Simulating the deployment of a sonobuoy dropped from air and landing in seawater using ICFD solver in LS-DYNA

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Phenomena to be studied

- Object to be dropped from air into water
- Object contains equipment that needs sustain impact loads
- Deployment of antenna above surface
- Deployment of antenna below surface
- Effect of waves on the antenna

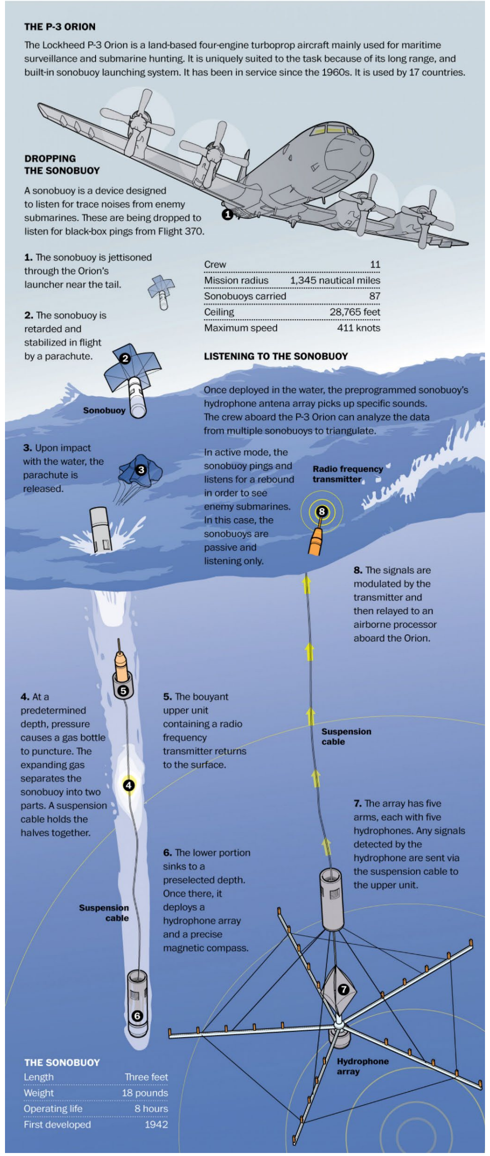
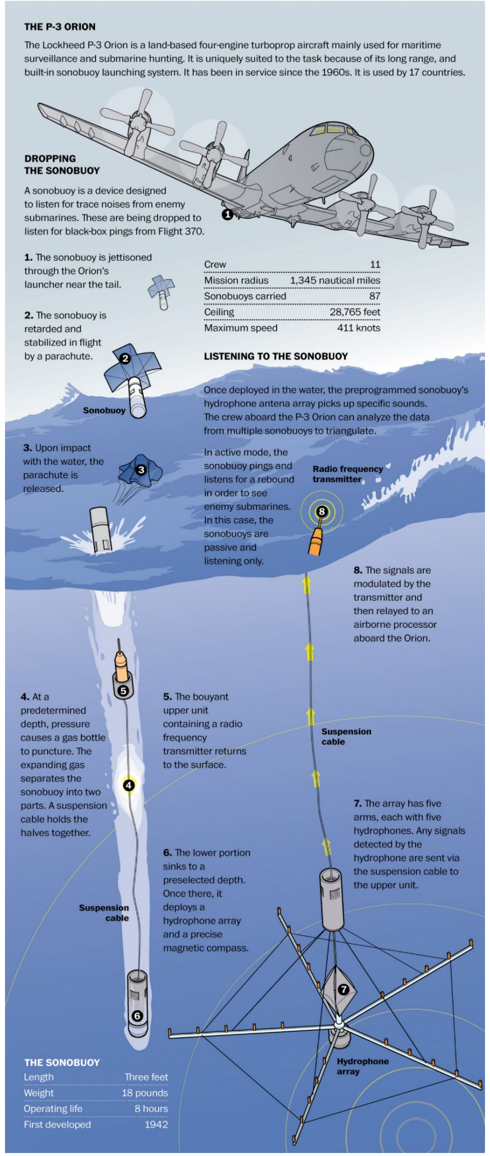


Image SRC: https://visual.ly/community/Infographics/transportation/sonobuoy-hunting-flight-370

Physical problem

- Study the entire process of Sonobuoy deployment
- The entire drop and deploy process is a complex Multiphysics phenomena and has to be split and studied
- Steps in the split
  1. Drop through air with parachute opening
     a. Launch, Stabilize, retard
  2. Splash down impact with water
  3. Underwater deploy of airbag for buoyant upper unit
  4. Opening of antenna
  5. Motion of Antenna in water with lateral waves



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LS-DYNA ICFD/FSI Technology for Porous Parachute Modeling

- Solver Technology:
- 1-way/2-way Strong Partitioned FSI coupling (& all multi-physics equations coupled in one solver, no need of co-simulation),
- ICFD: Incompressible Navier-Stokes, 2nd order Fractional Step with Finite Elements,
- Coupling with LS-DYNA structural solver (Implicit and Explicit), through solid/shells surfaces (body-fitted strategy),
- Can model Porous and Non-Porous Fabrics,
- Adaptive Mesh Refinement,
- RANS/LES Turbulence modeling.

Porous Parachutes Flight Dynamics in ICFD LS-DYNA

Engineering Goals

- **Provide** a High-Fidelity physics-based FSI evaluation tool for the deployment, flight and control of parachutes and parafoils built with porous fabrics.
- **Accelerate** device development and design. **Test** parachutes performances when changing any design and flight parameters, etc.,
- **Develop** coupled physic-based tool for payload dropout and delivery,
- **Reduce** conceptual design stage and in-flight testing.

Solution

- **Fast Pre and Post-processing**: a complete eco-system for pre and post processing, optimization as well as a full suite of design and analysis tools like SpaceClaim, Discovery, Ensight and Workbench meshing,
- **Accuracy**: Implicit time integration solution for nonlinear material models for parachutes, suspension lines and surrounding atmosphere,
- **Robustness:** Strongly coupled Fluid Structure Interaction (FSI) provides stable solutions for fluid flows, external aerodynamics and coupled mechanics.

Benefits

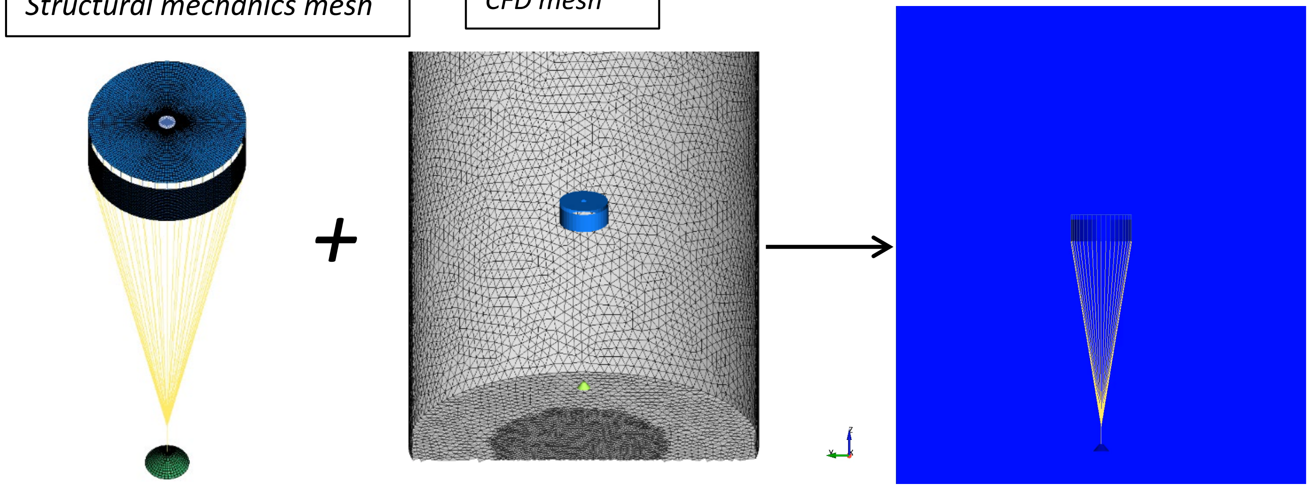
- The **fluid flow and nonlinear material physics are coupled together** to demonstrate the fully coupled solution for the flight of flimsy structures**.** This **Coupled Multiphysics capability is strongly coupled in one code/executable/binary** allowing the solution of this complex problem in a single run,
- **Predict** device flight characteristics and **Reduce** the cost of physical testing.

Unified pre-processing, run, and post-processing for parachute dynamics, fluids and structures, and its physical coupling. No need of co-simulation.

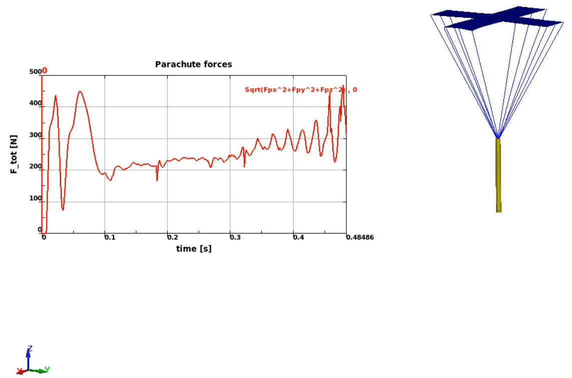
Structural mechanics mesh

CFD mesh

Coupled Analysis



Free fall analysis and aerodynamics forces.



FSI Modeling of flow through Porous Membranes and Fabrics

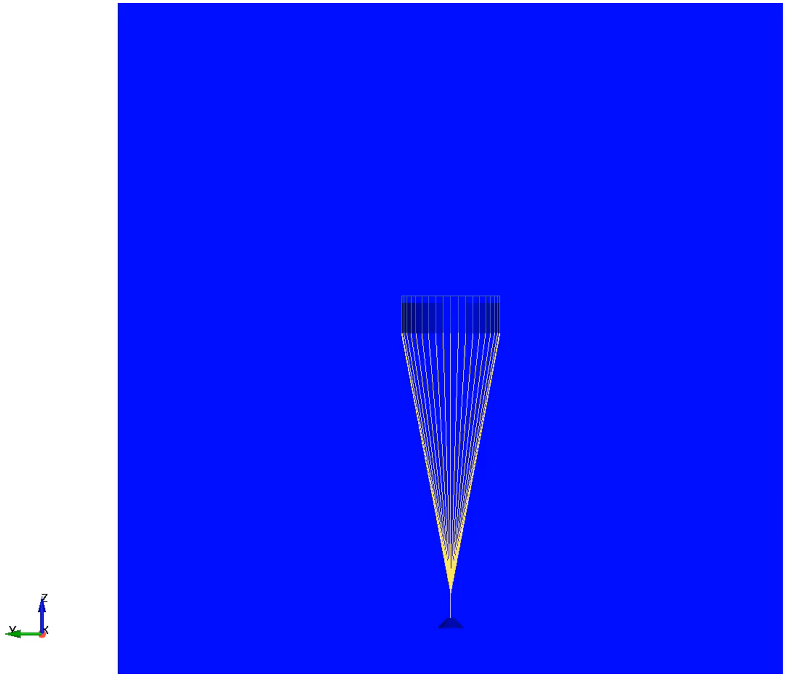
- 2D and 3D implicit FSI porous/permeable parachutes and membranes modeling,

- Pressure drop through the fabric thickness is modeled as a Darcy flow (jump cond.) $\frac{\partial p}{\partial n} = \alpha\,(u * n) + \beta|u|(u * n)$.

- $\alpha = f(\mu, \kappa)$ and $\beta = f(\rho, \epsilon, \kappa, F)$. Where μ is the fluid dynamic visc., ρ the fluid density, ϵ the fabric porosity, κ the fabric permeability, F the Forchheimer Factor, and n the normal to the parachute surface.

- A flexible user interface to define the porous parameters through *ICFD_MODEL_POROUS keyword and PMIDs =8,10,11.

Orion Space Capsule Parachute



2D models
(adapting mesh refinement)

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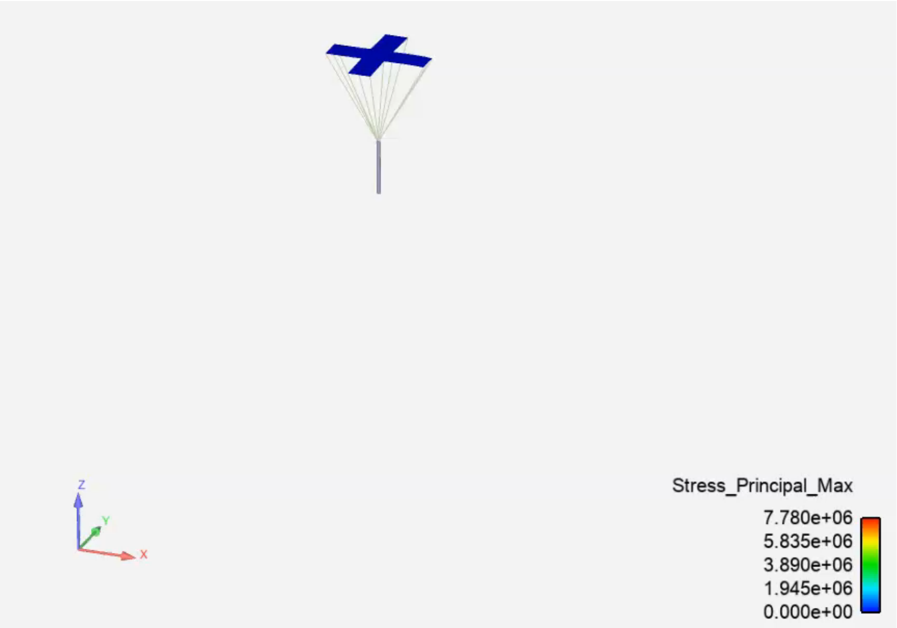
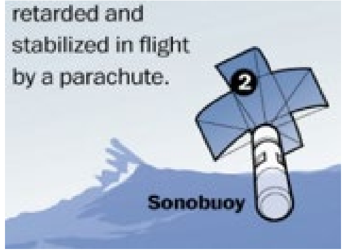
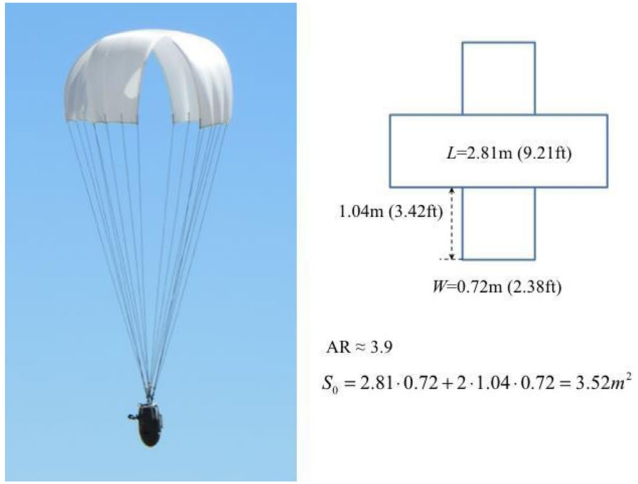
Step 1







Geometry of a subscale cruciform canopy.

- *https://www.researchgate.net/figure/Geometry-of-a-subscale-cruciform-canopy_fig2_317756417*

Typical Mesh sizes and MPP running details:

- ICFD Mesh: ~ 3M tets,
- Runtime to complete 4 secs for full FSI is O(1day) in 24-36 procs (slow cluster, need to update for cdc cluster timing),
- Pure ICFD run completes 4secs in <6 hours.
- 1-way FSI running time is similar to pure ICFD (no-FSI).
- Fabric permeabilities O(1.e-10-1.e-12 m^2).
- Porous properties can be defined through Pressure-Velocity experimental data of fabrics.

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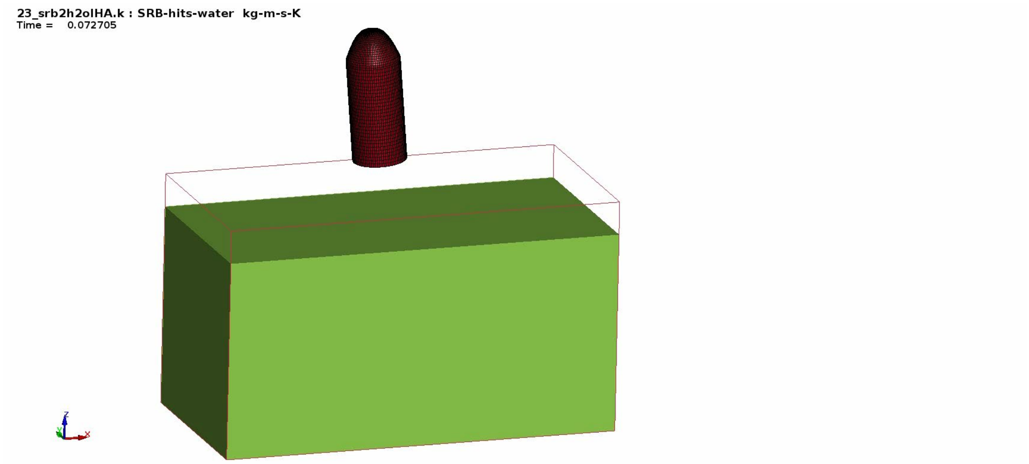
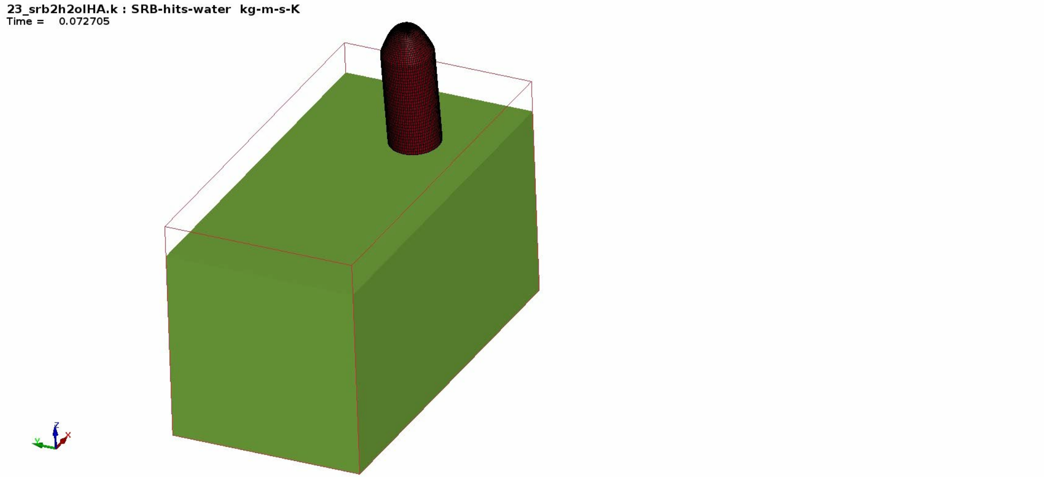
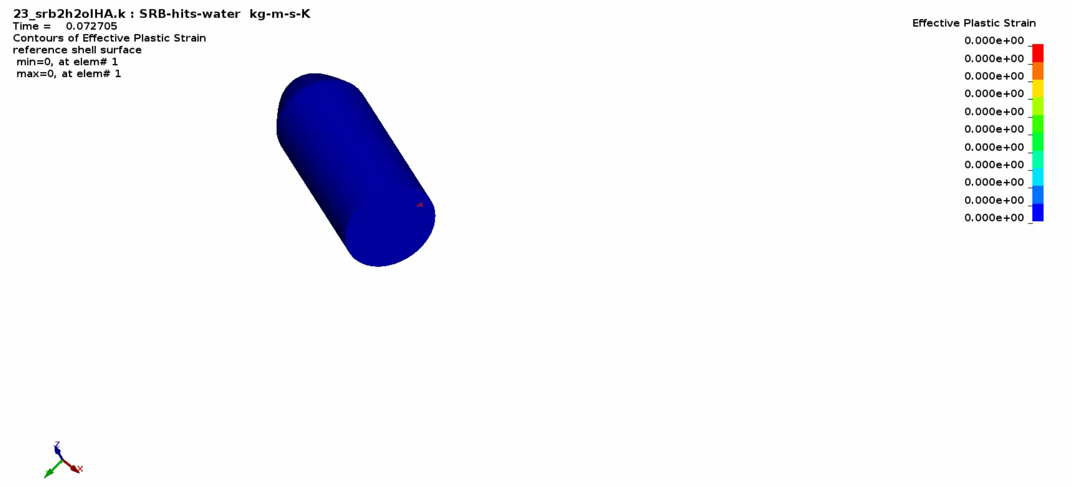
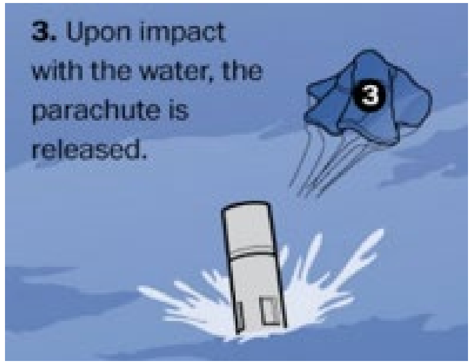
STEP 2: Splashdown (performed in both ALE and ICFD)

- Drop impact









STEP 3: Sonobuoy deployment simulation

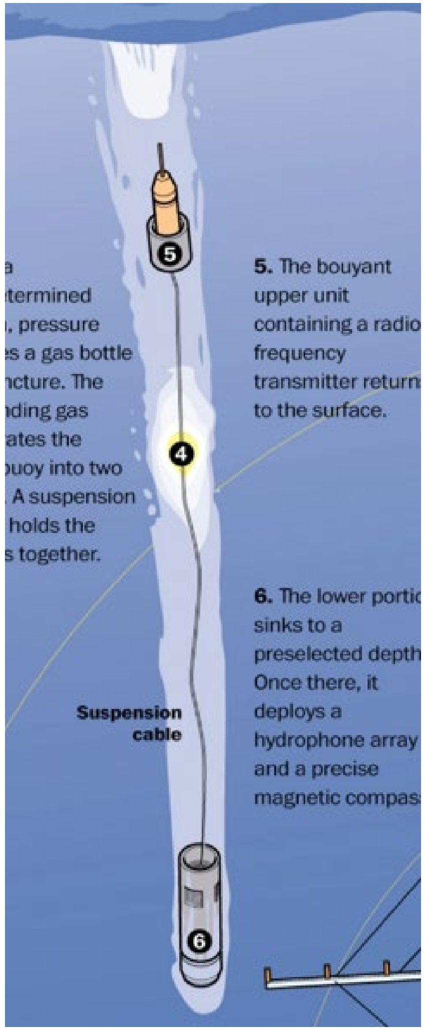
P3 Sonobuoy Deployment
https://www.youtube.com/watch?v=eidMDdMK38s

Time Sequence:
11:03:14 Released from plane
11:03:20 Impacts water (6 s flight)

09:04:13 Starts to sink
09:04:17 Buoy deploys
09:04:19 Fully inflated & starts to ascend
09:04:22 Reaches surface of water

04:39:53 Main unit descending (?)
04:39:56 Main unit initiates release of array

0:32 Start of release of top white housing
0:35 Array strings clear the black tube
0:36 = 04:40:07 Bottom white array starts to be pulled out
0:39 = 04:40:10 Bottom white array is out = array deployment starts
0:50 = 04:40:21 Bottom white array fully deployed



LS-DYNA ICFD/FSI Technology for Free-Surface Flows.

- Solver Technology:
- 1-way/2-way Strong Partitioned FSI coupling (& all multi-physics equations coupled in one solver, no need of co-simulation),
- ICFD: Incompressible Navier-Stokes, 2nd order Fractional Step with Finite Elements,
- Coupling with LS-DYNA structural solver (Implicit and Explicit)
- FEM Stabilized Level-Set tracking for the free-surface flow,
- 1st-5th Stokes and Irregular (ocean/tsunamis) wave patterns generation,
- RANS/LES Turbulence modeling.

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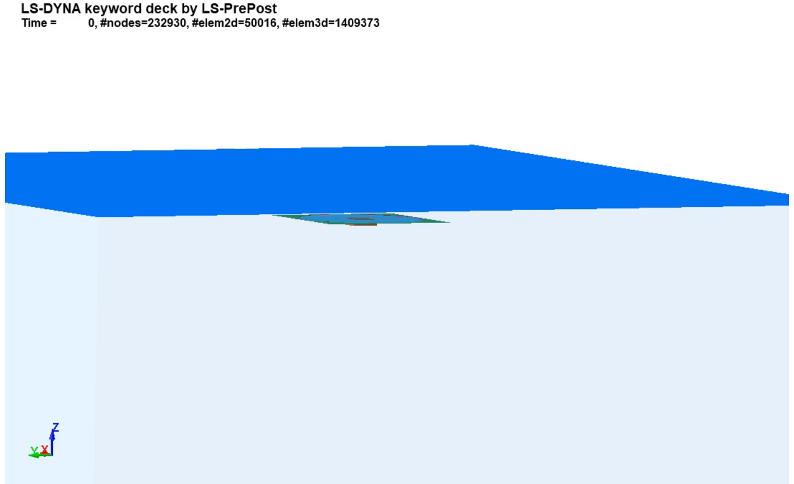
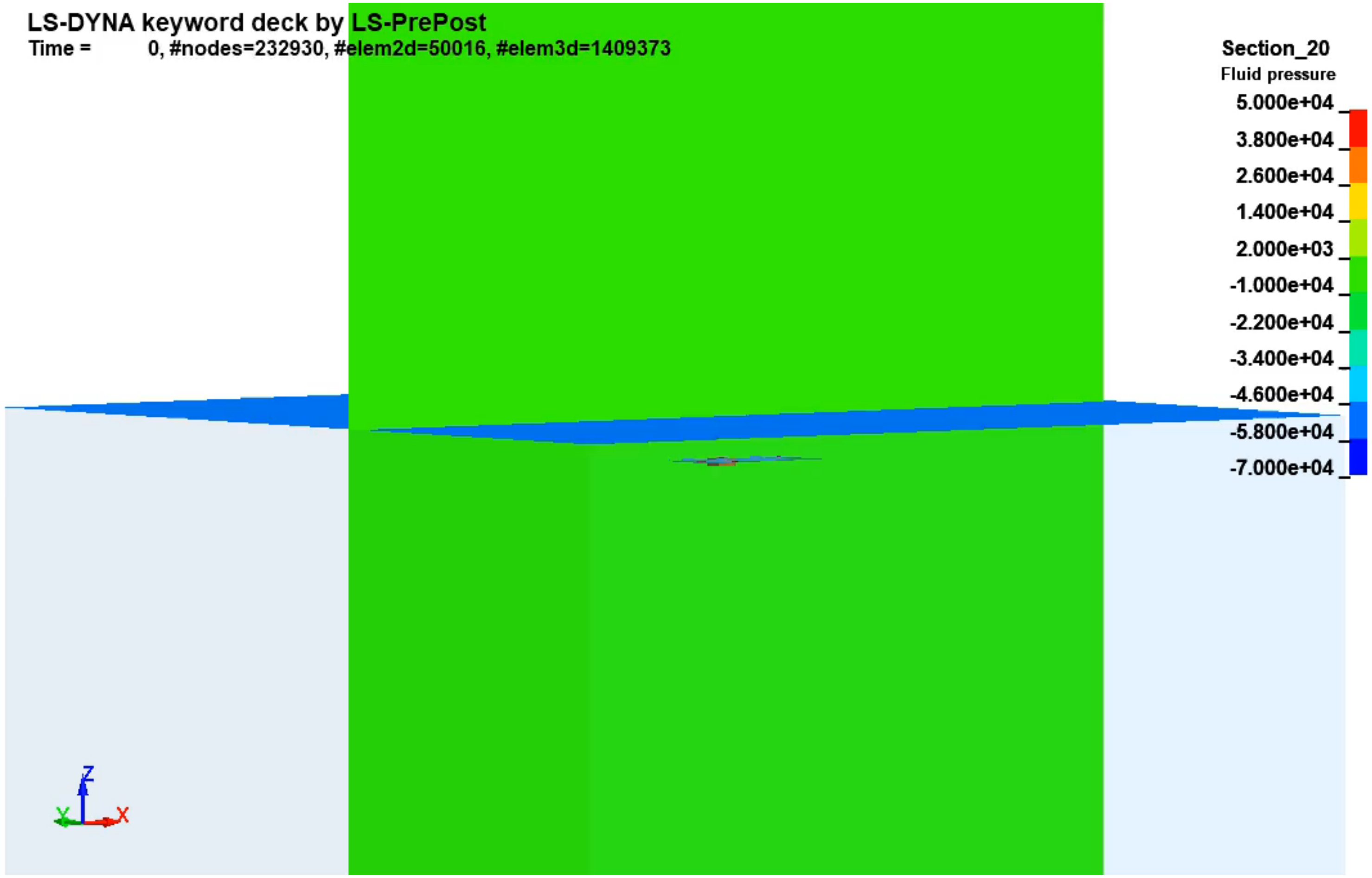
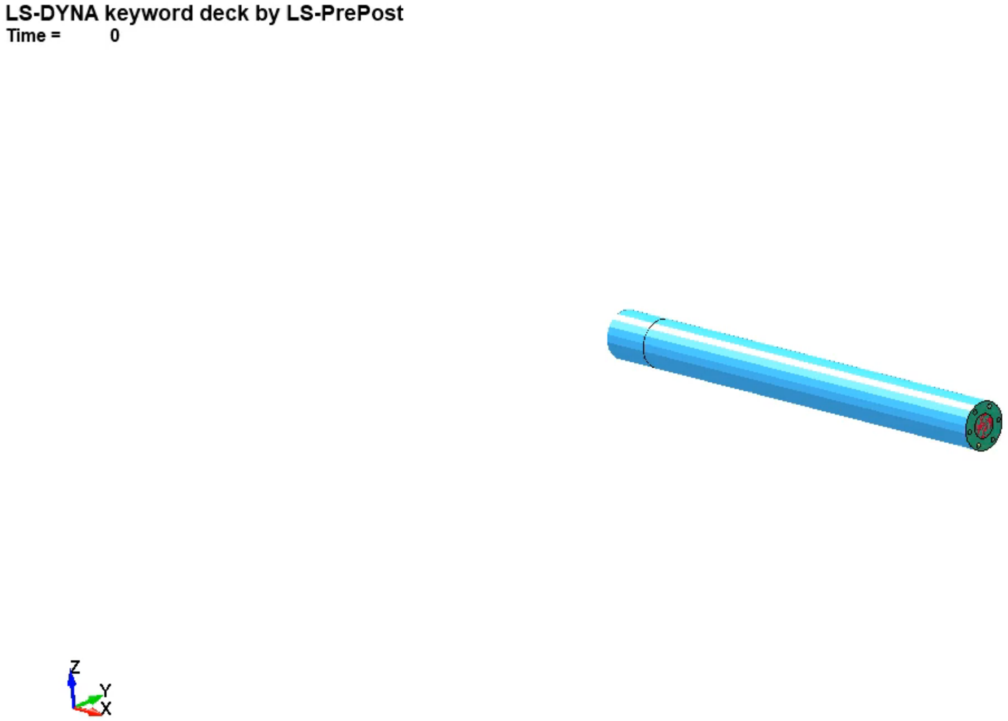
ICFD Based Airbag Float

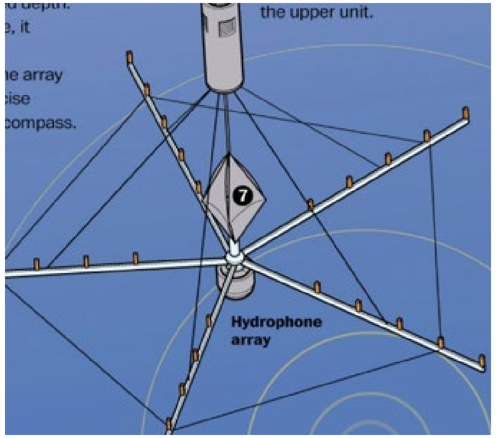




Step 4

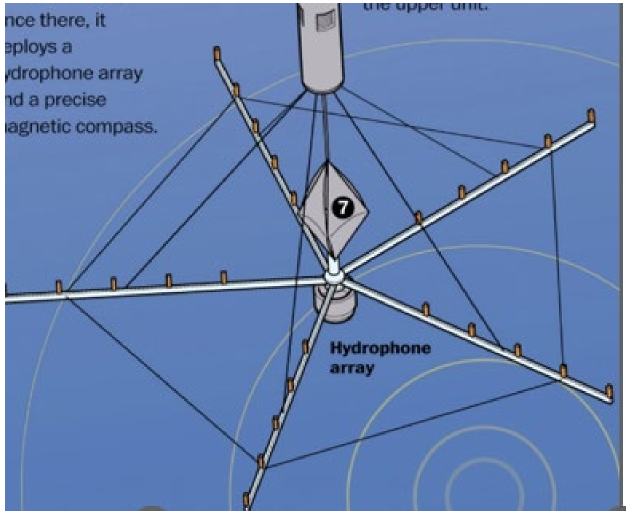
- Deployment of Antenna

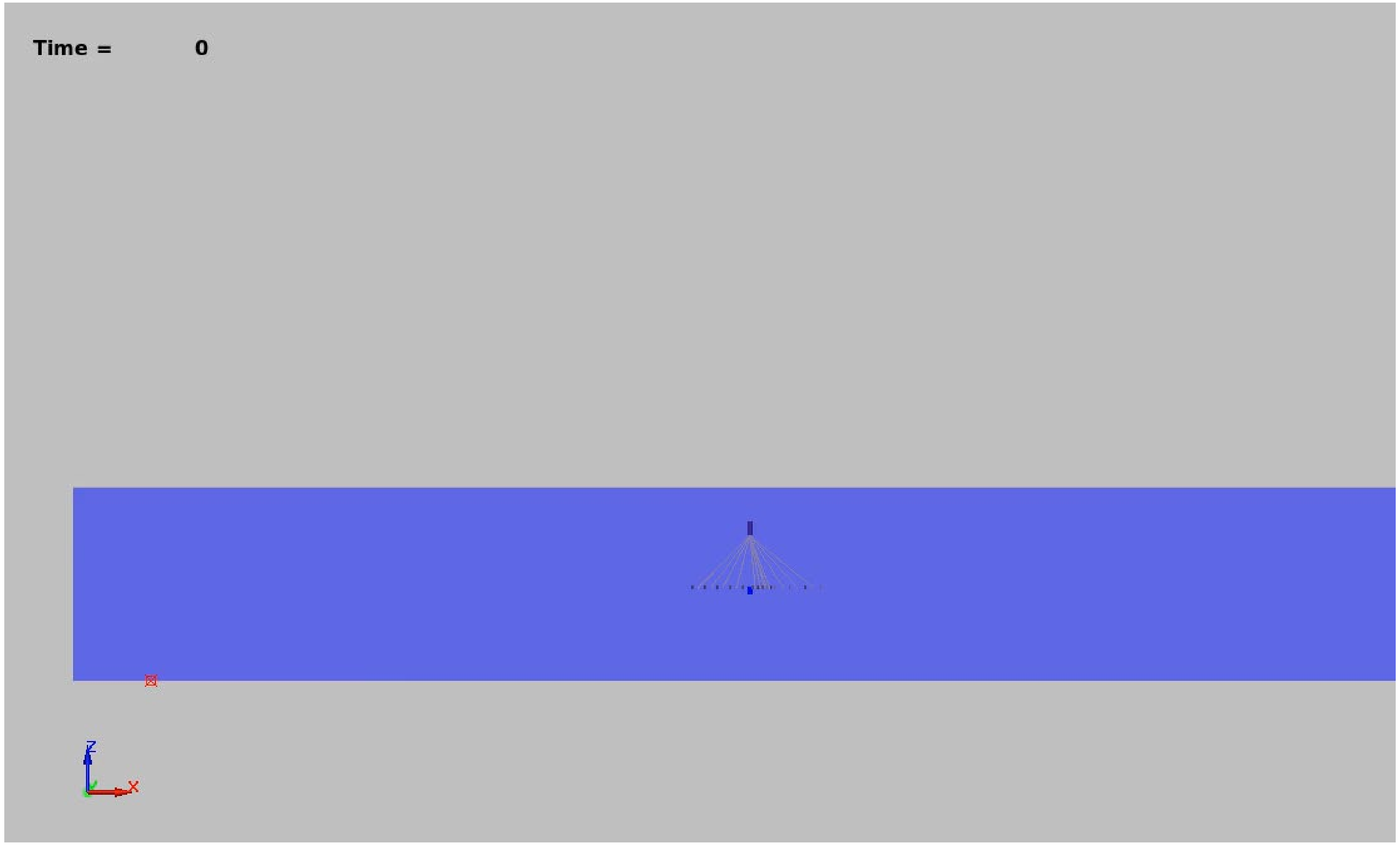




Step 5: Antenna Motion in water

- Create beam element mesh
- Coat beam with DEM particles
- ICFD will interact with Antennae array with wave motion





Summary

- All these steps take simulation time and effort in setup
- Learning path
  - Spaceclaim for Meshing (Geometry and Meshing)
  - LS-DYNA explicit
  - LS-DYNA implicit
  - ICFD/FSI
  - SALE
  - LS-PREPOST (Pre and post processing)
  - Model Center Integrate for mission control and sequential workflow

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