Numerical simulations of fluids-membrane interaction in satellite tanks

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Context

What is inside a spherical satellite tank ?

- **Liquid ergol**: a perfectly wetting propellant,
- **Helium gas:** to pressurize the tank.

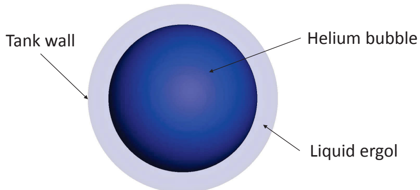

Figure 1. Inside a satellite tank

What is **ergol sloshing** ?

- Motion of fluids inside the tank which generates forces and torques on the tank wall and disrupts the stability of the satellite.

How to reduce ergol sloshing ?

- Add a thin hyperelastic membrane separating the ergol and the Helium

⟹ **Diaphragm tanks.**

Goal: Predict fluids and membrane behaviors inside the diaphragm tank.

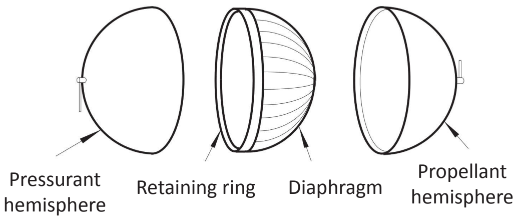

Figure 2. Exploded view of a diaphragm tank[1].

How to model sloshing ?

Experimental method: the **Fluidics** experiment.

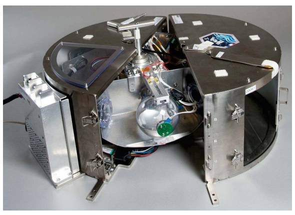

Figure 3. The Fluidics experiment

⇒CNES experiment sent to the ISS in 2017,
⇒Sloshing measurement inside a simple tank.

Numerical method: the **monolithic approach**.

⇒A single numerical code deals with the fluid and solid mechanics on a same mesh.

⇒Numerical approach used in biomechanics, on deformation of biological cells.

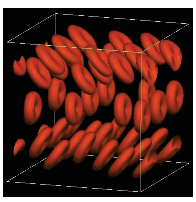

Figure 4. Numerical simulations of red blood cells in a flow[2].

Two-phase flow solver

Position of the two fluids with the **Level Set Method,** the signed distance from the interface:

$$\begin{cases} \varphi > 0: & \text{Presence of liquid ergol,} \\ \varphi = 0: & \text{Interface between the two fluids,} \\ \varphi < 0: & \text{Presence of Helium gas.} \end{cases}$$

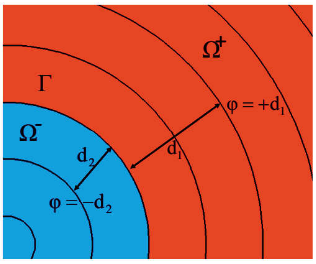

Figure 5. Level set scalar field.

Irregular domain method for the spherical tank wall:

- Second level set function φ_S for the interface between the tank wall and the fluids,
- Specific boundary conditions.

Two-phase flow solver:

- Solve the Navier-Stokes equations,
- Consider the jump conditions on the viscosity and density.

Eulerian membrane model

Some definitions:

- A hyperelastic behavior is an elastic behavior even for large strains.
- The zero level set of φ corresponds to the position of the thin membrane in the domain.

Membrane model algorithm[2]:

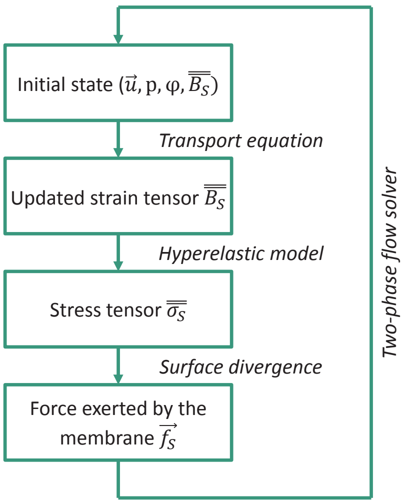

Chart 1. Implemented algorithm of the membrane model.

Validation on test cases

2D stretched pressurized membrane[3]:

- Material model : linear Hooke law,
- Same fluid inside and outside the membrane,
- Computational domain : closed box.

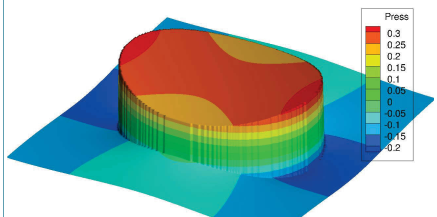

Figure 6. Pressure jump at the membrane.

⇒Relaxation or oscillation of the membrane around its equilibrium position depending on the Reynolds number.

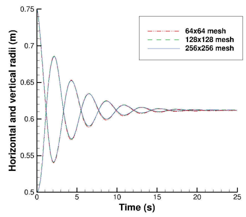

Figure 7. Radii evolution of the 2D membrane for a high Reynolds number.

3D capsule immersed in a shear flow[4]:

- Spherical membrane at rest,
- Material model : Neo-Hookean law,
- Same fluid inside and outside the capsule.

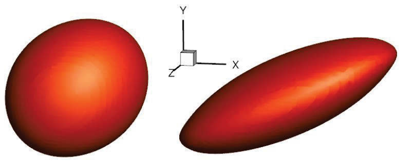

Figure 8. Two deformed surfaces of the capsule.

⇒Elongation of the capsule depending on the ratio between the fluid viscosity and the membrane elasticity G.

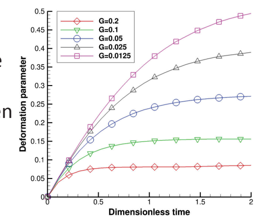

Figure 9. Evolution of the deformation parameter of the 3D capsule.

Conclusions

- Numerical model of the fluids and membrane behaviors using a monolithic approach.
- Solver based on a two-phase flow solver upgraded with an eulerian membrane model.
- Validation on classical membrane test cases by comparing with literature results.

Perspectives:

- Different fluids inside/outside the membrane,
- Contact of the membrane with a wall,
- Simulation of a real diaphragm tank.

References

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