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.
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Jeffrey Csank and Thomas Stueber
NASA Glenn Research Center
Cleveland, Ohio
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

Low-Speed Flow Path
(turbine engine)

High-Speed Flow Path
(DMSJ engine)
CCE-LIMX Model

Under Mounted High-Speed Flow Path

Pivot for AoA

Tunnel Ceiling

Variable Ramp

Pre-compression forebody plate

Flow

Low-Speed Cowl / Splitter

High-Speed Cowl

Isolator

Low-Speed Plug

High-Speed Plug

Tunnel Floor

30 feet
CCE-LIMX Model

- Pre-compression forebody plate
- Variable Ramp
- High Speed Cowl
- Overboard Bypass
- Low-Speed Cowl / Splitter
- High-Speed Plug
- Isolator
- Pivot for AoA
- 30 feet
CCE-LIMX LSFP Terminology

Inlet Unstart Region

Inlet Start Region

Normal Shock

Throat

Diffuser

UnStarted Inlet

High mass recovery
High pressure recovery
Low distortion
Low drag

Causes of Inlet Unstart:
Compressor stall
Free stream changes

Increased Performance

Increased Stability Margin

Compressor stall
Combustor flame-out

Airflow Direction
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

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®)

HiTECC Simulink Model

SimMechanics Link

Simulink Model
Redesign Geometry, Actuators, and Control Systems

Mach 4.0

X Position, in
Y Position, in
-10
-20
-30
100 150 200

Area Error, %
0
2
-2

X Position, in
Mach 4.0
100 150 200

Mach 3.1

X Position, in
Y Position, in
-10
-20
-30
100 150 200

Area Error, %
0
2
-2

X Position, in
Mach 3.1
100 150 200

Mach 2.5

X Position, in
Y Position, in
-10
-20
-30
100 150 200

Area Error, %
0
2
-2

X Position, in
Mach 2.5
100 150 200

CCE-LIMX  HiTECC
HiTECC Subsonic Volume Initial Conditions

Supersonic Flow

Subsonic Flow

\[ \frac{dx}{dt} \]

P15
T15

W16

P17
T17

W18

P19
T19

Normal Shock
HiTECC Initial Conditions

- Control
- Hydraulic/Kinematic
- Thermal
- Propulsion
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

- Top graph: Pressure Ratio vs. Time (s)
- Bottom graph: Shock Position (in) vs. Time (s)
• 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

Air Flow

Plug

Plug Position

Pressure Ratio

Plug Position, % Full Stroke

0 10 20 30 40 50 60 70 80 90 100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Plug Position, % Full Stroke

Pressure Ratio

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Plug Position, % Full Stroke

Pressure Ratio
Addition of the Cold Pipe Volume

Supersonic Flow

Subsonic Flow

P15 T15

P17 T17

P19 T19

W16

W18
HiTECC Wind Tunnel Model Plots

- Splitter, deg
- LSFP Mass Flow Plug, in
- Shock Position, in
- Pressure Ratio

Graphs showing time in seconds and changes in various parameters.
HiTECC Wind Tunnel Model Plots

- **Splitter, deg**
  - Time, s: 0, 0.5, 1, 1.5, 2, 2.5
  - Values: -14, -12, -10, -8

- **Bypass Gate, sq in**
  - Time, s: 0, 0.5, 1, 1.5, 2, 2.5
  - Values: 0, 2, 4, 6

- **Shock Position, in**
  - Time, s: 0, 0.5, 1, 1.5, 2, 2.5
  - Values: 0.4, 0.5, 0.6, 0.7

- **Pressure Ratio**
  - No CP, CP
  - Time, s: 0, 0.5, 1, 1.5, 2, 2.5
  - Values: 0.4, 0.5, 0.6, 0.7
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.
Thank you
Any Questions?