Chamber Dynamic Response Modeling

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Accomplishments

• IFE Chamber dynamics code **SPARTAN** is developed: 
  Simulation of **Physics** by **Algorithms** based on **Robust Turbulent Approximation** of **Navier-Stokes** Equations.

• **SPARTAN** current features:
  – 2-D Navier Stokes equations, viscosity and thermal conductivity included
    – arbitrary geometry
    – Adaptive Mesh Refinement

• **SPARTAN** tests:
  – Acoustic wave propagation.
  – Viscous channel flow.
  – Mach reflection.
  – Analysis of discretization errors to find code accuracy.

• Initial conditions from **BUCKY** code are used for simulations.

• Two Journal articles on **SPARTAN** are in preparation.
Adaptive Mesh Refinement

- **Motivation**: efficient grid distribution results in reasonable CPU time.
- Grid organized into levels from coarse to fine.
- Solution tagging based on density and energy gradients.
- Grid is refined at every time step.
- Solution interpolated in space and time between the grid levels.
Example of Adaptive Mesh Refinement

geometry

density contour plot
IFE Chamber Dynamics Simulations

Objectives
• Determine the influence of the following factors on the chamber state at 100 ms:
  - viscosity
  - blast position in the chamber
  - heat conduction from gas to the wall.
• Chamber density, pressure, temperature, and velocity distribution prior to insertion of next target are calculated.
Numerical Simulations

IFE Chamber Simulation
- 2-D cylindrical chamber with a laser beam channel on the side.
- 160 MJ NRL target
- Boundary conditions:
  - Zero particle flux, Reflective velocity
  - Zero energy flux or determined by heat conduction.
- Physical time: 500 \(\mu\)s (BUCKY initial conditions) to 100 ms.
Numerical Simulations

Initial Conditions

- 1-D BUCKY solution for density, velocity and temperature at 500 µs imposed by rotation and interpolation.
- Target blast has arbitrary location near the center of the chamber.
- Solution was advanced by SPARTAN code until 100 ms were reached.
Estimating Viscosity:

- Neutral Xe gas at 800K: $\mu = 5.4 \times 10^{-5}$ Pas
- Ionized Xe at (10,000 – 60,000)K: $\mu = (4.9 \times 10^{-11} - 4.4 \times 10^{-9})$ Pas

Simulations are done with ionized gas values (to be conservative).
Simulations indicate viscosity is important even at such small values.
Analysis should include a combination of neutral and ionized gas.
Effect of Viscosity on Chamber State at 100 ms

inviscid flow at 100 ms

pressure, $p_{\text{mean}} = 569.69$ Pa

temperature, $T_{\text{mean}} = 5.08 \times 10^4$ K

$(\rho C_v T)_{\text{mean}} = 1.412 \times 10^3$ J/m$^3$

viscous flow at 100 ms

pressure, $p_{\text{mean}} = 564.87$ Pa

temperature, $T_{\text{mean}} = 4.7 \times 10^4$ K

$(\rho C_v T)_{\text{mean}} = 1.424 \times 10^3$ J/m$^3$

Temperature is more evenly distributed with viscous flow.
Effect of Viscosity on Chamber State at 100 ms

Pressure across the chamber at 0.1s.

Pressure at the chamber wall versus time.

- viscous
- inviscid
Effect of Blast Position on Chamber State at 100ms

- **Centered blast at 100 ms**
  - Pressure, $p_{\text{mean}} = 564.87$ Pa
  - Temperature, $T_{\text{mean}} = 4.7 \times 10^4$ K

- **Eccentric blast at 100 ms**
  - Pressure, $p_{\text{mean}} = 564.43$ Pa
  - Temperature, $T_{\text{mean}} = 4.74 \times 10^4$ K

Both cases feature random fluctuations, little difference in the flow field.
Effect of Blast Position on Chamber State at 100 ms

Mirror is normal to the beam tube.
Pressure is conservative by an order of magnitude.
Pressure on the mirror is so small that the mechanical response is negligible.
Effect of Wall Heat Conduction on Chamber State at 100 ms

**Estimated Thermal Conductivity:**
- Neutral Xe gas at 800K: \( k = 0.013 \text{ W/m-K} \)
- Ionized Xe at (10,000 – 60,000)K: \( k = (0.022 – 1.94) \text{ W/m-K} \)

\[
k = 5.86 \cdot 10^{-10} \frac{T^{2.5}}{Z \ln \lambda} \frac{W}{\text{mK}}
\]

- Initial simulations are done with ionized gas values (to assess impact of ionized gas conduction).
- Simulations indicate substantial impact on gas temperature with higher conductivity value.
- Analysis should include a combination of neutral and ionized gas.
Effect of Wall Heat Conduction on Chamber State at 100 ms

**insulated wall**

- Pressure, $p_{\text{mean}} = 564.431$ Pa
- Temperature, $t_{\text{mean}} = 4.736 \times 10^4$ K

**wall conduction**

- Pressure, $p_{\text{mean}} = 402.073$ Pa
- Temperature, $t_{\text{mean}} = 2.537 \times 10^4$ K

Wall heat conduction helps to achieve a more quiescent state of the chamber gas.
Prediction of chamber condition at long time scale is the goal of chamber simulation research.

- Chamber dynamics simulation program is on schedule. Program is based on:
  - Staged development of Spartan simulation code.
  - Periodic release of the code and extensive simulations while development of next-stage code is in progress.

- Documentation and Release of Spartan (v1.0)
  - Two papers are under preparation

- Exercise Spartan (v1.x) Code
  - Use hybrid models for viscosity and thermal conduction.
  - Parametric survey of chamber conditions for different initial conditions (gas constituent, pressure, temperature, etc.)
    - Need a series of Bucky runs as initial conditions for these cases.
    - We should run Bucky using Spartan results to model the following shot and see real “equilibrium” condition.
  - Investigate scaling effects to define simulation experiments.
Several upgrades are planned for Spartan (v2.0)

Numeric:
- Implementation of multi-species capability:
  - Neutral gases, ions, and electrons to account for different thermal conductivity, viscosity, and radiative losses.

Physics:
- Evaluation of long-term transport of various species in the chamber (e.g., material deposition on the wall, beam tubes, mirrors)
  - Atomics and particulate release from the wall;
  - Particulates and aerosol formation and transport in the chamber.
- Improved modeling of temperature/pressure evolution in the chamber:
  - Radiation heat transport;
  - Equation of state;
  - Turbulence models.