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

Acoustical Society of America Meeting

San Diego, California

11/03/11

Gabriel Putnam

ESTS Group/All Points Logistics/ER42/MSFC

Outline

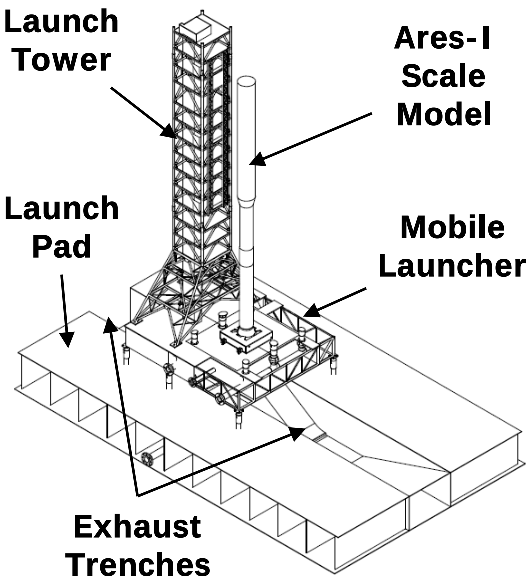
- Introduction
  - Overview of the Ares Scale Model Acoustic Test (ASMAT)
  - Simulation goal and procedure

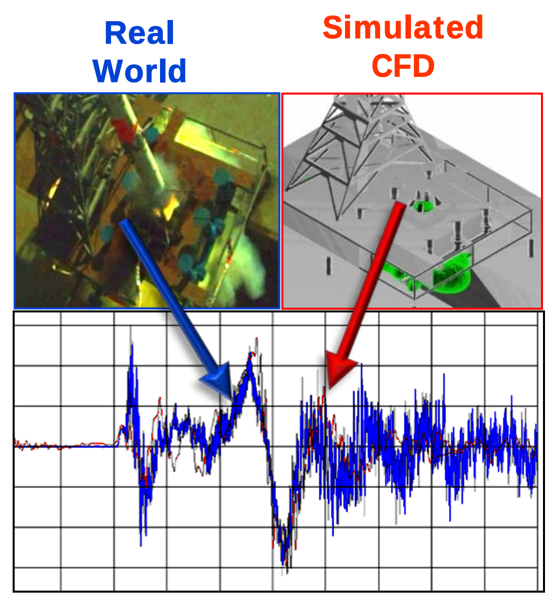
- Case Progression
  - Initial Attempt at Elevation 0’ (Pathfinder)
  - Ignition Transient and Throat Plug Release
  - Model Refinement

- 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

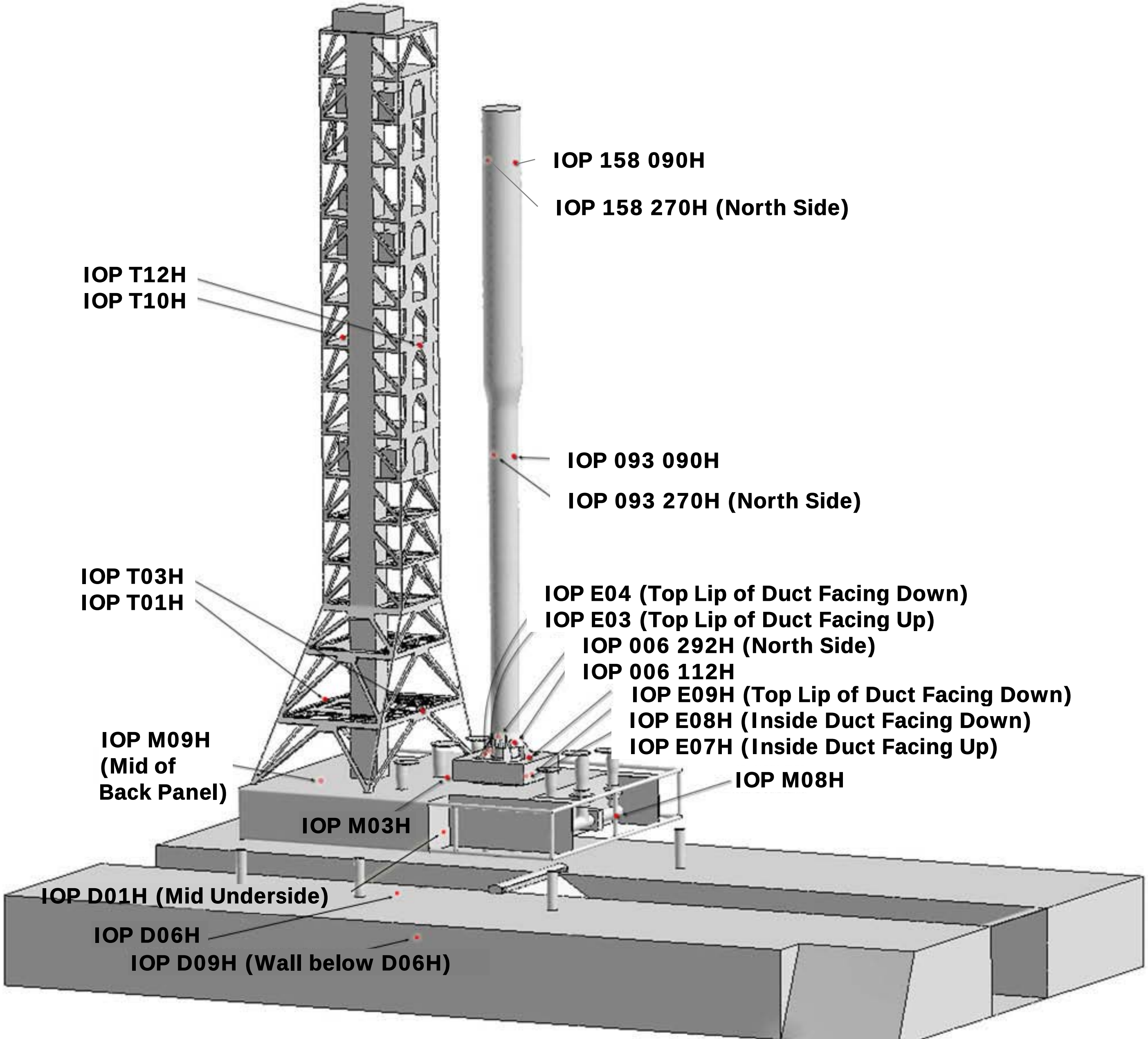




Introduction : Goals and Procedure

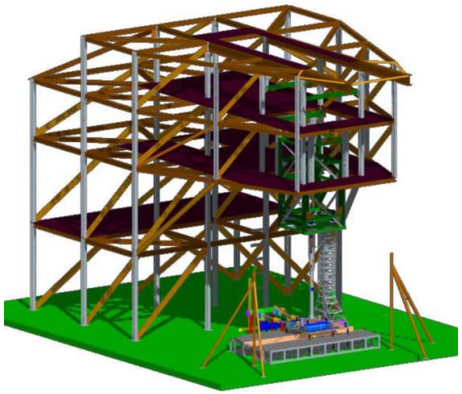
- Simulate transient startup of the ASMAT tests
- Evaluate pressure / temporal / spectral accuracy of code.
- Predict the Igition Over-Pressure (IOP) on a launch pad
- General Procedure
  - Execute CFD simulations of the first 0.1 seconds of the tests
    - Ignition and throat plug loss
    - Ramp up 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

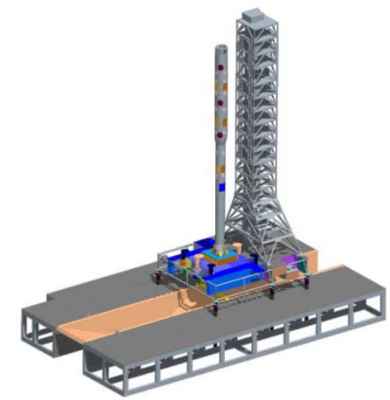
Sensors Used for Comparison

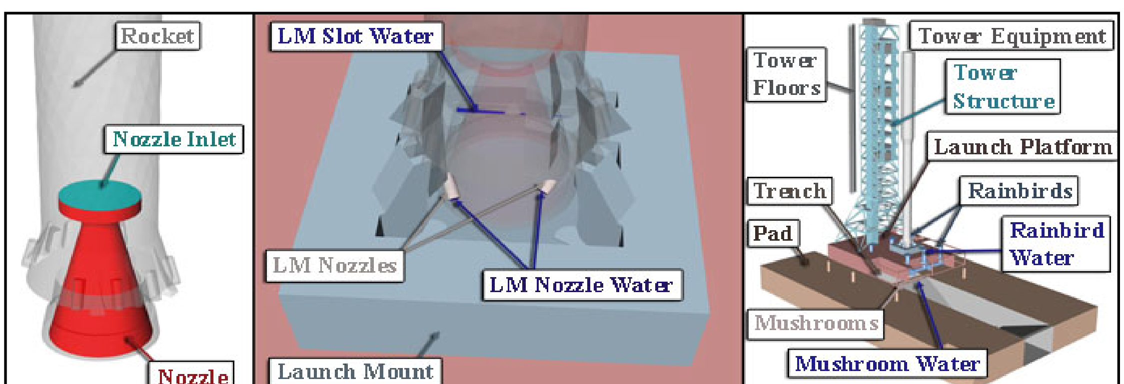


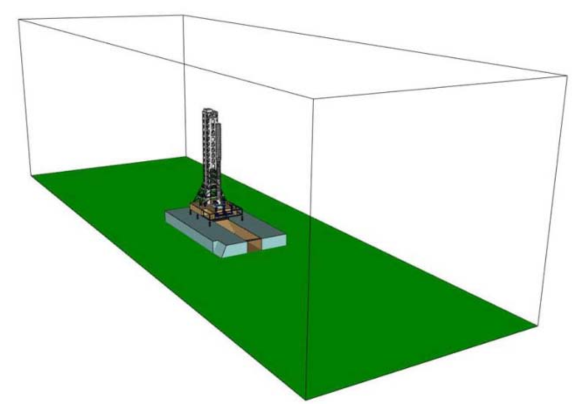
Case Progression : Pathfinder : Setup

- 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)



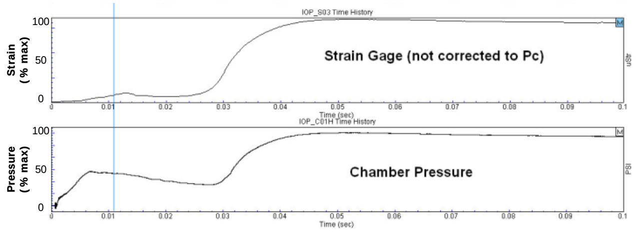




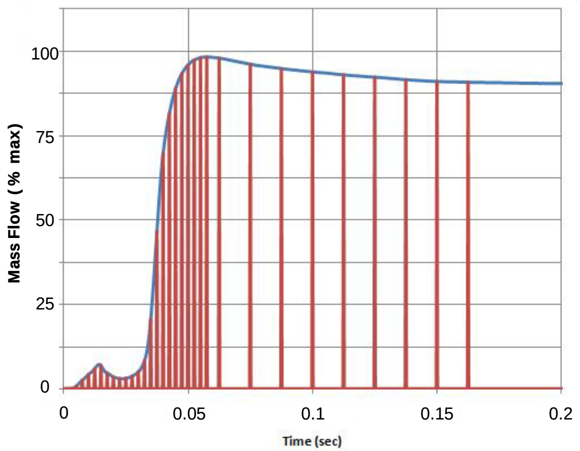


Case Progression : Pathfinder : Setup

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

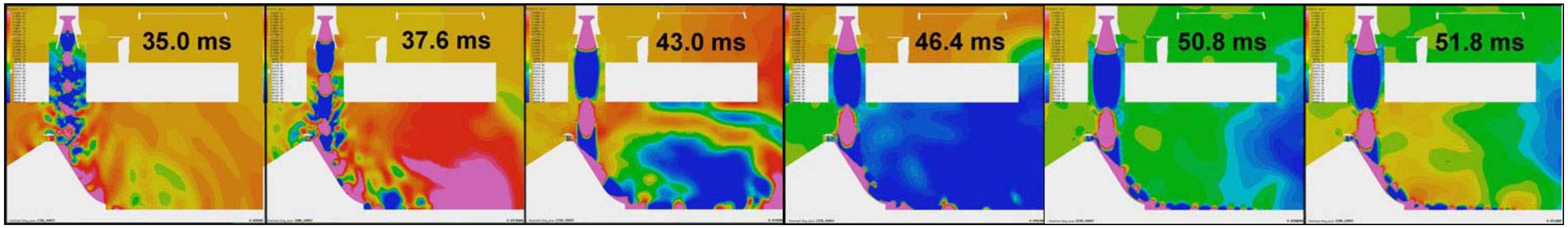


- Creating a mass flow profile
  - Started with pressure trace
    - Initially from from chamber pressure
    - Ignition corrected using casing strain gages
  - Assumed mass flow proportional to pressure
  - Scale max mass flow to match RATO specs
    - Obtained from ESTSG-FY10-02462
    - Manufacturer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

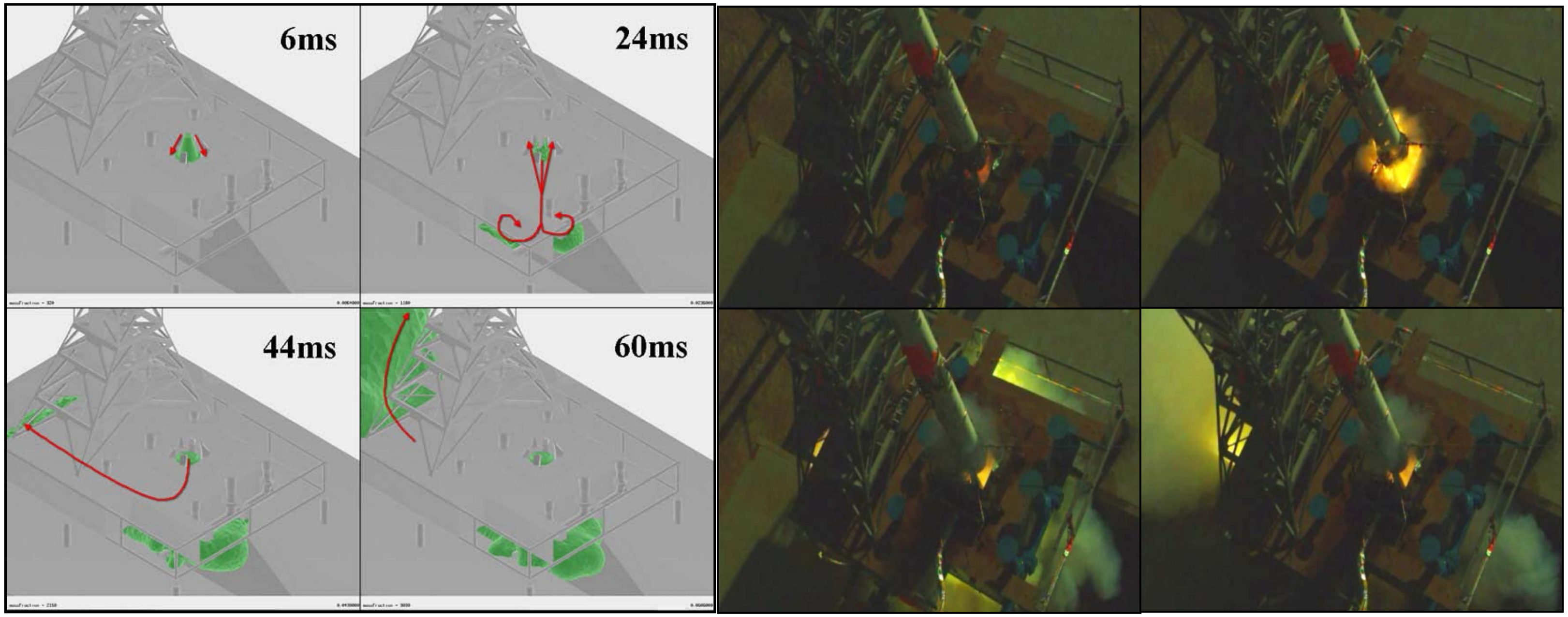


Case Progression : Pathfinder : Results

- Qualitative visualization of overpressure formation (video)

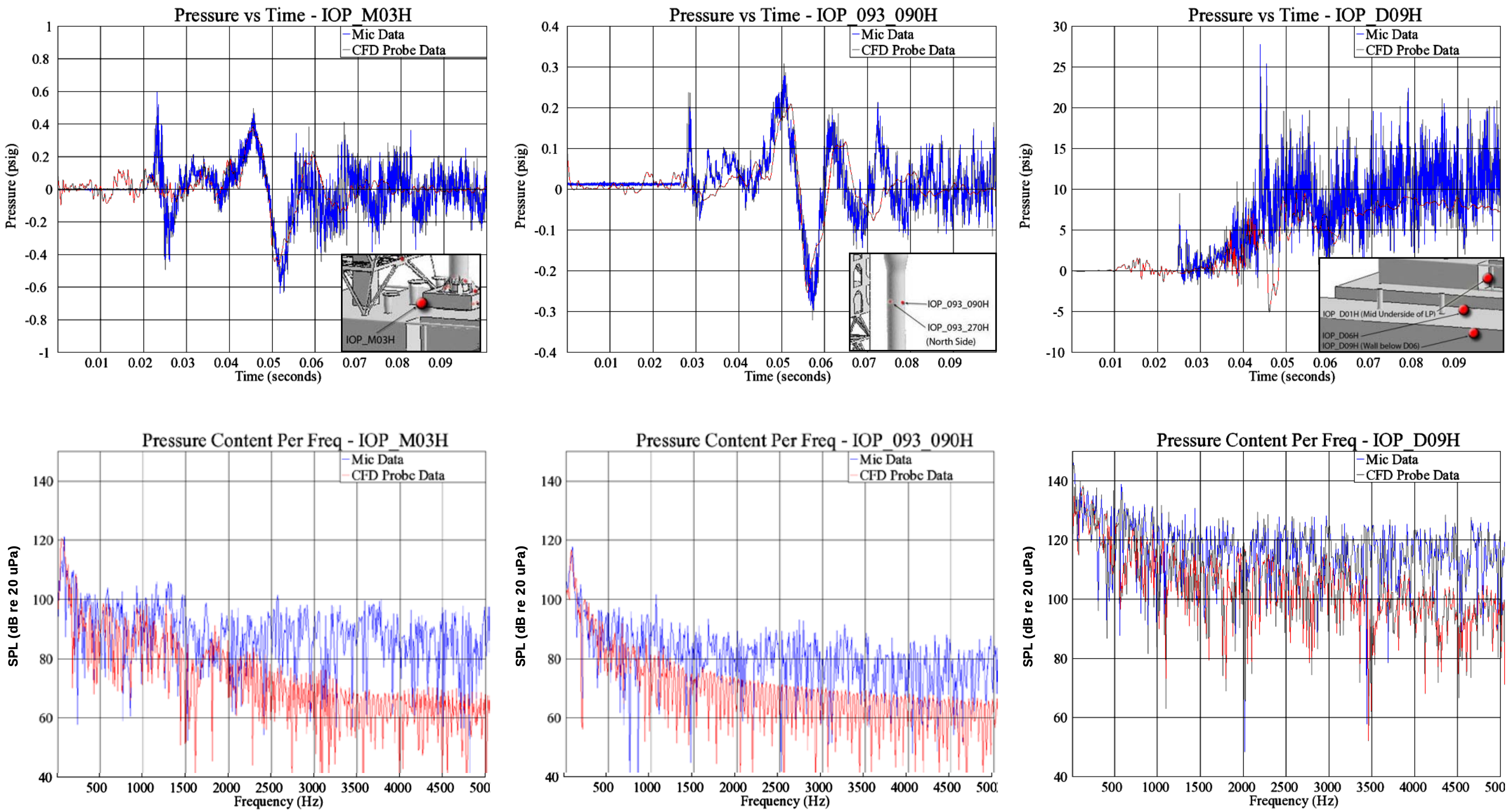


- Qualitative comparison of effluent to imagery (video)



Case Progression : Pathfinder : Results

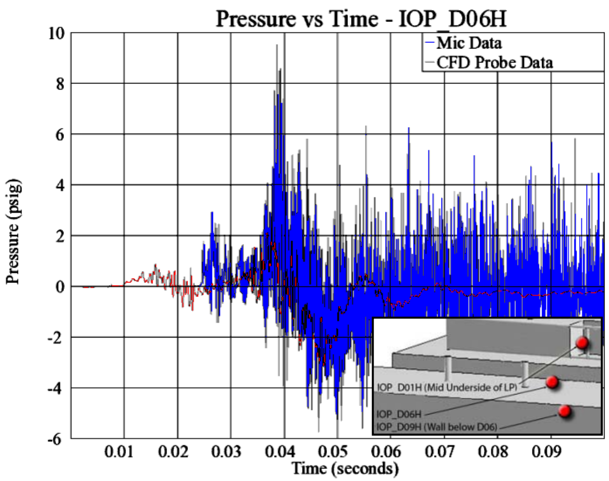
- Quantitative comparison of time and freq domain signals

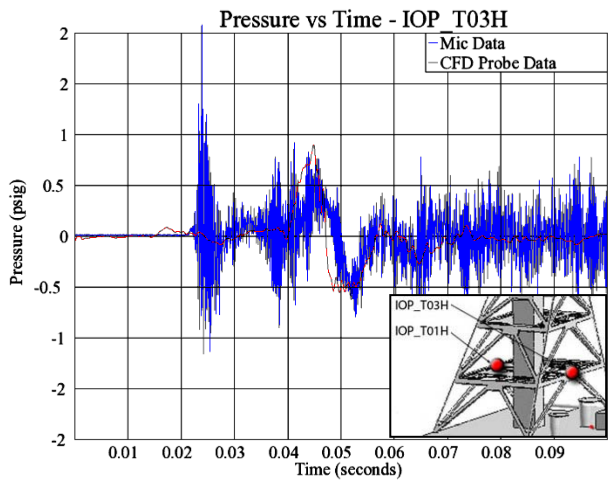


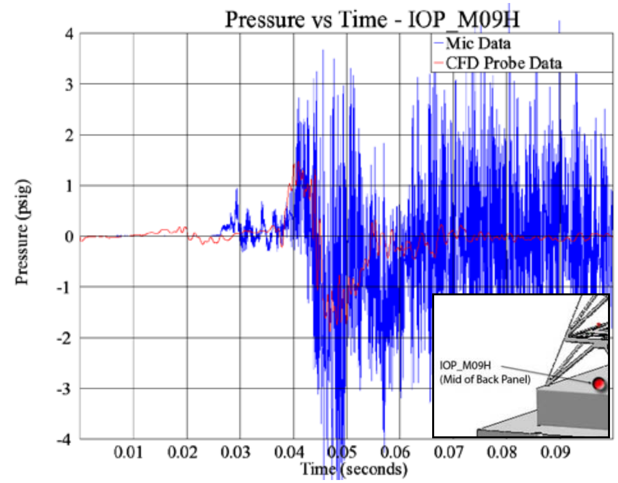
BLUE is test data, **RED** is CFD data

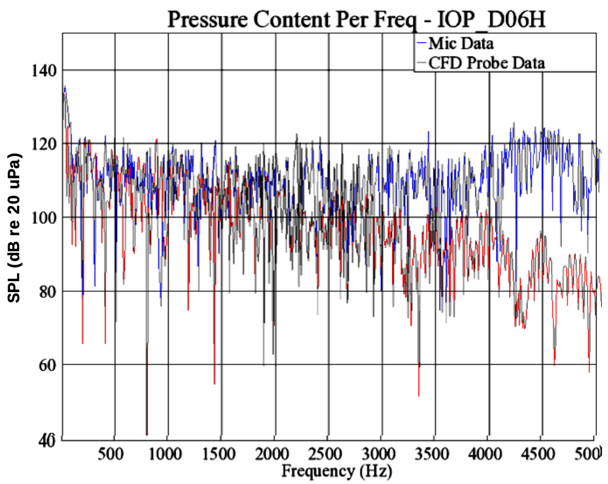
Case Progression : Pathfinder : Results

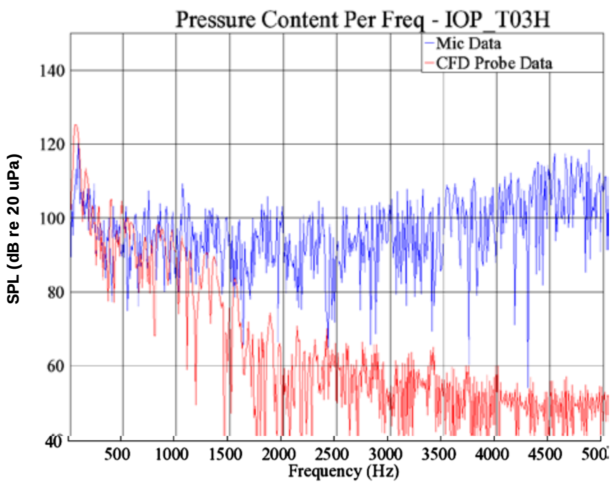
- Quantitative comparison of time and freq domain signals

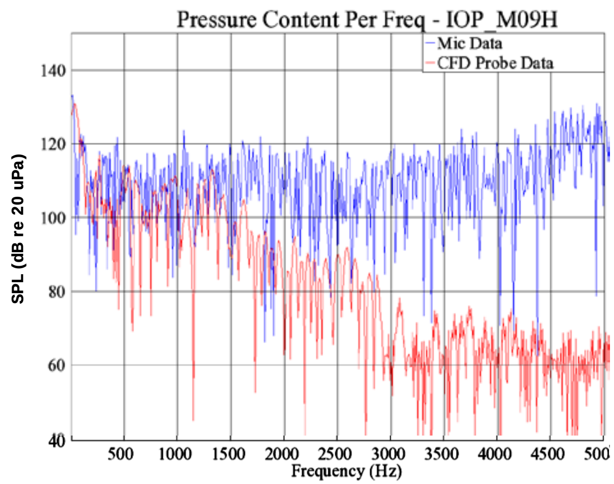








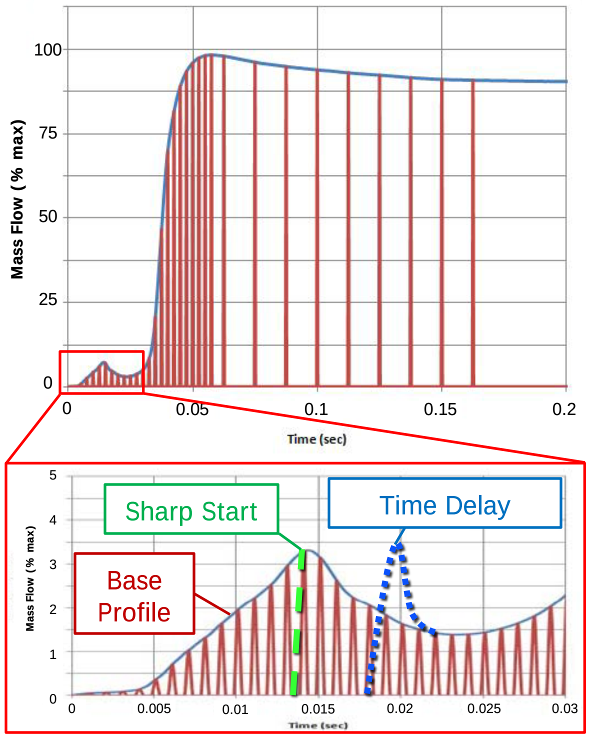


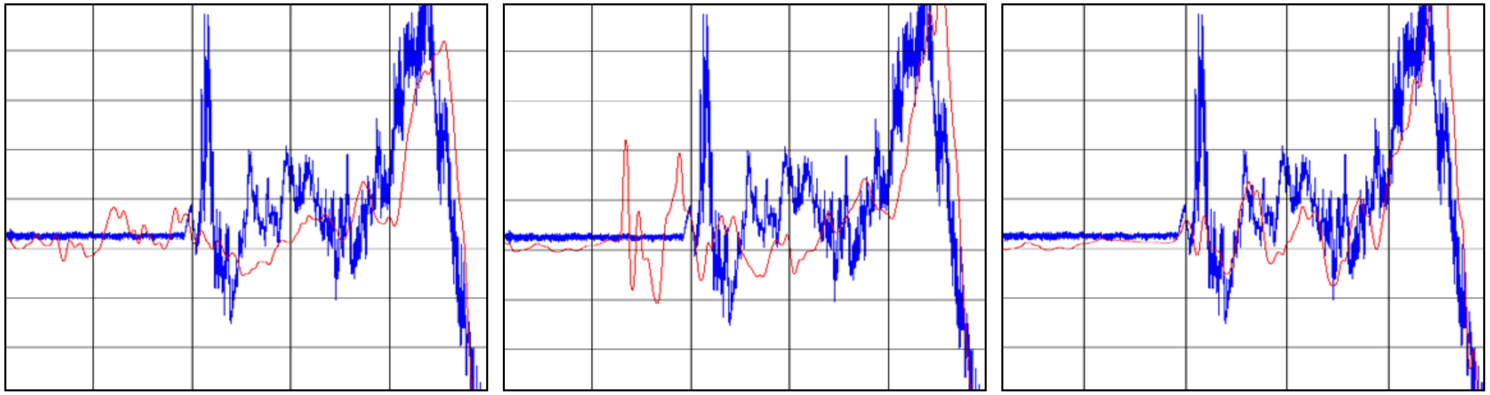


BLUE is test data, **RED** is CFD data

Case Progression : Ignition and Throat Plug

- 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





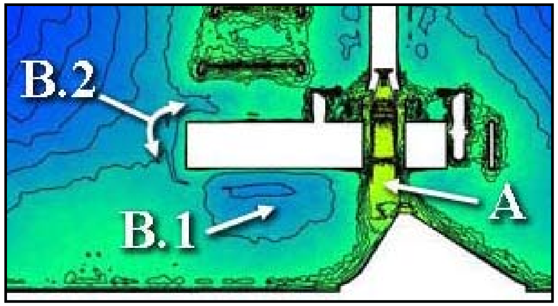
Original Flow Profile

With Sharp Start

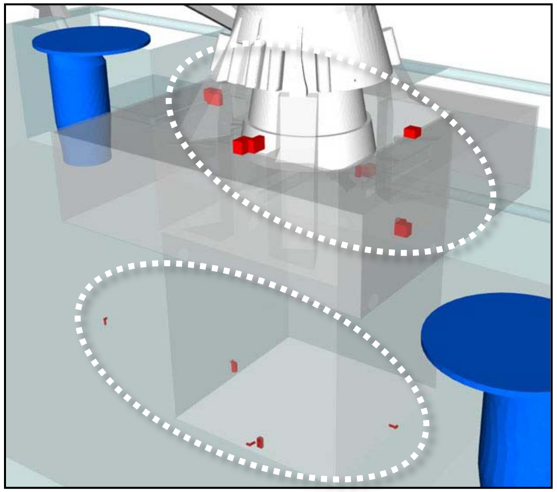
Time Delayed Sharp Start

Case Progression : Model Refinement

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

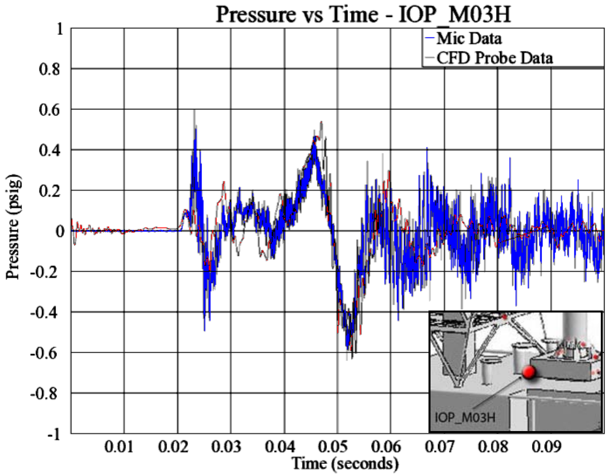


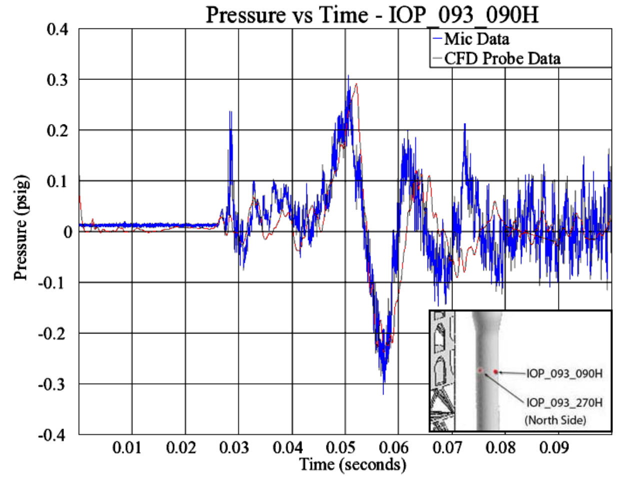
- What was changed in the refinement
  - Fixed all low resolution areas
  - Added microphone mounts for all mics used
  - Overal resolution increase in trench and near rocket skin
  - Included time-delayed, sharp start for ignition and throat plug loss mass flow

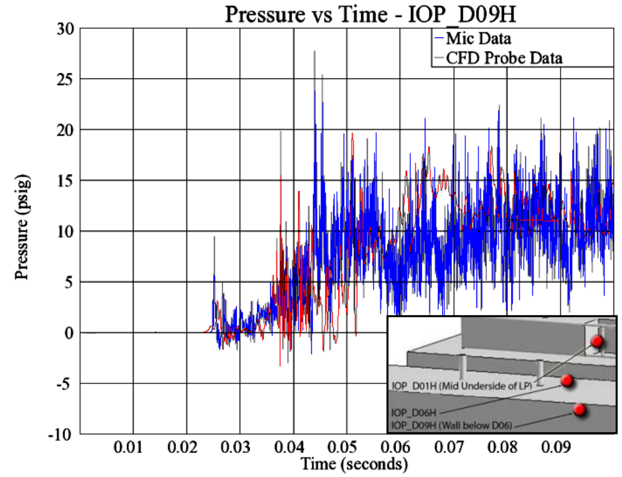


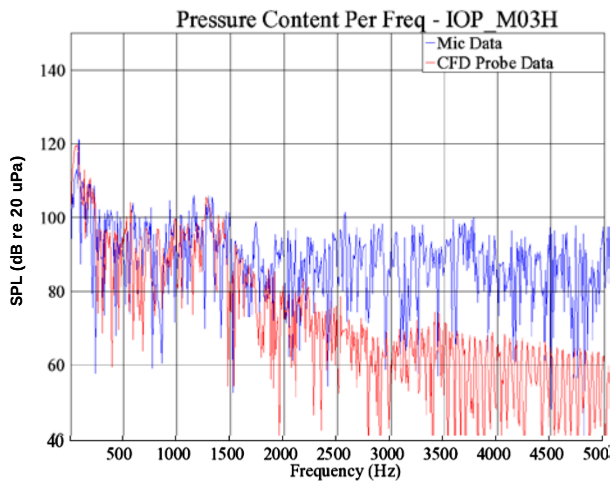
Case Progression : Pathfinder Refined : Results

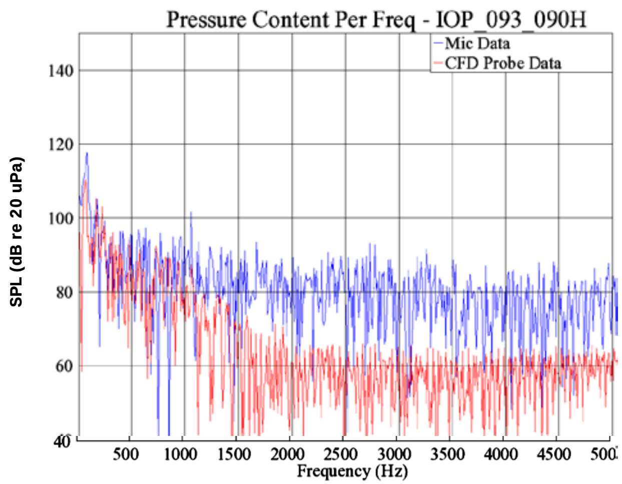
- Quantitative comparison of time and freq domain signals

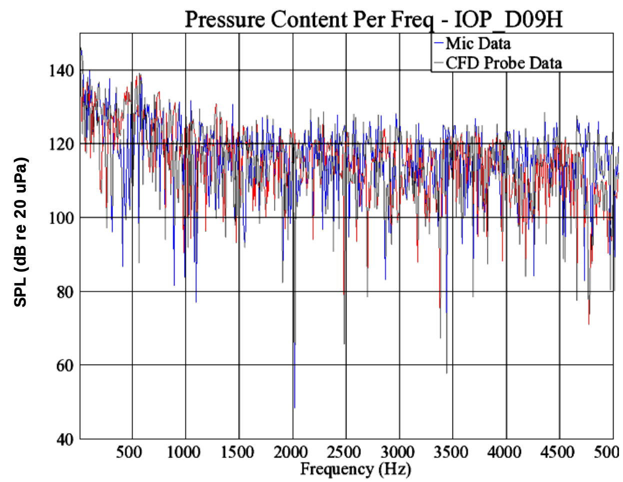






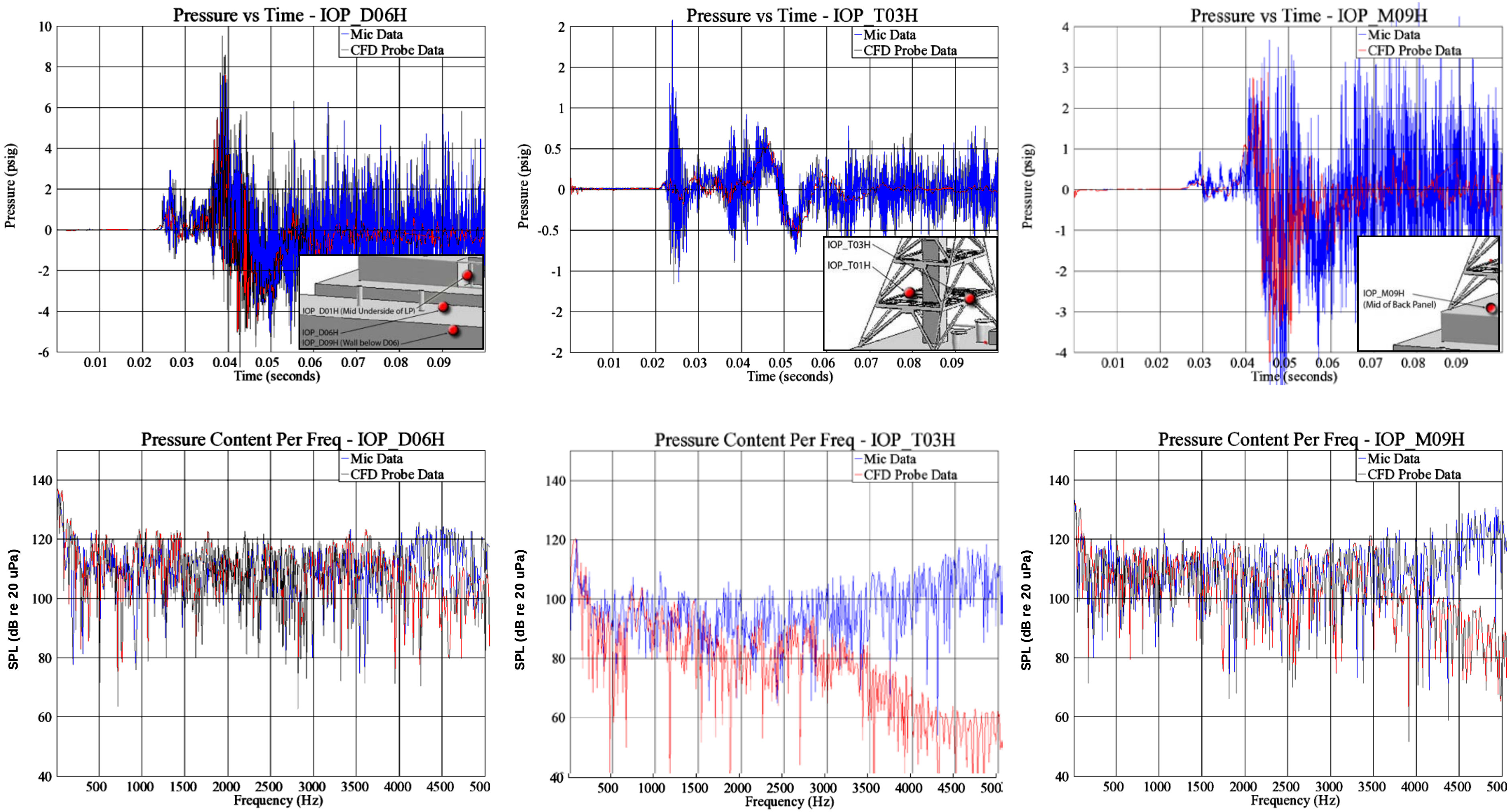






BLUE is test data, **RED** is CFD data

- Quantitative comparison of time and freq domain signals



BLUE is test data, **RED** is CFD data

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

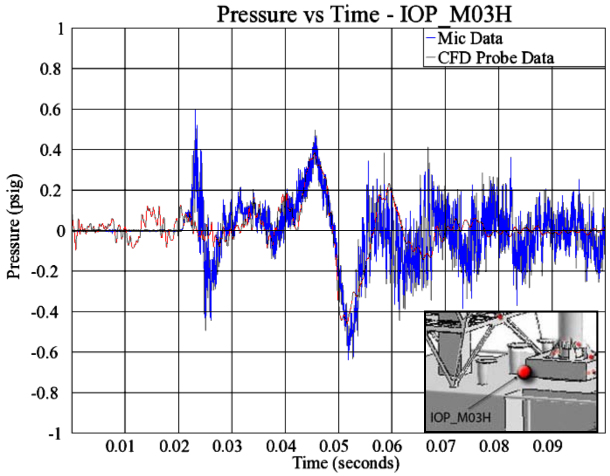
Backup Slides

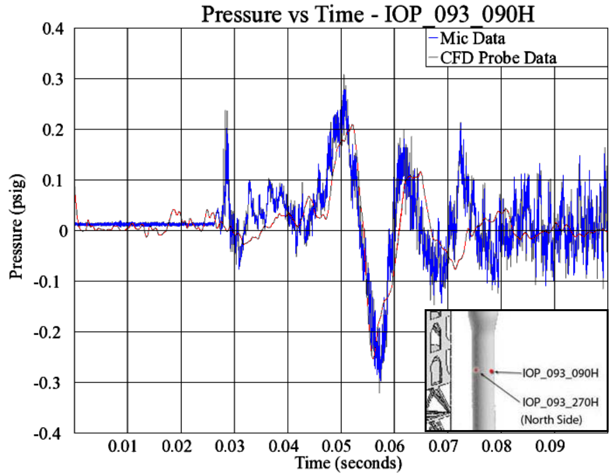
CFD Parameters Used

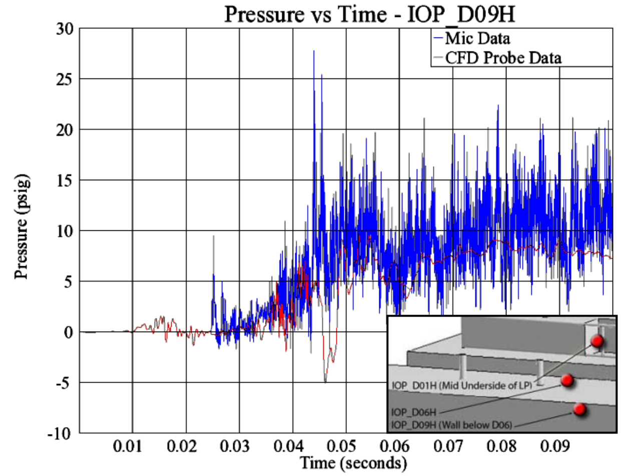
- Gas Chemistry:
  - Frozen chemistry, mixed heavy gas model
  - Air, and RSRM effluent (a heavy gas, RATO motor, effluent approximation) as the working fluids.
- Transport Model:
  - Sutherland model for viscosity and thermal conductivity using properties for air.
- Diffusion Model:
  - Laminar Schmidt
  - 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.)

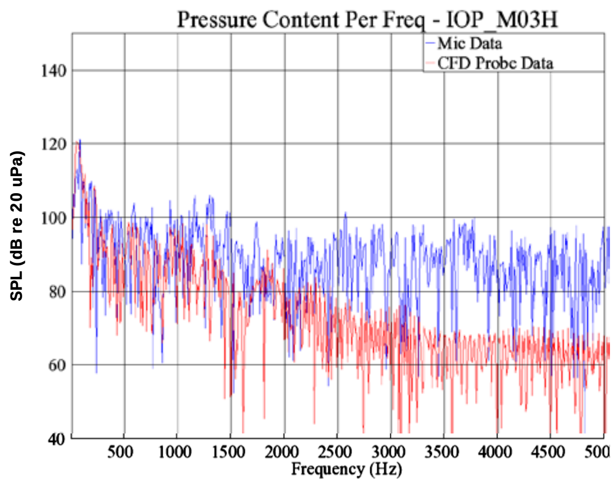
Case Progression : Pathfinder : Results

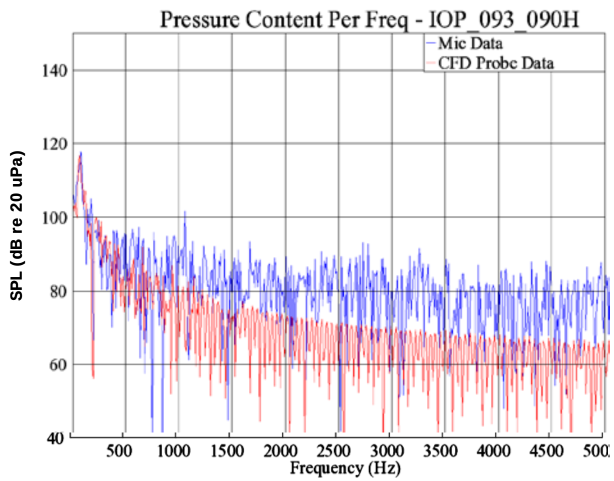
- Quantitative comparison of time and freq domain signals

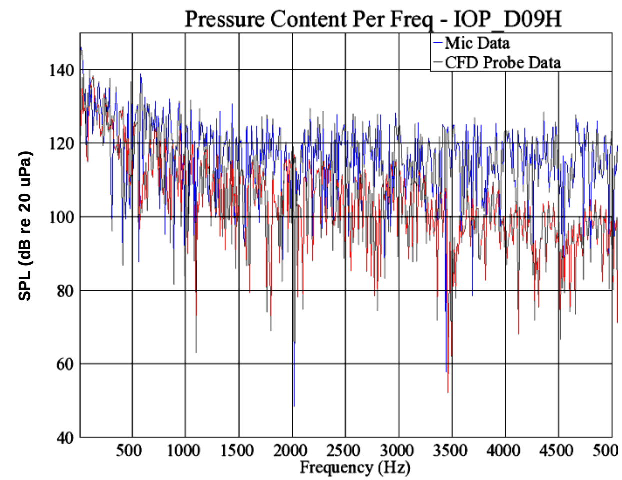






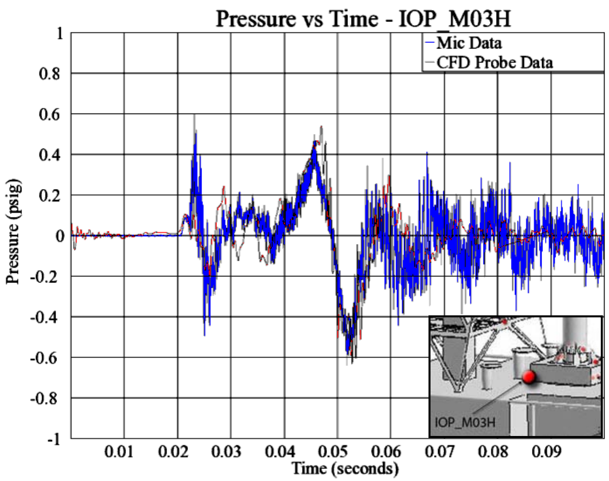


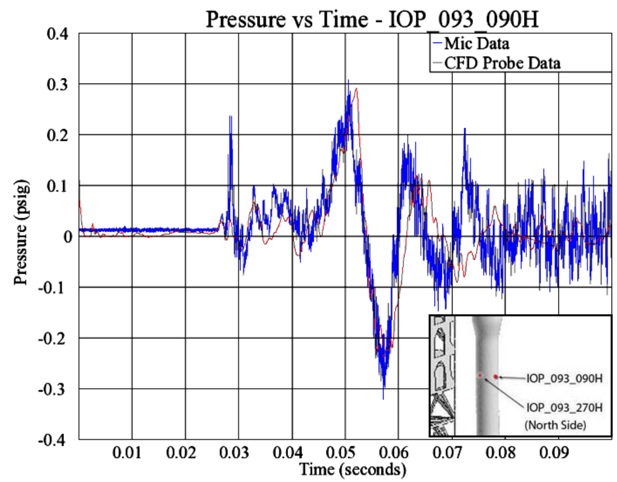


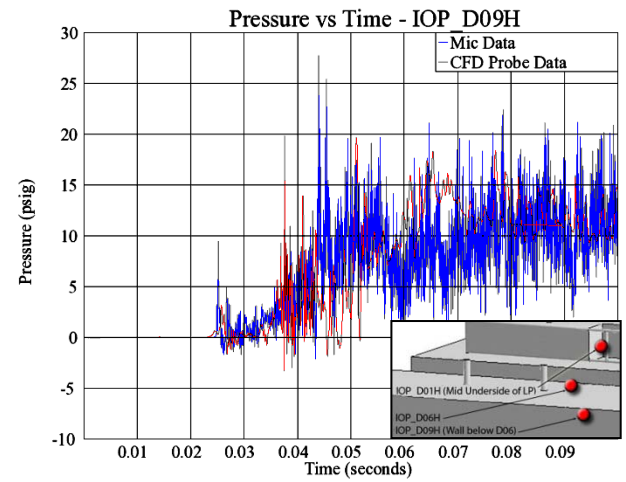


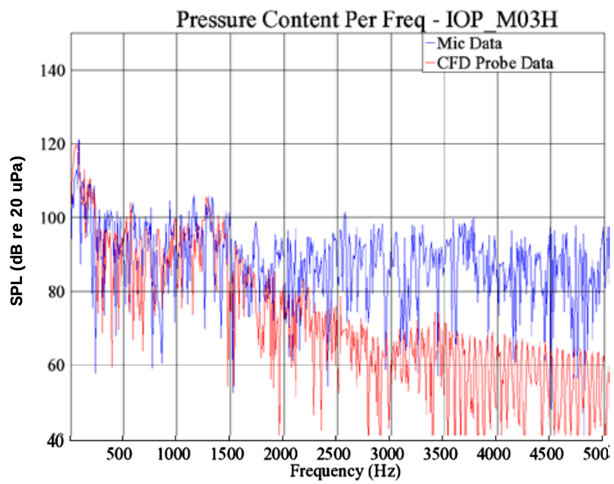
BLUE is test data, **RED** is CFD data

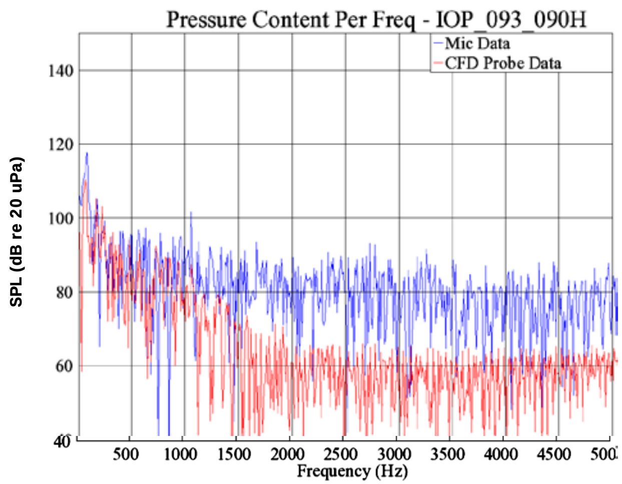
- Quantitative comparison of time and freq domain signals

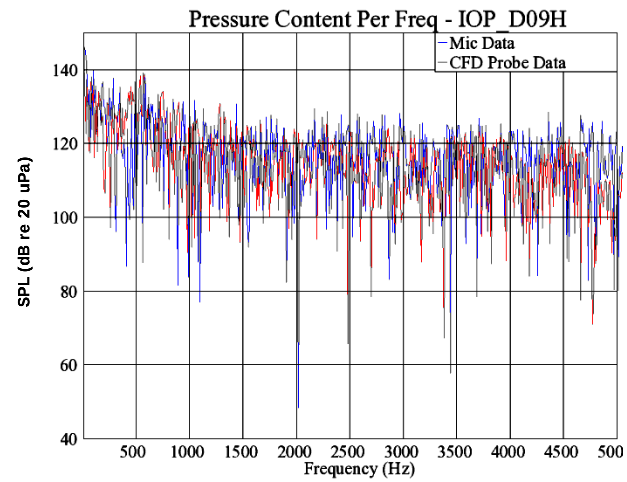








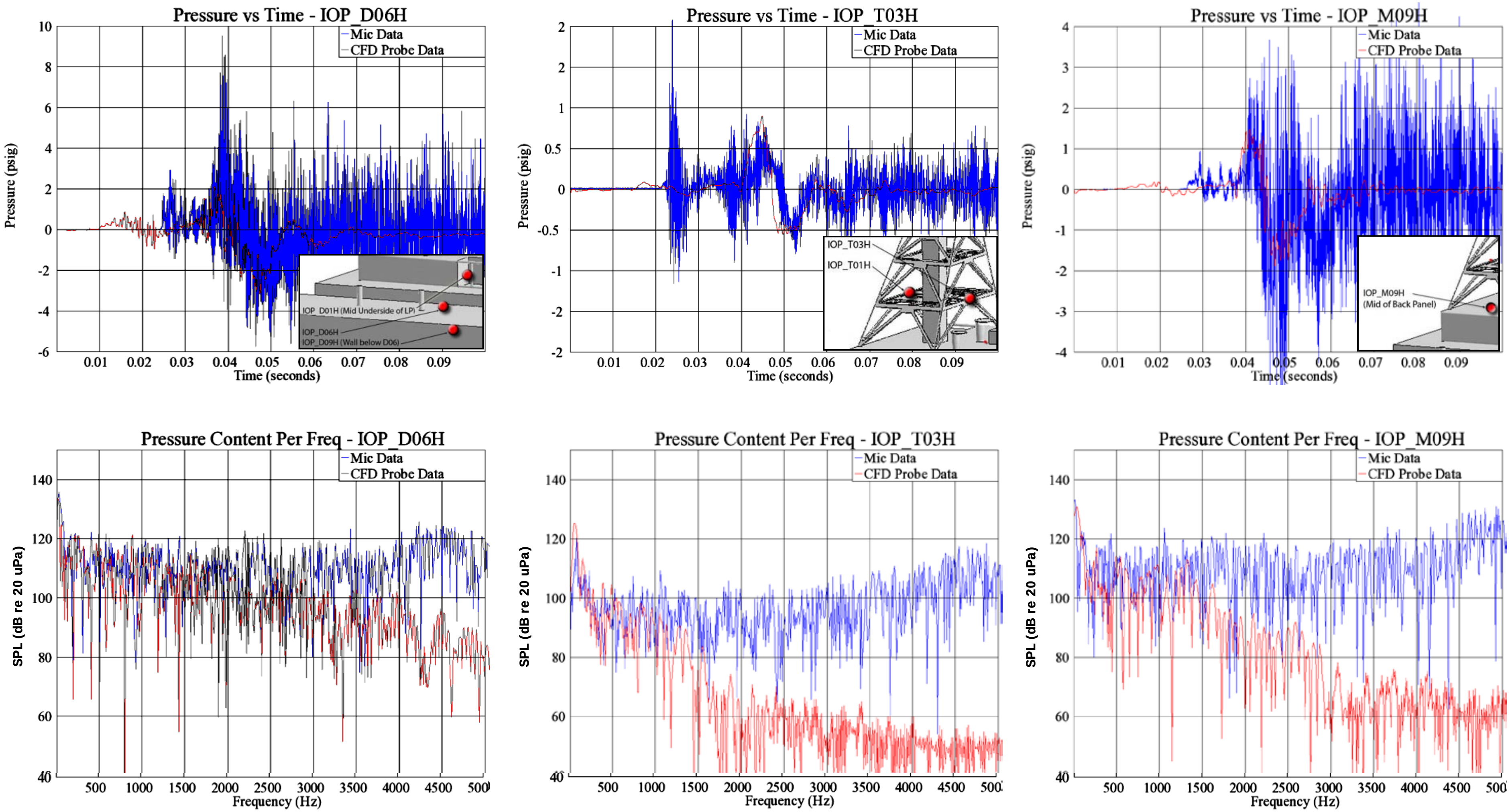




BLUE is test data, **RED** is CFD data

Case Progression : Pathfinder : Results

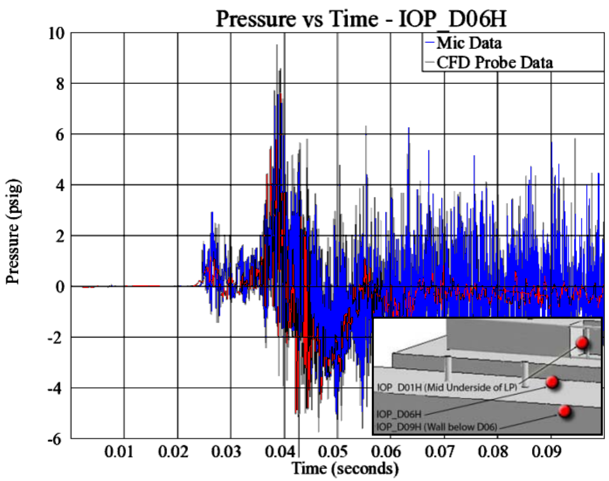
- Quantitative comparison of time and freq domain signals

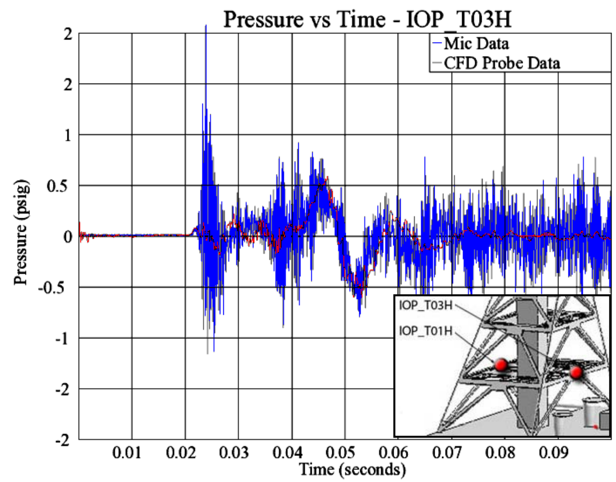


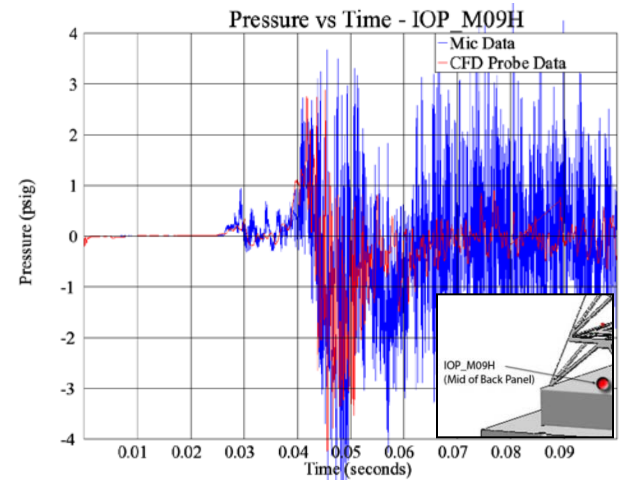
BLUE is test data, **RED** is CFD data

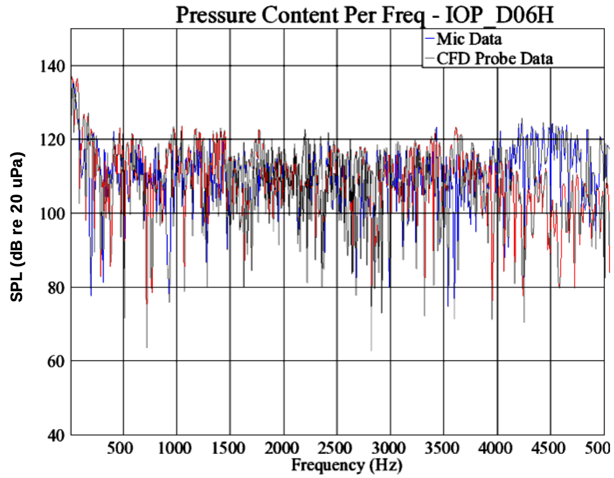
Case Progression : Pathfinder Refined : Results

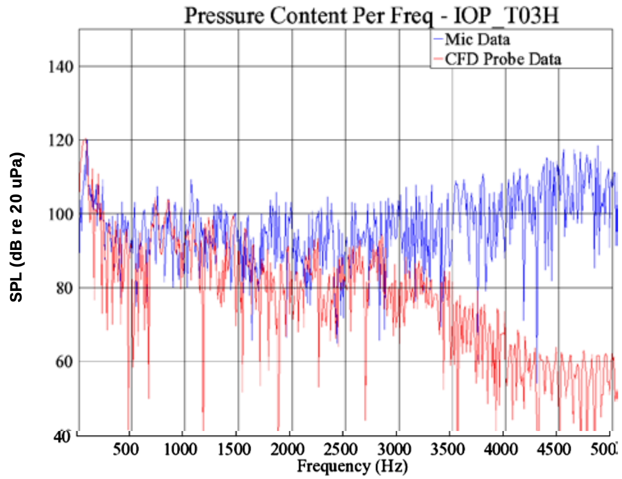
- Quantitative comparison of time and freq domain signals

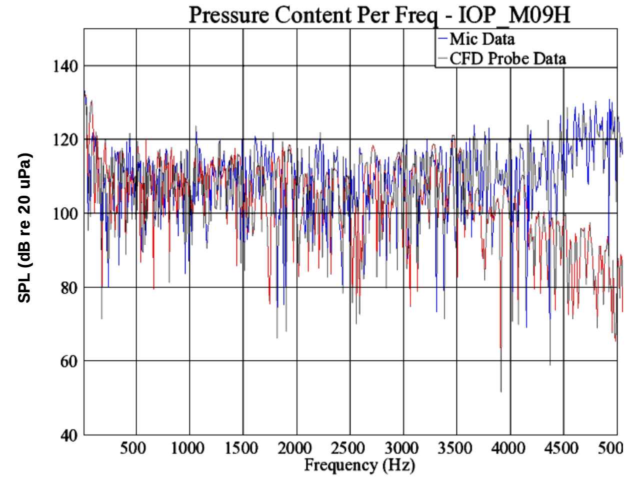












BLUE is test data, **RED** is CFD data