RANS CFD Simulations of Scramjet Flow Path Transients

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Overview

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Mr. Kevin Jackson, AFRL/RQ
Dr. Jiwen Liu, Taitech, Inc.
Personal Background

• B.S. Mechanical Engineering
  – University of Akron
  – May 2012
  – Minor in applied mathematics

• PhD Aerospace Engineering
  – The Ohio State University
  – Fall 2013-Fall 2017 (Expected)
  – Graduate Course Work
    › Hypersonic flows
    › Advanced air-breathing propulsion
    › Compressible CFD
    › Turbulence

• Research interests
  – Scramjet flow paths
  – Hypersonic roughness-induced boundary-layer transition

• Awarded DAGSI Fellowship
  – Begins: Fall 2014
  – Mentor: Dr. Jeff Donbar
Motivation

- Scramjets
  - Military applications
  - Access to space
  - High-speed transport
- Challenges
  - Chemistry
  - SBLI

Interest: transition between ramjet and scramjet operation
**HIFiRE-2 Program**

- Hypersonic International Flight Research Experiment
- Objective: study HC-fueled combustion during mode-transition ($M=6 \rightarrow 8$)
- Successful flight test May 2012

Extensive ground tests in addition to flight test
HIFiRE-2 Program

Primary emphasis on discovery, not demonstration

http://www.nasa.gov/topics/aeronautics/features/hifire.html

Image reproduced with permission from Jackson et al., 2011
What are the physics of mode-transition?
HIFiRE-2 Experiments

Ground (HDCR) Configuration

Flight Configuration

Difference in inlet geometry significantly affects flow field

Reproduced from Jackson et al., 2008

Reproduced from Gruber et al., 2008
HIFiRE-2 Experiments

Ground Configuration

Outboard

Secondary (x8)

Inboard

Primary (x8)

144 static pressure ports
19 surface thermocouples
4 heat flux gauges

Ground test pressure data used for validation

Reproduced from Jackson et al., 2008
Reproduced from Gruber et al., 2008

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Computational Approach

- URANS with CFD++ code by METACOMP, Inc.
- Taitech-Princeton Ethylene combustion (TP2) model
- Hybrid structured/unstructured grids, O(2.5M) cells

How does mode transition occur?

How do differences in geometry (ground versus flight) affect flow field?
Steady, Dual-Mode Operation

Good agreement between steady dual-mode/scramjet simulations and experiment
Mode-Transition: Physics

Dual-Mode

Shock train

Boundary layer separation caused by pressure rise

Combustion

Ma_0 > 1

Ma_c < 1

Scramjet-Mode

Shock train

Supersonic flow throughout

Combustion

Ma_0 > Ma_c > 1

Pressure

Dual-Mode pressure rise in isolator section

Scramjet-Mode pressure rise downstream of injectors

Axial position

Ma_0 > 1

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Mode-Transition: HDCR Geometry

Mode-transition characterized by loss of flame-holding in inboard primary-injectors

Does this occur in flight?
Mode-Transition: Flight versus Ground Geometries

Low energy region near centerline preserves inboard PI flame-holding in flight
Mode-Transition: Flight versus Ground Geometries

Gaitonde et al., 2003
Although the steady-operation simulations better reflect the actual progression of the experiment, the mode-transition simulation results better match the experimental data.
Looking Ahead: Investigation of Scramjet Unstart

- DAGSI Fellowship (Fall 2014) under mentorship of Dr. Jeff Donbar
- Unstart adversely affects engine performance
  - Want to capture large scale transients
    - Identify precursors to unstart
    - Quantify SBLI sensitivity to variations in fuel input
  - Understanding transient behavior will facilitate development of control systems to limit unstart

Can unstart be anticipated by measuring away from the wall?

Can quantities other than pressure be used to predict unstart?
Looking Ahead: Future Work

AFRL Direct Connect Rig
- Evaluate unstart detection techniques
- Build on exp. work of Donbar et al. 2010

HIFiRE-2 HDCR
- Unstart in dual-mode operation
- Validate with exp. work of Cabell et al. 2011

HIFiRE-2 Mode-Transition
- Full flight test geometry
- Rapid fuel flow perturbations
Summary

• Mode-transition CFD studies completed for HIFiRE-2
  – Model parameters validated against ground test data
  – Loss of flame-holding affected by SBLI/geometry
  – Difference in predicted HDCR scramjet-mode behavior between:
    › Steady-operation (static B.C.)
    › Mode-transition (transient B.C.)

• Work beginning on the transients associated with unstart
  – Probe flow away from wall to identify precursors
  – Application to developing better fuel control systems
Q&A

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