Simulation of Ares Scale Model Acoustic Test Overpressure Transients Using Computational Fluid Dynamics

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Outline

• Introduction
  – Overview of the Ares Scale Model Acoustic Test (ASMAT)
  – Simulation goal and procedure

• Case Progression
  – Initial Attempt at Elevation 0’ (Pathfinder)
  – Ignition Transient and Throat Plug Release
  – Model Refinement

• Conclusions / Future Work
Introduction: ASMAT Overview

- **Ares Scale Model Acoustic Test**
  - Tests of 5% scale model of Ares I vehicle
  - Addressed vibration / acoustic risks from Constellation Program.

- **Physical Test Setup**
  - Scale model powered by Rocket Assisted Take-Off (RATO) motor
  - Vehicle at point of, or just after, lift-off
  - Stationary in space during firing
  - 100+ pressure transducers on the launch structure and vehicle (locations later)

- **Simulation Interest**
  - Well documented set of high fidelity measurements for CFD validation
  - Demonstration of CFD capability for IOP prediction
Introduction : Goals and Procedure

• Simulate transient startup of the ASMAT tests
• Evaluate pressure / temporal / spectral accuracy of code.
• Predict the Ignition Over-Pressure (IOP) on a launch pad

• General Procedure
  – Execute CFD simulations of the first 0.1 seconds of the tests
    • Ignition and throat plug loss
    • Ramp up to full power
    • Overpressure wave propagation
    • Simulation times of roughly 1 week using 1000 CPUs at Pleiades
  – Compare simulation data to pressure transducer data
    • Range of sensors across the vehicle, trench, pad, and tower
      – Specific sensors and locations on next page
    • Compare Pressure vs Time and SPL vs Freq
  – Compare wave / flow propagation to available imagery
    • Visible / IR wave cameras
Sensors Used for Comparison

IOP 158 090H
IOP 158 270H (North Side)
IOP 093 270H (North Side)
IOP 093 090H
IOP E04 (Top Lip of Duct Facing Down)
IOP E03 (Top Lip of Duct Facing Up)
IOP 006 292H (North Side)
IOP 006 112H
IOP E09H (Top Lip of Duct Facing Down)
IOP E08H (Inside Duct Facing Down)
IOP E07H (Inside Duct Facing Up)
IOP M08H
IOP D06H (Wall below D06H)
IOP D01H (Mid Underside)
IOP D06H
IOP D09H (Wall below D06H)
Case Progression: Pathfinder: Setup

- Obtained CAD model of ASMAT structure from ET50
  - Overly detailed (two upper right images)
  - Visited pad and took lots of pictures to understand important features
- Created a simplified version of structure
- Used ANSA to divide model into components, create mesh, and place structure within a computational domain (bottom images)
Case Progression: Pathfinder: Setup

- **Target comparison case – IOP3**
  - Dry launch pad
  - 0’ elevation, no drift

- **Creating a mass flow profile**
  - Started with pressure trace
    - Initially from chamber pressure
    - Ignition corrected using casing strain gages
  - Assumed mass flow proportional to pressure
  - Scale max mass flow to match RATO specs
    - Obtained from ESTSG-FY10-02462
    - Manufacturer supplied maximum
  - Took targeted samples of profile
  - Allowed CHEM to interpolate between them
Case Progression: Pathfinder: Results

- Qualitative visualization of overpressure formation (video)

- Qualitative comparison of effluent to imagery (video)
Case Progression: Pathfinder: Results

- Quantitative comparison of time and freq domain signals

**BLUE** is test data, **RED** is CFD data
Case Progression: Pathfinder: Results

- Quantitative comparison of time and freq domain signals

**SPL (dB re 20 uPa)**

**BLUE** is test data, **RED** is CFD data
• First profile based on pressure rise rate
  – Scaled from pressure rise rate
  – Throat plug loss not taken into account

• Changed profile in the ignition region
  – First used sharp start at pressure peak to simulate throat plug loss
    • Captured sharp spike at flow start
    • Timing mismatch with measured signals
  – Moved pressure peak to match time delay.

• Effect on simulated pressure

<table>
<thead>
<tr>
<th>Original Flow Profile</th>
<th>With Sharp Start</th>
<th>Time Delayed Sharp Start</th>
<th>Base Profile</th>
<th>Sharp Start</th>
<th>Time Delay</th>
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Case Progression : Model Refinement

• Issues with prior simulations and meshes
  – Poor mesh quality below the deck and tower
  – Lack of proper microphone mounts

• What was changed in the refinement
  – Fixed all low resolution areas
  – Added microphone mounts for all mics used
  – Overall resolution increase in trench and near rocket skin
  – Included time-delayed, sharp start for ignition and throat plug loss mass flow
Case Progression: Pathfinder Refined: Results

- Quantitative comparison of time and freq domain signals

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Conclusions / Forward Work

- Overpressure can be simulated in a dry state
  - Major pressure peak amplitudes captured with 5-10% error
  - Major pressure peak timings captured similarly well

- Unresolved Issues with timing and water
  - Timing of ignition transient and throat plug loss that still needs to be explained, although time delay appears to match well
  - Large scale water use currently fails when water is compressed against solid walls and limits applications for in-trench deluge
    - Short-term – Implement method to automatically remove overly dense liquids near walls
    - Long-term - Implement shallow liquid pooling models for near-wall liquid collection

- Forward work
  - Freq content of signals currently captured out to 1500-3000 Hz depending on sensor and transmission path
  - Attempt simulation of quasi-steady acoustics
Backup Slides
CFD Parameters Used

• Gas Chemistry:
  – Frozen chemistry, mixed heavy gas model
  – Air, and RSRM effluent (a heavy gas, RATO motor, effluent approximation) as the working fluids.

• Transport Model:
  – Sutherland model for viscosity and thermal conductivity using properties for air.

• Diffusion Model:
  – Laminar Schmidt
  – Simultaneous mass and momentum diffusion convection processes with Laminar Schmidt Number = 0.9

• Turbulence Model and Method:
  – Menter’s Shear Stress Transport (SST) two equation eddy viscosity turbulence model with limiters and vorticity source term (SST-V)
  – Coupled with Nichols-Nelson Hybrid RANS/LES model (Multiscale turbulence model where eddy viscosity is a function of two turbulent length scales).

• Time Integration:
  – Time Accurate, 2e-5 sec timesteps.
  – 7 Gauss Seidel iterations
  – 7 Newton sub-Iterations

• Fluid Linear Solver:
  – Symmetric Gauss Seidel solver.

• Inviscid Flux Treatment:
  – Riemann solver using Roe scheme with HLLE (Harten-Lax-van Leer-Einfeldt) algorithm for strong shock s.

• Flux Limiter:
  – Venkatakrishnan (Second-order spatial accuracy gradient reconstruction limiter with threshold of acceptance for small variances.)
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**Pressure vs Time - IOP_M03H**

**Pressure vs Time - IOP_093_090H**

**Pressure vs Time - IOP_D09H**

**Pressure Content Per Freq - IOP_M03H**

**Pressure Content Per Freq - IOP_093_090H**

**Pressure Content Per Freq - IOP_D09H**

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