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Flowpath Integration for Combined Cycle Propulsion Systems - Project Summary

Approval Review Copy

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June 9, 2010

Contract #: NNL08AA16B Task Order #: NNL08AB43T
NASA Langley with NASA Glenn Support
David Witte (NASA Langley) NASA NRA Technical Monitor

Agenda

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- **General Overview**
- **Technical Approach**
- **Technical Progress**
- **Future Plans**
- **Backup Material**

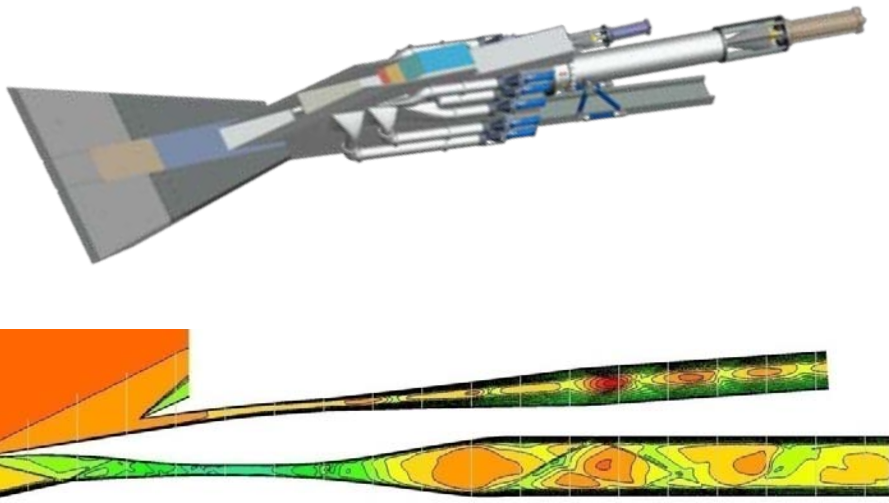
Geometries Used in the Project (Three Tasks, Two Geometries)

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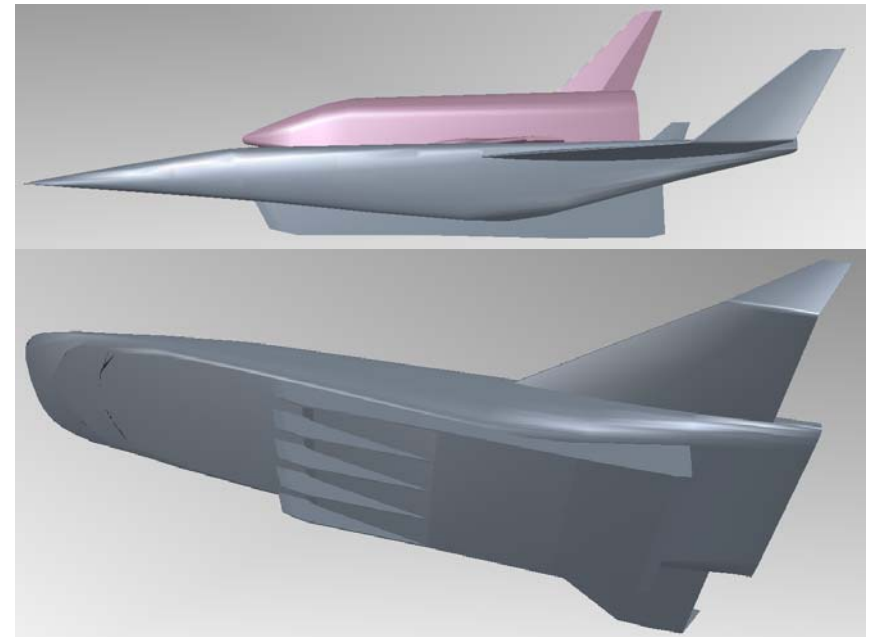
LIMX/IMX

- IMX (1x1) and LIMX (10x10)
Wind-tunnel Models
 - Task 1
 - Task 3



RALV

- RALV TBCC low-speed (turbine) and high-speed (scramjet) flowpaths
 - Task 2



Technical Approach & Task Descriptions (Three Tasks, Two Geometries)

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Task 1: Integrated Combined Cycle Analysis and Design Process Validation

- A combined cycle flowpath design supplied by NASA analyzed using CFD for prediction of wind-tunnel performance prior to test with CFD validation following test
- Schedule: March 2008 – Sept 2010
- Deliverables: CFD Analysis and Validation Plan, Flowpath Performance Database, Analysis and Process Validation Report

Task 2: Flowpath Multi-Disciplinary Optimization and Process Development

1. Develop and analyze the low-speed turbine flowpath for the HRRLS/RALV vehicle (Task 2 Add-On)
 - Schedule: March 2009 – March 2010
2. Conduct multi-disciplinary optimization of a combined cycle flowpath supplied by NASA
 - Schedule: October 2009 – September 2010
 - Deliverables: Flowpath Design and Performance Report, Recommended Design Process Report, Scripts, wrappers, and other software developed during the project.

Task 3: Control Loads Database Generation (Task 1 Add-On) (Completed 2009)

- Analyzed LIMX inlet for load calculation on the control surfaces for sizing of control actuators and generation of control laws
- Schedule: August 2008 – June 2009
- Deliverables: Control Loads Performance Database, Results Summary, and Supplemental Data Reduction

BCFD

- **Flow Solver**
 - BCFD (Boeing CFD)
 - Based on the NASA WIND/WIND-US Code
 - Boeing Proprietary Enhancements
 - Boeing Public Enhancements shared with the NPARC development community
 - 3-D Reynolds-Averaged Navier Stokes (RANS)
- **Grids**
 - Unstructured Tetrahedral
 - Rectangular Prism Boundary Layers
 - Roughly 15mil Cells Per Grid run on 24-96 Nodes/Cores per Job
- **Back-Pressure Method**
 - Ring of mass injection 45deg downstream creating virtual CD nozzle
- **Bleed Method**
 - Bleed per surface area
 - Plenum Bleed Model (bleed based on plenum pressure or exit area)
 - Developed by John Slater

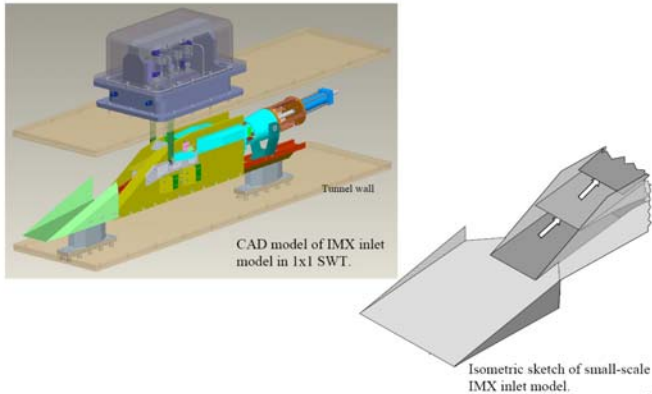
IMX (1'x1') and LIMX (10'x10') Geometries

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TechLand Research, Inc. Inlet Mode Transitioning for a Dual-Flow Turbine-Based Combined Cycle Hypersonic Propulsion System NASA GRC

Small-Scale Inlet Mode Transition (IMX) Model

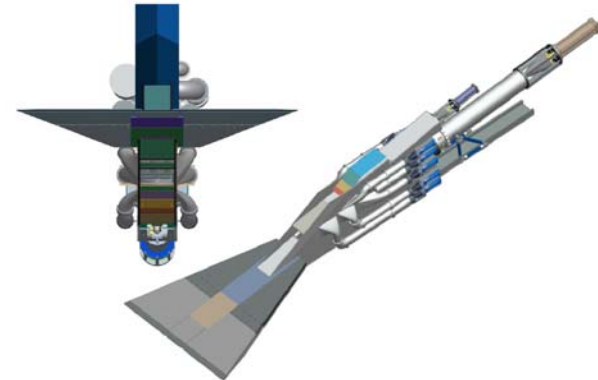


NASA Hypersonics Project NRA Review: San Antonio, TX: 24 January 2008

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TechLand Research, Inc. Inlet Mode Transitioning for a Dual-Flow Turbine-Based Combined Cycle Hypersonic Propulsion System NASA GRC

Large-Scale Inlet Mode Transition (LIMX) Model: CAD Solid Model Representations

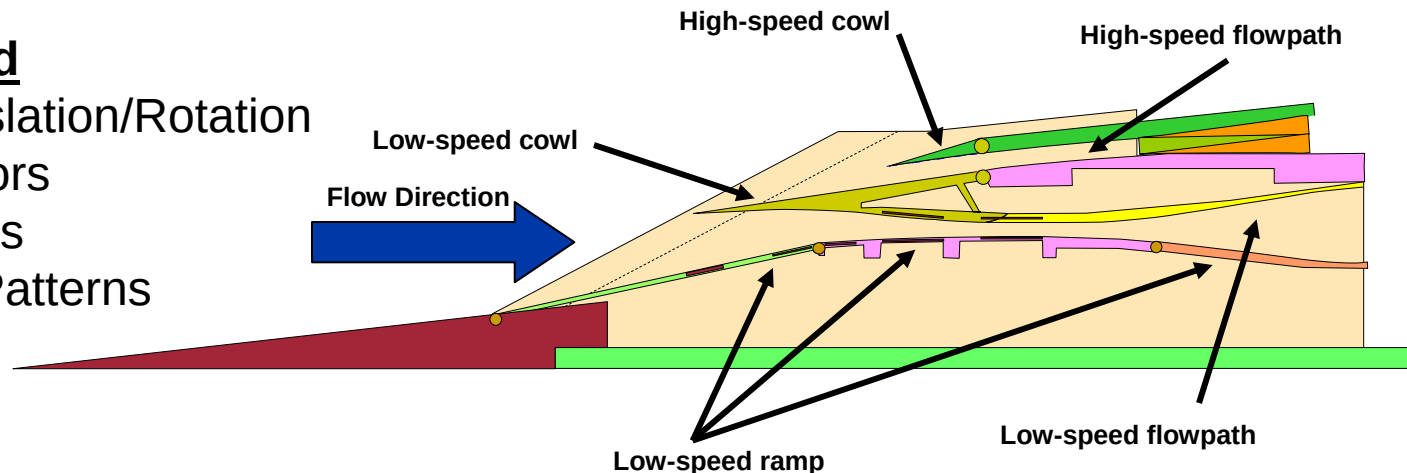


NASA Hypersonics Project NRA Review: San Antonio, TX: 24 January 2008

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Features Modeled

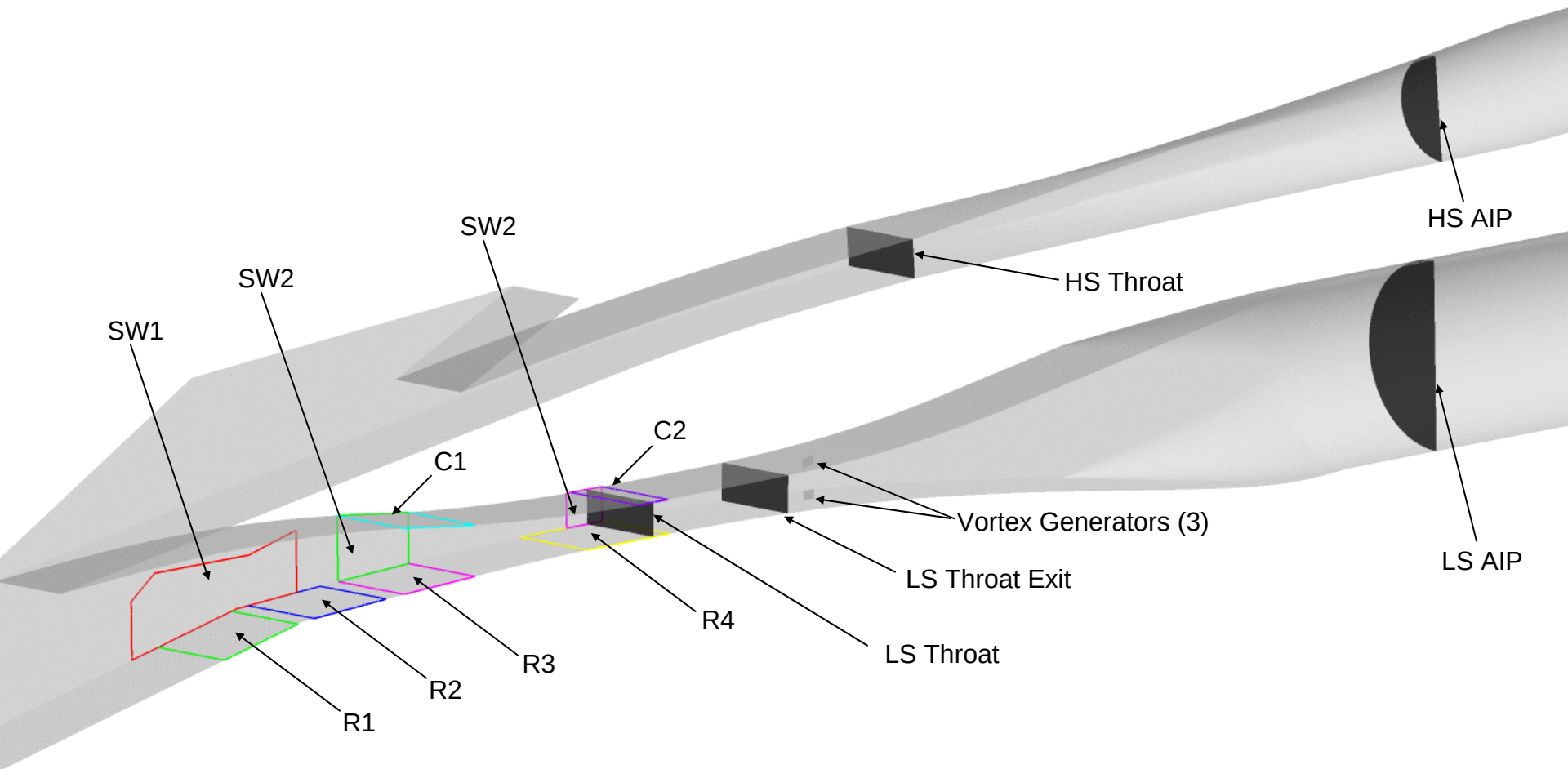
- Geometry Translation/Rotation
- Vortex Generators
- 9 Bleed Surfaces
- Multiple Bleed Patterns



IMX and LIMX Features of Interest

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Task 1: Automated Production of Performance Database

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Case Parameters

- Inlet Conditions/Configuration
- Tunnel Conditions

Local Flow Conditions

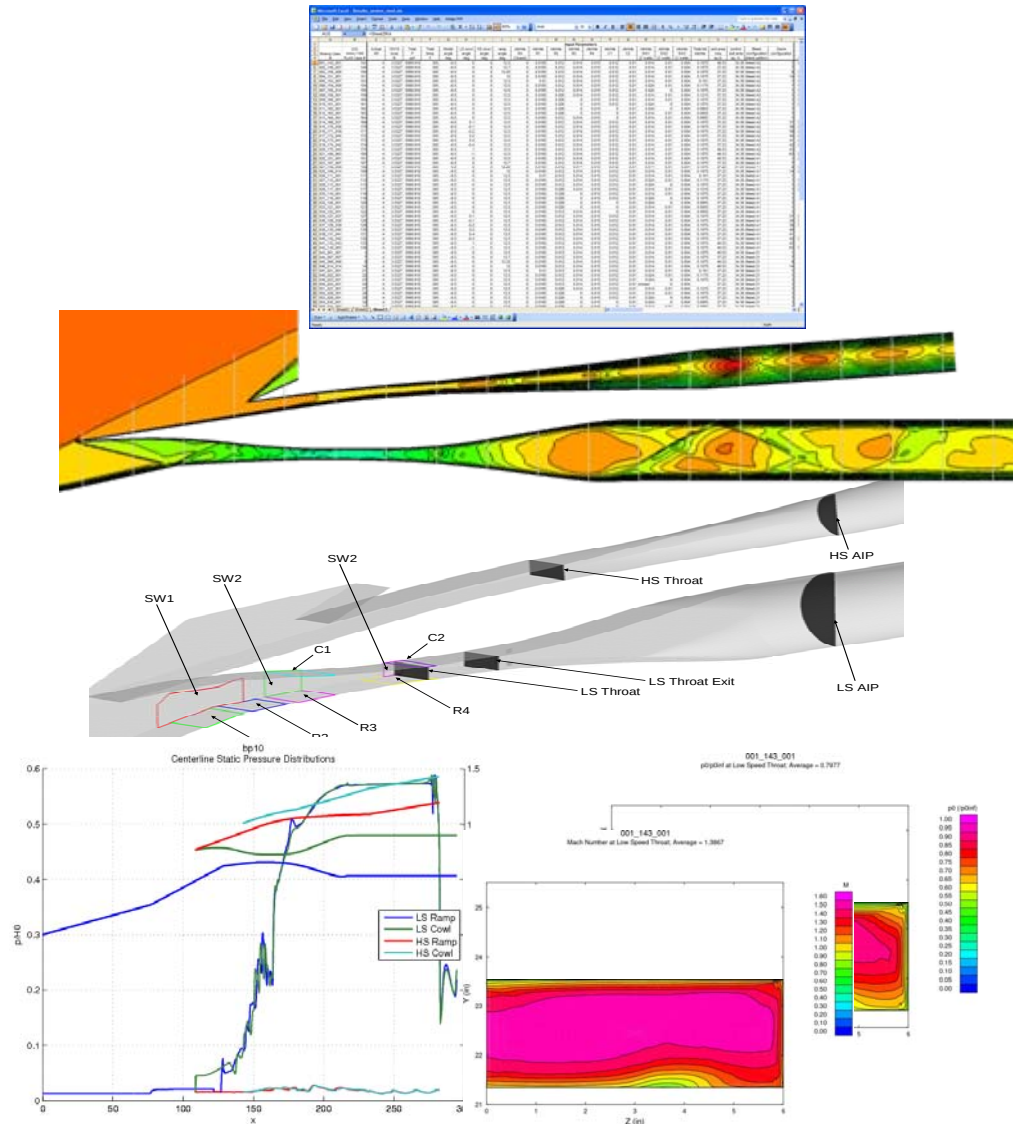
- Local Mach Number
- Local Mass Flow Rate
- Local Total Pressure Recovery

Location Based Parameters

- Blowing Rates (for Backpressuring)
- Bleed Rates
- Outflow Mass Flow Rates
- Forces/Moments Integration

Plots

- Streamwise Mach and Pressure Recovery Contours
- Spanwise Mach and Pressure Recovery Contours
- Centerline Surface Static Pressure



Year 3 Progress: Where we were last year

Task 1: Combined Cycle Analysis

- **Flowpath Performance Database Completed**
- **Pre-Test CFD Continues:**
 - **Alternate Bleed Patterns**
 - **Alternate Vortex Generator Patterns**
 - **Alternate Bleed Levels**
 - **High Speed Backpressure Runs**
 - **High Speed Flap Position**

Task 2

- **HS Inlet Design developed by NASA**
- **LS Inlet Design being developed by Boeing**
- **Planning for Combined Cycle Flowpath Optimization**

Task 3

- **Completed LIMX Control Loads Characterization for NASA**

Progress Since October 2009

Task 1

- **Additional prioritized pre-test CFD for LIMX test**
 - **Supported refinement of bleed patterns for test matrix**
- **Prepared presentation for the JANNAF Distortion Workshop in December 2009**
 - **“Propulsion Integration Considerations for TBCC Distortion - Previous and Current Projects”**

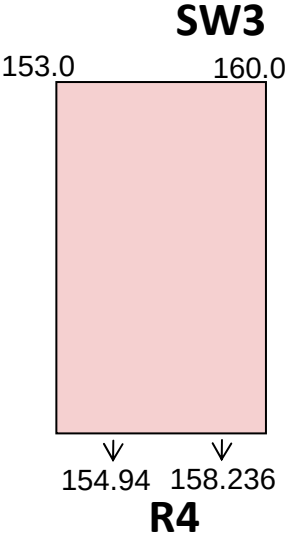
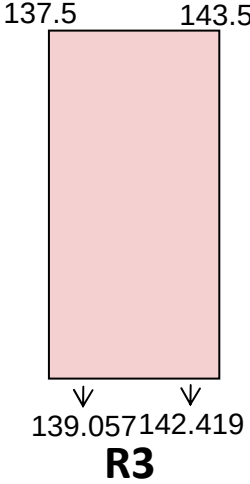
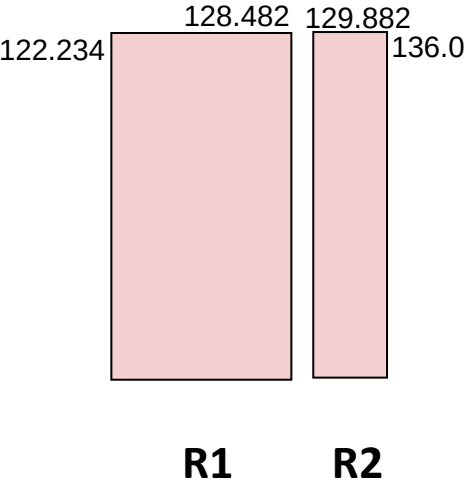
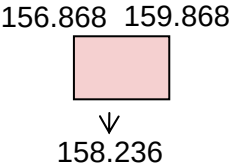
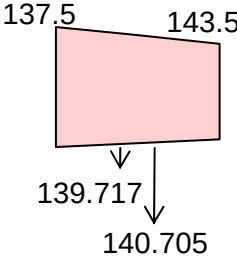
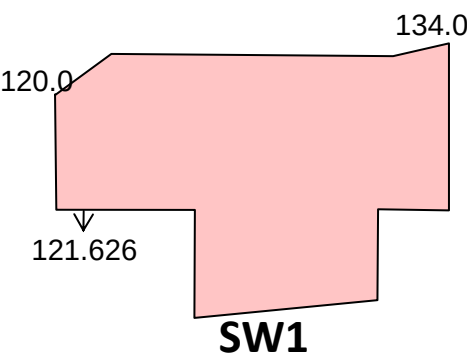
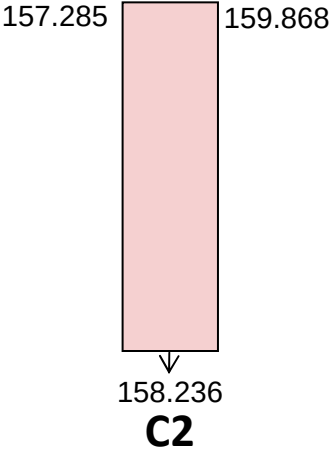
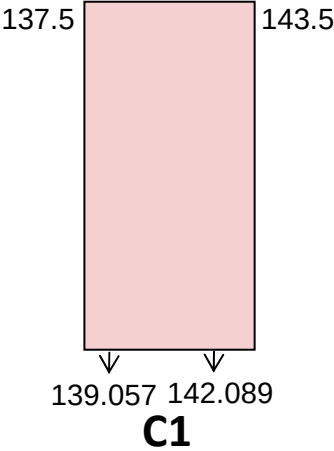
Task 2

- **Received RALV High Speed Flowpath from NASA**
- **Developed RALV Low Speed Flowpath (Deliverable)**
- **Developed RALV Low Speed Flowpath Performance (Deliverable)**
- **Developed plan for RALV flowpath optimization**
- **Began geometry parametrics on RALV flowpath using 2-D and 3-D CFD tools and models**

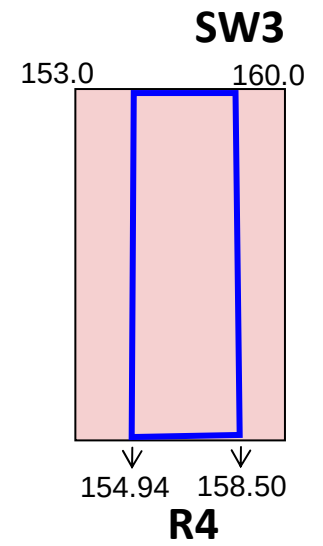
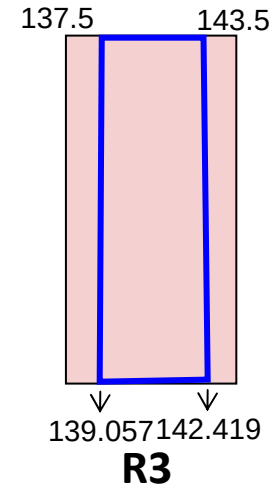
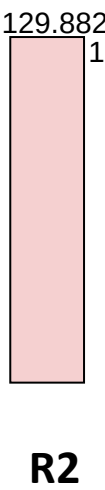
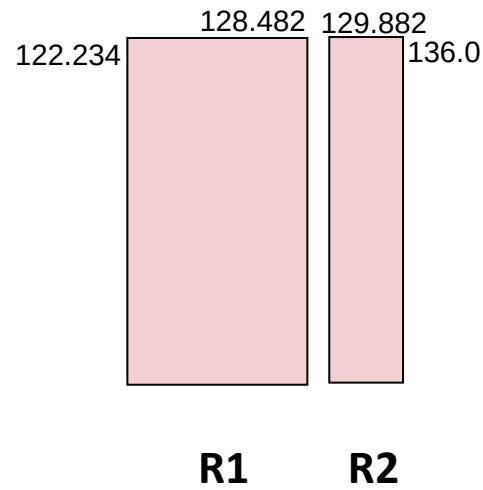
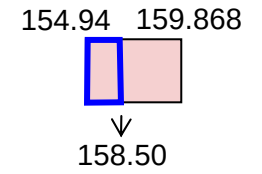
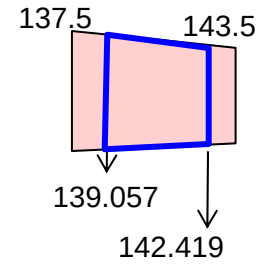
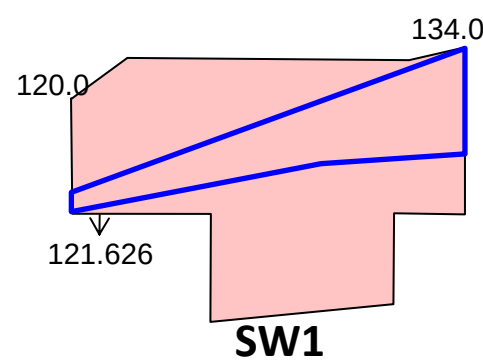
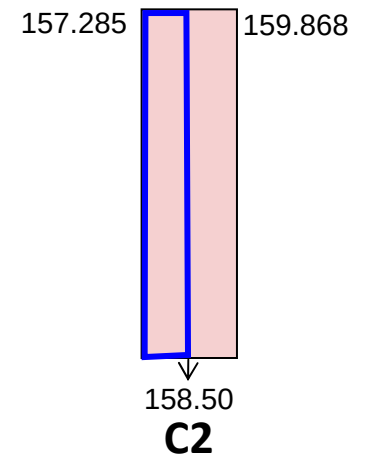
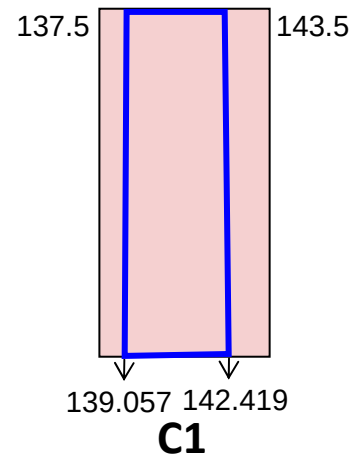
Task 1 – LIMX Bleed Zone Refinement (A7 Bleed Pattern)

- **A7 Bleed Pattern needed for sealing LS cowl when fully closed**
 - Does not extend SW1 surface into HS flowpath when LS cowl is fully closed
- **Comparison with A2 bleed pattern showed favorable comparison**
- **Similar results to A2 bleed pattern results**

LIMX A2



LIMX A7



Task 2 – Optimization Plan

- **Conduct analysis at Mach 1.25 and Mach 3.5 to address two most critical modes (transonic pinch & transition)**
- **Focus on low speed geometry - freeze high speed flowpath geometry (allow to follow schedule vs. Mach)**
- **Figures of merit (FOM's)**
 - Inlet recovery, distortion
 - Nozzle CFG
 - Flowpath thrust - drag
 - Required rocket thrust at $M=1.25$ to maintain 0.2 g's axial acceleration
- **Parametrics**
 - **Mach 1.25 Parametrics**
 - High speed flowpath open, mid., and closed
 - External burning vs. ramjet operation vs. no burning
 - AOA 0, 5, 10 deg
 - **Mach 3.5 Parametrics**
 - AOA 0, 5, 10 deg
 - Flap position to close the turbine (& high speed cowl and flap)
 - **Low Speed Inlet Geometry Parametrics**
 - Diffuser area distribution
 - "Line of death" – slide inlet down
 - Total bleed flow rate
 - **Low Speed Nozzle Geometry Parametrics**
 - Nozzle flap length & geometry
 - "Line of death" – slide nozzle down



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NASA Hypersonic NRA on Combined Cycle Propulsion (CCP)

LOW-SPEED PROPULSION SYSTEM DEVELOPMENT/INTEGRATION

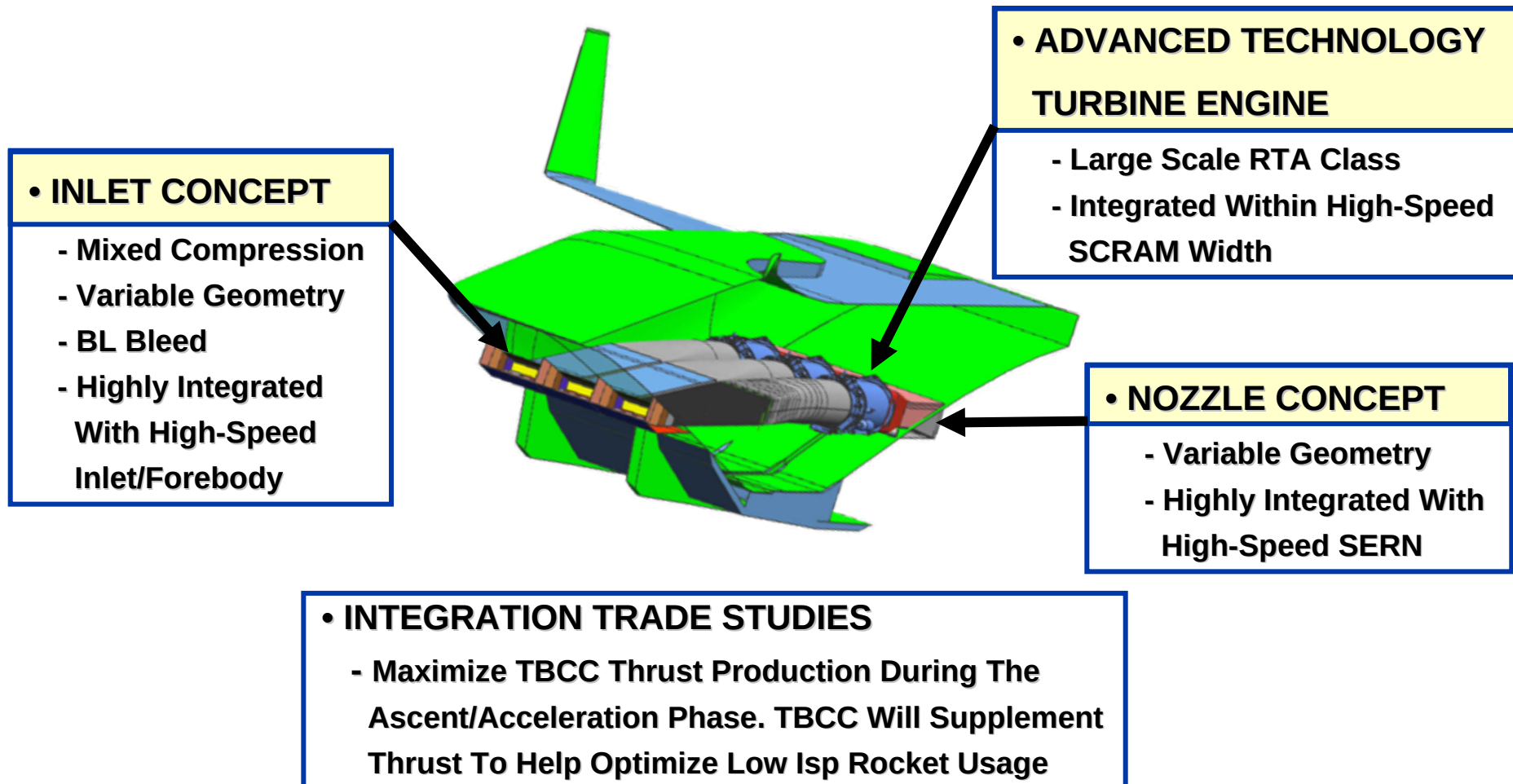
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LOW-SPEED SYSTEM DEVELOPMENT / INTEGRATION

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- **OBJECTIVE :** *ESTABLISH A TURBINE-BASED COMBINED CYCLE (TBCC) LOW-SPEED SYSTEM CONCEPT FOR NASA TSTO-2009B-oml2 VEHICLE*

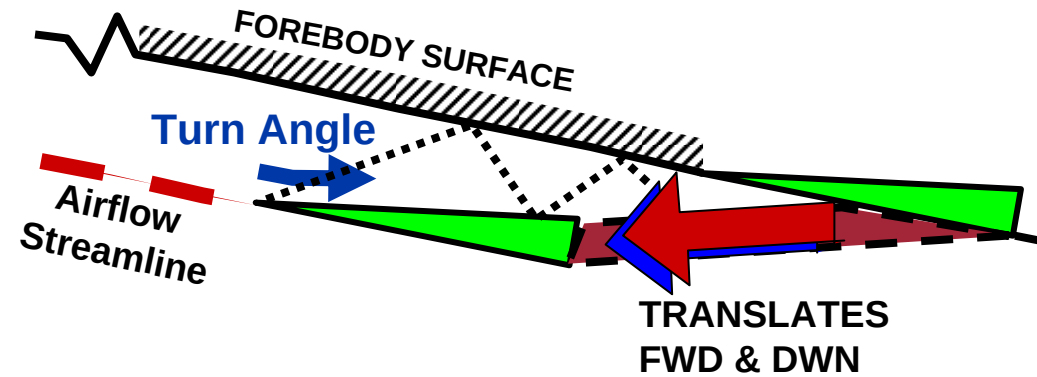


LOW-SPEED PROPULSION DESIGN/INTEGRATION

INLET CONCEPT

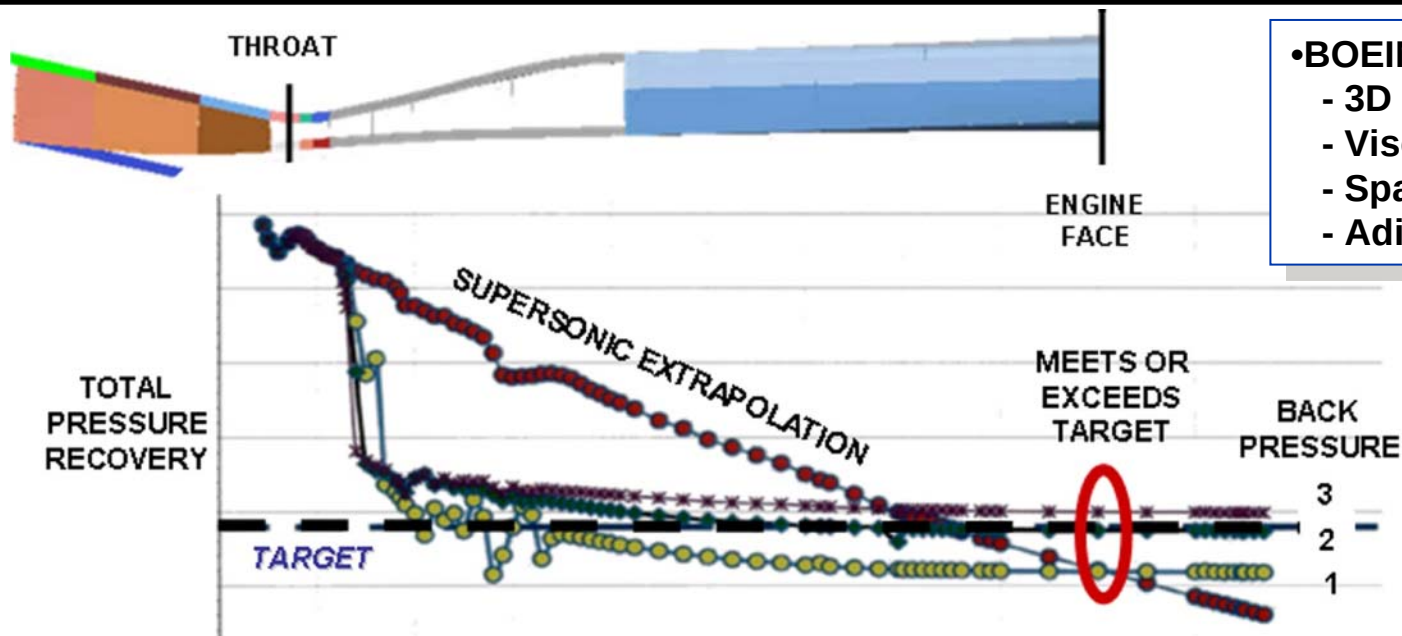
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• TRANSLATING SCOOP INLET

- INTEGRAL PART OF FOREBODY TRANSLATES FWD AND DWN TO CAPTURE AIRFLOW
- MAINTAINS LOW INFLOW TURN ANGLE TO MINIMIZE STRENGTH OF SHOCK GOING INSIDE
- NO ROTATING FLAPS



• BOEING BCFD

- 3D unstructured grid
- Viscous
- Spalart Turbulence
- Adiabatic

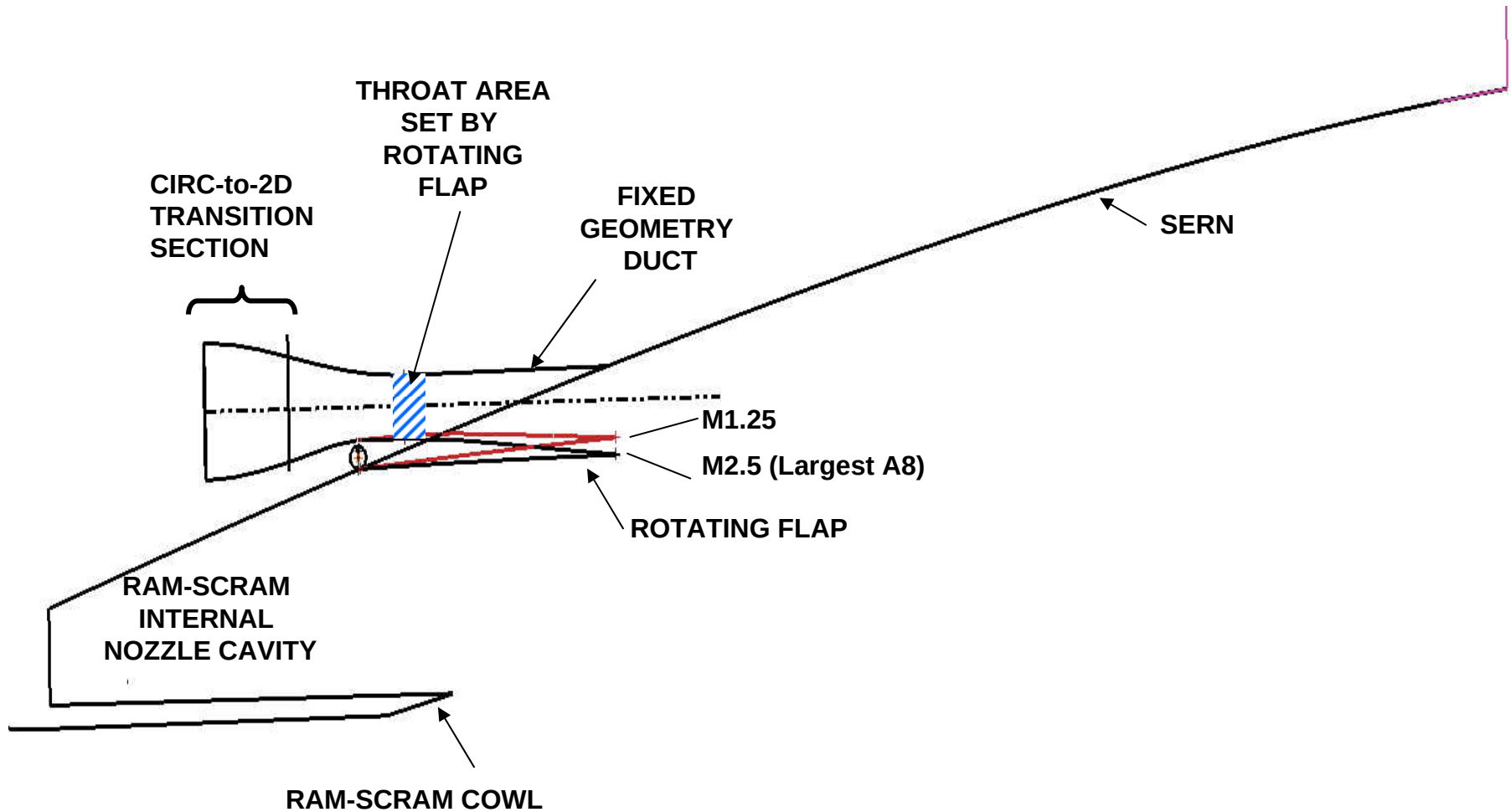
INLET CONCEPT ESTABLISHED, 3D CFD CHARACTERIZATION IN PROGRESS

LOW-SPEED PROPULSION DESIGN/INTEGRATION

NOZZLE CONCEPT

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NOZZLE CONCEPT ESTABLISHED, 3D CFD CHARACTERIZATION PLANNED

LOW-SPEED SYSTEM – RAM/SCRAM INTERACTION

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• OBJECTIVE:

- DETERMINE INTERACTIONS BETWEEN OPERATIONAL TBCC SYSTEM AND FUEL-OFF RAM/SCRAM IN VARIOUS FLOW-THRU FLOWPATH MODES

• APPROACH:

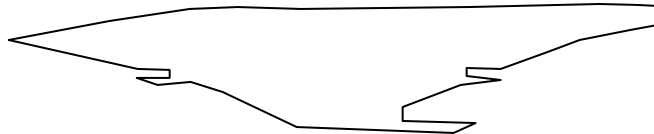
- INTEGRATE BOEING BCFD 2D SOLUTIONS TO DETERMINE DELTA NET FORCES ON VEHICLE DUE TO VARIOUS CONFIGURATIONS

- TJ ON
- TJ INLET/NOZZLE OPEN
- R/S OFF
- R/S INLET CLOSED
- R/S NOZZLE OPEN

- TJ ON
- TJ INLET/NOZZLE OPEN
- R/S OFF
- R/S INLET OPEN
- R/S NOZZLE OPEN

- TJ ON
- TJ INLET/NOZZLE OPEN
- R/S OFF
- R/S INLET MID OPEN
- R/S NOZZLE OPEN

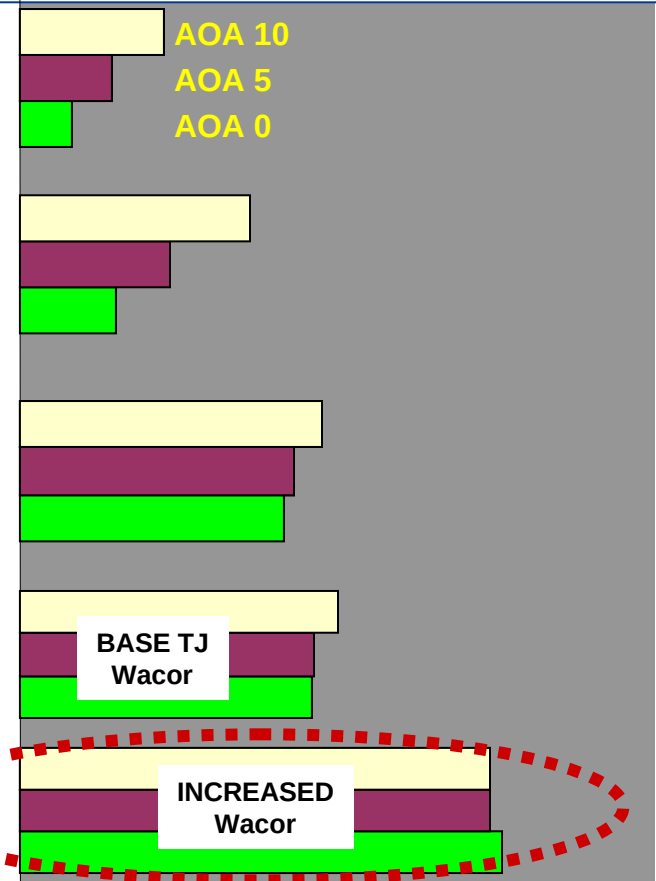
- TJ ON
- TJ INLET/NOZZLE OPEN
- R/S OFF
- R/S INLET MID OPEN
- R/S NOZZLE MID OPEN



PREFERRED

BEST

%Δ REDUCTION IN VEHICLE UNDERSIDE DRAG



LOW-SPEED INLET /NOZZLE POSITION PARAMETRIC

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- TJ ON
- TJ INLET/NOZZLE OPEN
- R/S OFF
- R/S INLET MID OPEN
- R/S NOZZLE MID OPEN

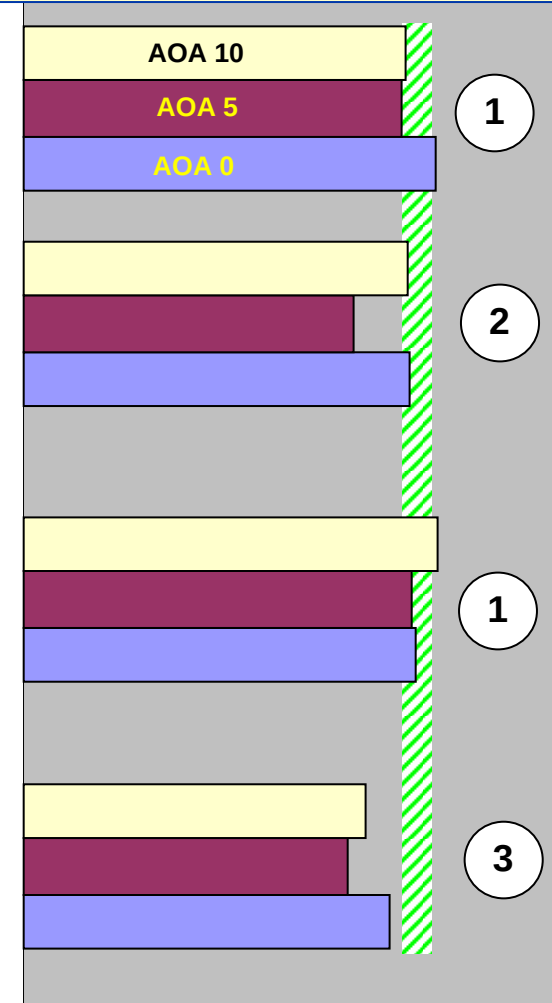
"PREFERED" FROM R/S INTERACTION STUDY

- RELOCATED INLET BELOW LOD

- RELOCATED INLET AND NOZZLE BELOW LOD

- RELOCATED INLET AND NOZZLE BELOW LOD
+
RS NOZZLE FULL OPEN

%Δ REDUCTION IN VEHICLE UNDERSIDE DRAG

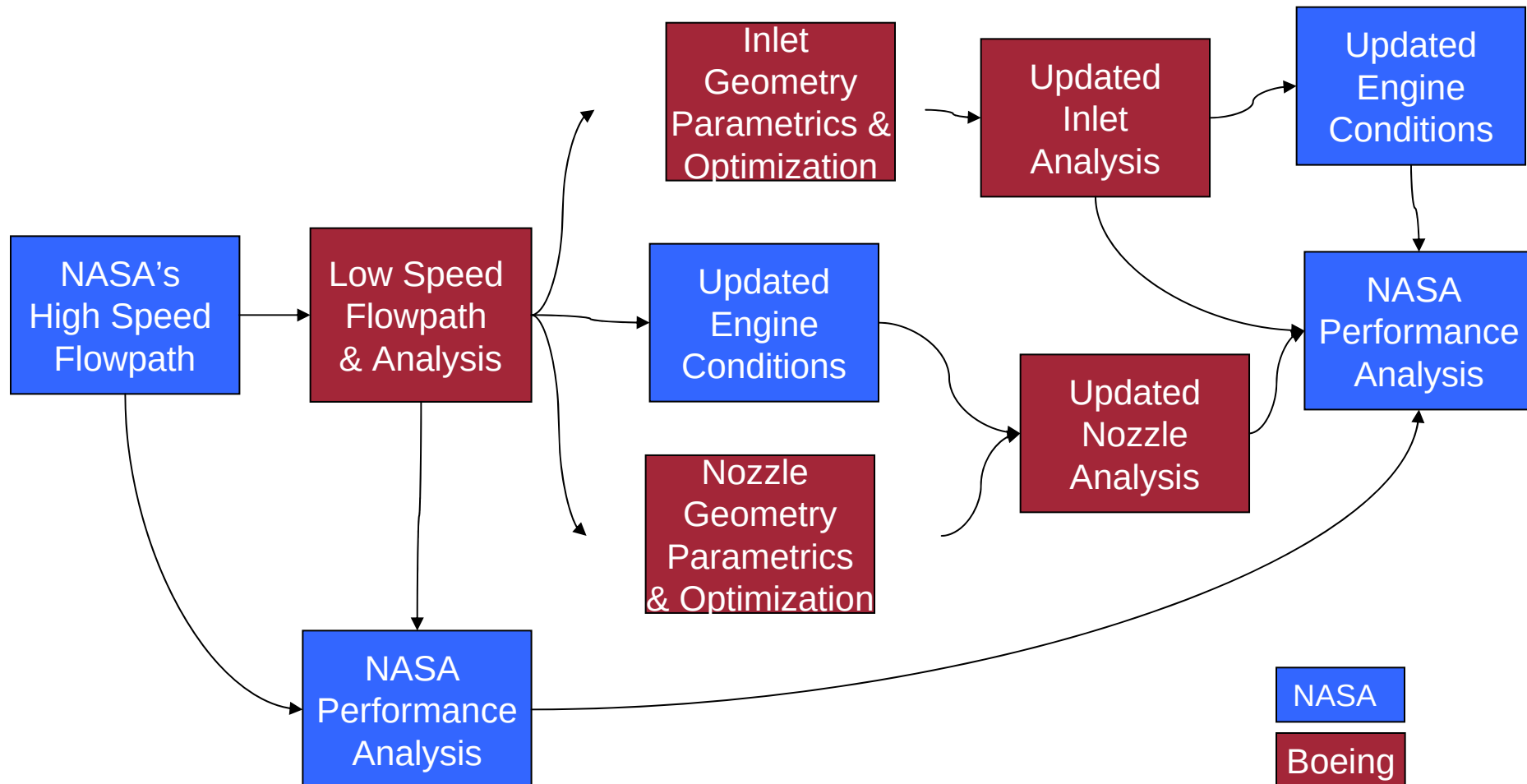


"PREFERED" OPTION STILL No. 1 CHOICE

Task 2 Optimization – Subtask Flow

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Task 1

- **Receipt of LIMX test results**
- **Comparison to LIMX test results**
- **Deliverable: Analysis and Process Validation Report**
- **Will require no-cost contract extension past Sept 2010**

Task 2

- **Complete geometry and operating mode parametrics and optimize RALV flowpath using 3-D CFD tools and engine models**
- **Deliverable: Flowpath Design and Performance Report**



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Backup Slides

General Overview:

Flowpath Integration for Combined Cycle Propulsion Systems

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- Hypersonic propulsion is needed for efficient, low-cost space access and faster global transportation
- One key problem is how to make a high-speed engine operate at low speeds (Mach 0-3+)
- Combined Cycle Propulsion takes a low-speed engine and a high-speed engine and forms a propulsion system that changes from one to another during a transition process that depends on vehicle speed
- The details of this transition process are not well defined, understood, or optimized
- This Project, “*Flowpath Integration for Combined Cycle Propulsion Systems*” develops and validates Computational Fluid Dynamics (CFD) processes against wind-tunnel tests to understand the interaction of the two engine flowpaths during transition. This process will then be used to predict and optimize engine performance on future hypersonic combined cycle propulsion systems.

Objectives and Milestones Supported

Objectives

- **Develop high fidelity, highly integrated design, analysis, and modeling capabilities, including their validation, for hypersonic turbine-based combined cycle (TBCC) systems**
- **Develop a turbine-based low-speed propulsion baseline design for a NASA TBCC vehicle**
- **Develop and apply a multi-disciplinary analysis & optimization (MDAO) process to a NASA TBCC design**

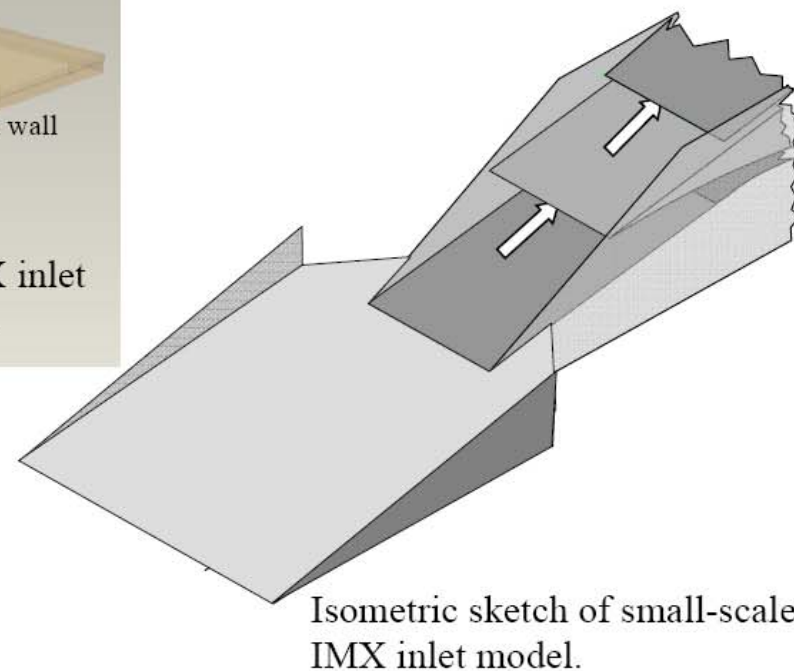
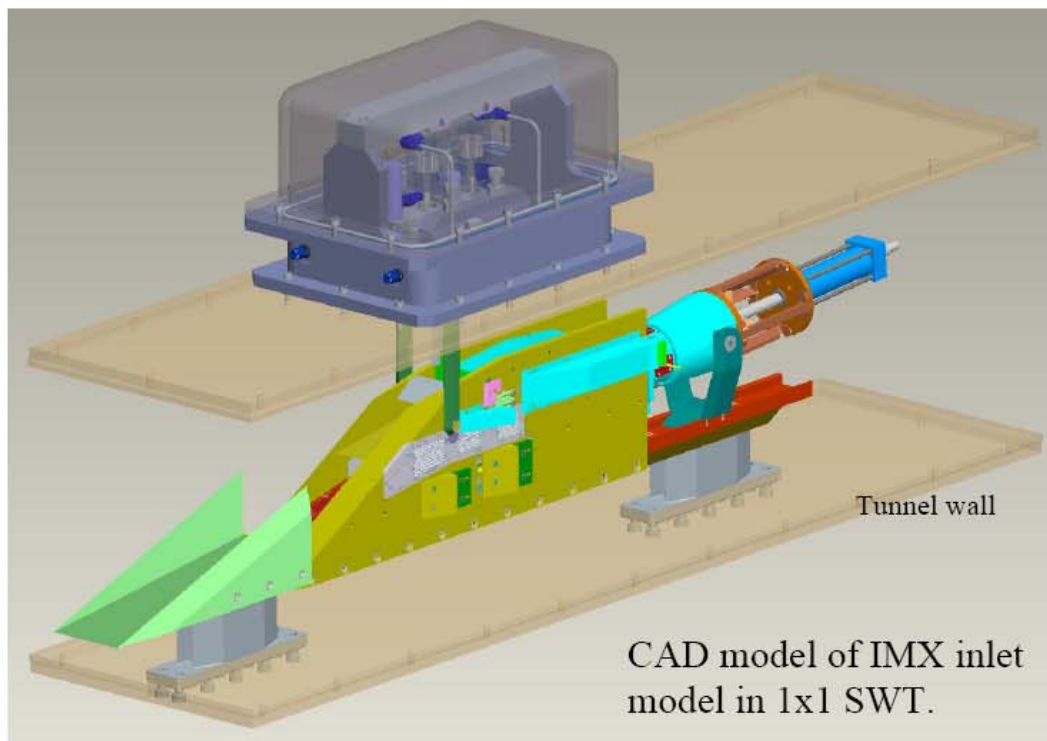
Milestones Supported

- **HYP.3.01.29 Propulsion System Design for TBCC TSTO HRRLS/RALV mission**
- **HYP.4.01.10 Improved Methods/Tools**
- **HYP.4.01.19 Tool and Method Review**
- **HYP.4.01.12 PB-MDAO Integrated Capability**
- **HYP.2.02.P3 TBCC Performance Assessment**
- **HYP.1.02.49 Three-Dimensional Inlet Modeling**

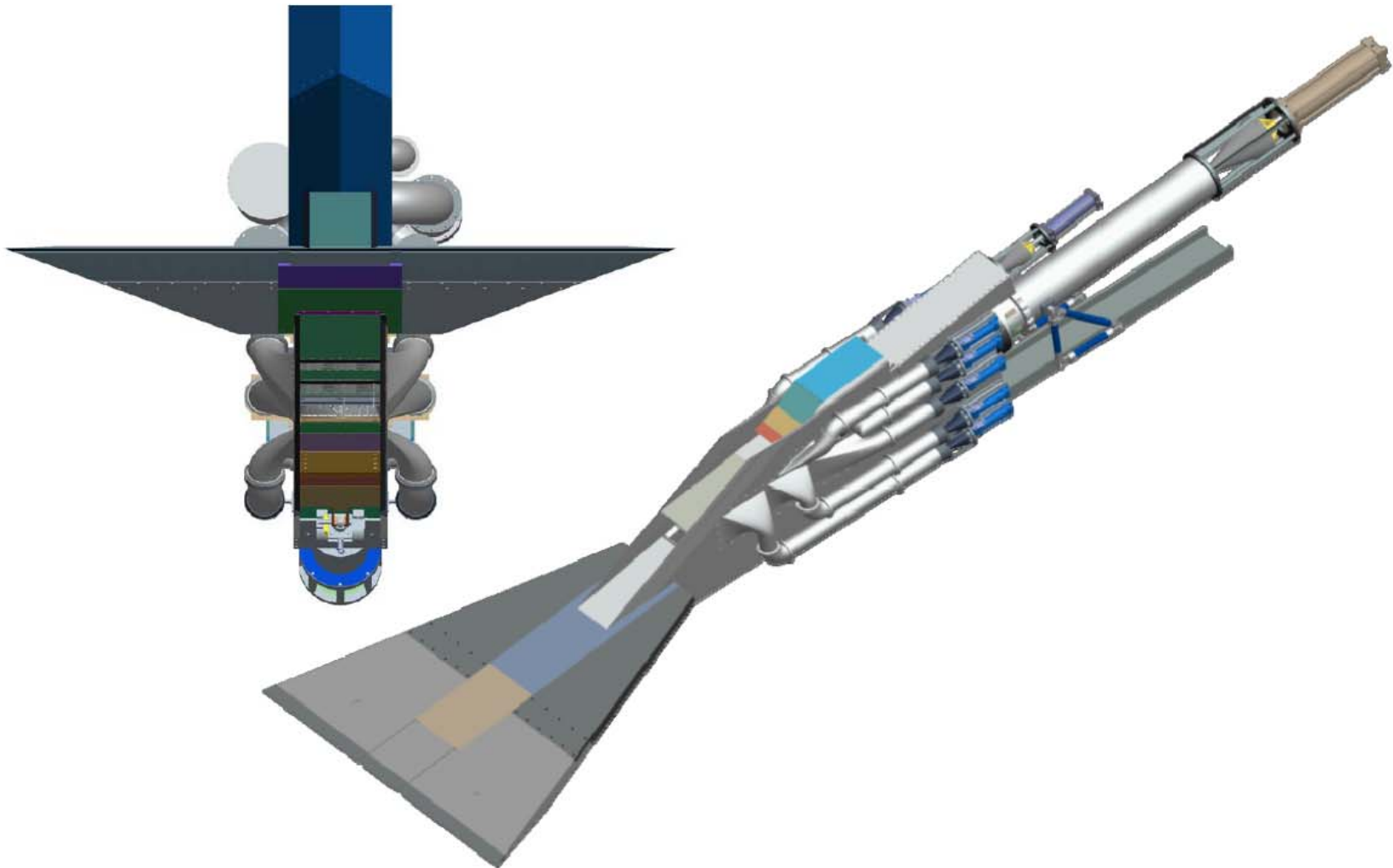
Partners

- **NASA Langley Research Center**
- **NASA Glenn Research Center**
- **NASA Ames RTJONES Supercomputer Cluster**
- **TechLand Research Inc. (Related NRA on TBCC inlet testing)**
- **SPIRITECH Advanced Products Inc. (Related NRA on TBCC flowpath modeling)**

Small-Scale Inlet Mode Transition (IMX) Model



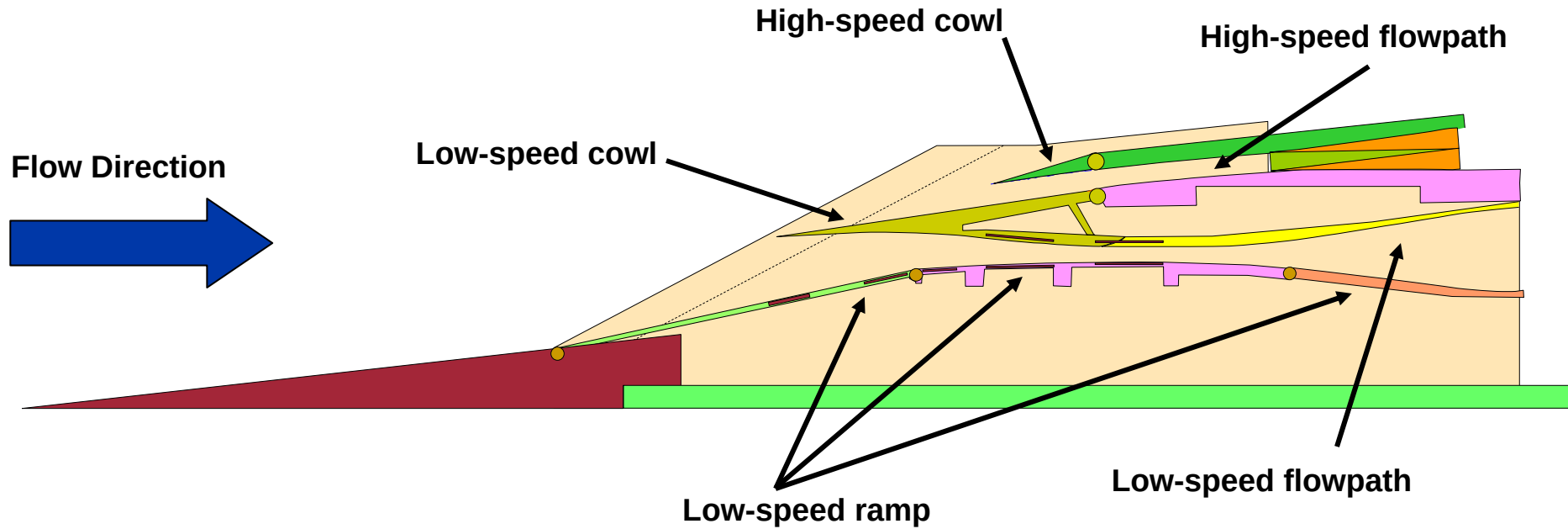
Large-Scale Inlet Mode Transition (LIMX) Model: CAD Solid Model Representations



LIMX Wind Tunnel Model

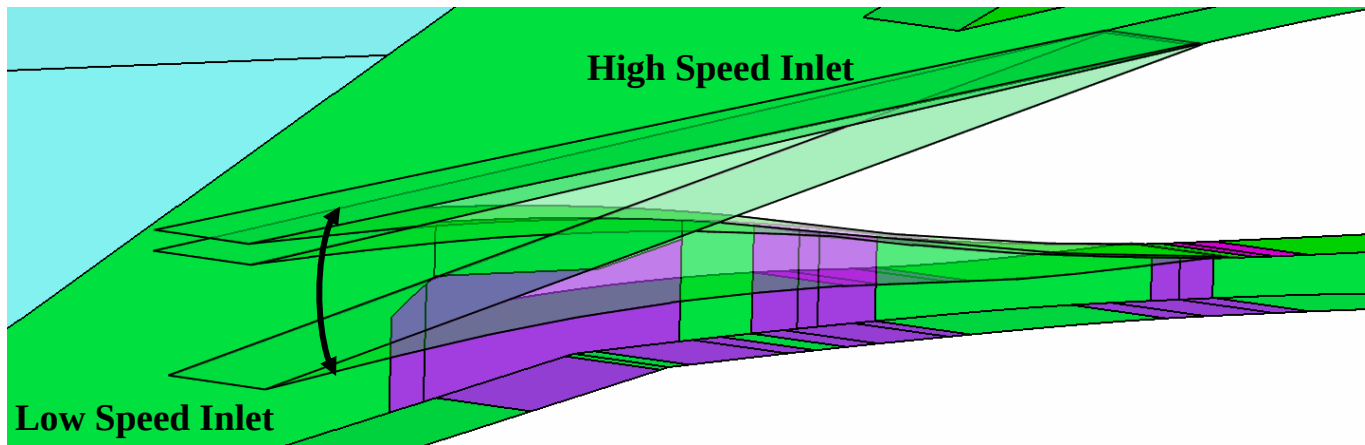
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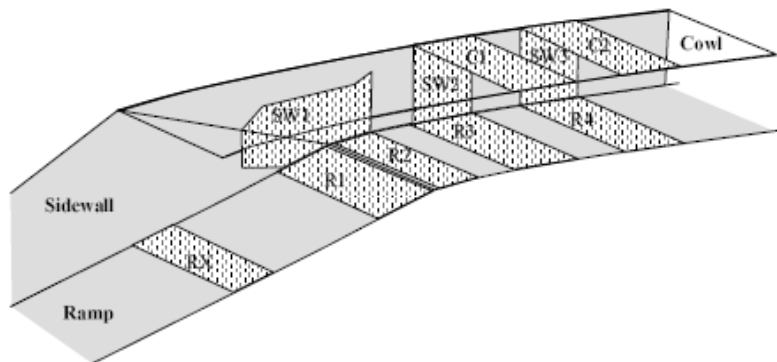


Geometry Modeling for CFD

Parametric Geometry (HS and LS Cowl and Ramp Positions)

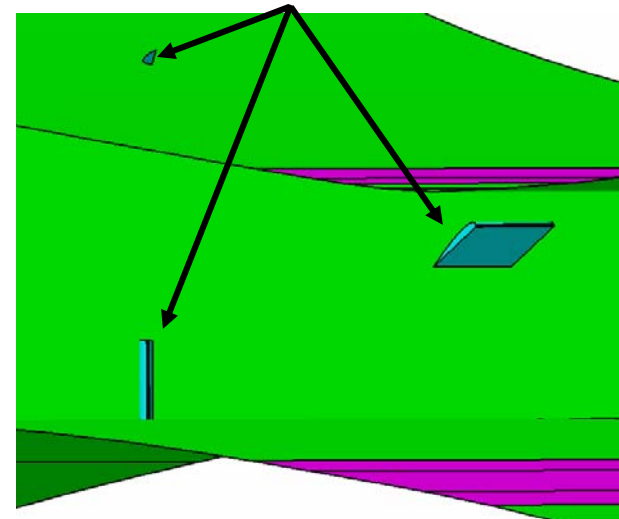


Bleed Zones (5 Configurations)



Bleed Region
RX (Ramp)
R1 (Ramp)
R2 (Ramp)
R3 (Ramp)
R4 (Ramp)
C1 (Cowl)
C2 (Cowl)
SW1 (Sidewall)
SW2 (Sidewall)
SW3 (Sidewall)

Vortex Generators (3)



Task 1 and 3: Sample CFD Post-Processed Results

Mach, Pressure, Recovery, Throat & Interface Integrations

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