out of results – papers planned for JPC (July 2012) and JANNAF (December 2012)**
- **FY14 – Large Scale Inlet Controlled Mode Transition Testing (Partnership Required)**
- **FY15 – Large Scale Inlet Controlled Mode Transition Testing with Turbine Engine (Partnership Required)**

- **Issues/ Concerns**
  - **Turbine Based Combined Cycle Propulsion activities will not be supported within the Hypersonics project beyond FY12 and any continuation of this work is currently unfunded.**

NASA

Combined Cycle Engine Large Scale Inlet Mode Transition Experiment (CCE LIMX) in the GRC 10x10 SWT





Testbed Features

- Variable Low Speed Cowl
- Variable High Speed cowl
- Variable Ramp
- Variable Compartmented Bleed (13)
- Low Speed Mass flow / Backpressure Device
- High Speed Mass flow / Backpressure Device
- Inlet Performance Instrumentation (~800)
- Engine Face: Flow Characteristics (AIP)

Test Approach - 4 Phases

1. Inlet performance and operability characterization, Mode Transition Sequencing
2. System Identification of inlet dynamics for controls
3. Demonstrate Control strategies for smooth & stable mode transition without inlet unstart
4. Add turbine engine/ nozzle for integrated system test with simulated Scramjet