Combined Cycle Engine (CCE) Mode Transition

Fundamental Aeronautics – Hypersonic Project

Thomas J. Stueber
NASA Glenn Research Center
Cleveland, Ohio

Propulsion Control and Diagnostics (PCD) Workshop
Cleveland OH, February 29, 2012

Overview

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Team

- Communication, Instrumentation, and Controls Division / Research
  - Controls and Dynamics Branch (RHC)
    - Jeffrey T. Csank
    - Thomas J. Stueber
    - Randy Thomas
  - Digital Communications and Navigation (RHD)
    - Joseph A. Downey
    - Jennifer M. Nappier
    - Binh V. Nguyen
- Systems Engineering and Analysis Division / Engineering
  - Propulsion & Control Systems Engineering (DSS)
    - Dzu K. Le
    - Daniel R. Vrnak
- NASA Research Announcement 2005-2008 (NRA)
  - Spiritech Advanced Products Incorporated

Hypersonic Research Task Objective

Guidance Navigation and Control Team

- Design controllers for an air breathing propulsion system of a hypersonic vehicle to address the following issues:
  - Improve operability
  - Improve safety
  - Increase efficiency
  - Reduce cost

Roadmap to Controls Experiments

- Computational simulation development
- System identification (SysID) experiments with hardware
- Control design model (CDM) development
- Controls research and design
- Test controllers on computational simulation
- Controls experiments on hardware

Hypersonic: Combined Cycle Engine Mode Transition

- Overview of project activities (Stueber)
  - Propulsion system concept
  - Combined Cycle Engine (CCE) Large-Scale Inlet for Mode Transition Experiments (LIMX) introduction. **CCE-LIMX**
  - Simulation buildup
    - Controlling the Large Perturbation Inlet Simulation with Matlab Simulink software LAPIN-in-the-Loop
    - High Mach Transient Engine Cycle Code (HiTECC)
  - Wind tunnel experiments
- Hypersonic propulsion system simulation (Csank)
- CCE-LIMX wind tunnel experiments (Stueber)

Hypersonic: Combined Cycle Engine Mode Transition

- Overview
- Hypersonic Propulsion System Simulation Development
- CCE-LIMX Wind Tunnel Experiments

Propulsion System Concept

- Two stage to orbit (TSTO) reusable air breathing launch vehicle (RALV)
- Combined cycle engine (CCE) benefits
- TBCC propulsion system

Propulsion System Concept

- Two stage to orbit (TSTO) reusable air breathing launch vehicle (RALV)
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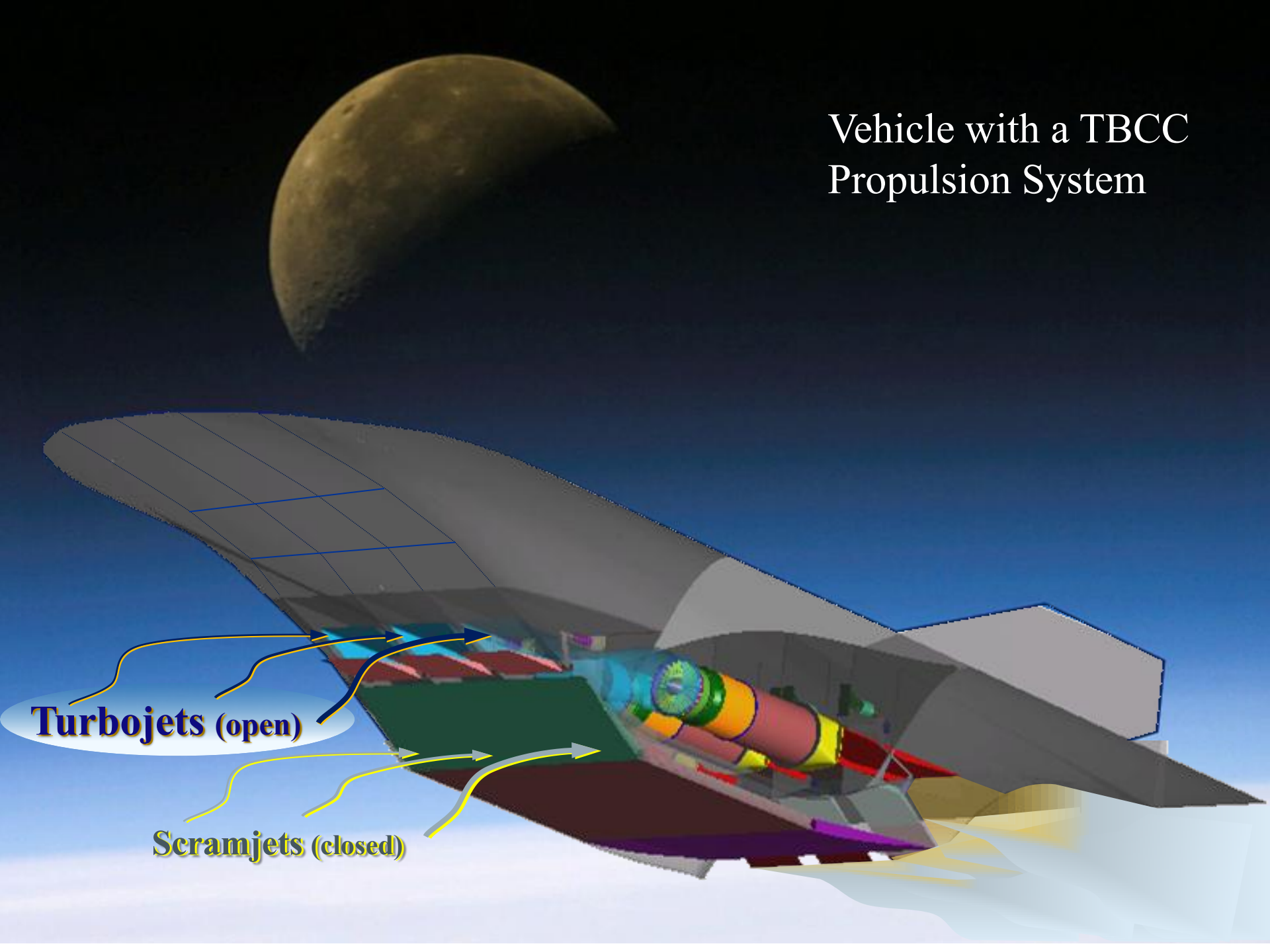
Turbine Based Combined Cycle

National Aeronautics and Space Administration

Hypersonics Project

Reusable Air Breathing Launch Vehicle (RALV) Concept

Vehicle with a TBCC Propulsion System



TBCC Propulsion Benefits : Efficiency, Safety, Reliability

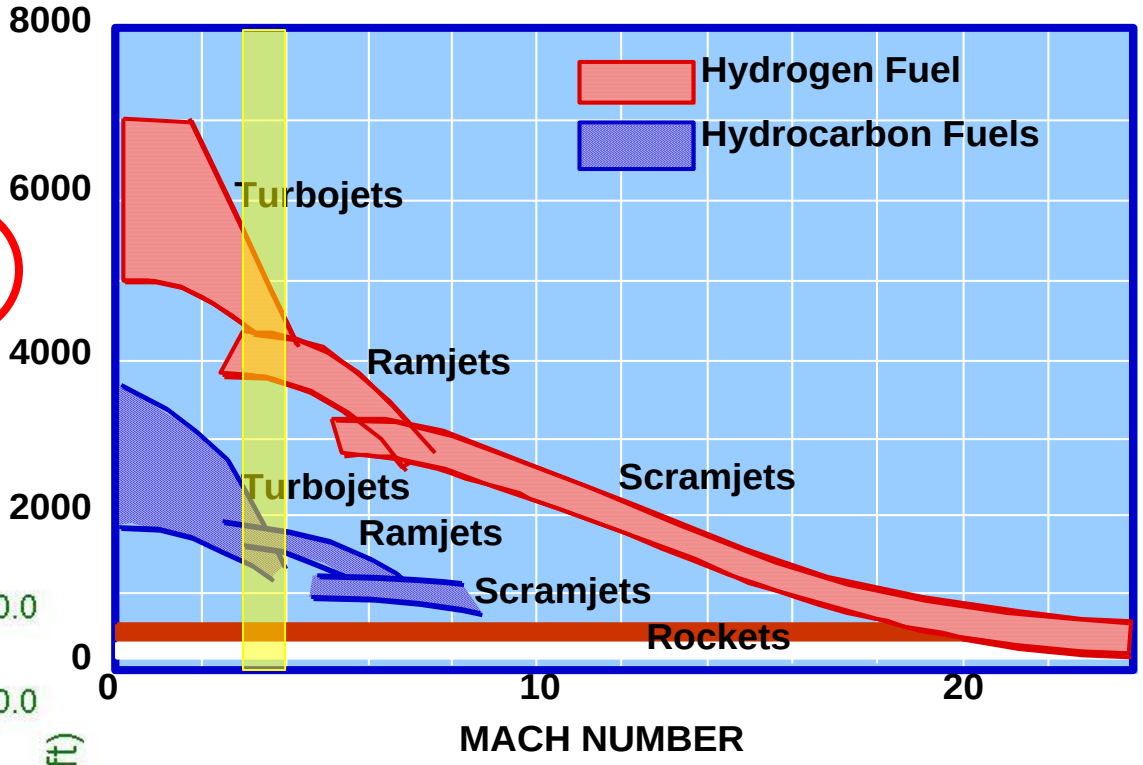
I_{SP} = *Thrust (lbf) per propellant mass flow rate*

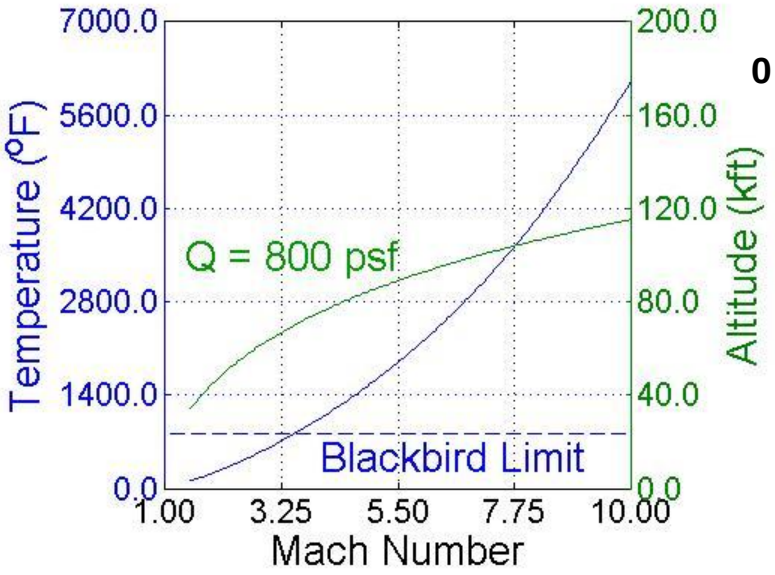
$$I_{SP} = \frac{F}{\dot{m} g_0}$$

$g_0 = 32.174\ ft/sec^2$

Specific Impulse

I_{sp}





- **Horizontal takeoff and landing enhances launch, flight and ground operability**
  - ✓ **Benign ascent abort/engine out**
  - ✓ **Launch pad not needed**
  - ✓ **Flexible operations & quick turn around time (Aircraft like operations)**

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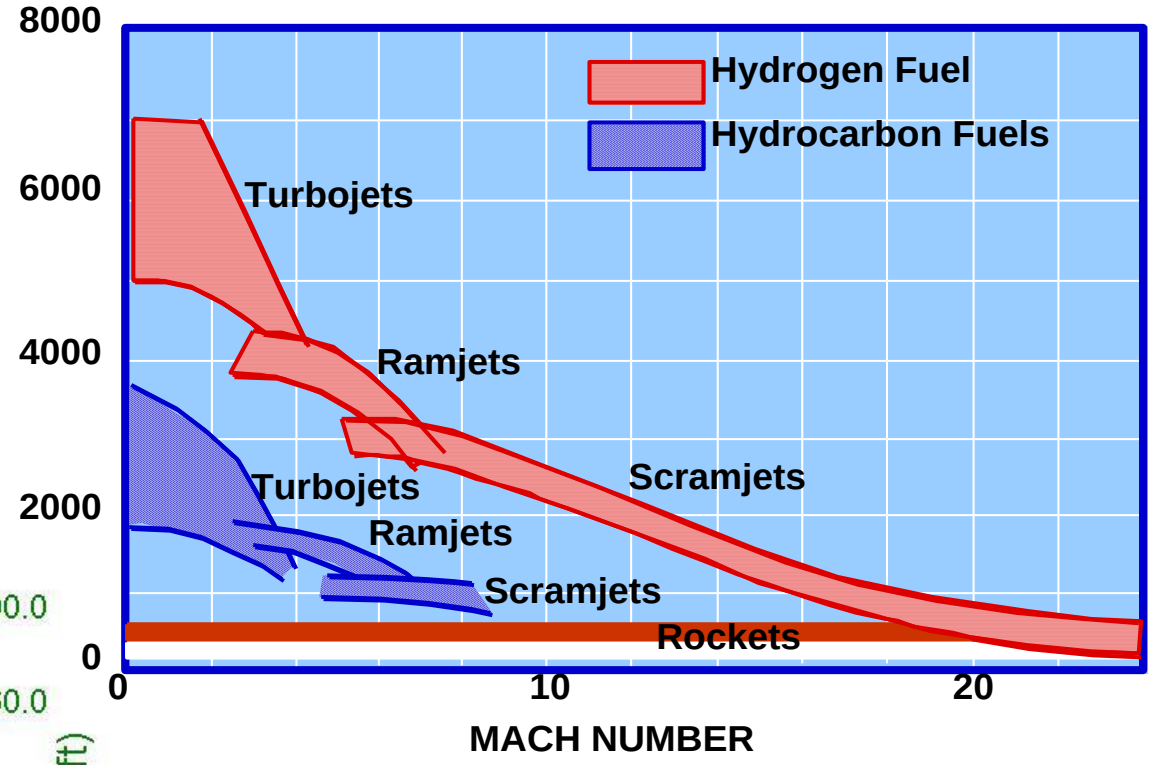

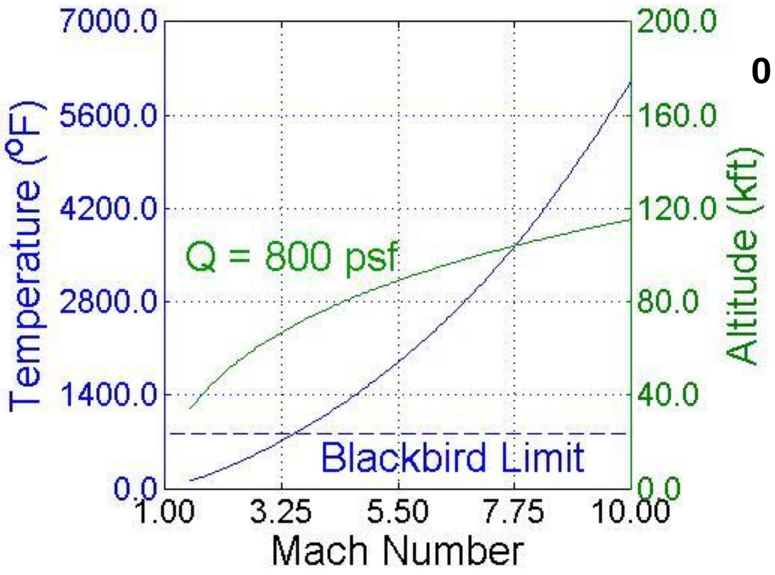

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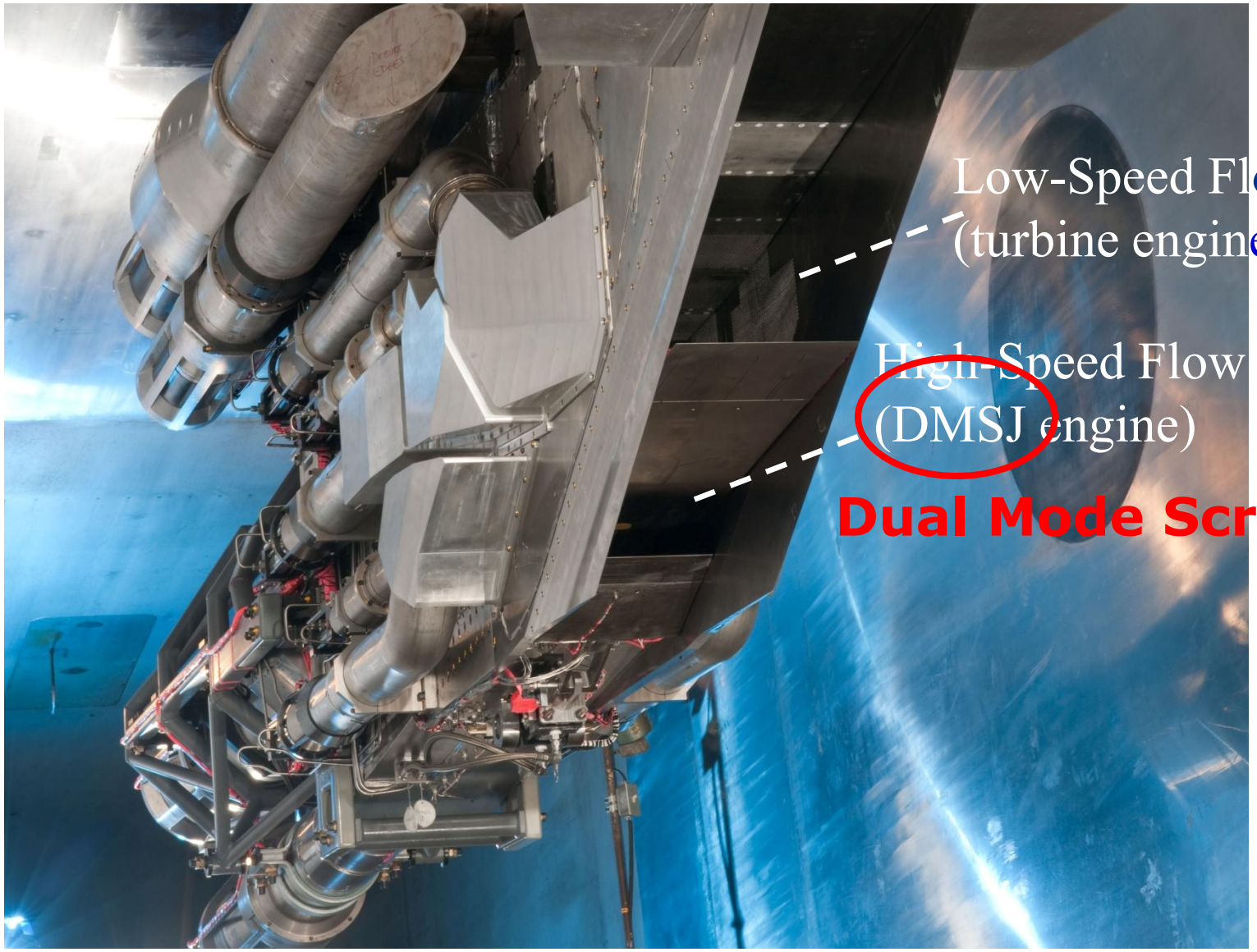
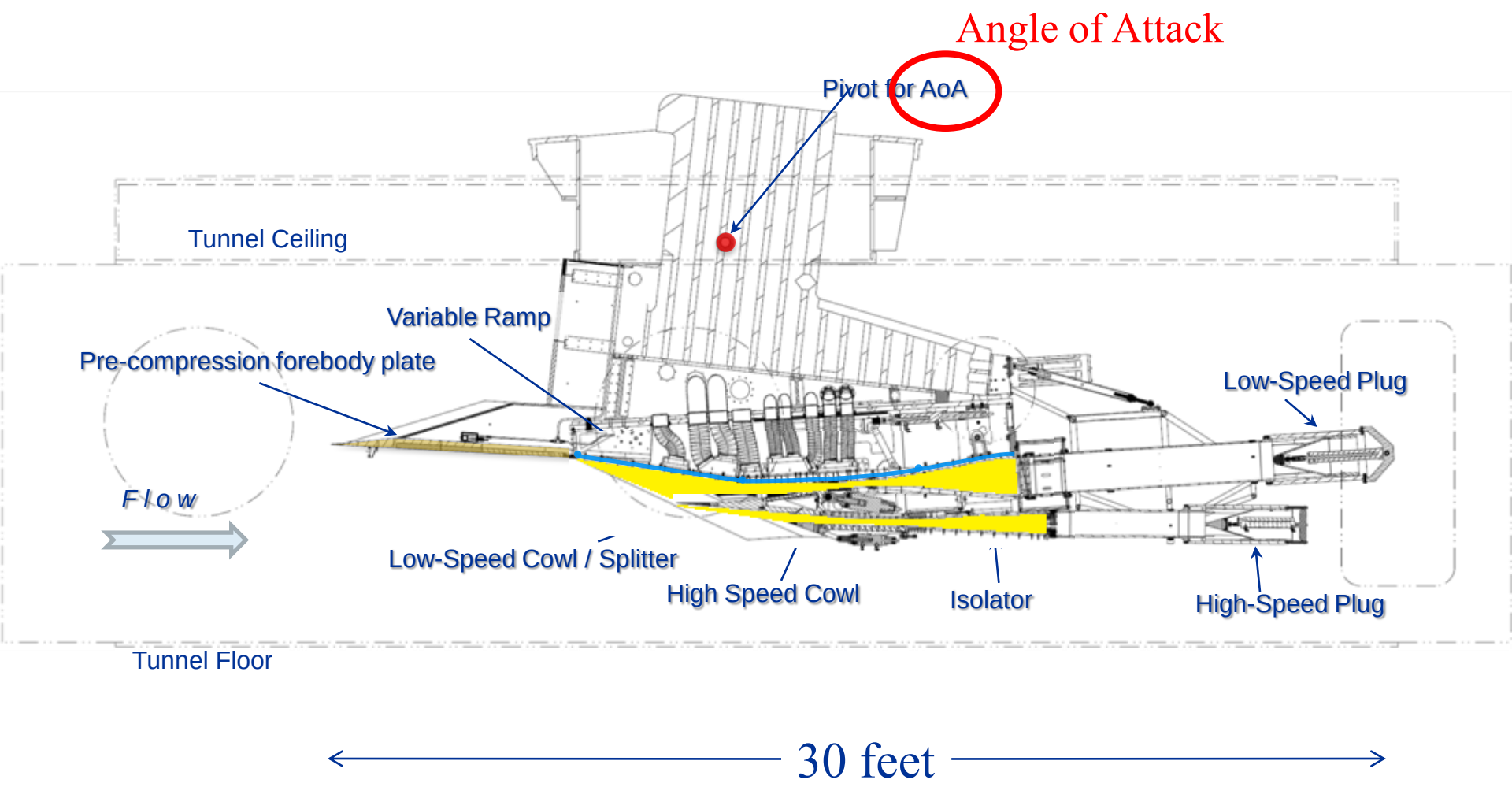
Combined Cycle Engine (CCE)
Large-Scale Inlet for Mode Transition Experiments (LIMX).
CCE-LIMX

CCE-LIMX Model



CCE-LIMX Model Features



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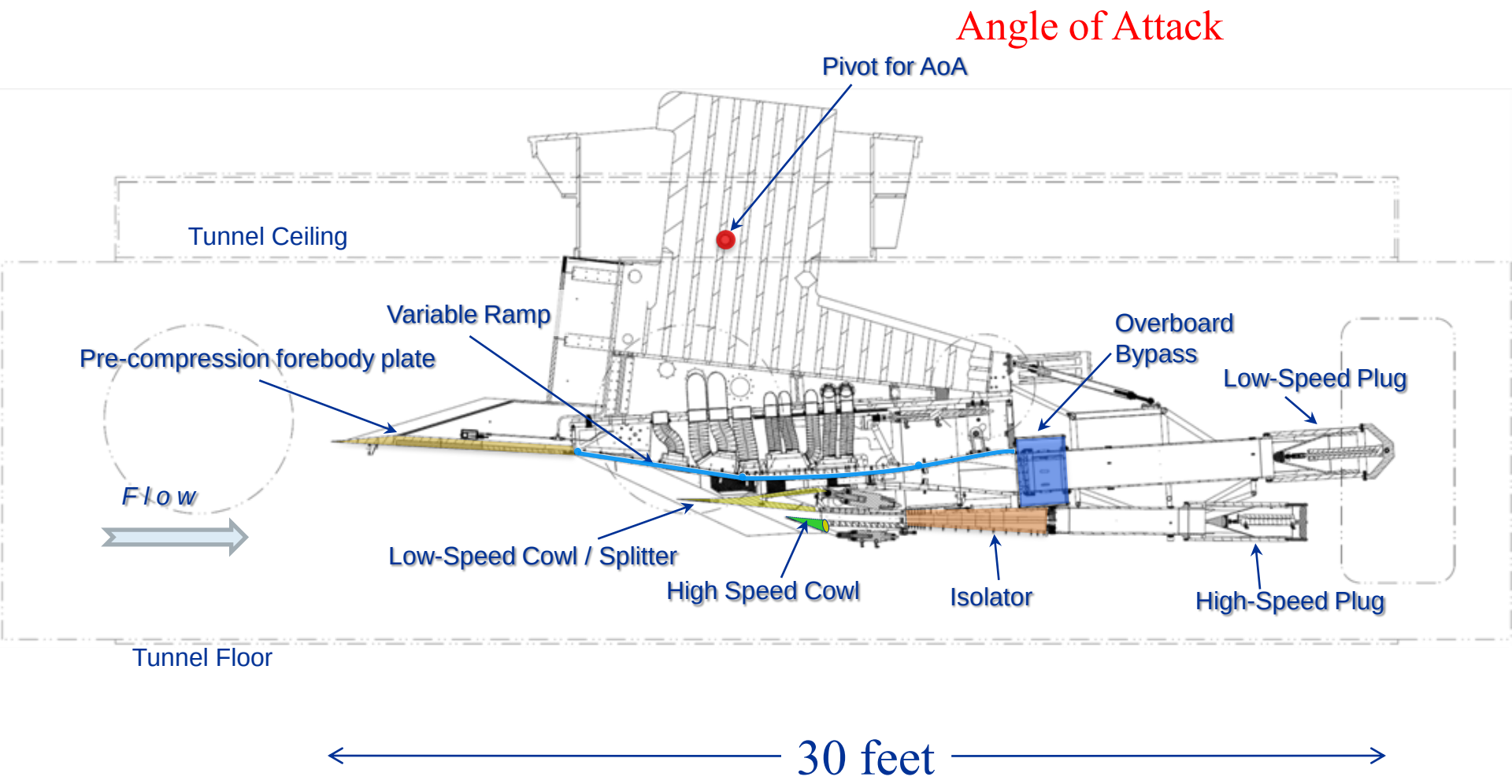
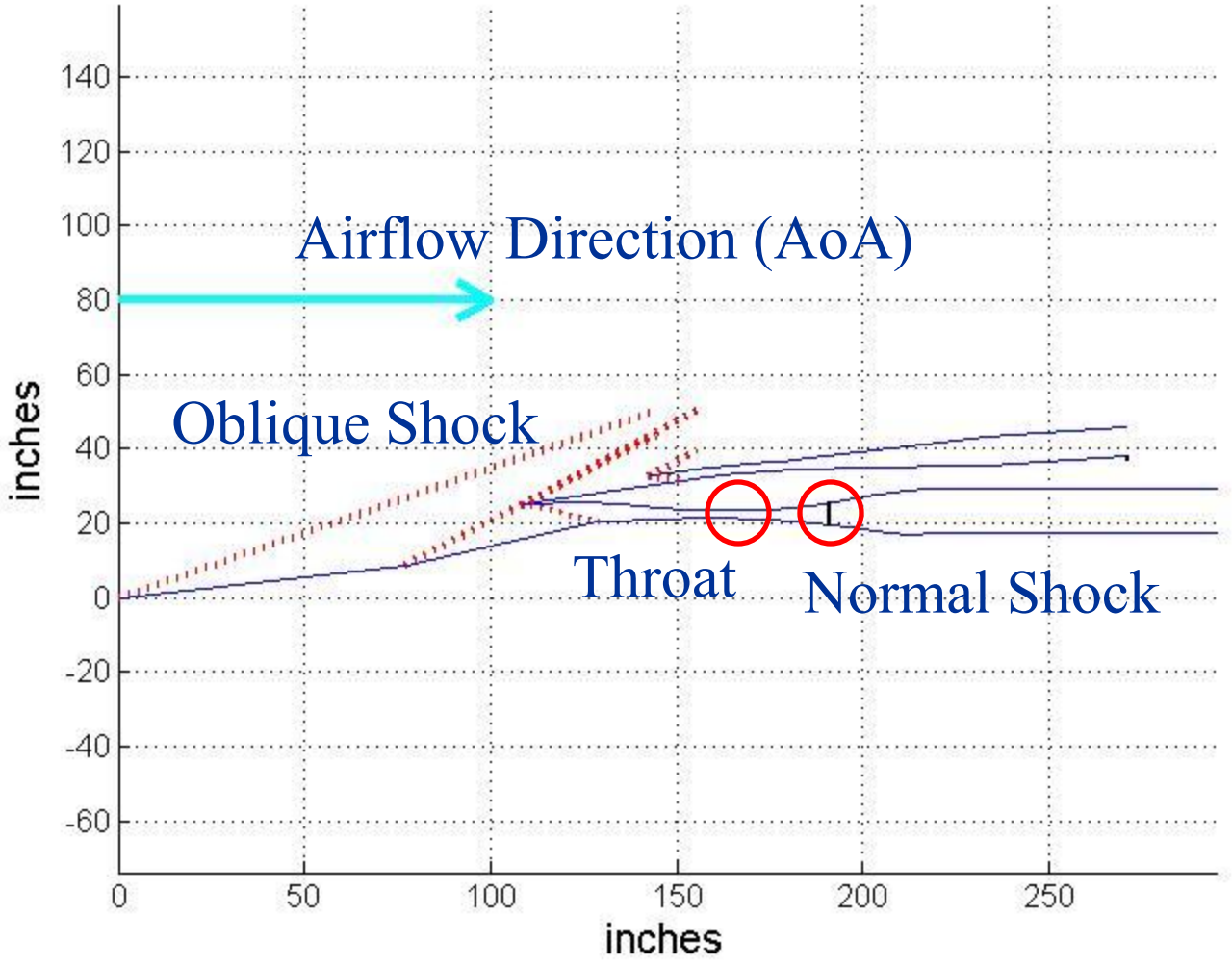


CCE-LIMX Inlet Terminology



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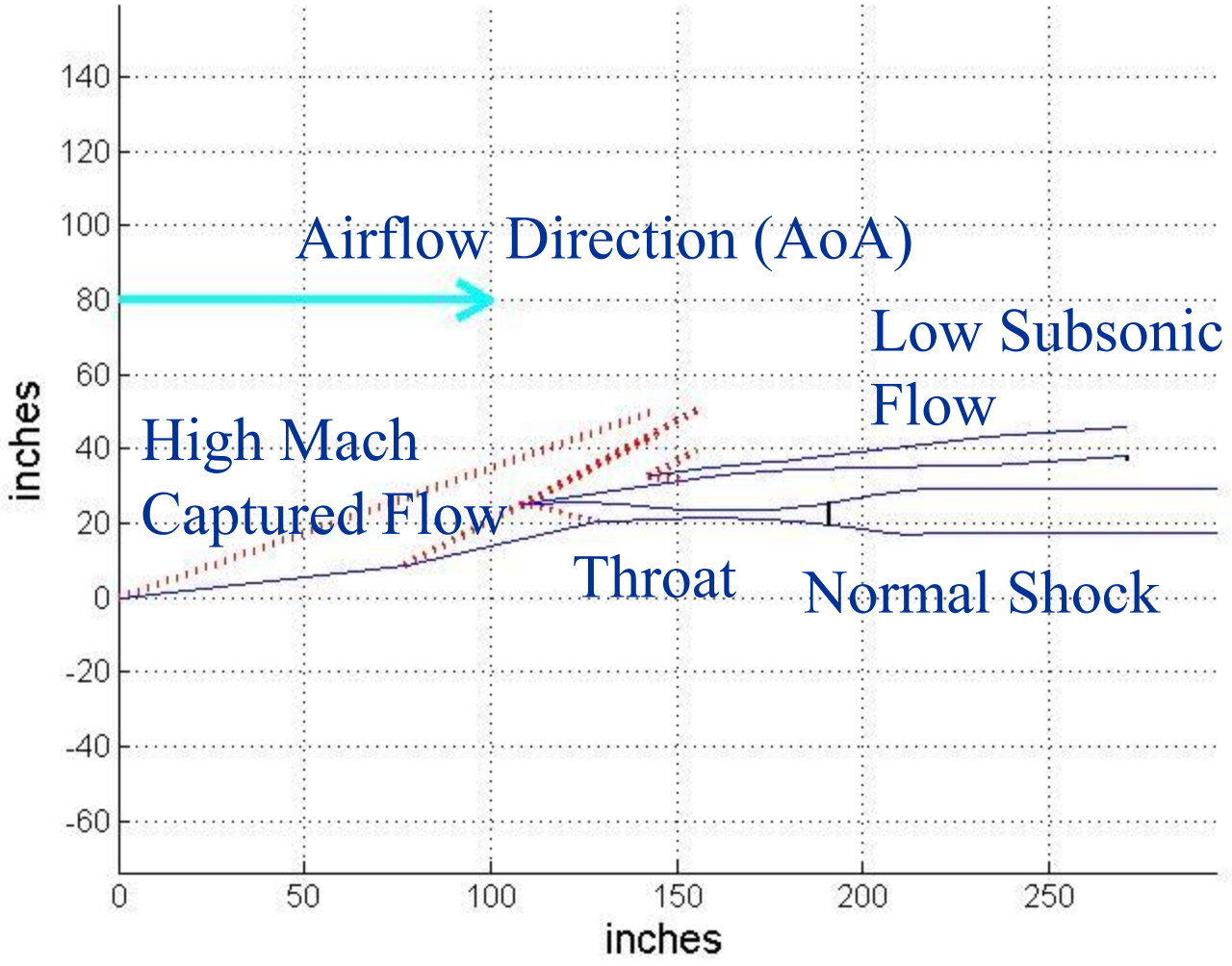


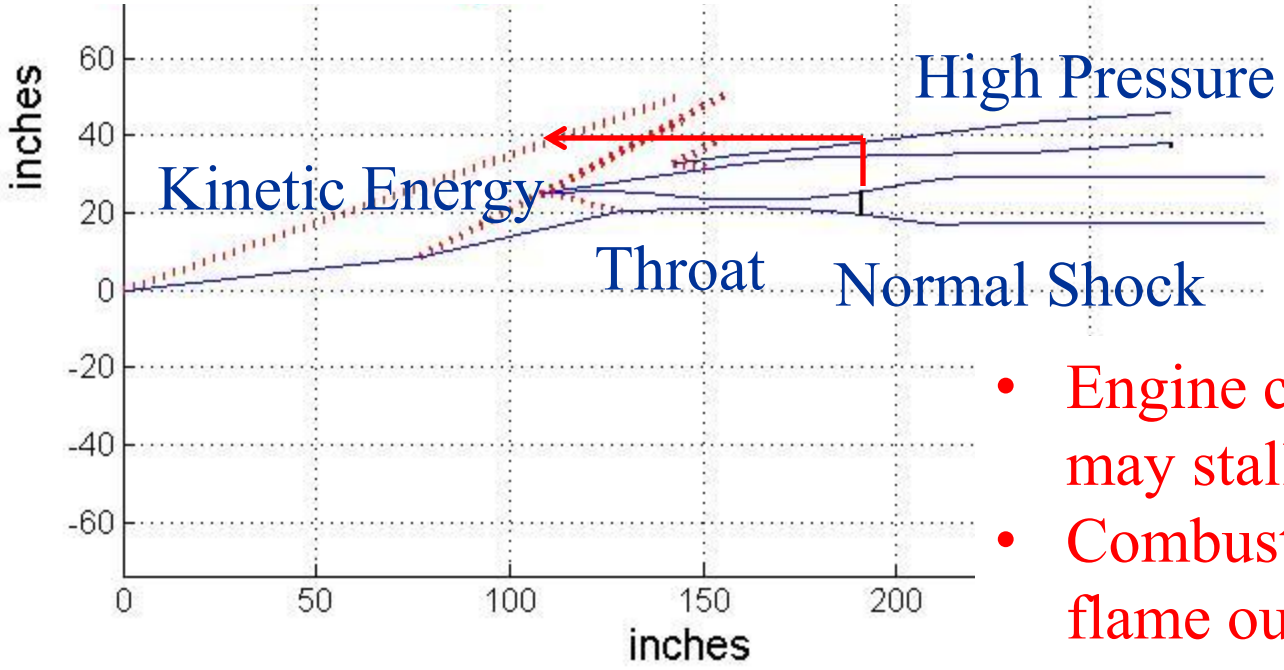
CCE-LIMX Inlet Terminology

Causes of unstart:

- Compressor stall
  - Rapid throttle change
  - Afterburner ignition
  - Inlet airflow distortion
  - Rapid changes in inlet air temperature

UnStarted Inlet

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



- Engine compressor may stall
- Combustor may flame out

CCE-LIMX Inlet Terminology

Causes of unstart:

- Compressor stall
- Free stream changes

UnStarted Inlet

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~~High pressure recovery~~
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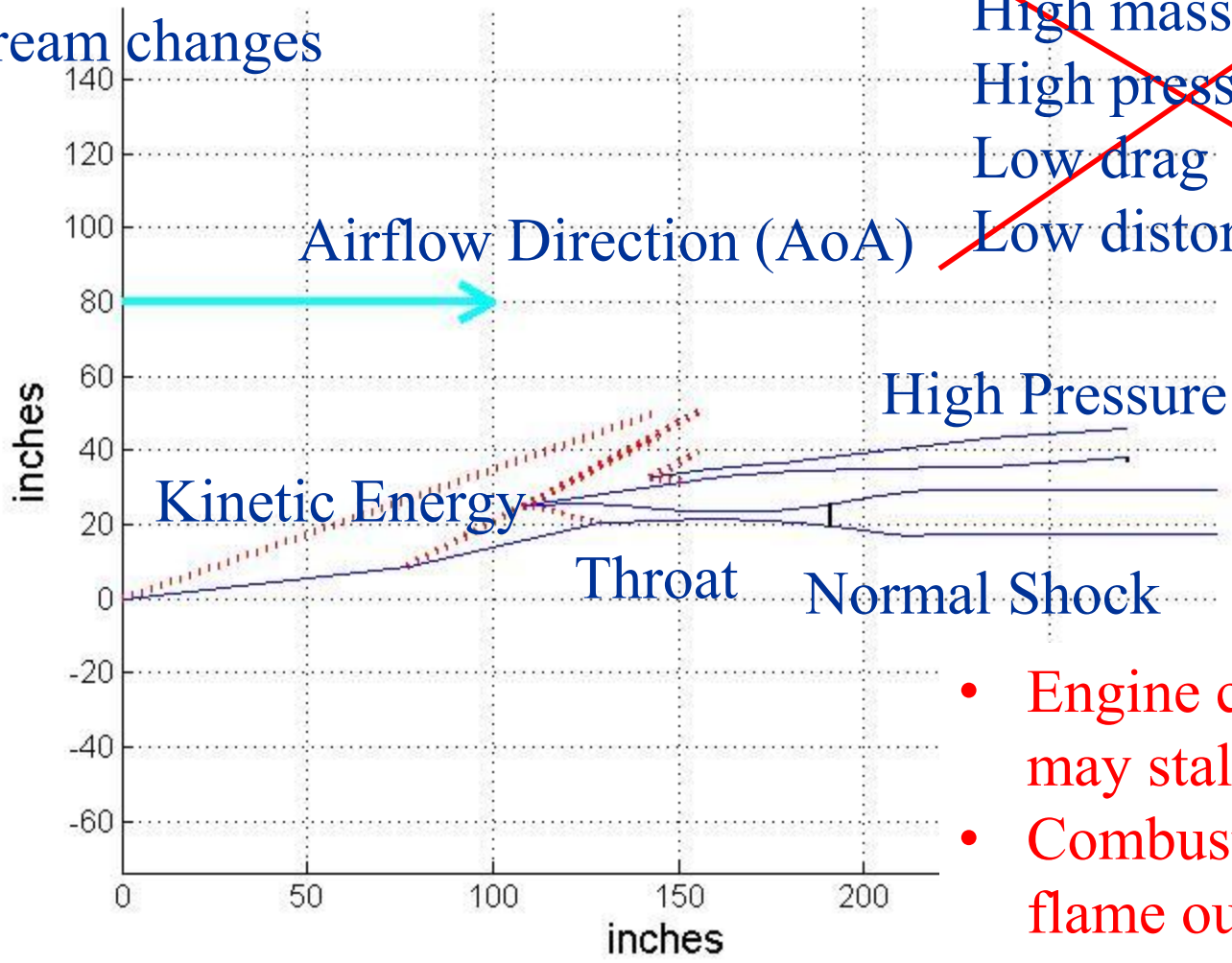

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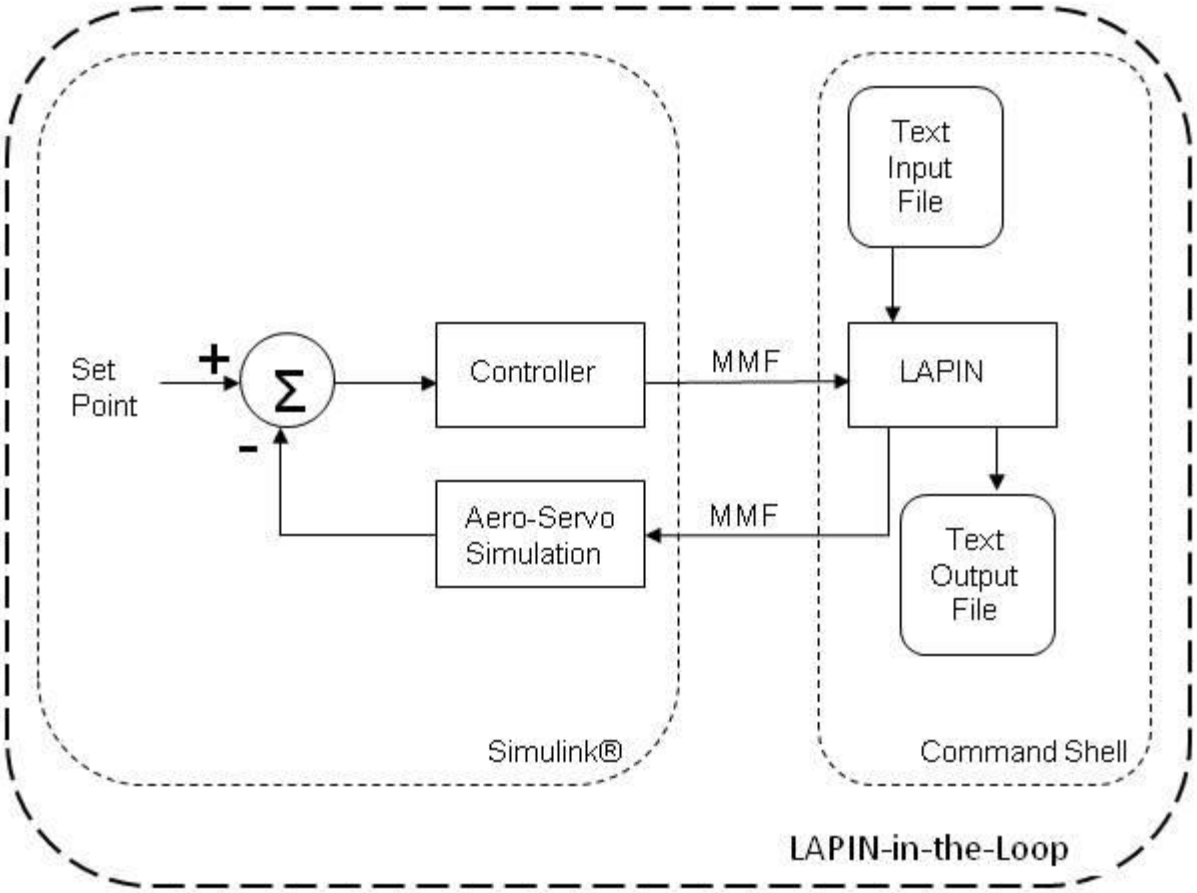
Computational Simulations

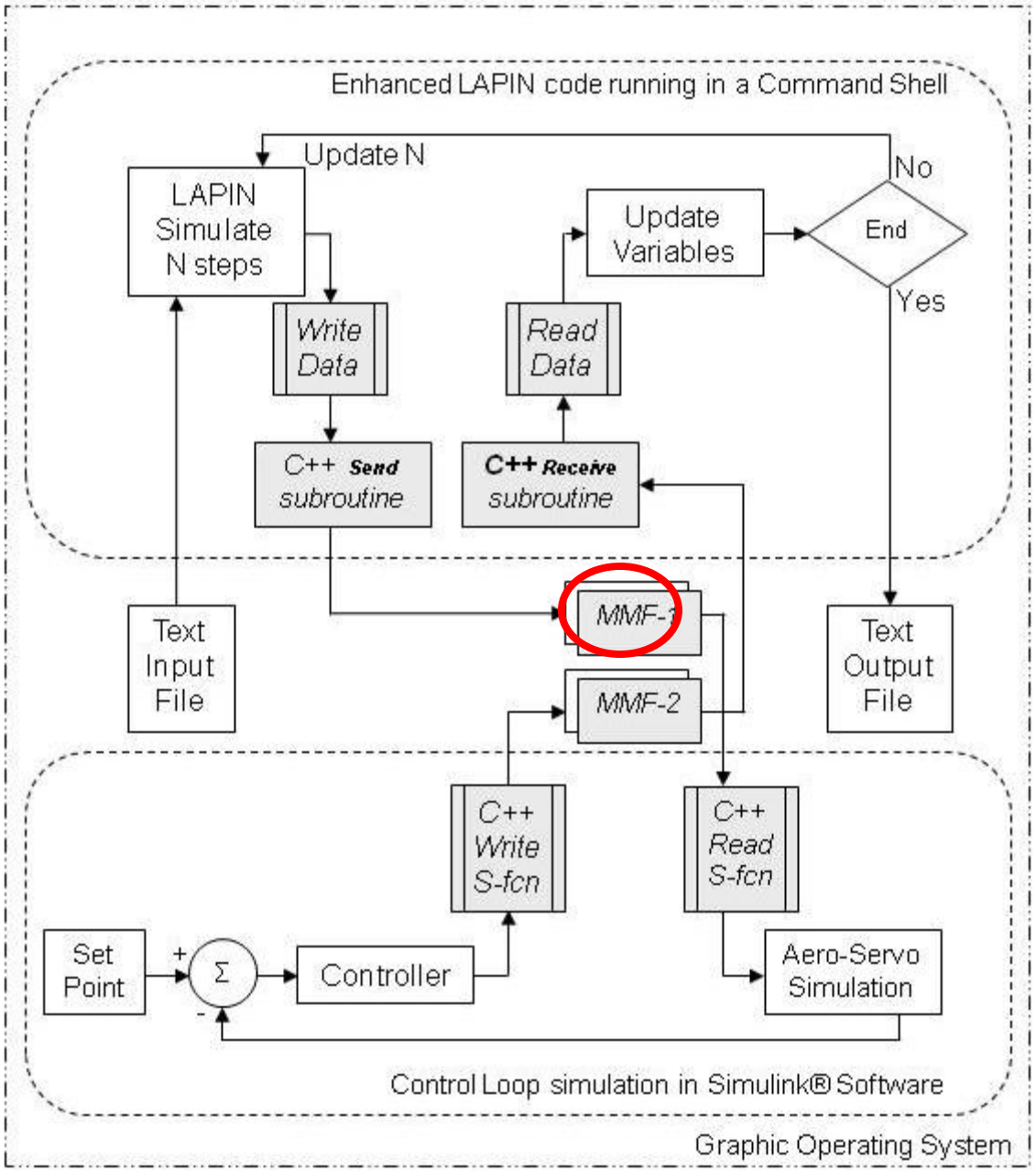
- LAPIN-in-the-Loop
- HiTECC (Jeffrey Csank)

LAPIN-in-the-Loop

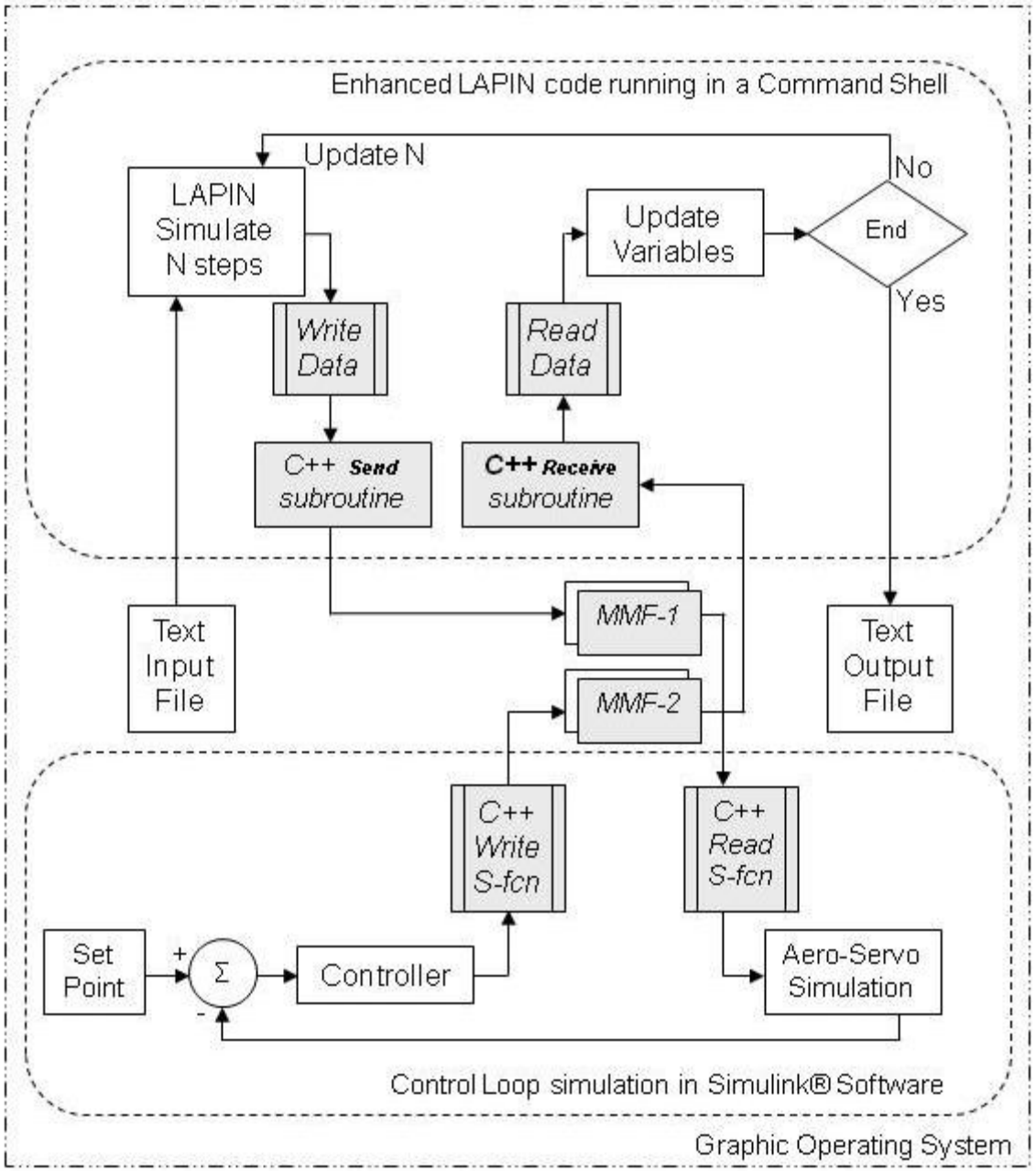


LAPIN-in-the-Loop

Memory Mapped File



LAPIN-in-the-Loop



CCE Inlet Wind Tunnel Experiments

- CCE-LIMX hardware testing is conducted in the following four phases:
  - Phase 1 Inlet characterization and performance testing
    - Static inlet operating points
    - Mode transition schedule
  - Phase 2 System identification
    - Step response analysis
    - Sinusoidal sweep response analysis
  - Phase 3 Controls testing
    - Disturbance rejection testing
    - Controlled mode transition
  - Phase 4 Propulsion system testing
    - Turbine engine for LSFP
    - Dual-mode combustor for HSFP

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