A Turbine Based Combined Cycle Engine Inlet Model and Mode Transition Simulation Based on HiTECC Tool

An inlet system is being tested to evaluate methodologies for a turbine based combined cycle propulsion system to perform a controlled inlet mode transition. Prior to wind tunnel based hardware testing of controlled mode transitions, simulation models are used to test, debug, and validate potential control algorithms. One candidate simulation package for this purpose is the High Mach Transient Engine Cycle Code (HiTECC). The HiTECC simulation package models the inlet system, propulsion systems, thermal energy, geometry, nozzle, and fuel systems. This paper discusses the modification and redesign of the simulation package and control system to represent the NASA large-scale inlet model for Combined Cycle Engine mode transition studies, mounted in NASA Glenn's 10-foot by 10-foot Supersonic Wind Tunnel. This model will be used for designing and testing candidate control algorithms before implementation.

National Aeronautics and Space Administration

A Turbine Based Combined Cycle Engine Inlet Model and Mode Transition Simulation Based on HiTECC Tool

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Atlanta, GA
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Outline

- Introduction
  - NASA Hypersonics Project
  - Combined Cycle Engine Large-scale Inlet for Mode transition eXperiments (CCE-LIMX)
- High Mach Transient Engine Cycle Code (HiTECC) Simulation
  - Updating HiTECC to match CCE-LIMX specifications
  - New model to support CCE-LIMX Experiments
- Conclusions and Future Work

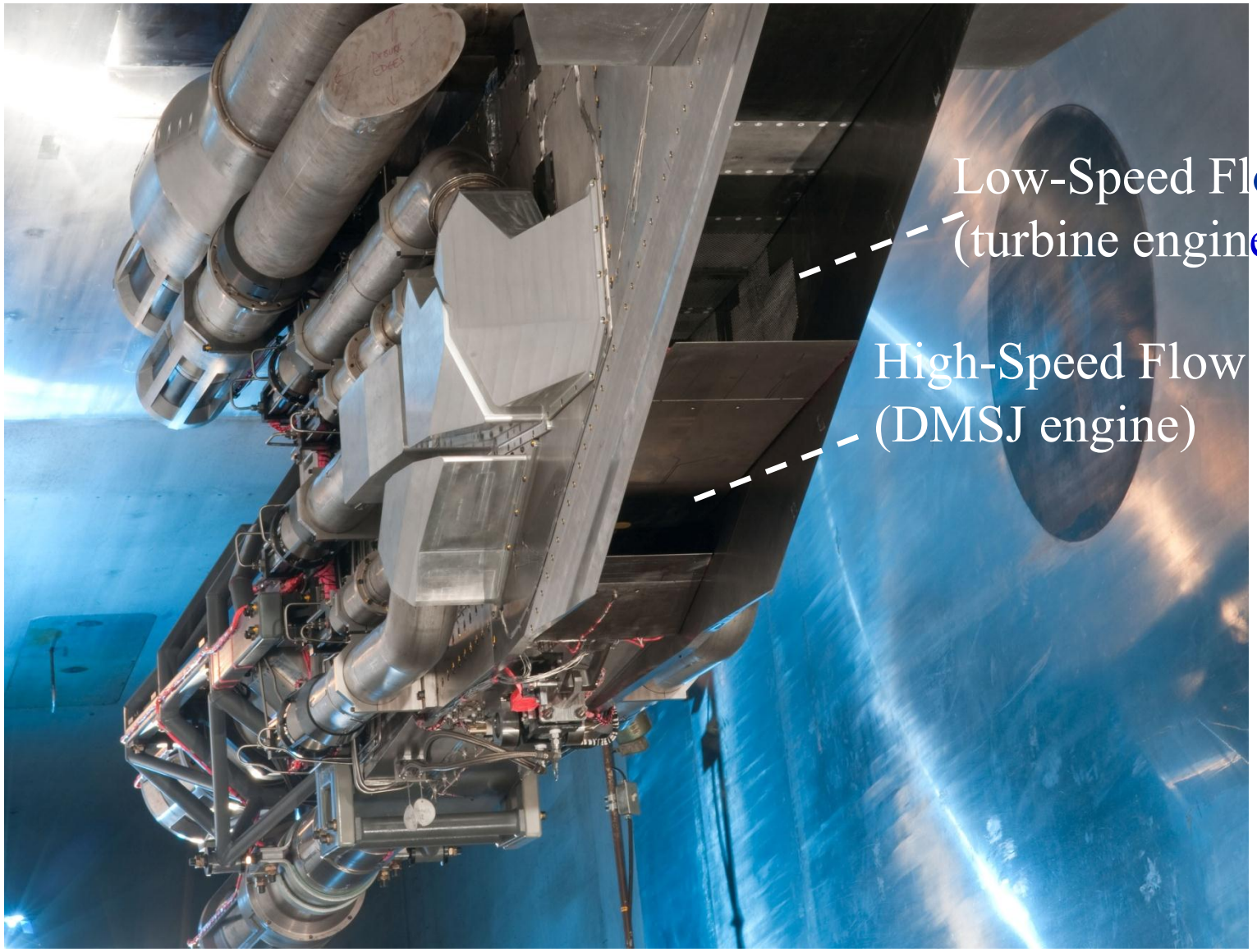
NASA Hypersonics Project

- Hypersonics Research
  - Develop tools and technologies to design and control Reusable Airbreathing Launch Vehicles (RALVs) to provide hypersonic flight through the Earth's atmosphere and create routine, airline-type access to space
  - Two-stage-to-orbit (TSTO) vehicles
    - One vehicle responsible for horizontal takeoff and acceleration to staging point.
    - Horizontal takeoff and landing enhances launch, flight and ground operability
      - Launch pad not needed
      - Flexible operations and quick turnaround time (Aircraft like operations)

NASA Hypersonics Project

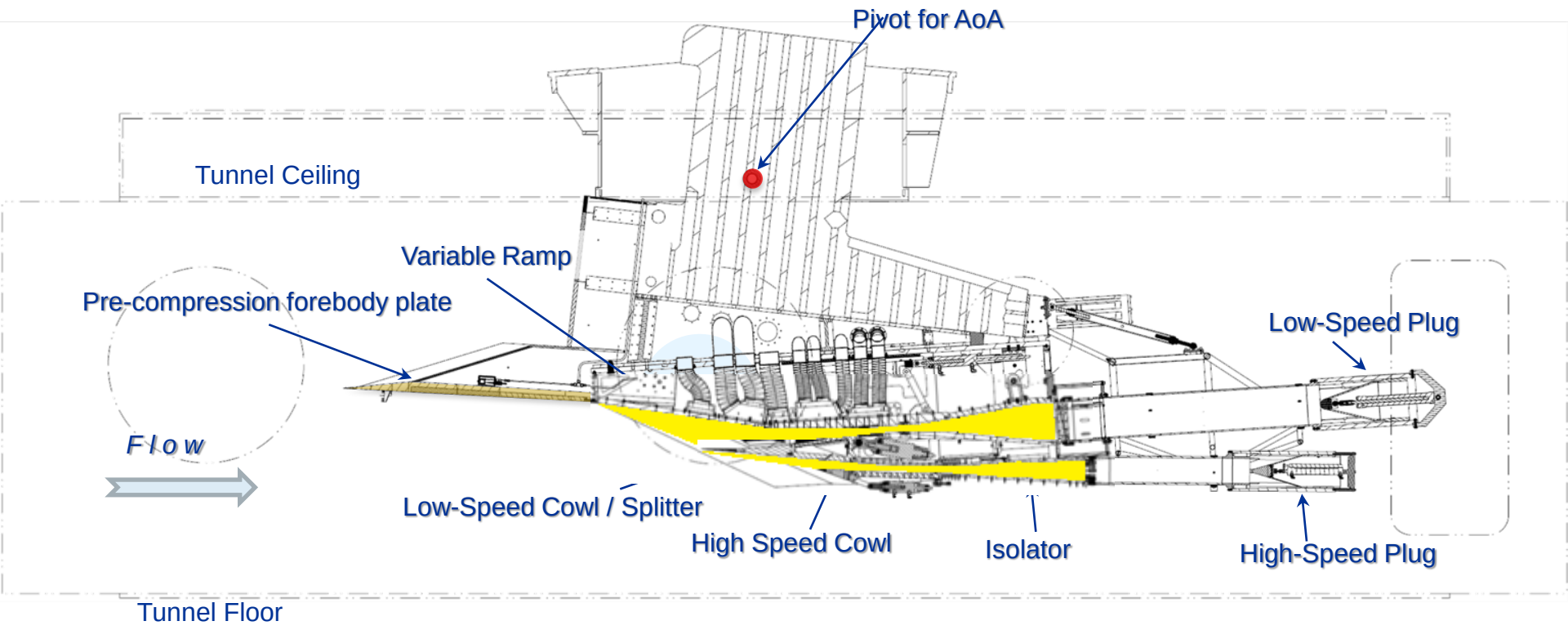
- Turbine Based Combined Cycle (TBCC) propulsion system
  - Turbine Engine and Dual-Mode Scramjet
- Combined Cycle Engine Large-scale Inlet for Mode transition eXperiments (CCE-LIMX)
- Hardware designed and built in the NASA Glenn Research Center 10ft x 10ft Supersonic Wind Tunnel

CCE-LIMX Model



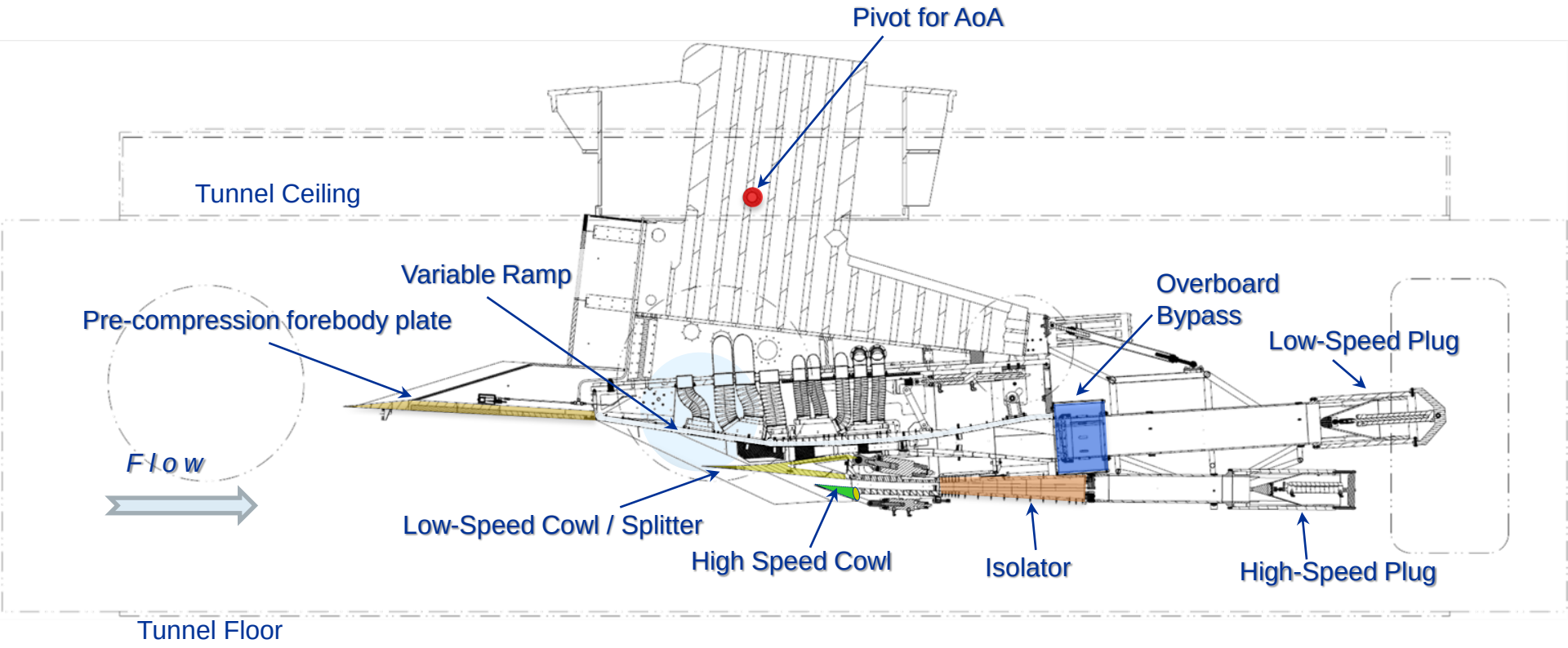
CCE-LIMX Model

Under-Mounted High-Speed Flow Path



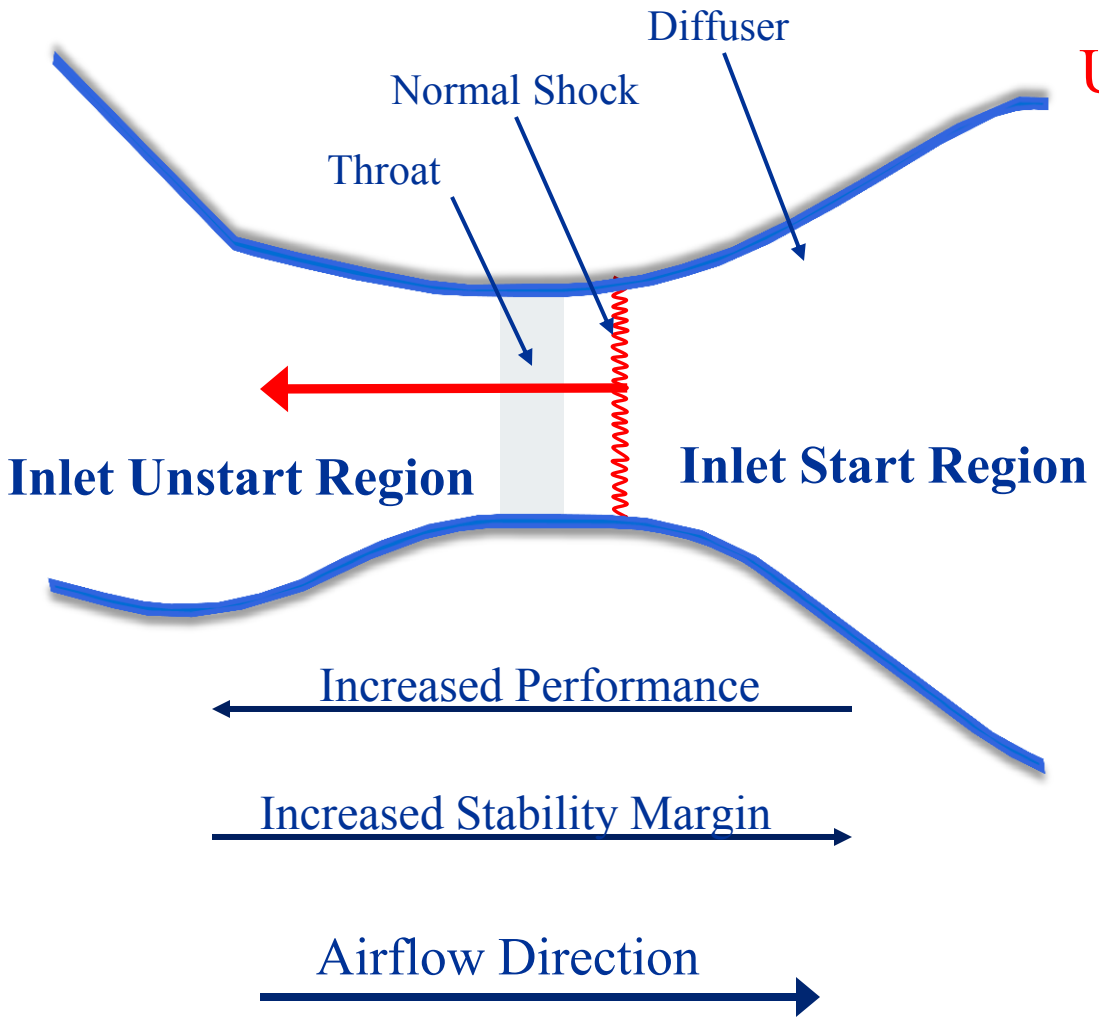
30 feet

CCE-LIMX Model



30 feet

CCE-LIMX LSFP Terminology



UnStarted Inlet

~~High mass recovery~~
~~High pressure recovery~~
~~Low distortion~~
~~Low drag~~

Causes of Inlet Unstart:

- Compressor stall
- Free stream changes

Compressor stall
Combustor flame-out

CCE-LIMX Test Plan

- Phase 1 – Inlet characterization and performance testing
  - Static inlet operating points
  - Mode transition schedule
- Phase 2 – System identification
  - Step response
  - Sinusoidal sweep response
- Phase 3 – Controls testing
  - Disturbance rejection testing
  - Controlled mode transition
- Phase 4 – Propulsion system testing
  - Turbine engine for LSFP
  - Dual-mode combustor for HSFP

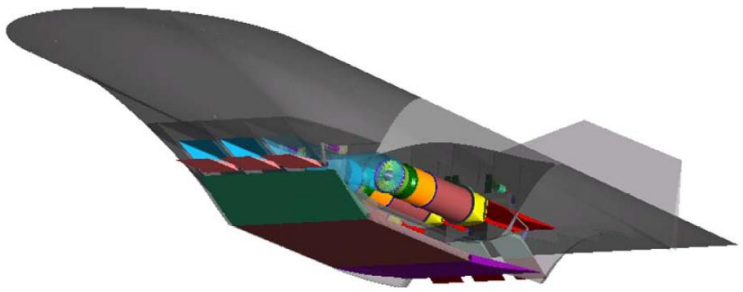
Guidance Navigation and Control Team

- Develop tools and procedures to streamline:
  - Experimental data analysis
  - Inlet mode transition controls design
  - Controls evaluation

- Simulation models:
  - LArge Perturbation INlet (LAPIN)
  - Aerosim interactive simulation
  - High Mach Transient Engine Cycle Code (HiTECC)

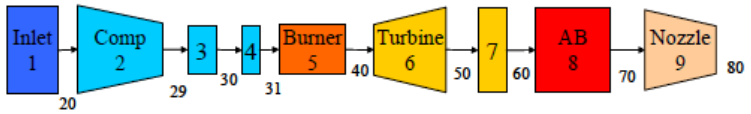
HiTECC Simulation

- High Mach Transient Engine Cycle Code (HiTECC)
- Simulation package originally developed by SPIRITECH Advanced Products Inc.
- Demonstrate all modes of operation of a TBCC propulsion system
  - Afterburner, turbine engine, and dual-mode scramjet
  - Simulate mode transition sequence of events
- Designed to be generic and modular
  - Inlet geometry described using the Mathworks® Simscape™
  - Fast prototyping of inlet designs

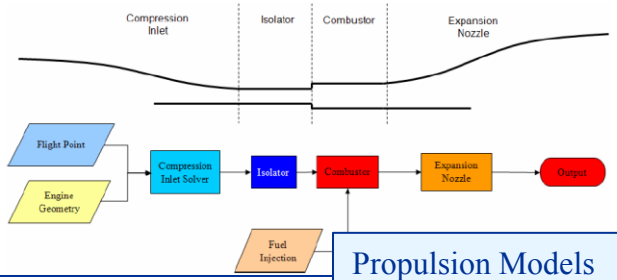


High Mach Transient Engine Cycle Code (HiTECC)

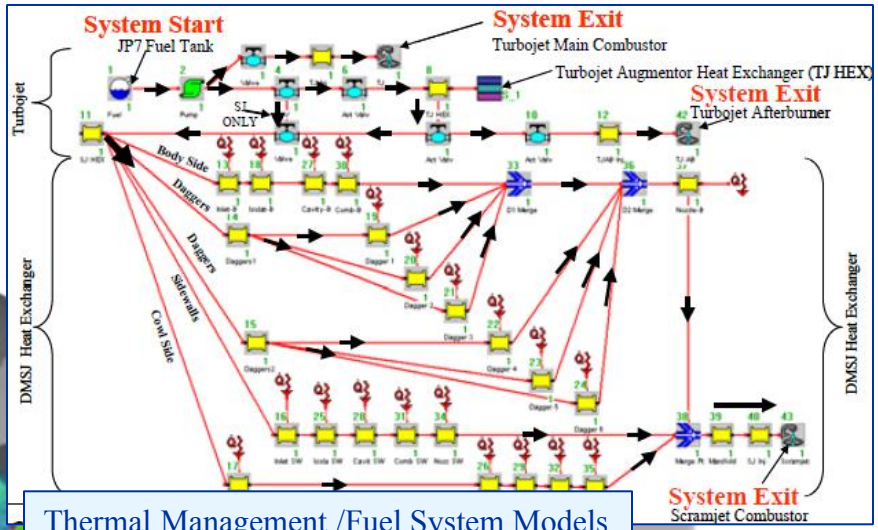
Turbo Jet Engine Model



Dual Mode Scramjet Model

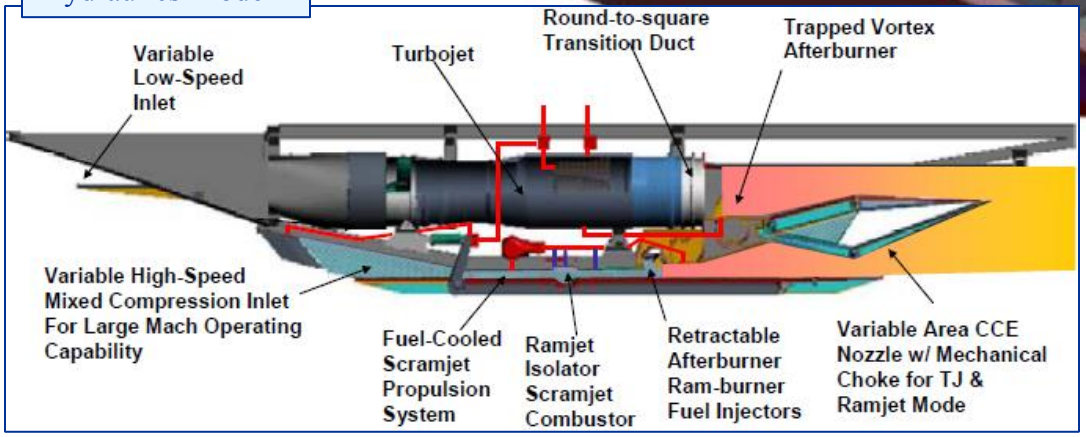


Propulsion Models

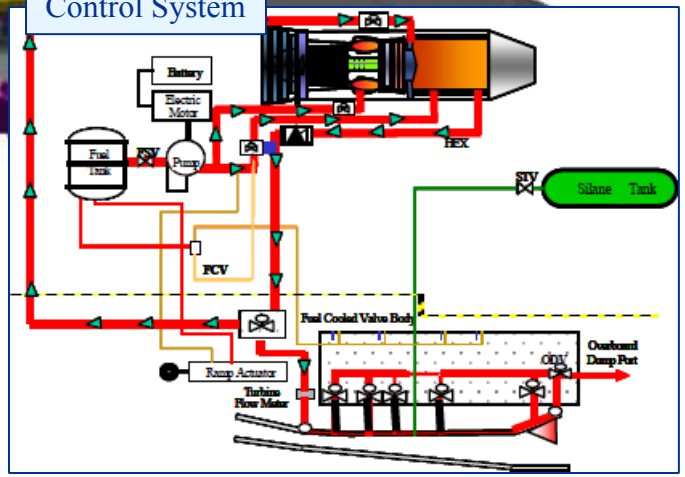


Thermal Management /Fuel System Models

Hydraulics Model

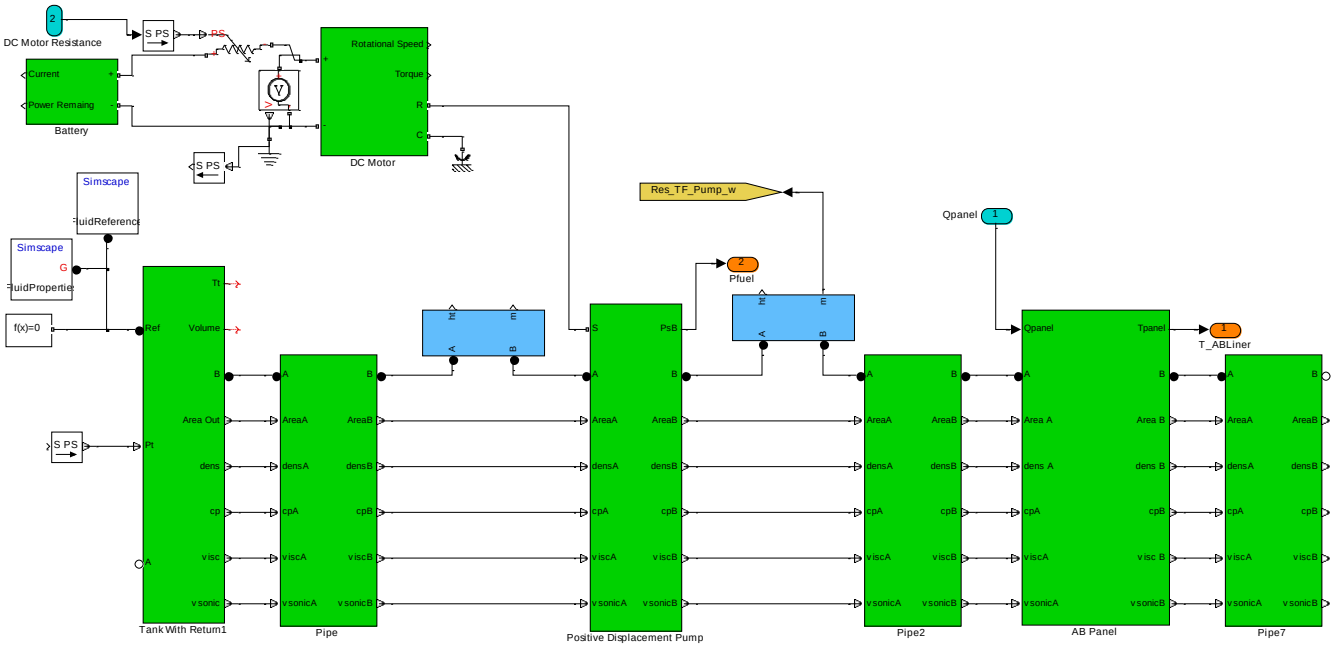


Control System



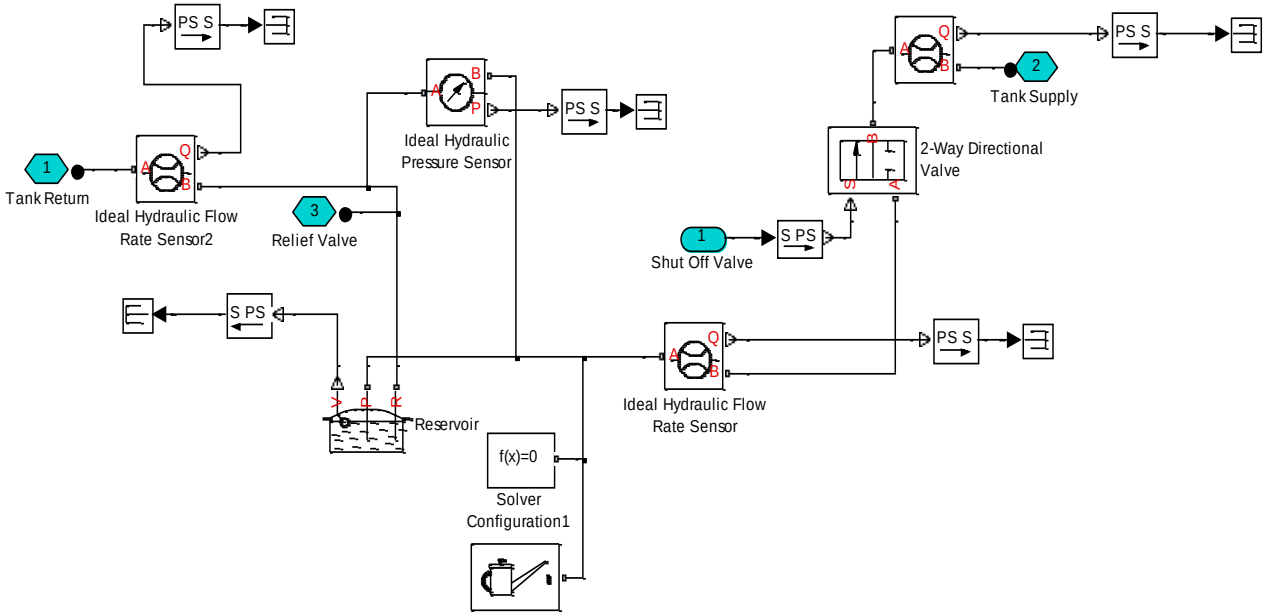
Thermal Management / Fuel Systems

- Simulates fuel flow, fluid energy, and thermal energy transfer for both the LSFP and HSFP
- One-dimensional compressible flow solver allows a variety of fuels, including hydrogen, to be modeled



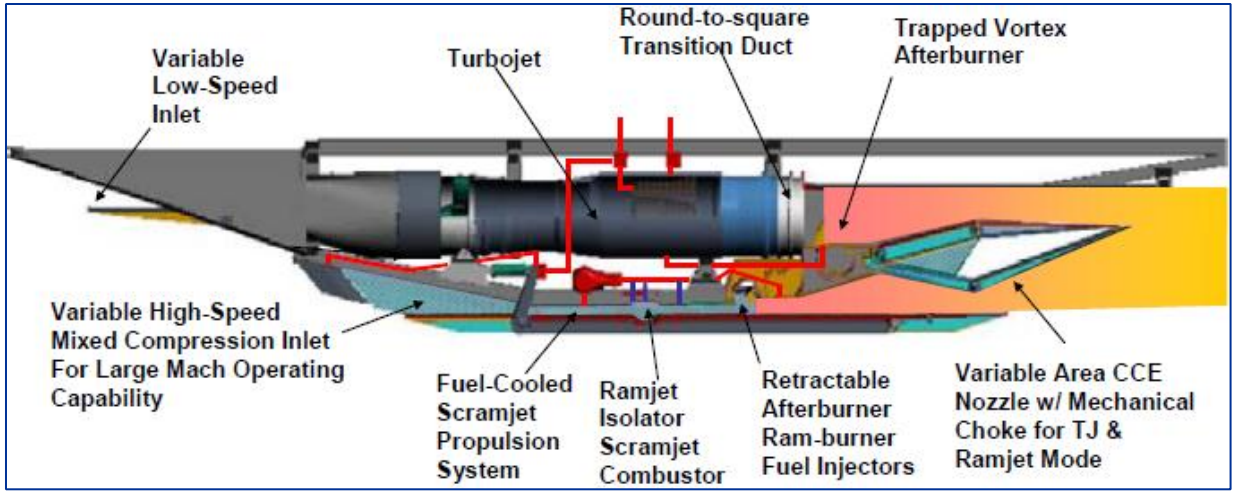
Hydraulics Model

- Simulates the kinematic features of the variable inlet and nozzle for both flow paths
- Models the dynamic response of the hydraulic fluid
- Models for the power storage and generation for pumping the hydraulic fluid



Propulsion System

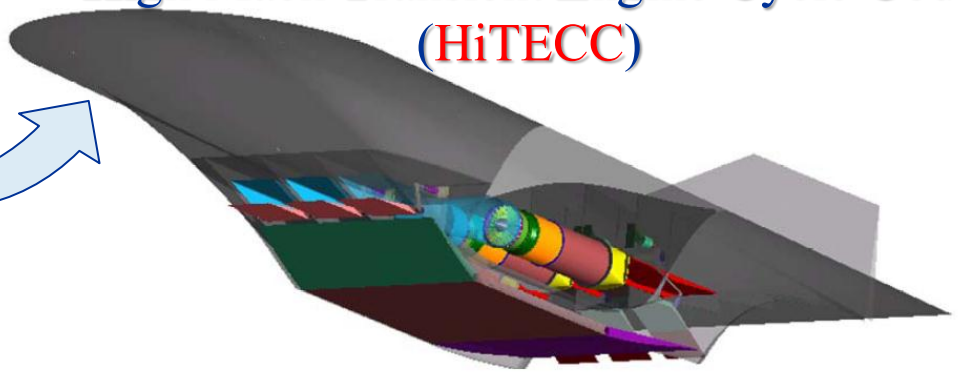
- Variable Inlet (P,T,W)
- Gas Turbine (with afterburner)
- Dual Mode Scramjet
- Assume Started Low-Speed and High-Speed Inlets (No external normal shocks)



HiTECC Configured for CCE-LIMX Inlet

Wind Tunnel Model for Testing and Evaluation of Control Algorithms

High Mach **T**ransient **E**ngine **C**ycle **C**ode (HiTECC)

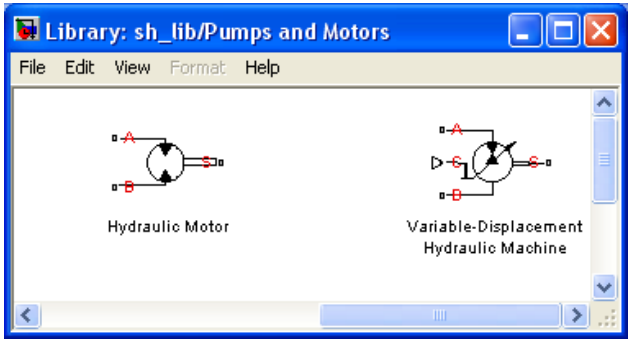


Update Model to Match CCE-LIMX Model

SimScape® (The Mathworks, Inc)

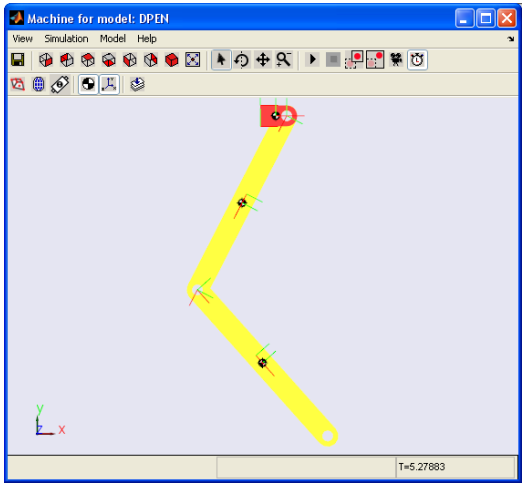
SimHydraulics®

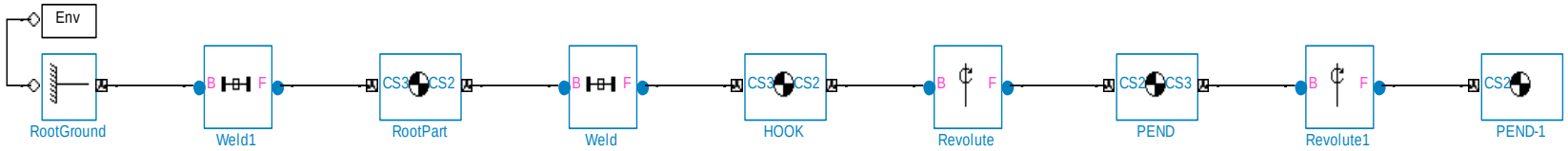
- Models hydraulics power and control systems
- Library of components (pumps, valves, accumulators, pipelines)
- Customizable library of common hydraulic fluids

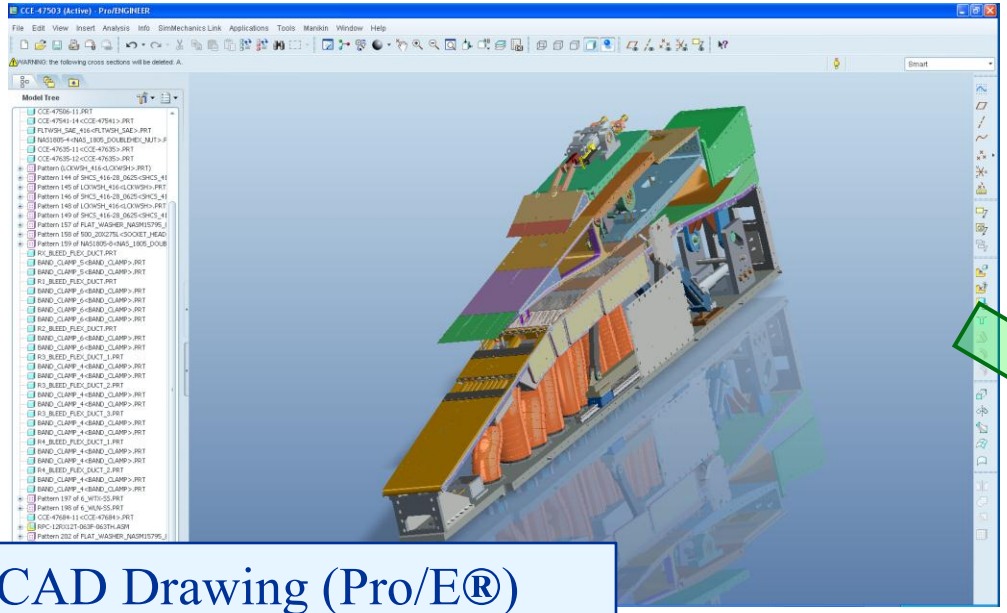


SimMechanics®

- Models 3-D rigid-body mechanical systems
- Analyzes motion and calculates forces
- Visualize and animate mechanical system dynamics with 3-D body geometry
- Integration in Simulink
- **Provides interfaces to CAD platforms (Pro/E®)**

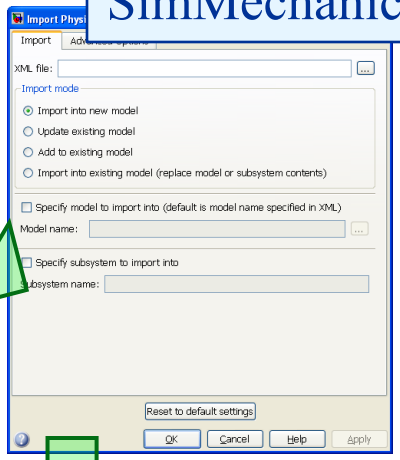




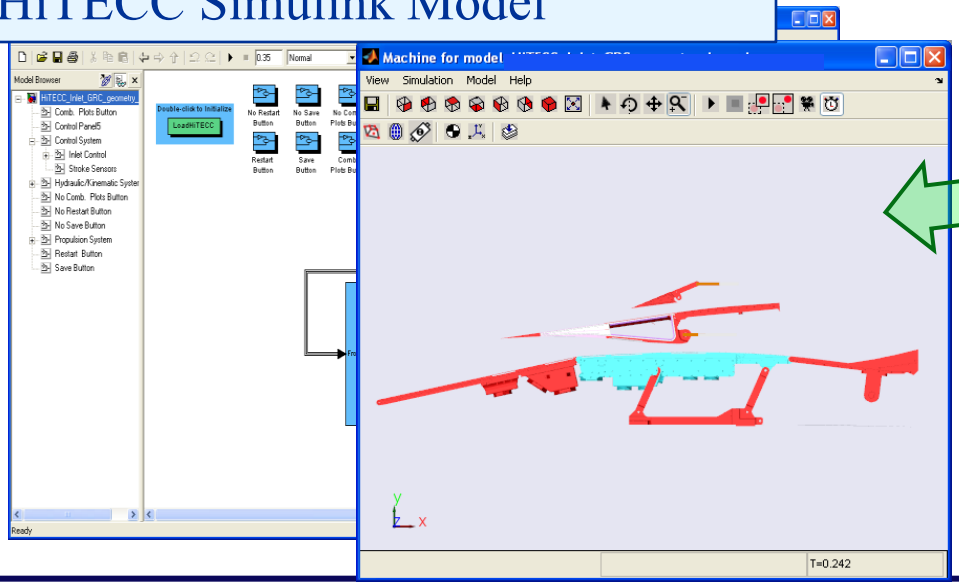


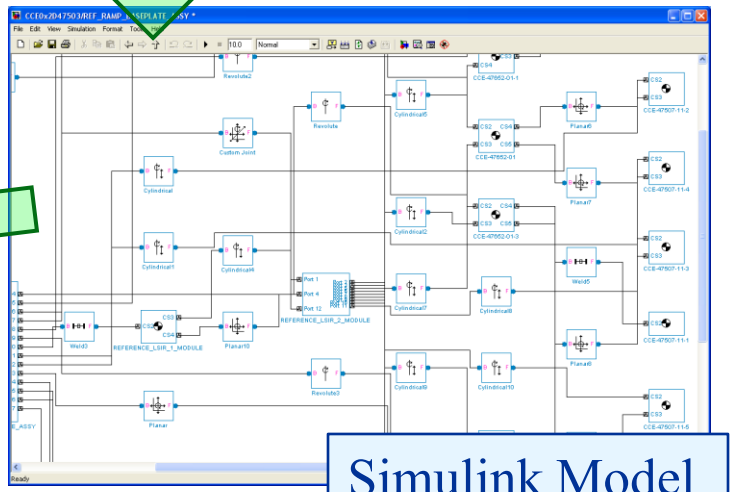
CAD Drawing (Pro/E®)

SimMechanics Link

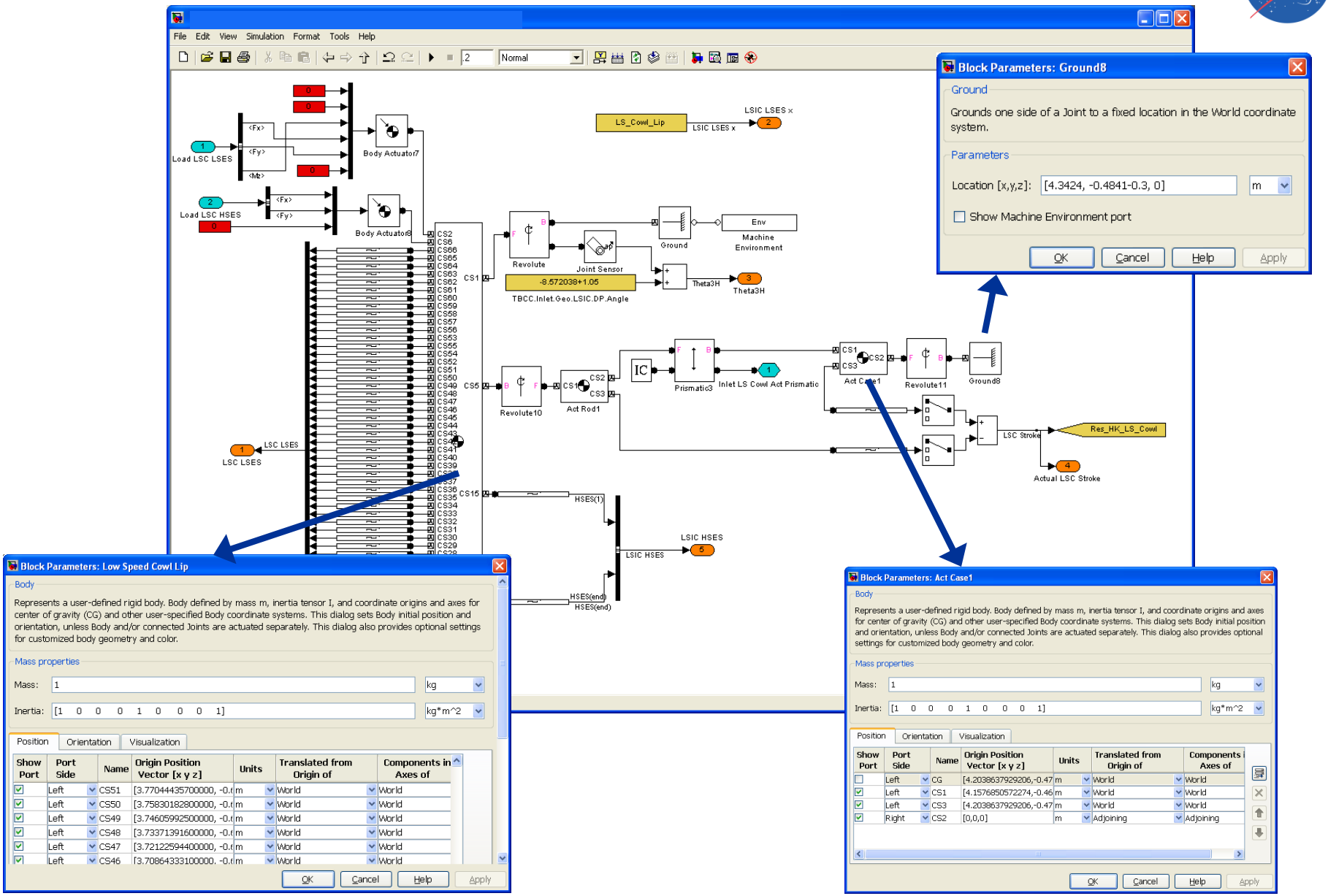


HiTECC Simulink Model

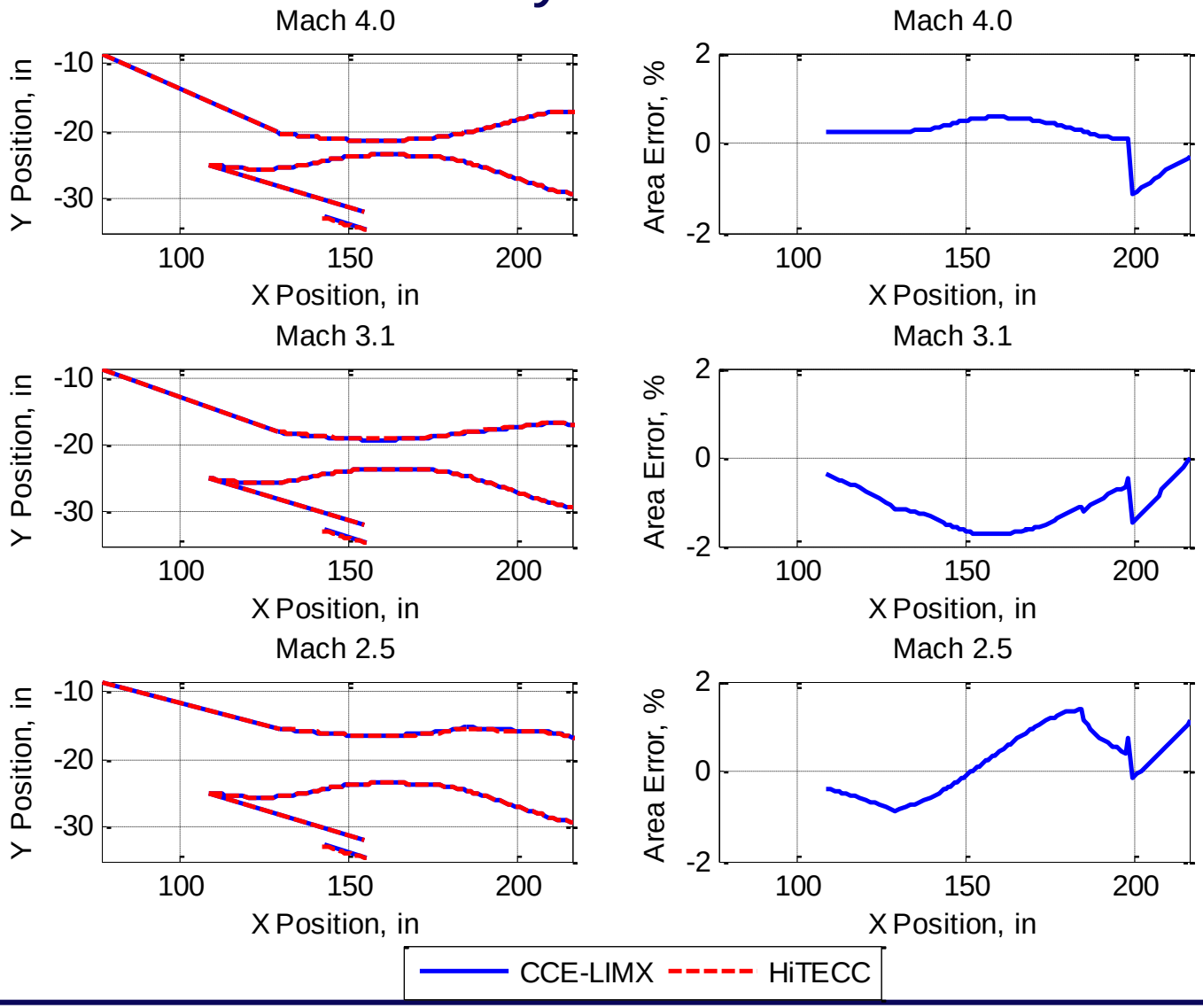




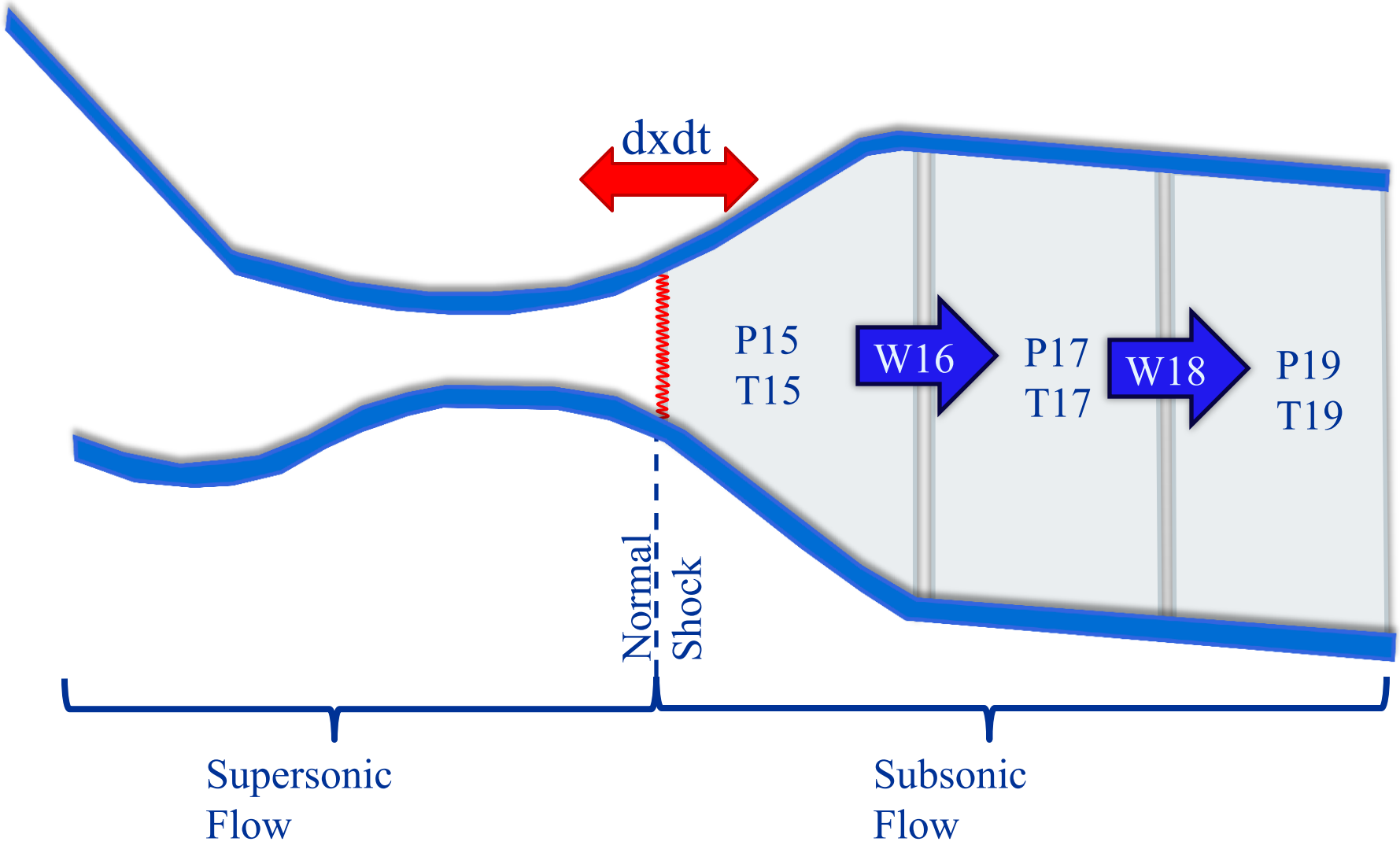
Simulink Model


File Edit View Simulation Format Tools Help
Normal
Load LSC LSES
Load LSC HSES
Body Actuator7
Body Actuator8
LS_Cowl_Lip
LSIC LSES x
Revolute
Joint Sensor
Ground
Env
Machine Environment
-8.572038+1.05
TBCC.Inlet.Geo.LSIC.DP.Angle
Theta3H
Revolute10
Act Rod1
Prismatic3
Inlet LS Cowl Act Prismatic
Act Case1
Revolute11
Ground8
LSC Stroke
Res_HK_LS_Cowl
Actual LSC Stroke
LSC LSES
HSES(1)
HSES(end)
LSIC HSES
Block Parameters: Ground8
Ground
Grounds one side of a Joint to a fixed location in the World coordinate system.
Parameters
Location [x,y,z]: [4.3424, -0.4841-0.3, 0]
m
Show Machine Environment port
OK Cancel Help Apply
Block Parameters: Low Speed Cowl Lip
Body
Represents a user-defined rigid body. Body defined by mass m, inertia tensor I, and coordinate origins and axes for center of gravity (CG) and other user-specified Body coordinate systems. This dialog sets Body initial position and orientation, unless Body and/or connected Joints are actuated separately. This dialog also provides optional settings for customized body geometry and color.
Mass properties
Mass: 1 kg
Inertia: [1 0 0 0 1 0 0 0 1] kg*m^2
Position Orientation Visualization
Show Port | Port Side | Name | Origin Position Vector [x y z] | Units | Translated from Origin of | Components in Axes of
Left | CS51 | [3.77044435700000, -0.(| m | World | World
Left | CS50 | [3.75830182800000, -0.(| m | World | World
Left | CS49 | [3.74605992500000, -0.(| m | World | World
Left | CS48 | [3.73371391600000, -0.(| m | World | World
Left | CS47 | [3.72122594400000, -0.(| m | World | World
Left | CS46 | [3.70864333100000, -0.(| m | World | World
OK Cancel Help Apply
Block Parameters: Act Case1
Body
Represents a user-defined rigid body. Body defined by mass m, inertia tensor I, and coordinate origins and axes for center of gravity (CG) and other user-specified Body coordinate systems. This dialog sets Body initial position and orientation, unless Body and/or connected Joints are actuated separately. This dialog also provides optional settings for customized body geometry and color.
Mass properties
Mass: 1 kg
Inertia: [1 0 0 0 1 0 0 0 1] kg*m^2
Position Orientation Visualization
Show Port | Port Side | Name | Origin Position Vector [x y z] | Units | Translated from Origin of | Components in Axes of
Left | CG | [4.2038637929206,-0.47 | m | World | World
Left | CS1 | [4.1576850572274,-0.46 | m | World | World
Left | CS3 | [4.2038637929206,-0.47 | m | World | World
Right | CS2 | [0,0,0] | m | Adjoining | Adjoining
OK Cancel Help Apply

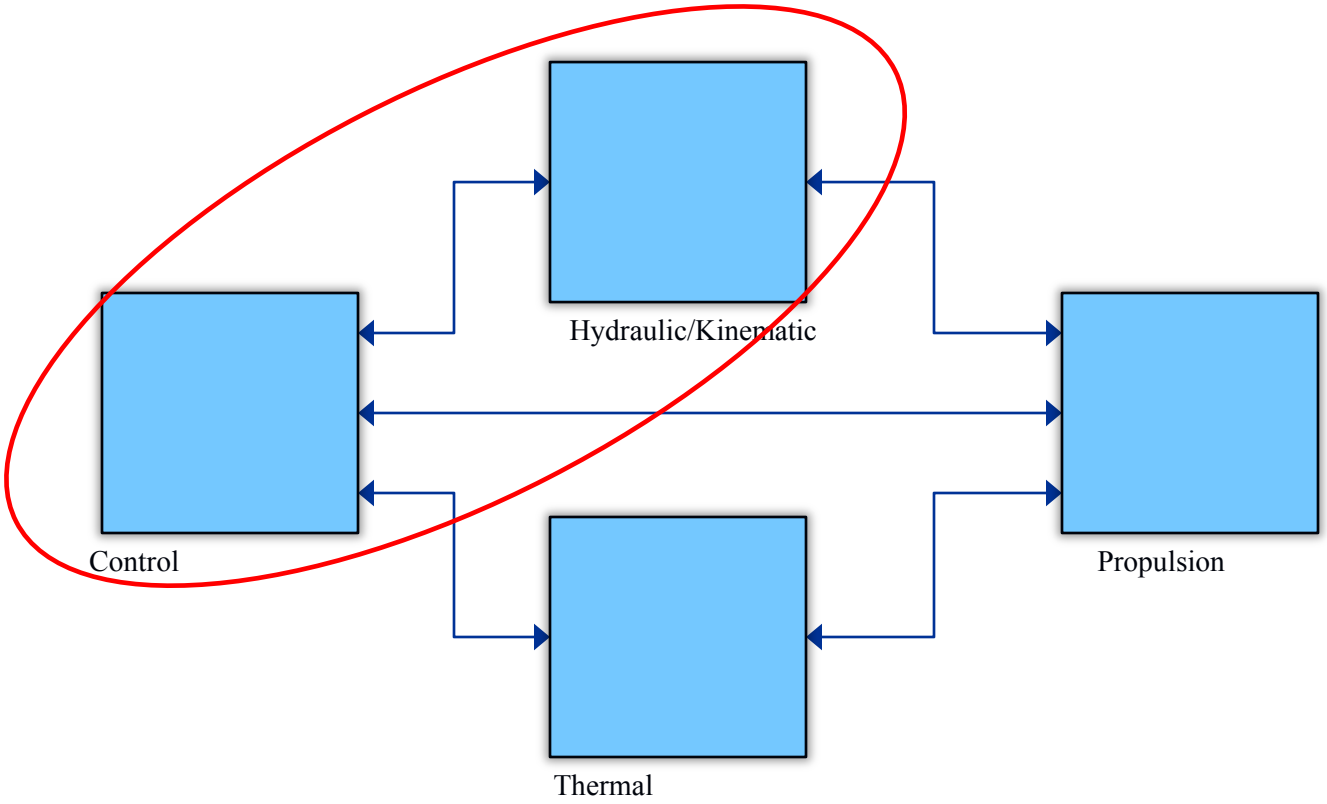
Redesign Geometry, Actuators, and Control Systems



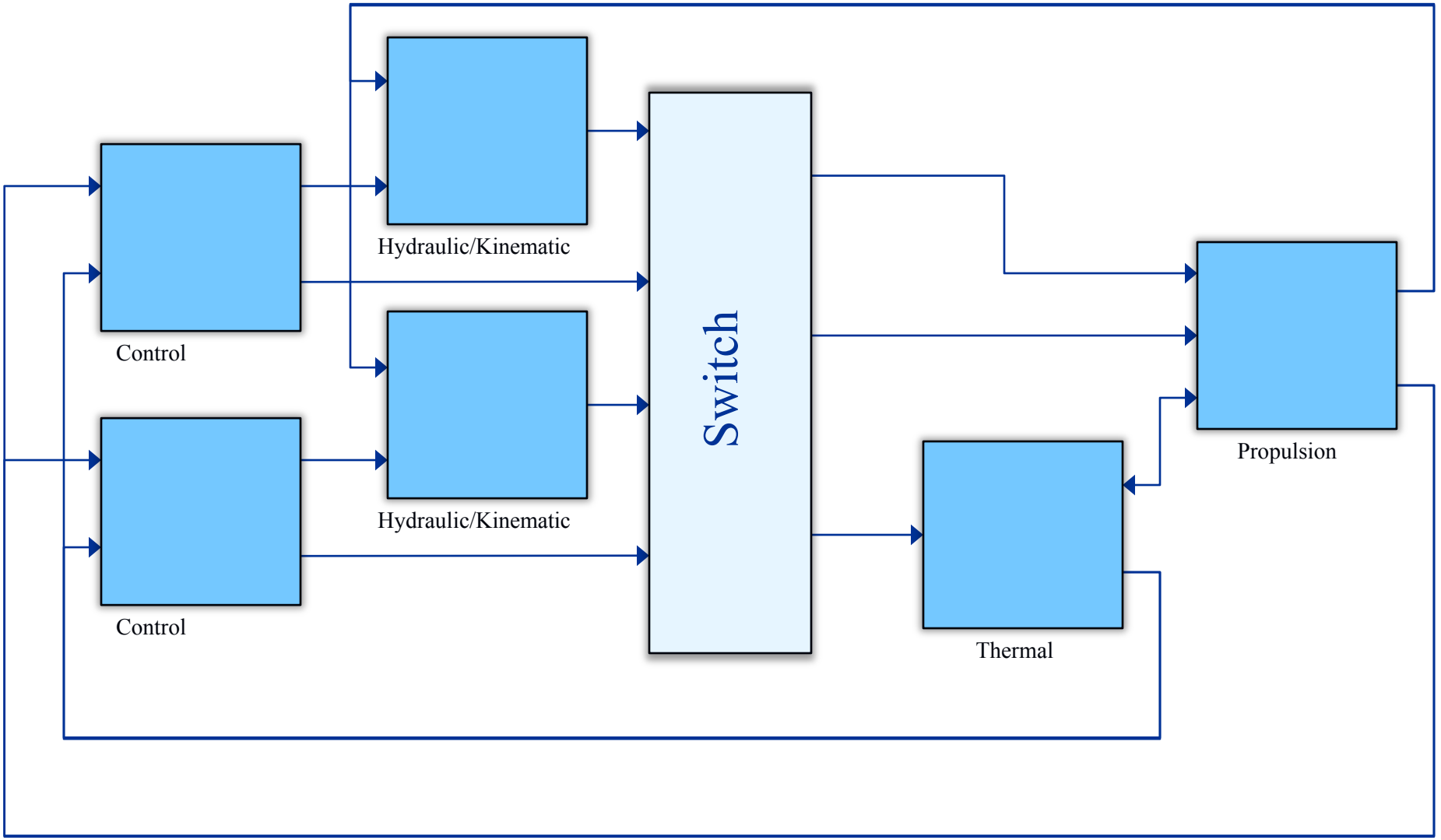
HiTECC Subsonic Volume Initial Conditions



HiTECC Initial Conditions

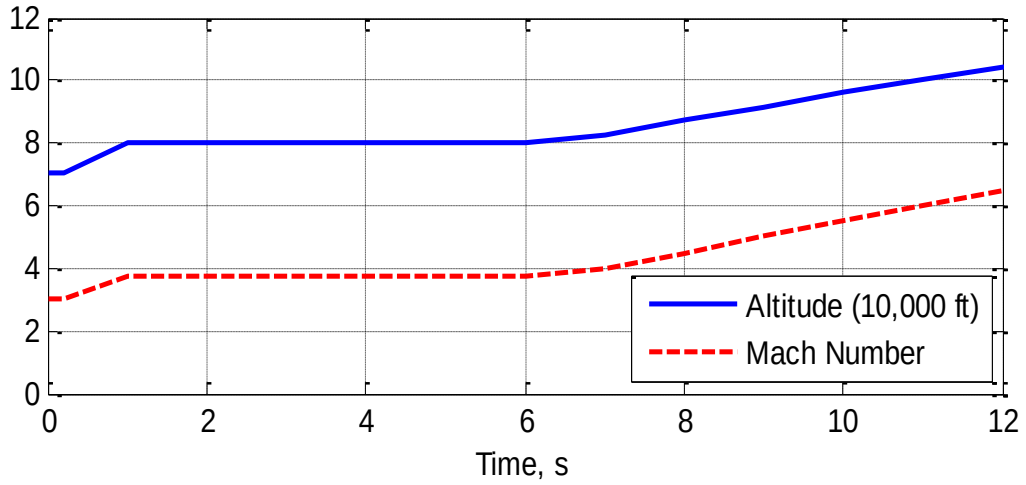


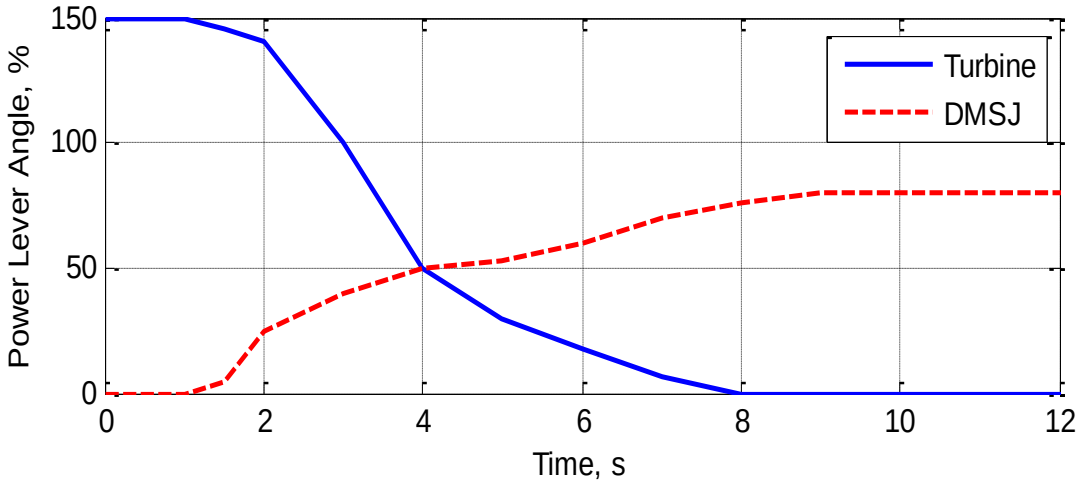
HiTECC Initial Conditions



Mode Transition

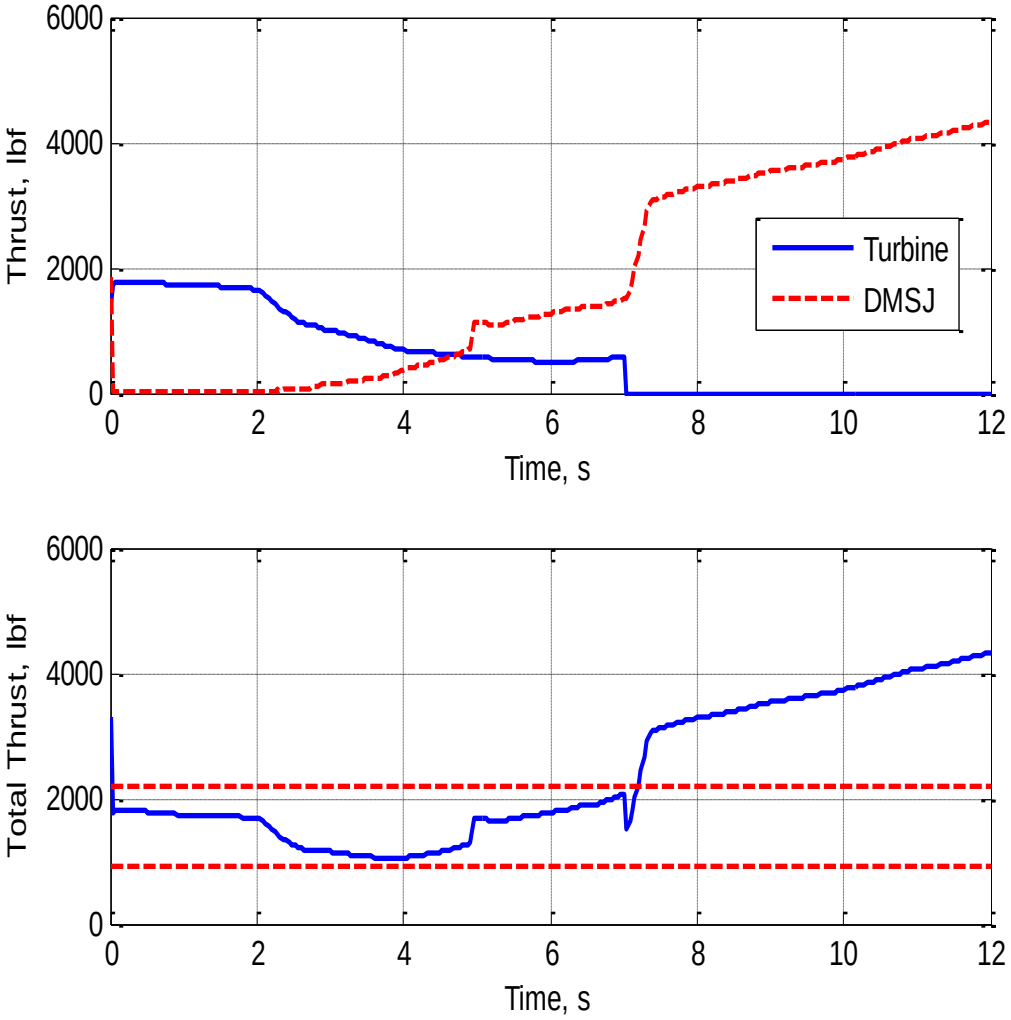
- Mode transition with HiTECC
  - Mach 3.75
  - Afterburner shutdown (PLA 150 -100)
  - Start DMSJ
  - Transition power
  - Shutdown Engine
  - Close off LSFP
  - Continue with mission



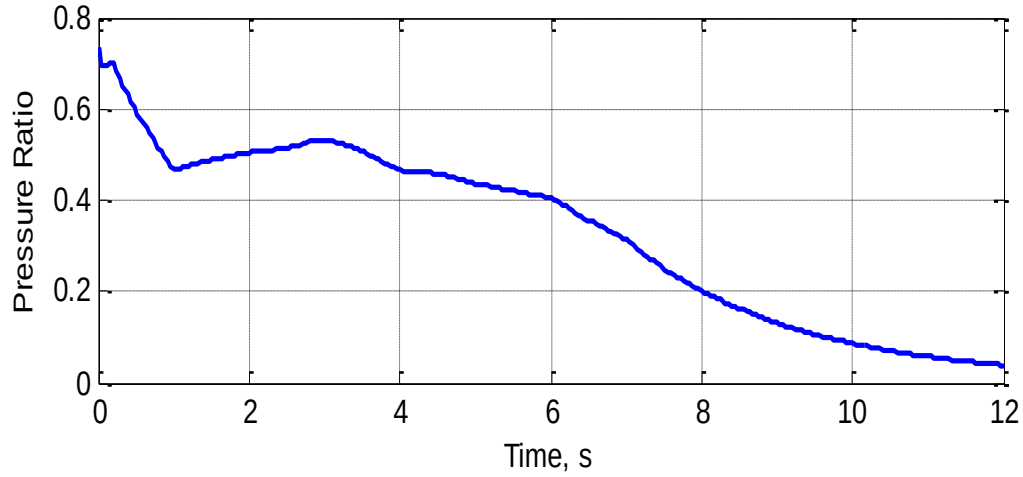


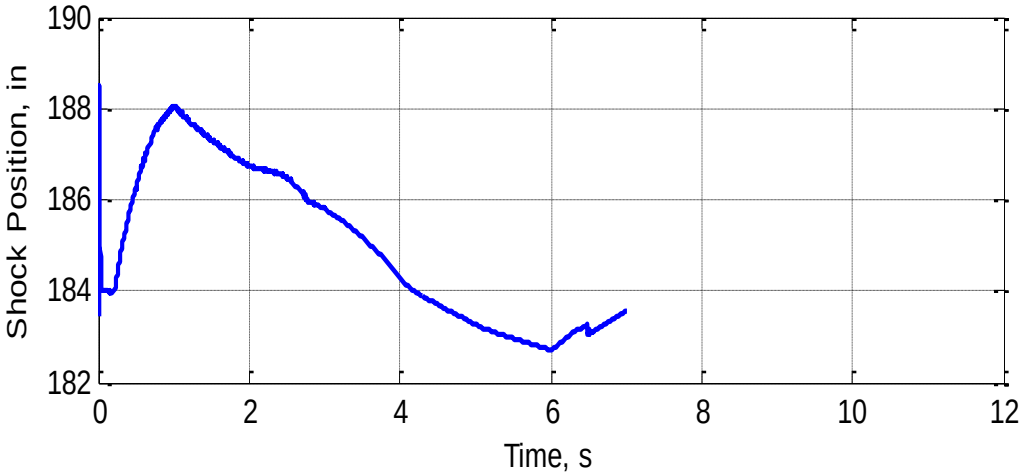
Mode Transition

- During mode transition, propulsion system must produce enough thrust to keep vehicle at Flight Condition.
- TBCC produces thrust between the min/max bounds

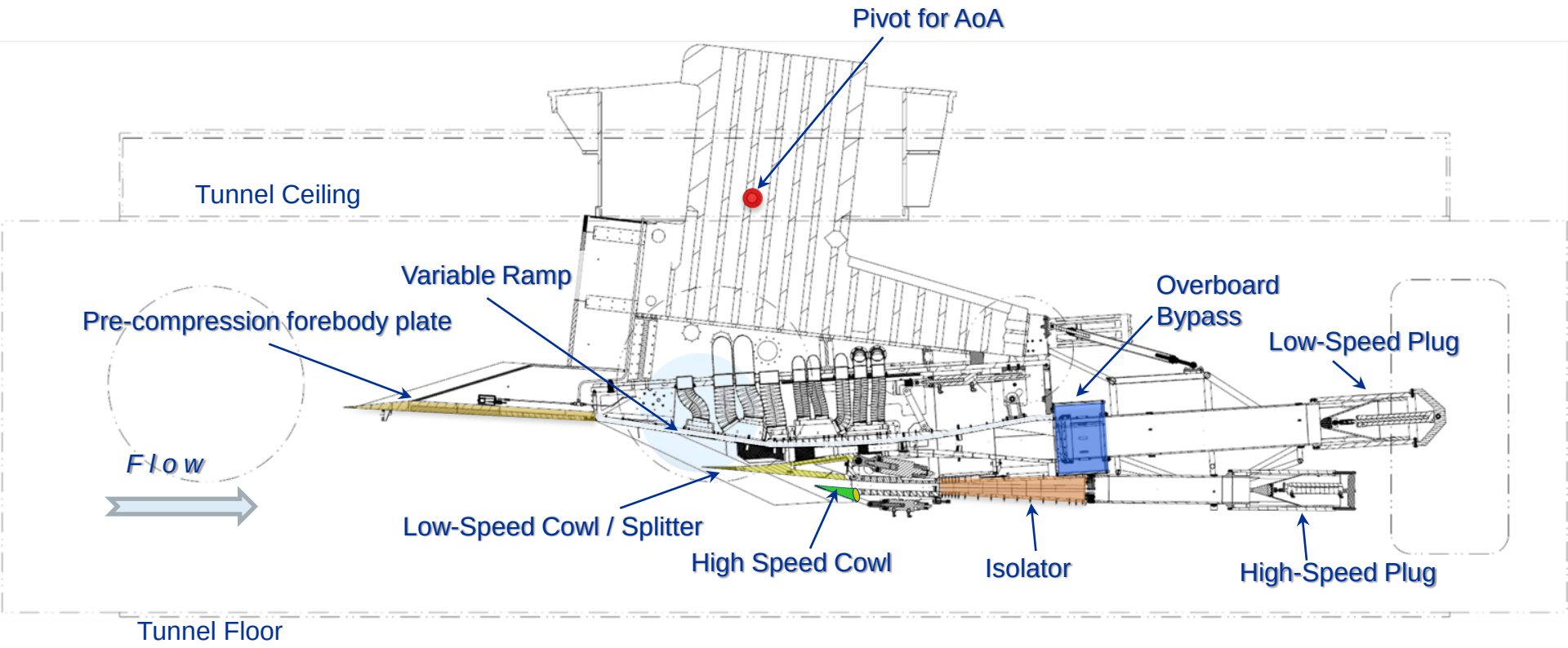


Mode Transition Plots



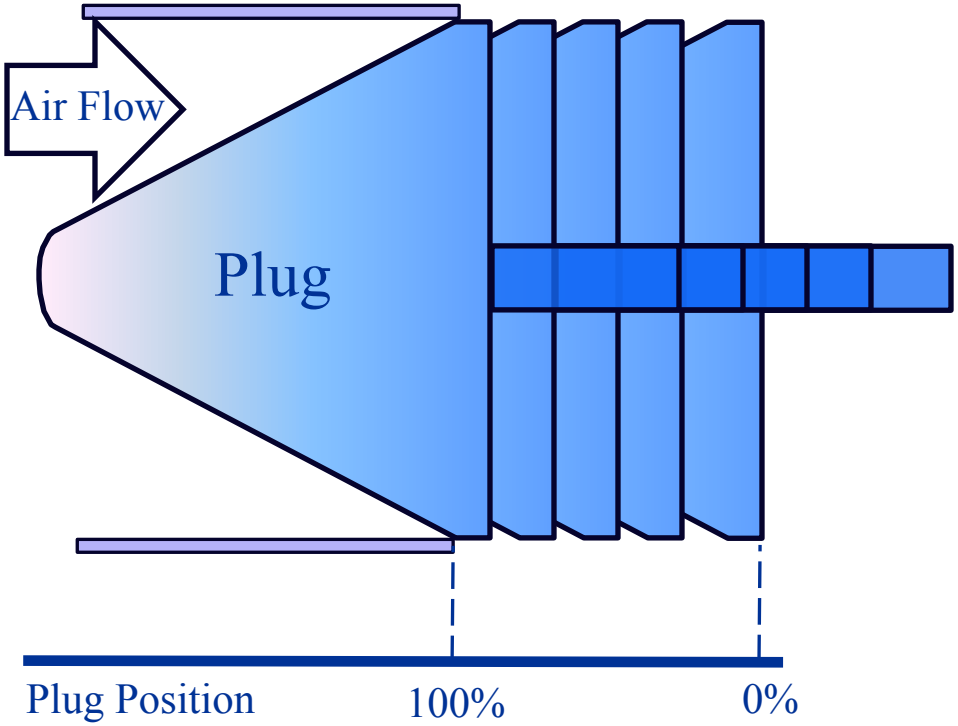


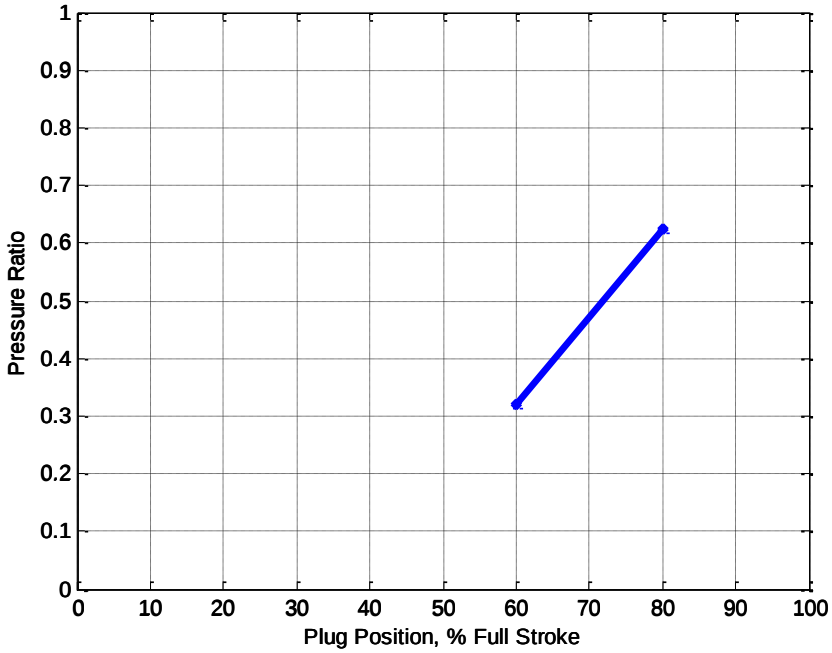
CCE-LIMX Model



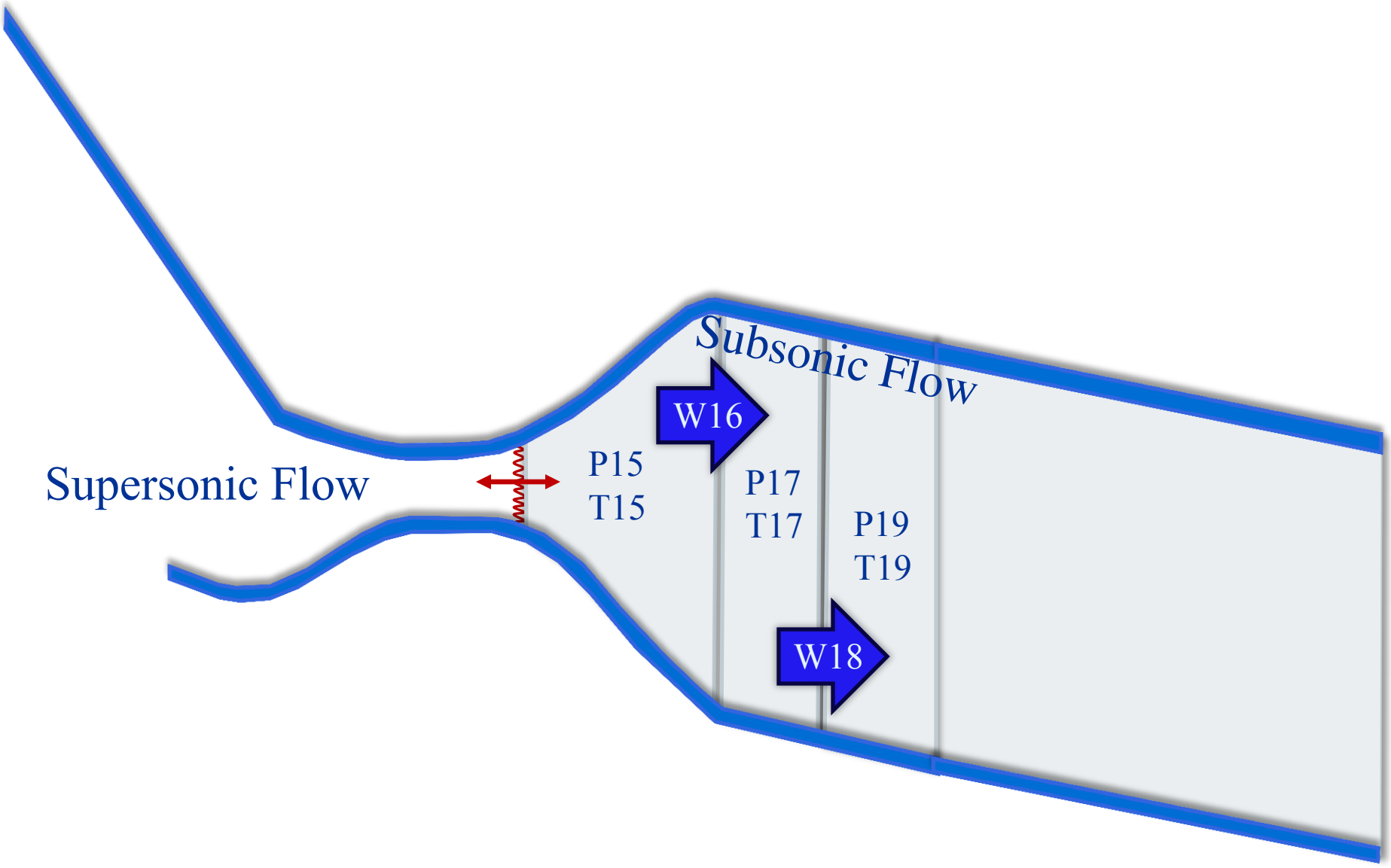
- Testing candidate mode transition and shock position control algorithms before implementation
- Compare performance of HiTECC to wind tunnel data model validation

Replacement of Turbine Engines with a Plug

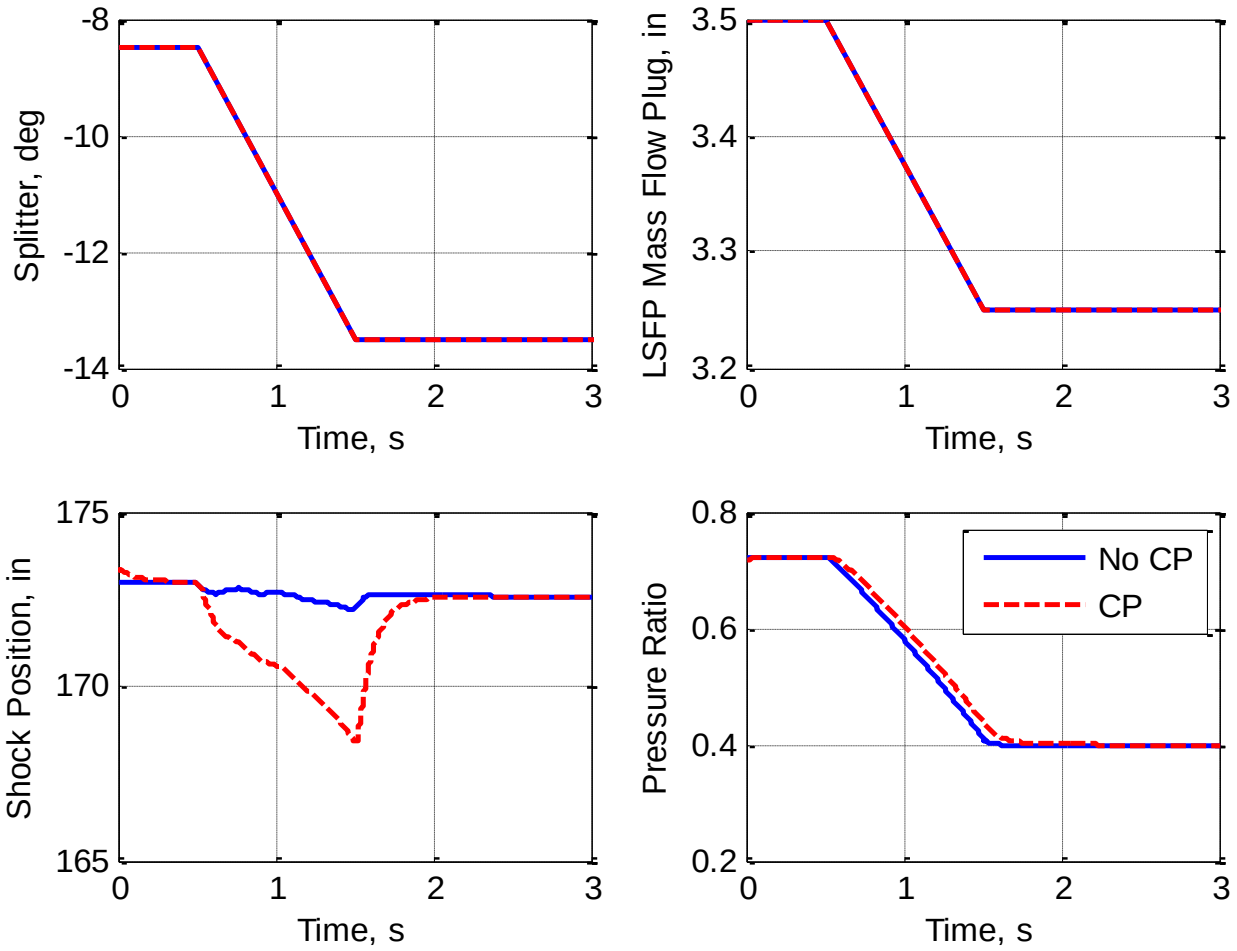




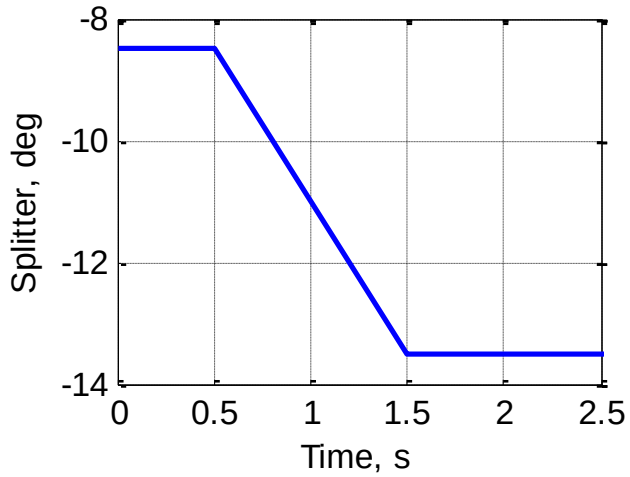
Addition of the Cold Pipe Volume

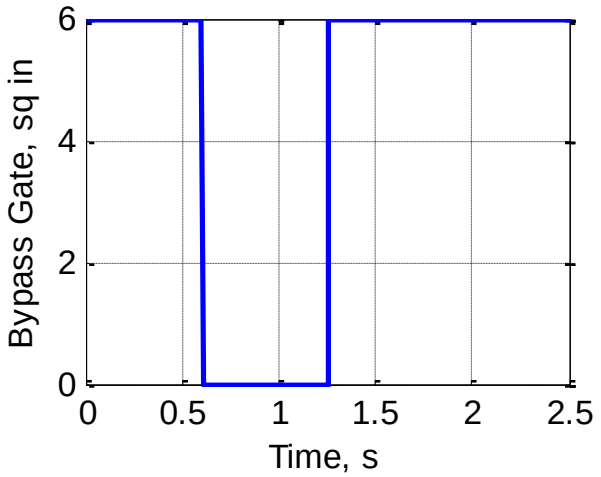


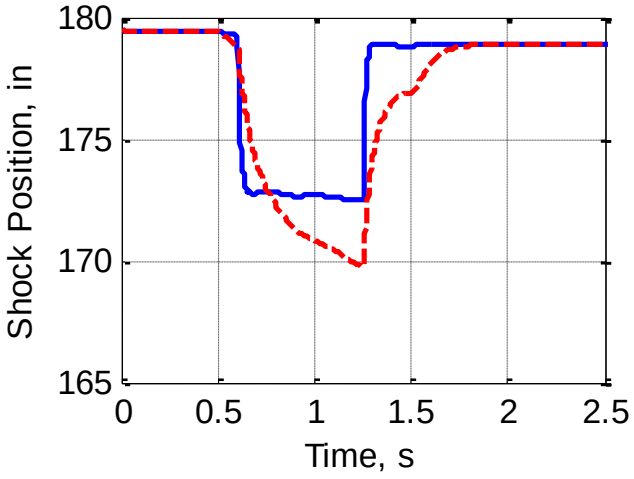
HiTECC Wind Tunnel Model Plots

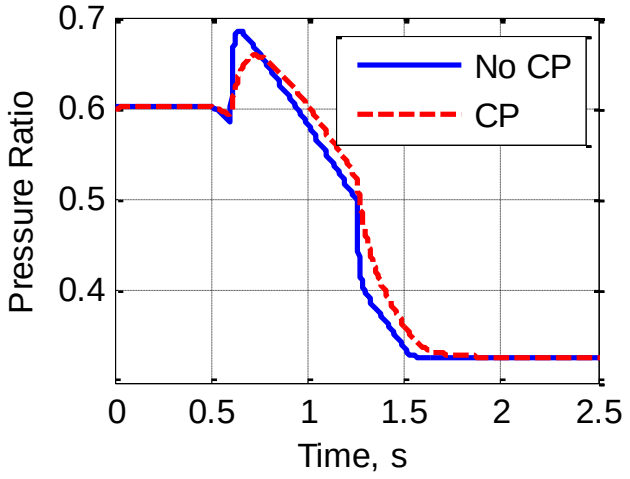


HiTECC Wind Tunnel Model Plots









Conclusions

- CCE-LIMX Experiments
  - Accomplished Phase I and II of testing
    - Developed a mode transition schedule
    - Collected experimental data to be used for model development
- GN&C Team
  - Updated HiTECC model to match the CCE-LIMX inlet geometry
  - Fixed and improved the HiTECC code
  - Created a new model based off HiTECC to be used for:
    - Model validation against experimental data
    - To be used for control design and evaluation

Future/Ongoing work

- Compare HiTECC to captured wind tunnel data. Results will be published and presented at the 2012 JANNAF Conference in Monterey, CA, 12/2012.

- Use HiTECC to design shock position control algorithms. Results will be published and presented at the 2012 JANNAF Conference in Monterey, CA, 12/2012.

National Aeronautics and Space Administration

Thank you
Any Questions?