EFFECTS OF CHAMBER GEOMETRY AND GAS PROPERTIES ON HYDRODYNAMIC EVOLUTION OF IFE CHAMBERS

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Motivation

• The focus of our research effort is to model and study the chamber dynamic behavior on the long time scale, including:
  – the hydrodynamics;
  – the transfer mechanisms such as
    • photon and ion heat deposition
    • chamber gas conduction, convection and radiation;
    • chamber wall response and lifetime;
    • cavity clearing.
• In order to investigate these phenomena, a fully integrated numerical code SPARTAN is being developed as assembly of well documented algorithms.
• This talk is concerned with
  – multidimensional geometry effects which arise as fluid interacts with the vessel wall containing various beam access ports.
  – Effect of molecular diffusion and background plasma on chamber state evolution.
IFE Chamber Models

• SPARTAN numerical algorithms:
  – Godunov solver of Navier-Stokes equations with state dependent transport properties.
  – Embedded boundary
  – Adaptive Mesh Refinement

• Two different aspects of the cylindrical chamber given here:
  – Cartesian geometry (everything along chamber axis is constant)
    • Arrays of beam lines along chamber axis replaced by 4 beam sheets.
  – Cylindrical Geometry: (everything along polar angle $\theta$ is constant).
    • Arrays of beam lines around chamber perimeter replaced by a single beam sheet.
    • A beam line placed on top and bottom.

Cartesian

Cylindrical

chamber dimensions:
  radius: 6.5 m
  height: 13 m

beam sheet dimensions:
  length: 20 m
  width: 1 m
Effects of Chamber Geometry on Evolution of Chamber State

- Details are given for neutral gas.
- Impact of background plasma will be addressed separately.
Effects of Chamber Geometry

Time = 0.5 ms

Cartesian
\[ T_{\text{max}} = 5.3 \times 10^4 \text{ K} \]

Cylindrical
\[ T_{\text{max}} = 5.3 \times 10^4 \text{ K} \]

Time = 3 ms

Cartesian
\[ T_{\text{max}} = 2.2 \times 10^5 \text{ K} \]

Cylindrical
\[ T_{\text{max}} = 3.1 \times 10^5 \text{ K} \]

Time = 8 ms

Cartesian
\[ T_{\text{max}} = 1.3 \times 10^5 \text{ K} \]

Cylindrical
\[ T_{\text{max}} = 2.2 \times 10^5 \text{ K} \]

For all cases: \( T_{\text{min}} = T_{\text{wall}} = 973.16 \text{ K} \)
Effects of Chamber Geometry

Time = 20 ms

Cartesian

$T_{\text{max}} = 1.2 \times 10^5 \text{ K}$

Cylindrical

$T_{\text{max}} = 1.3 \times 10^5 \text{ K}$

Time = 65 ms

Cartesian

$T_{\text{max}} = 2.8 \times 10^4 \text{ K}$

Cylindrical

$T_{\text{max}} = 5.1 \times 10^4 \text{ K}$

Time = 100 ms

Cartesian

$T_{\text{max}} = 2.3 \times 10^4 \text{ K}$

Cylindrical

$T_{\text{max}} = 3.2 \times 10^4 \text{ K}$

For all cases: $T_{\text{min}} = T_{\text{wall}} = 973.16 \text{ K}$
Evolution of Gas Energy from 0-100 ms

- Impact of transport phenomena on chamber system, such as:
  - Molecular conduction of neutral gas.
  - Conduction due to free electrons of background plasma.
  - Volumetric heat loss due to radiation of background plasma.
Gas Energy from 0-100ms

- Case I: Neutral Gas
Gas Energy from 0-100 ms

- **Case I: Neutral Gas**
- **Case II: Neutral Gas + Electron Conductivity**
Gas Energy from 0-100 ms

- **Internal Energy**
- **Kinetic Energy**
- **Heat Conducted to Wall**

**Cases:**
- **Case I:** Neutral Gas
- **Case II:** Neutral Gas + Electron Conductivity
- **Case III:** Neutral Gas + Electron Conductivity + Radiation
Chamber State at 100 ms

- Impact of electron conductivity.
- Impact of radiation.
Chamber State at 100 ms

Case I: Neutral Gas

Case II: Neutral Gas + Electron Conductivity

Case III: Neutral Gas + Electron Conductivity + Radiation

For all cases: $T_{\text{min}} = T_{\text{wall}} = 973.16 \, \text{K}$
Conclusions

• SPARTAN simulations of the hydrodynamic evolution of the IFE chamber indicate:
  – Multi-dimensional effects of chamber geometry are critical in assessing the chamber dynamics.
  – Radiation of background plasma is the most important mechanism of heat transfer.
• Is 2-D modeling good enough?
  – Maybe.
    • Present simulations with Cartesian and cylindrical geometry show similar trends in flow and heat transfer.
    • To fully answer this question, more different aspects of geometry to be probed by 2-D simulations, such as spherical chamber wall, different configuration of beam lines, etc.
    • Doing at least a few 3-D simulations might be a good idea.