LES of Shock-Boundary Layer Interactions
CCAS Review – May 2014

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Acknowledgements
Sponsors: CCAS
CPU: DoD HPCMP and OSC
Personal Background

• Academic Work
  – Florida Institute of Technology
    › B.S Aerospace Engineering (May 2012)
    › B.S Mathematical Science (May 2012)
  – The Ohio State University
    › Second year graduate student
    › Advisor: Prof. Datta V. Gaitonde
    › Completed required coursework

• Research
  – Interests
    › Inflow generation technique for SBLI
    › Unsteadiness in SBLI (2D and 3D)
  – Papers
    › Scitech 2014 (National Harbor, MD)
    › ASME 2014 (Chicago, IL)
    › Journal paper (J Comput Phys) – in progress
  – AFRL Summer student researcher
  – Regional Presentations (AIAA, ASME)
Motivation

• Propulsion flowpaths – inlets and isolators

• Performance inhibition
  – Unsteady – significant pressure fluctuations
  – Unsteady boundary layer separation
    › Reduced air intake efficiency
    › Unstart
Motivation

• Prediction and control of SBLI depends on accurate understanding of unsteady phenomena

• Physics of 3D interaction is inherently different from extensively studied nominally 2D interaction

• What are the mechanisms by which a swept shock processes turbulence in a boundary layer?

• What are the principal length and time scales of this interaction?

• Can we use unsteady excitations (plasma actuators) for control?

• Where will control be most effective?
Unsteadiness – Impinging Shock

- **Cause of unsteadiness?**
  - Oscillator model
  - Amplifier/Filter model

  Causation or correlation? --- Difficult to distinguish in separated region (subsonic)

2D theories suggest low frequency motions scale with freestream velocity and separation length.
Inflow Generation -- Method

- Trip laminar boundary layer with counter flow force (Dr. Visbal)
- Developed for supersonic flows
  - (Collaboration with Dr. Bisek)
- No direct frequency input
Inflow Generation -- Accuracy

- Expected mean and statistical behavior obtained
- No signature of trip

- Using hot wall in neighborhood of the trip speeds up transition
- Precursor to transition enables efficient parameter selection
- Extended to higher Mach numbers
General Stability Parameter

- Inlet behavior qualitatively similar
- Difference in peak magnitude but sign is the same
- Change in sign just downstream of reattachment

\[ \varphi = \frac{\partial}{\partial y} \left( \frac{\rho \partial \bar{u}}{\partial y} \right) \]
**Reduced Domain**

<table>
<thead>
<tr>
<th>Entire Domain (Mesh C)</th>
<th>Reduced Domain</th>
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<tbody>
<tr>
<td>95×25×5</td>
<td>50×25×2</td>
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It is sufficient to simulate only 10% of the domain. Can even use 2D simulation to predict.
Mean Flow Perturbation

Theory: Dynamical systems approach to understand low frequency motions in 3D interactions

- Examine time and spatial evolution of disturbance on base flow
- Maintain base flow at its original state
- Enables determination of most unstable mode
Mean Flow Perturbation

- **Mean flow**
- **Impose perturbation on mean flow**
- **Subtract mean flow**
- **t + Δt**
Mean Flow Perturbation – Preliminary Results
Method

Unsteadiness in 3D

3D mean flow perturbation

Double fin interaction mean flow

3D Inflow

Do we really need an LES of the swept interaction?

Unsteadiness in 2D- mean flow perturbation

Mean flow

Inflow

Mean separation

End of interaction

Mean reattachment
Suitably tailored RANS can provide reasonable mean flow solution for perturbation analysis.
Swept Interactions

- Mean 3D flowfield for swept interactions is open in nature
- Separation length varies in the spanwise direction

- How do these differences manifest in the unsteadiness of the interaction?
- Are there ways to use similarity or scaling laws to extrapolate from 2D?
- What specific frequency and wave number ranges are of interest?
Summary and Conclusion

• **Impinging Shock SBLI**
  – Technique for supersonic turbulent boundary layer developed and made efficient
  – Mean flow for impinging shock interaction with boundary layer obtained for multiple Mach numbers of interest
  – Continue parametric study on perturbation of nominally 2D flow

• **3-D Swept Interaction**
  – Obtain mean flow for double fin interaction
  – Perturbation of double fin interaction
  – Receptivity study

• **Employ mean flow perturbation approach on other Air Force systems of interest**
Questions?