Magnetic Positive Positioning

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Agenda

1. Introduction
2. Approach
3. Simulation with ANSYS Fluent
4. Conclusion

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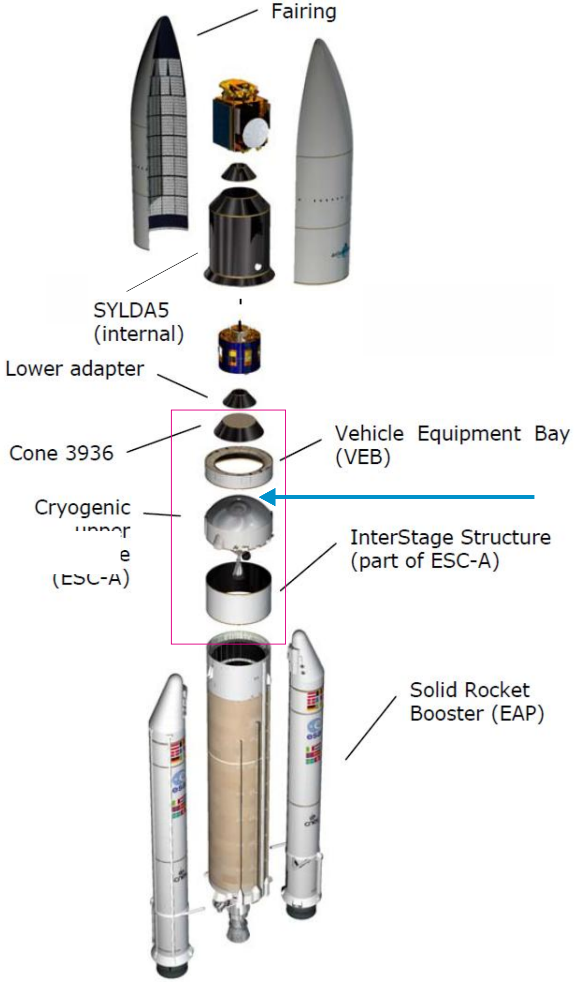
Introduction

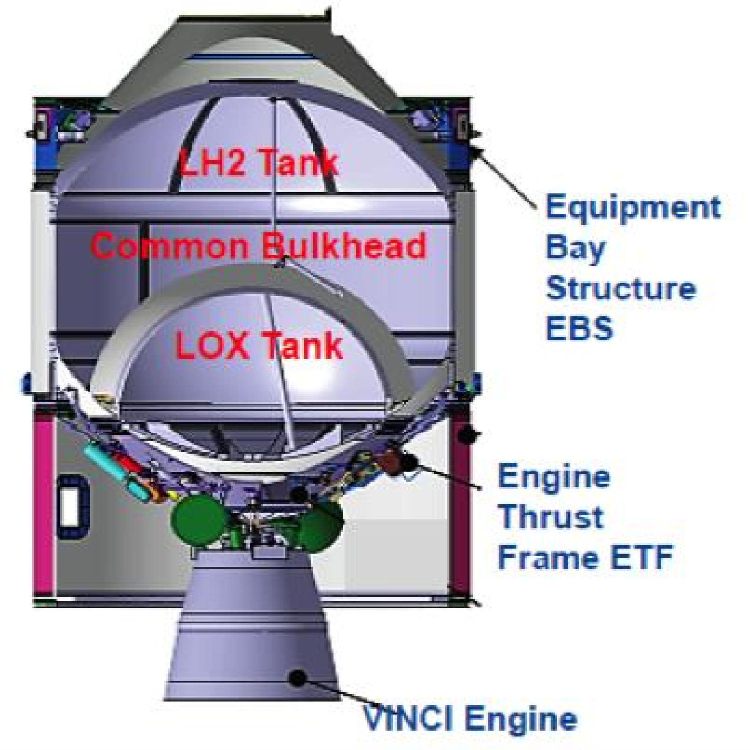
- Ariane 5 Launcher
- Mission - Ballistic Phase
- LOX MP²

Ariane 5 Launcher



- European Expendable Launch System
- Cryogenic first and second stage (LOX & LH2)
- Solid Boosters

- Lift off mass ~800t
- Payload mass into GTO ~12t



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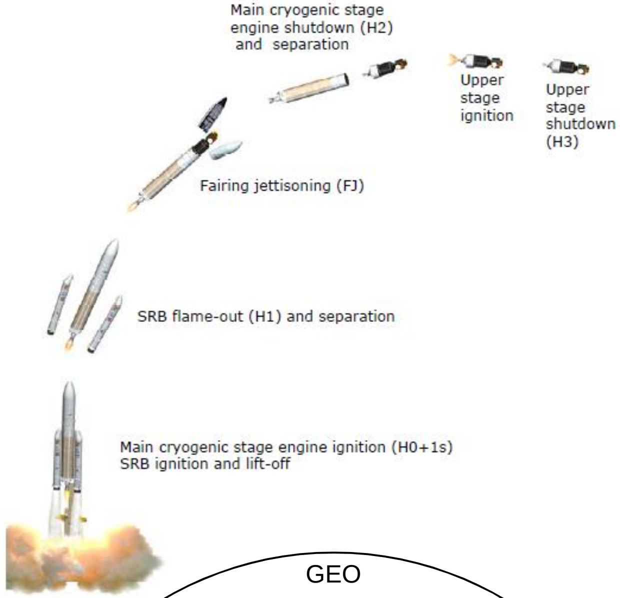
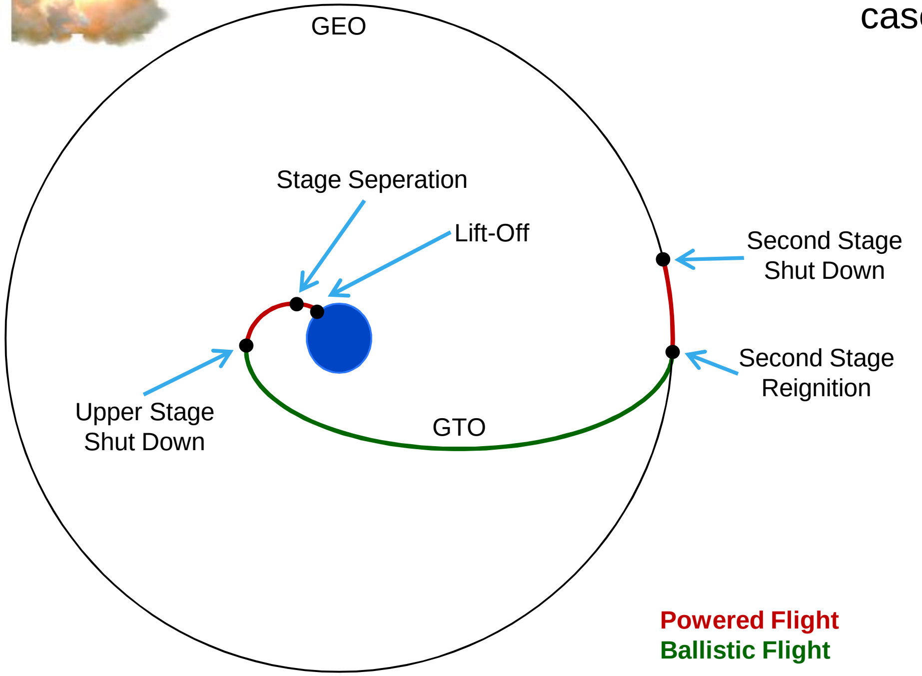
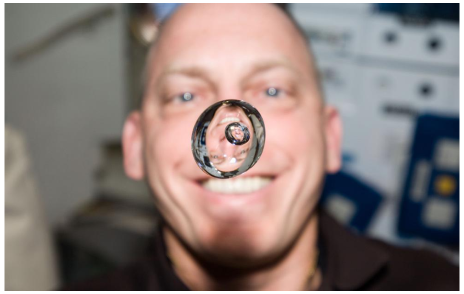
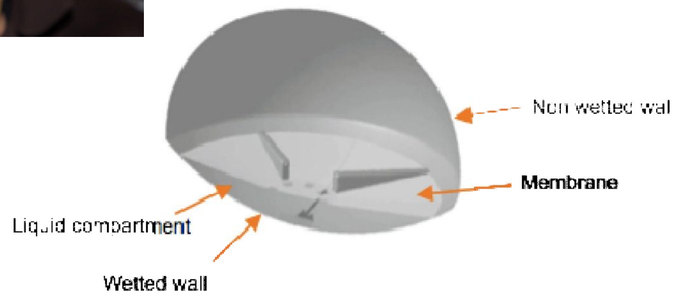
Mission - Ballistic Phase – Propellant Management





- Propellant thermal control problem:
  - wetting of hot or cold tank wall areas due to fluid motion under µg conditions
  - increase of propellant boil-off / thermal residuals or danger of propellant sub-cooling (in case of LOX A5ME)
- Classical Propellant Management Devices (PMD) available
  - Baffles or membranes position the fluid (based on surface tension force and/or subdivision of tank volume into smaller volumes)
  - Limited benefit for thermal control of propellants, especially in case of LOX sub-cooling for A5ME





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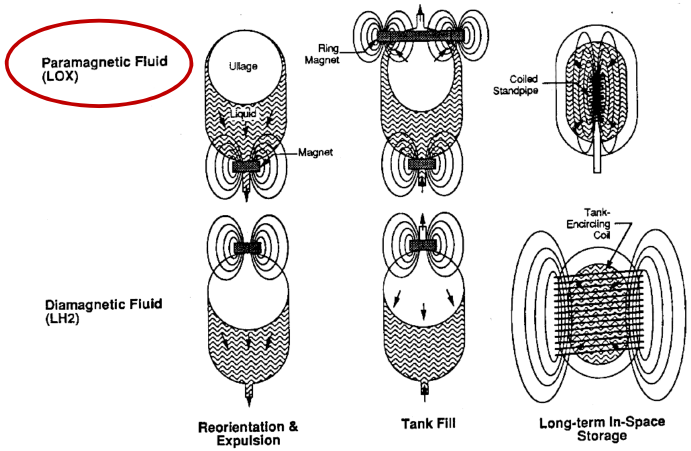
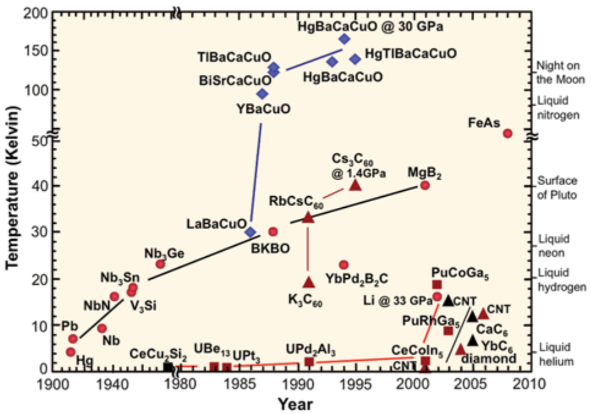
LOX – MP²



- Breakthrough of high temperature superconductors in the past decade
- Several technical applications of superconductors (SMES, energy transfer)

- LOX is paramagnetic
- Re-orientation under investigation since 1964



http://en.wikipedia.org/wiki/Superconductivity

History

- 1964 - Ferrohydrodynamic equations including magnetic forces by Neuringer and Rosensweig
- 1967 - Air Force investigated the feasibility of using electromagnetic fields to manage propellant in a microgravity environment (canceled due to safety risk and massive permanent magnets)
- 80's - R&D in the field of High Temperature Superconductors (HTS) enables high magnetic field intensities above 90 K (storage temperature of LOX).
- 1997 - MAPO experiment by NASA to simulate LOX positioning, numerical codes validated by MAPO experiment to enable flow field predictions
- 2004 - Research activities by Marchetta (University of Memphis) et al. in cooperation with ORBITEC. Various publications at AIAA and experiments at ZARM drop-tower.
- 2007 - Numerical analyses with ANSYS Fluent of different MAPO experiments

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Approach

- Workflow
- Software Tools
- Theory
- 1. Check of Approach: Comparison of Forces
- 2. Check of Approach: Comparison of Free Surface

Workflow

- Following common approach, considering LOX as non-conducting with comparable low and nearly constant magnetic susceptibility, allows a dis-coupled approach for magnetic field and resulting magnetic force calculation
- Magnetic field and force calculation are done in separate modules in a CFD pre-processing step

Magnetic Field

- Finite Element Analysis

Magnetic Force on LOX

- Script

Fluid Flow

- ANSYS Fluent used for transient diphasic fluid flow calculation enabeling VOF-Model
- User Defined Functions (UDF) used adding the magnetic force into the momentum equations
- Result is a transient di-phasic fluid behavior

Ferrohydrodynamics

Additional source term in momentum governing equation, depending on LOX volume fraction α_{LOX}

$$\frac{\partial}{\partial t}(\rho\vec{u}) + \nabla \cdot (\rho\vec{u}\vec{u}) = -\nabla \mathrm{p} + \nabla \cdot [\mu(\nabla\vec{u} + \nabla\vec{u}^T)] + \rho\vec{g} + \vec{F}$$

$$\vec{F} = \alpha_{LOX}\,\mu_0\,\overrightarrow{(M\,\nabla)}\vec{H}$$

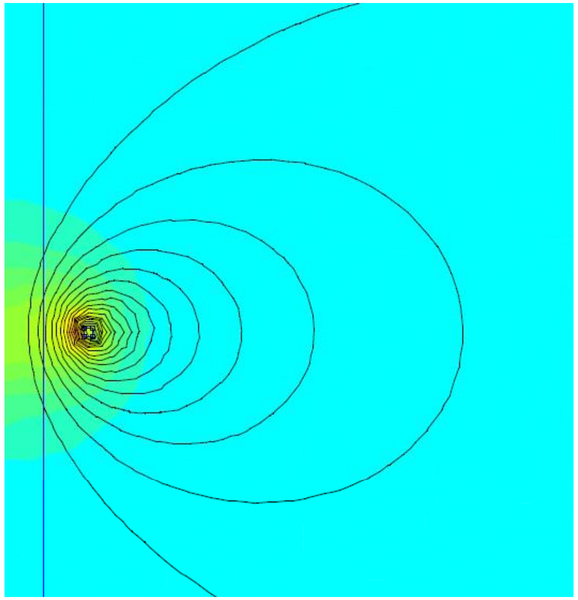
where $\vec{M} = \chi\vec{H}$ magnetization

$\vec{H} = \frac{\vec{B}}{\mu_0(1+\chi)}$ magnetic field

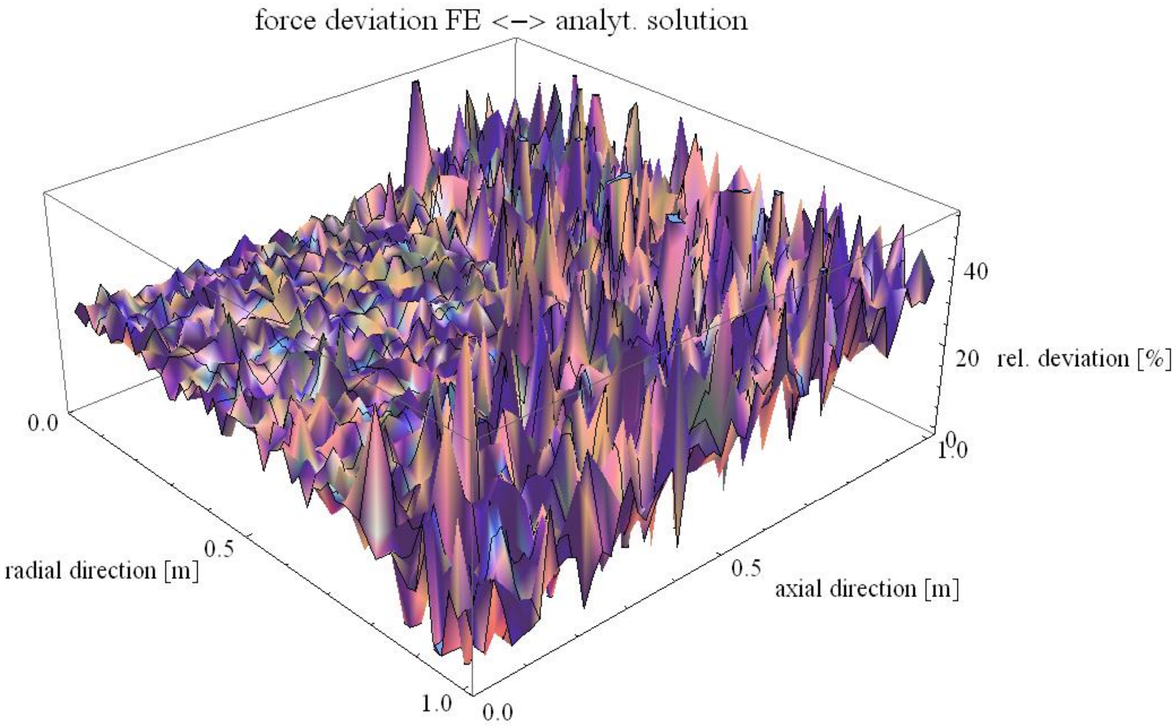
- Within ANSYS Fluent, the force densities at the cell centers has been stored in two User Defined Memory (UDM)
- The momentum sources have been enabled via UDFs

1. Check of Approach: Comparison of Forces for Solenoid

FE calculated H-field for f =10mm solenoid



Comparison



Analytical Expression for H-field

$$H_r = \frac{I\,k}{4\,\pi\,\mu_r\sqrt{a\,r}}\frac{z}{r}\left(-K(k^2) + \frac{a^2+r^2+z^2}{(a-r)^2+z^2}E(k^2)\right)$$

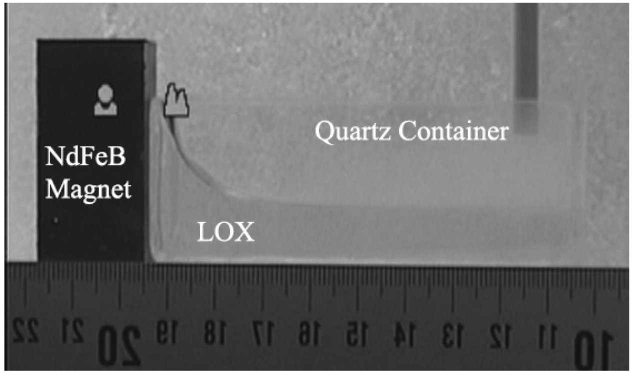
$$H_z = \frac{I\,k}{4\,\pi\,\mu_r\sqrt{a\,r}}\left(K(k^2) + \frac{a^2-r^2-z^2}{(a-r)^2+z^2}E(k^2)\right)$$

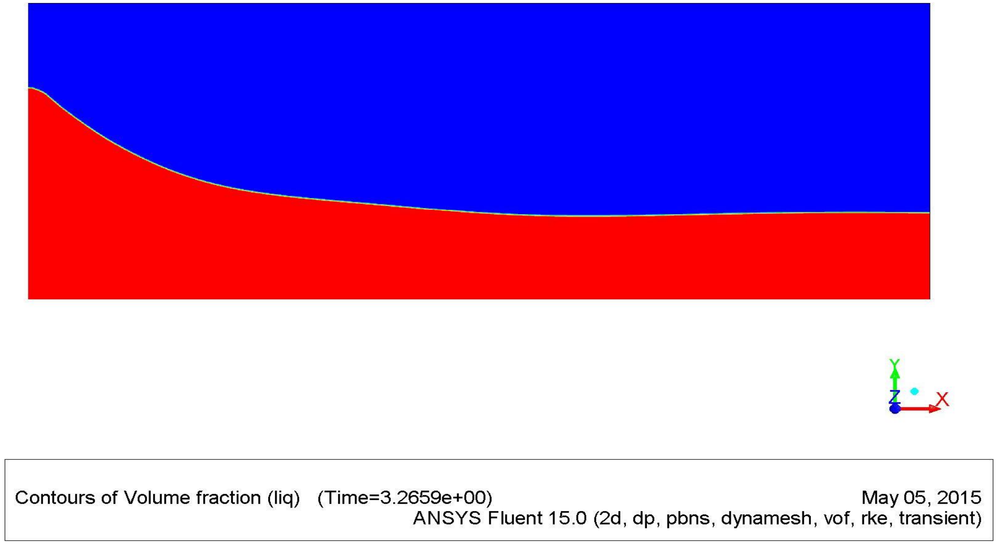
⇒ Globally good agreement

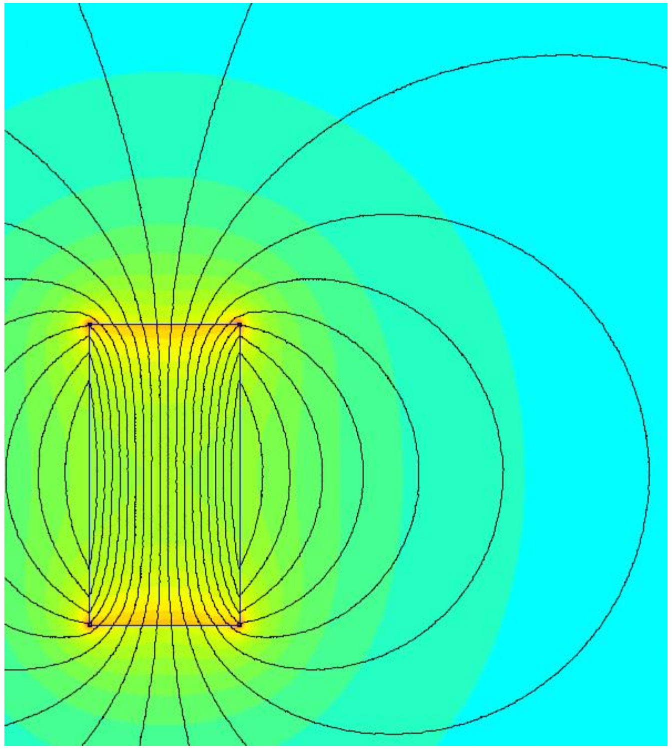
⇒ larger deviations in far-field are on an absolute low level (<$10^{-7}\,N/m^3$)

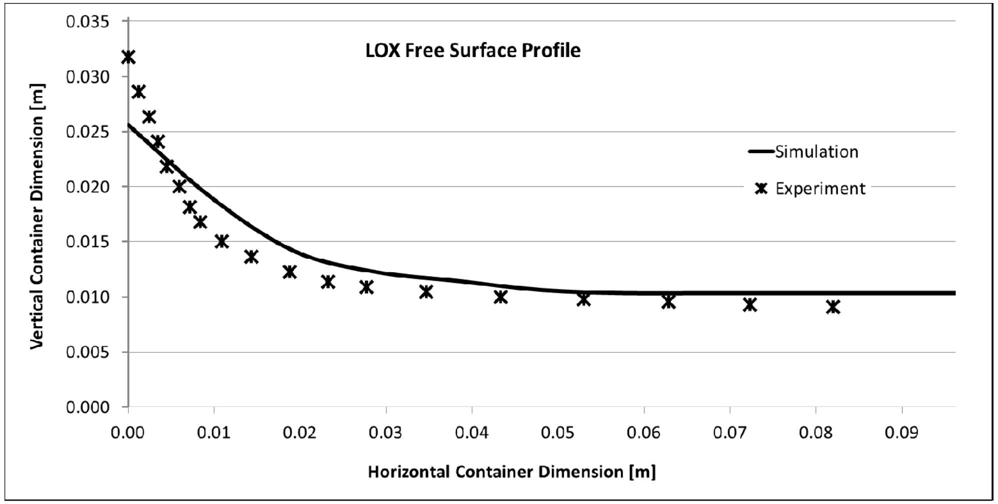
where $K(k^2)$ and $E(k^2)$ are the Complete Elliptical Integrals of 1st and 2nd Kind

2. Check of Approach: Comparison of LOX Free Surface Orientation









Þ Globally good agreement (despite some unknowns in the setup)

Simulation with ANSYS Fluent

Ariane 5ME Reference Tank

- Dimensioning Cases
- Geometry and Mesh
- Results

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Dimensioning Cases

Avoidance of LOX displacement from HTC

- Maneuver induces kinematic forces on LOX

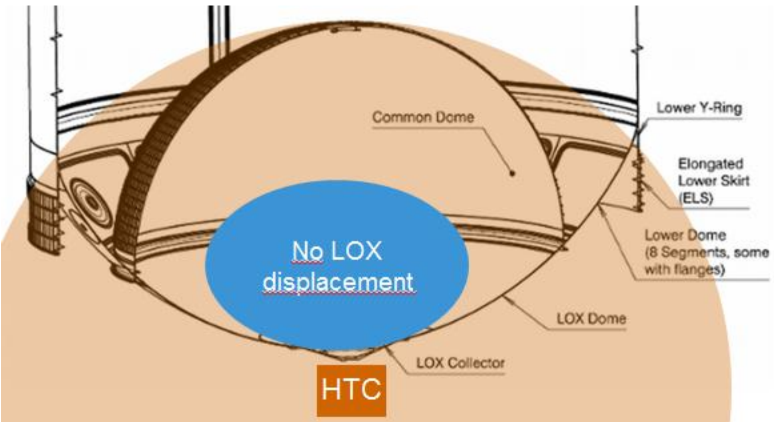
- Evaluation of minimal field intensity to keep HTC wetted

Time of LOX re-orientation

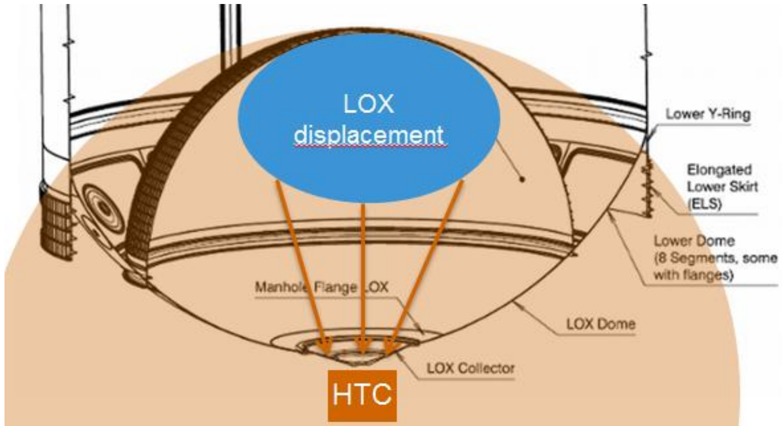
- Disturbance load leads to fluid displacement
- HTC ensures fluid settling

- Examination of re-orientation time dependent on magnetic field intensity

Spin Case



µg Case



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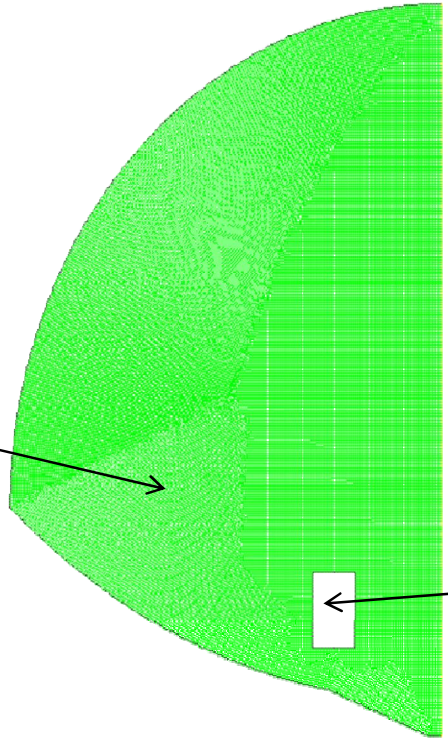
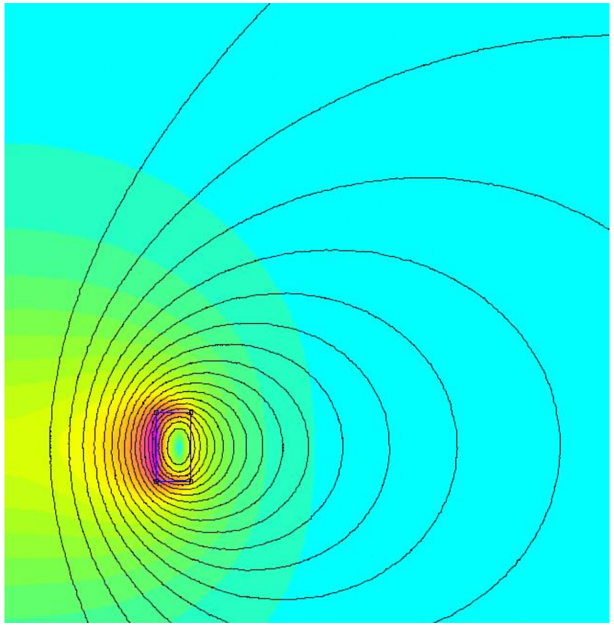
Geometry and Mesh

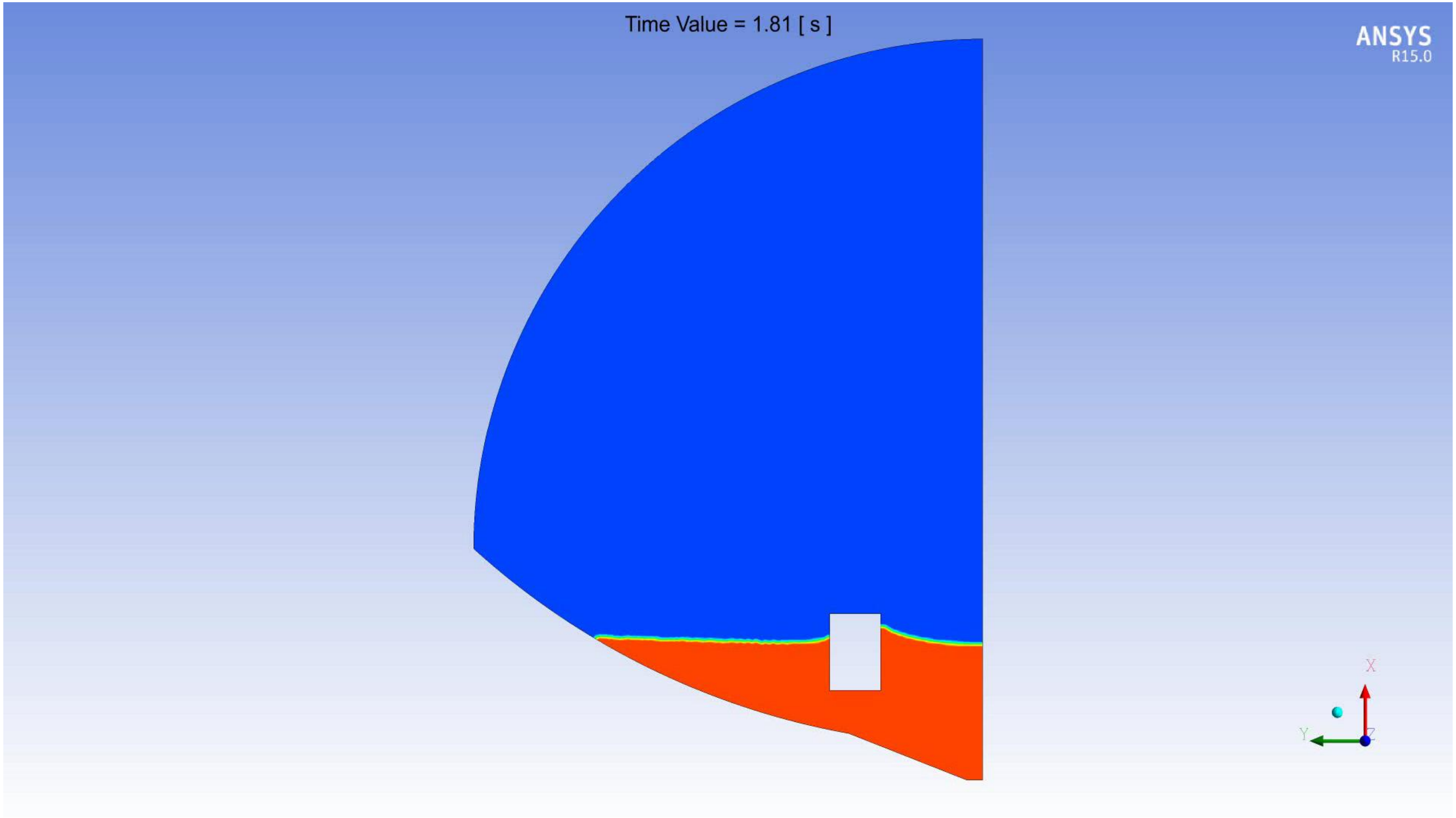


Single Coil:
500x200A

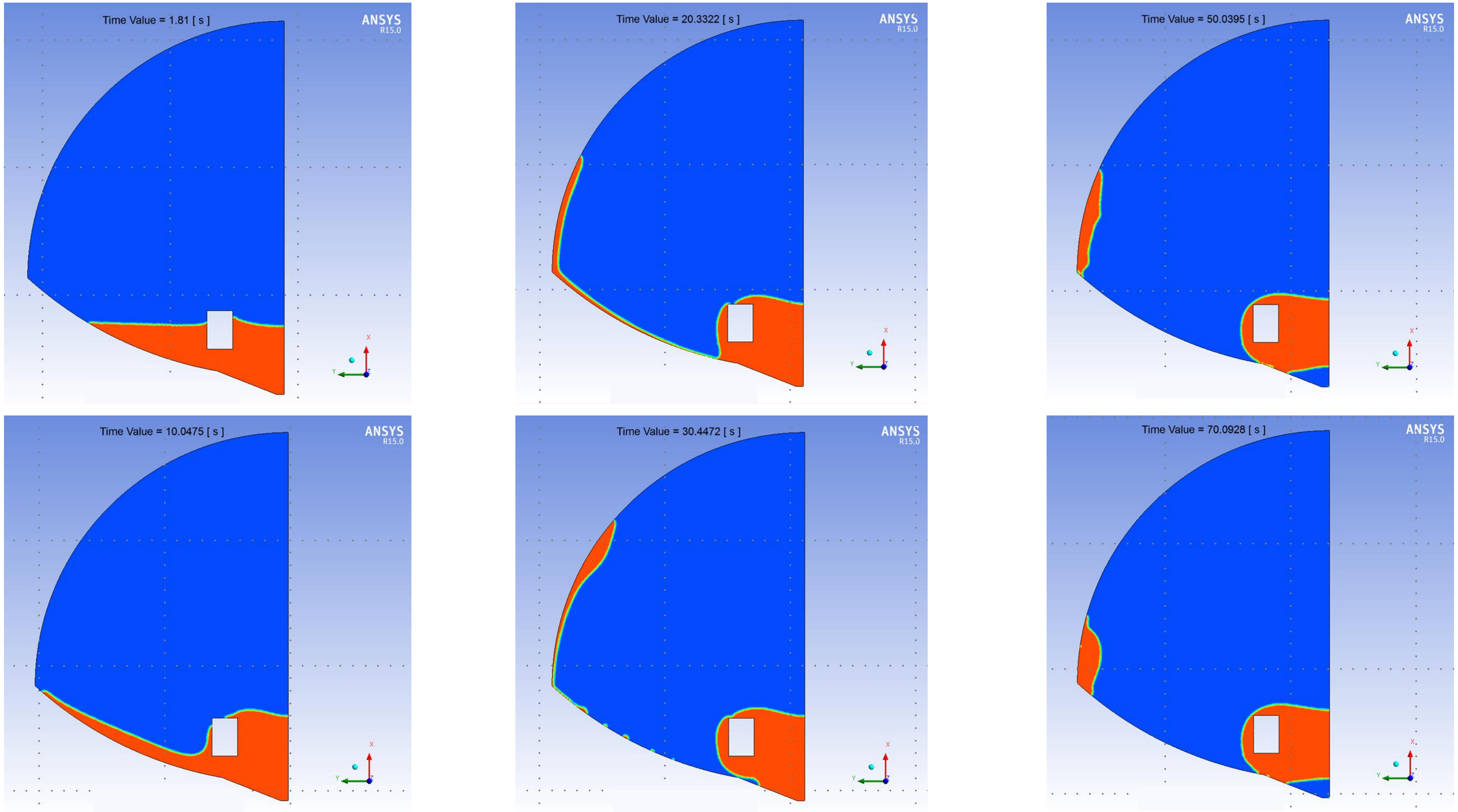


- 2d axis-symmetric model (modelling of droplets/bubbles or asymmetric sloshing modes not possible)
- Superconducting magnet is located at the tank bottom (next to the tank outlet)
- Fluent calculation
  - 46261 cells
  - VoF model
  - K-ε-turbulence model
  - Transient calculation
  - isotherm

Single Coil: Spin Case

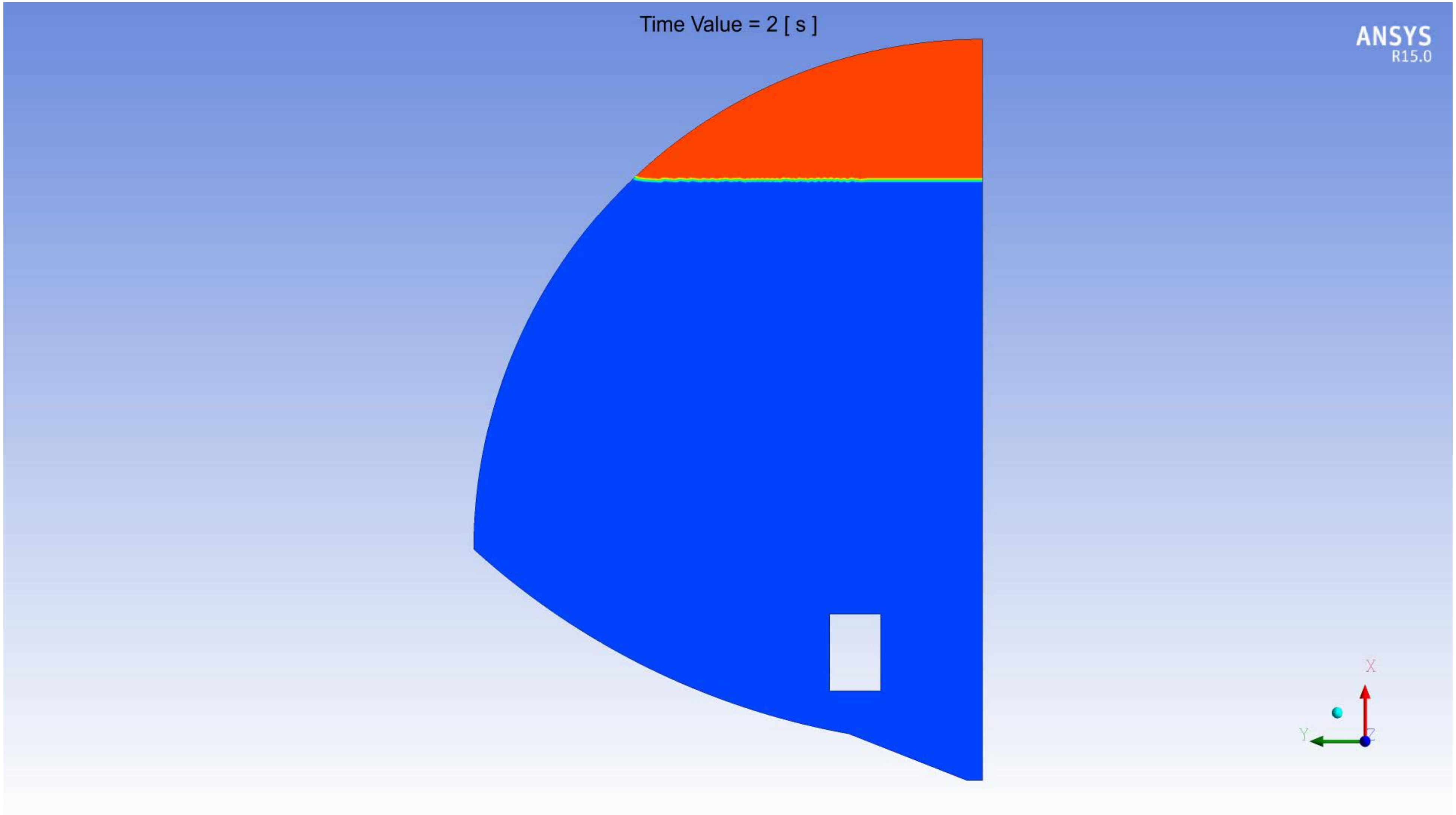


Single Coil: Spin Case

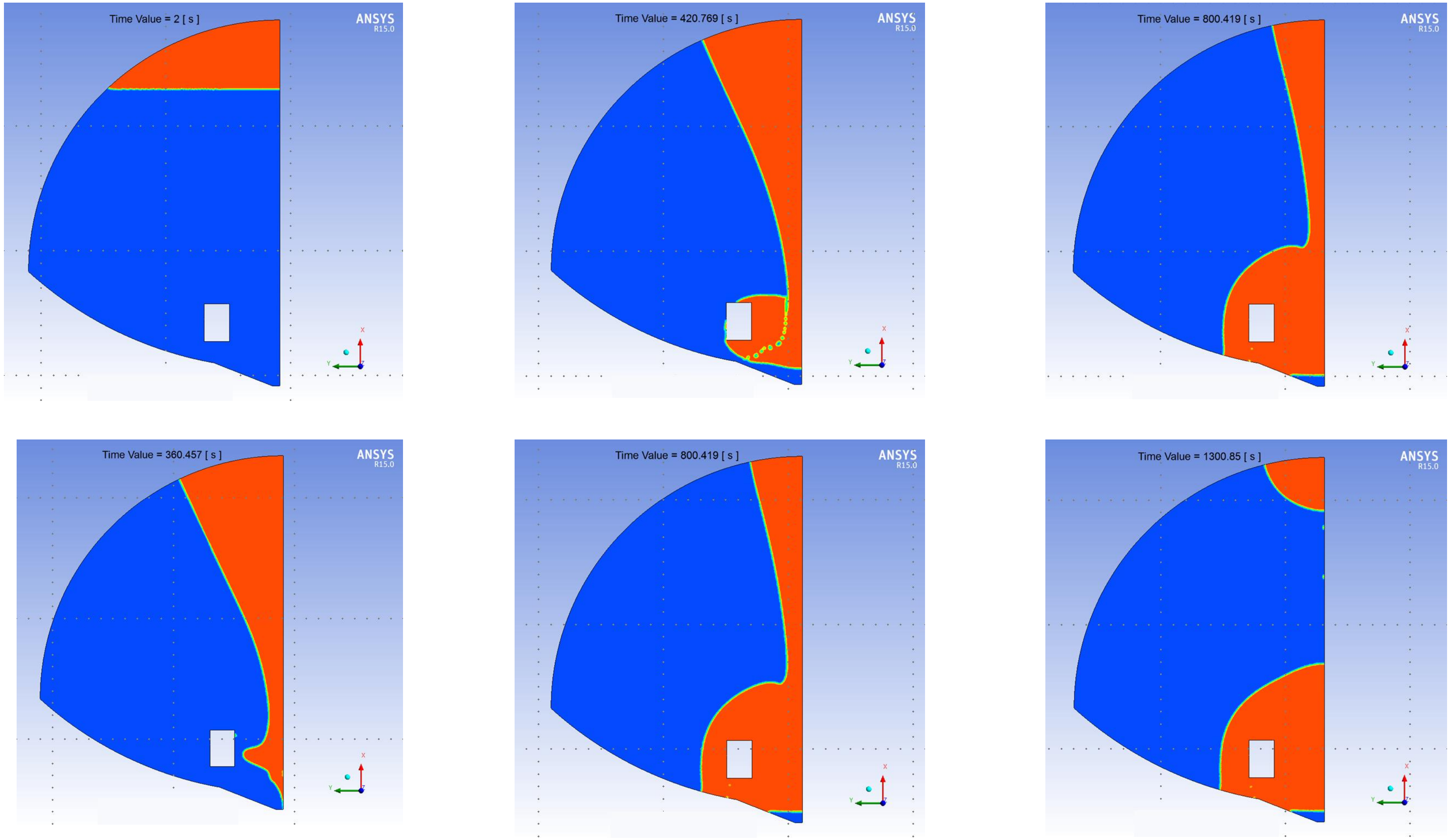


Applying a magnetic field of 0.1 T (at the center of the coil), ensures a continuous wetting of the superconducting magnet

Single Coil: µg Case



Single Coil: µg Case



The LOX reaches the 0.1 T magnet after ~360s,
which is deemed acceptable for a HTC with a transition temperature of 110K

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Conclusion

- Summary

Summary

- Interest in LOX-MP² for long ballistic phase application explained

- Dis-coupled approach for magnetic field interaction outlined

- Checks of approach given:
  - Forces checked against analytical expression for solenoid
  - Surface orientation checked against test under 1g

- First dimensioning studies for LOX-MP² application
  - Spin case
  - µg case

  Þ HTC magnet assembly show LOX positioning capabilities