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COMPARISON OF DYNAMIC EFFECTS OF A MOVING CAPSULE INSIDE A VERTICAL RIGID DUCT WITH DIFFERENT FLUIDS

Andre Santos Souza
Marcelo José Santos de Lemos
Instituto Tecnológico de Aeronáutica, São José dos Campos - SP, Brasil
andressouza13@gmail.com
delemos@ita.br

Abstract. *A CFD approach is used to study the effects of a moving capsule inside a vertical duct, taking into account the fluid mechanics phenomena and making a comparison using different fluids in interaction with the capsule. This work was developed by means of a commercial software estimating the vortices generation on both water-capsule and glycerin-capsule configurations and their respective inertial and viscous forces relevance. Further steps will investigate the mesh convergence, vibrations effects and influence of different fluids in contact with the capsule.*

Keywords: *CFD, moving capsule ,fluid mechanics, vortices generation.*

1. INTRODUCTION

Fluid mechanics problems have two areas of main concern. According to James *et al.* (1980), one is the aerodynamic lift and drag on circular and non-circular bodies, and the other is the crossflow drag characteristics of two-dimensional bodies in water. The present study is about the second area and how fluids with more viscosity impact this problems.

Capsules across ducts can be represented by different approaches, like transport of pills inside digestive canal and objects that have the capability to obstruct or clean ducts. At this point it is necessary to simulate those different situations mentioned previously. This study carries out an initial simple case using a rigid duct with a simple geometry capsule inside it.

2. METHODS

The methodology adopted here consists in predicting the vortices generation as well as estimating resultant forces in the capsule by means of STARCCM+ software simulating intrinsic responses. The motion theory used in this software is presented by Xing-Kaeding (2006), where the fluid dynamics, dynamics of rigid body and the interaction between flow and body are also explained by this author.

First step consists in designing the calculus domain, as presented in Figure 1. The calculus domain is defined for two volumes, where the first is the duct domain with no refined mesh and the second is a volume for the capsule which is free for motion and thus demands a refined mesh. A representation of the two meshes is presented in Figure 2. The mesh was set using trimmed cell mesher with chimera mesh (Hadzic (2006)).

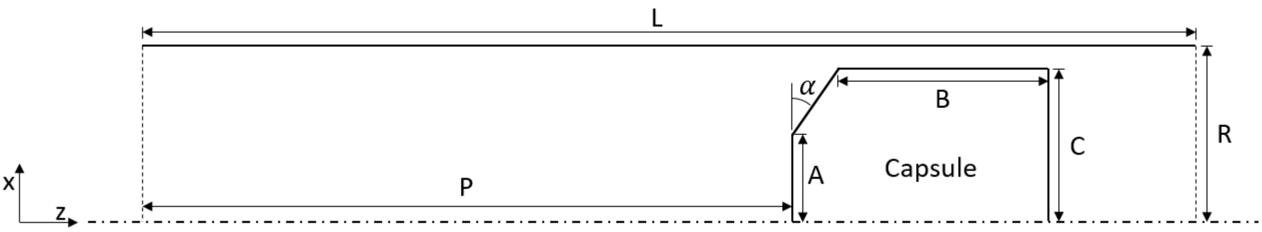

Figure 1. Rigid duct and capsule with their respective dimensions.

The second step consists in the free motion only in Z direction while the capsule have merely gravitational forces acting above it, configuring the system as an one degree of freedom (DOF) displacement. The third step consists in an imposed motion in Z direction and free translation and rotation in X and Y direction.

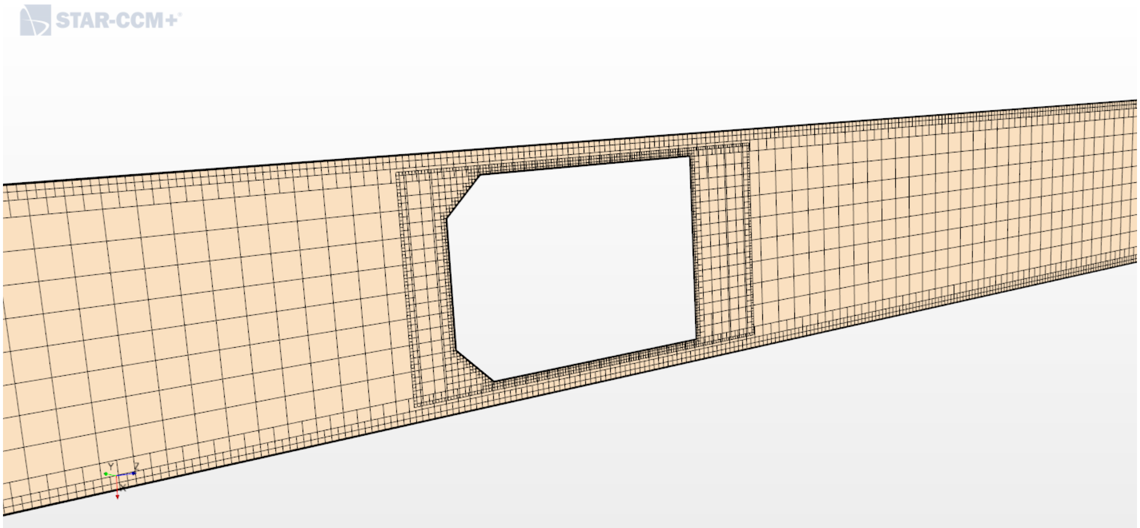

Figure 2. Representation of chimera mesh around the capsule and a no structured mesh along the entire duct.

2.1 FLUIDS DYNAMICS GOVERNING EQUATIONS

For this investigation, the fluid is assumed as incompressible and Newtonian. The walls are assumed to be rigid and the simulation is done taking into account a transient state. For this definitions the equations of Navier-Stokes are shown in Eq. 1 and Eq. 2, Ferziger and Peric (2012), where the equation of energy is not necessary for this study.

$$\frac{\partial(\rho u_j)}{\partial x_j} = 0 \tag{1}$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} + \frac{\partial p}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} - f_g = 0 \tag{2}$$

Where ρ is the fluid density, u is the velocity in each respective direction, p is the pressure, τ_{ij} is the tangential stress tensor, x is the axial direction and f_g are the external forces acting on fluid. To solve these equations, the software used methods developed by different authors, like Demirdžić *et al.* (1993) for couple pressure-velocity schemes, Jameson *et al.* (1981) for time step and Perić *et al.* (1988) for defining location of proprieties in volume cell.

2.2 GOVERNING EQUATIONS OF RIGID BODY MOTION

For a rigid body motion with six degrees of freedom, the method developed by Shabana (2001) is used to understand the dynamics and Xing-Kaeding (2006) demonstrated the coupling of fluid and dynamics of body. Equations 3 and 4 were presented for the last author, defined in Newtonian reference system.

$$\frac{\partial m v_c}{\partial t} = f \tag{3}$$

$$\frac{\partial M_c \omega_c}{\partial t} = m_c \tag{4}$$

Where m is mass of body, v_c is the velocity vector of center of mass of the body, M_c is the tensor of moments of inertia of the body, ω_c is a angular velocity vector of the body, f is the resultant vector of forces acting on the body and m_c represents the moments acting on the body with respect to its center of mass.

3. RESULTS

The flow effects caused by the capsule's free motion are considered as one can observe in Fig. 3, which demonstrates the difference between the usage of water or glycerin as path for the falling capsule. One can observe inconstant velocities

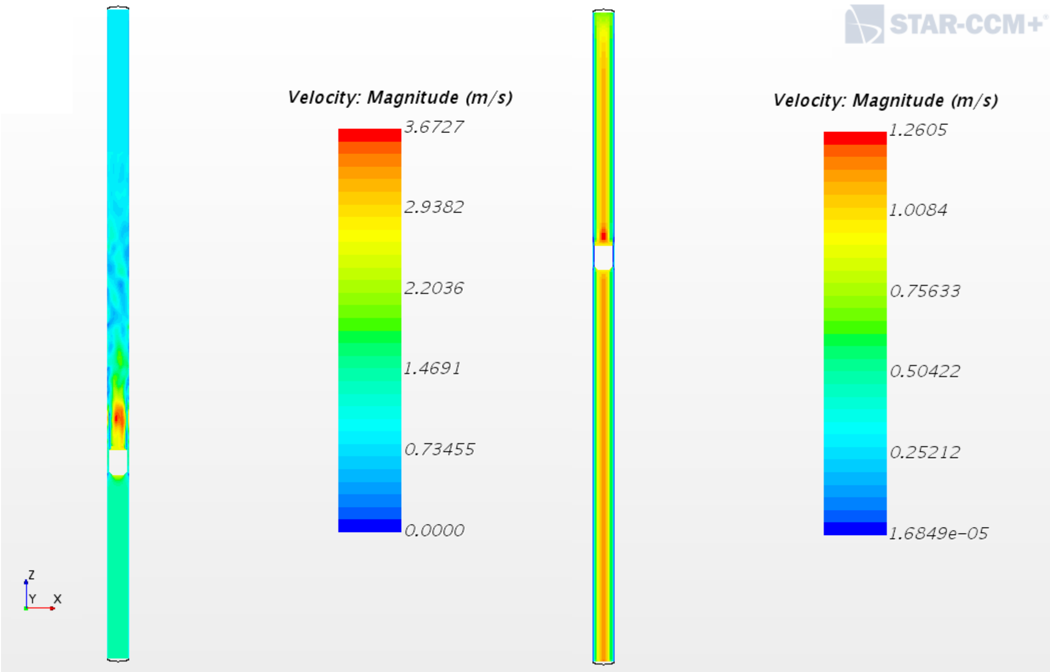

Figure 3. Comparison between flow velocity using water (left) and glycerine (right).

when water is applied as its effects represents turbulence above the capsule. On the other hand when glycerin is used the flow presents constant velocity above and below the capsule, implying a laminar flow throughout the duct.

Along with the velocity ascertainment, the different resultant forces acting on the capsule are investigated and the representation of this forces is demonstrated in Fig. 4. Due to turbulent flow observed when water is used as a fluid, the resultant forces acting on the capsule demonstrates to be greater than resultant forces when glycerine is used. However, the resultant forces exhibits variations that can indicate mesh problems or low number of fluid mechanics iterations.

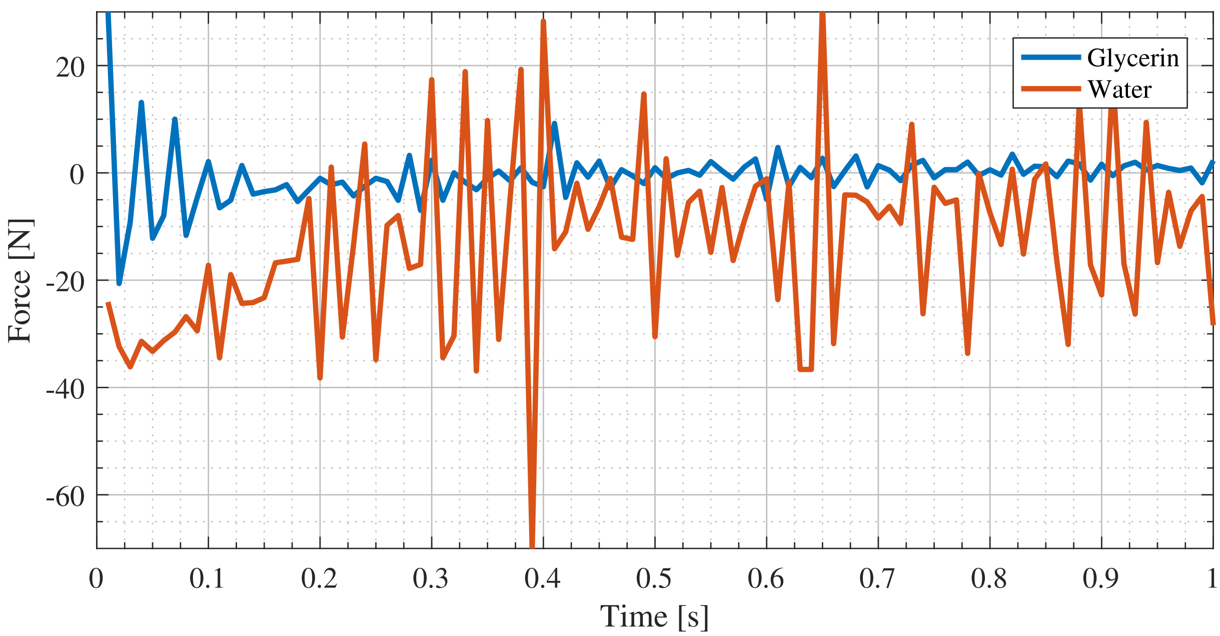

Figure 4. Comparison between resultant forces in Z direction using water (left) and glycerine (right).

Looking forward for better results, the mesh has been refined and the number of fluid and body iterations has increased. Then a constant velocity is applied in Z direction and the GDL of translation and rotation in X and Y directions are free. Figures 5 and 6 present the velocity field results for water and glycerine in planes X and Y. In both cases, one can notice that the capsule moves towards the sidewall, which was not foreseen for the proposed model. This capsule observed inclination which implicates in simulation undesirable error. Still, if the capsule is made of fragile material or is transporting reactive elements, such contact can compromise this task with those aforementioned requirements.

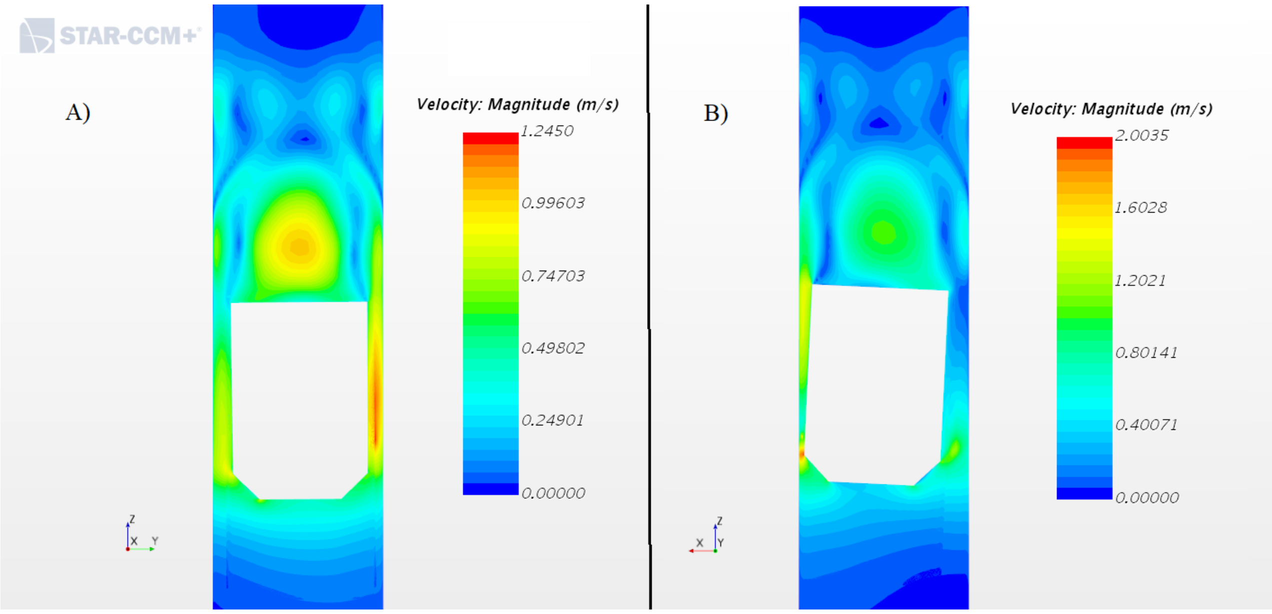

Figure 5. Flow velocity using glycerine as fluid. A) Plane X. B)Plane Y.

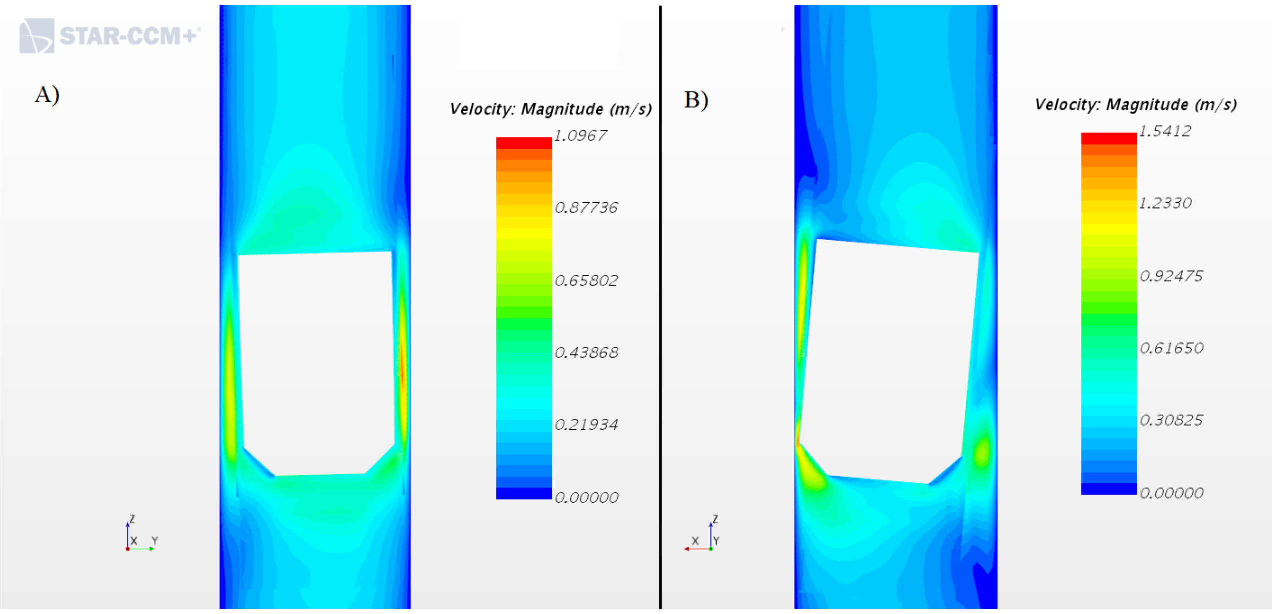

Figure 6. Flow velocity using water as fluid. A) Plane X. B)Plane Y.

Rotation movement is also verified in this simulation, which is caused by sudden perturbation created by the capsule as it passes through an initially stationary fluid, inducing fluid recirculation which rotates the body. The representation of this is presented in Fig. 7, which illustrates the fluid streamlines, showing the recirculation before the body.

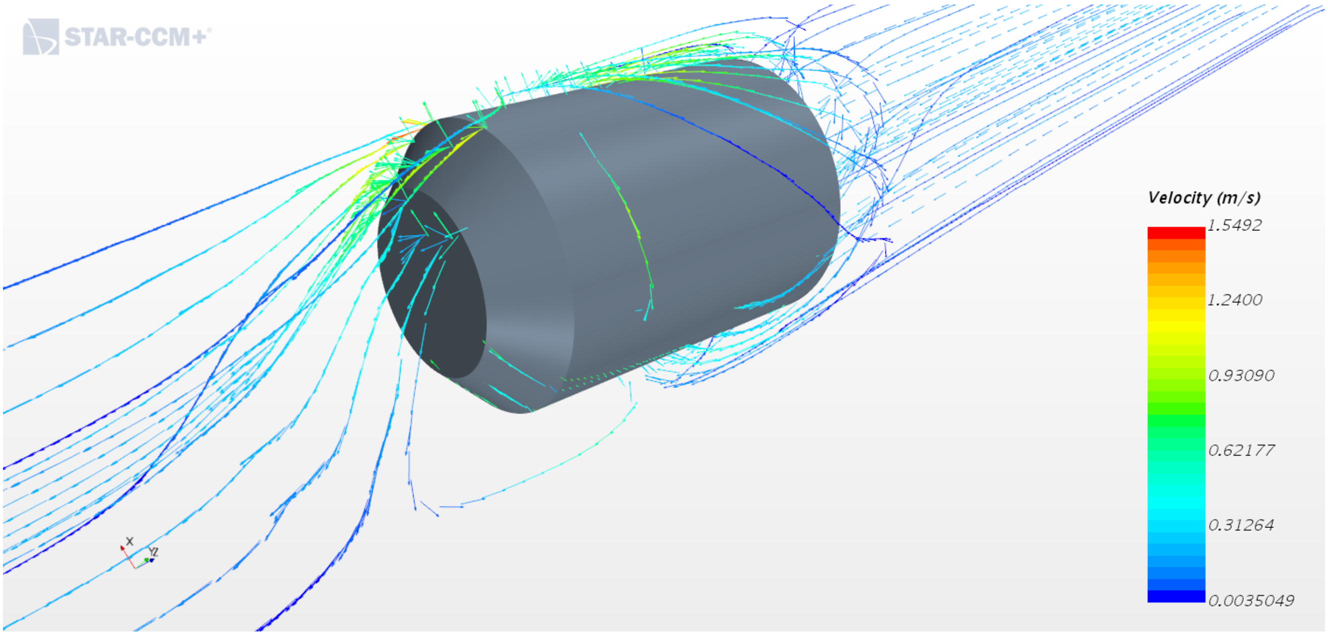

Figure 7. Streamline vector for velocity using water. Representation of recirculation in front the capsule.

Other important observation is the time when contact occurred. Figure 8 demonstrates the resultant forces acting in the body in X e Y directions. For glycerine, the contact occurred in $0.22s$, and for water, occurred in $0.4s$. This difference of time is caused because glycerine is more viscous than water, owning more resistance for the capsule motion. Figure 9 represents the resultant force in Z direction, which is possible to see when water is used as the force modulus is greater than when glycerine is used, demonstrating again the viscous flow effects.

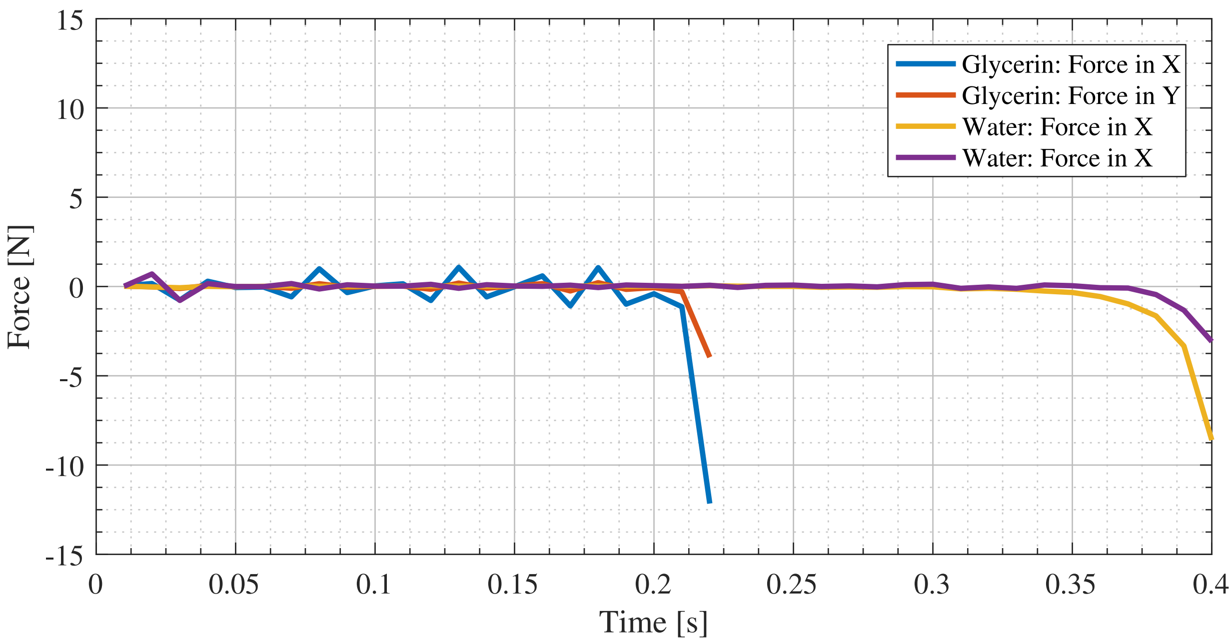

Figure 8. Comparison between resultant forces in X and Y directions.

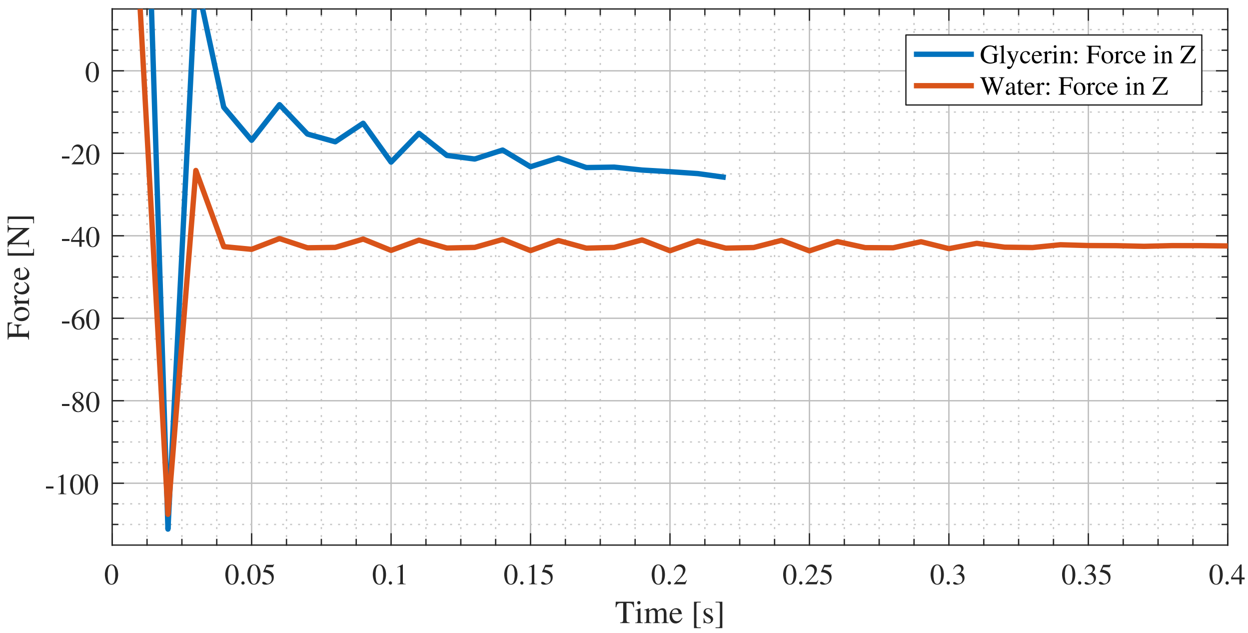

Figure 9. Comparison between resultant forces in Z direction using water.

To solve the contact problem, a constant inlet velocity is imposed at the open top, with the same magnitude of the body velocity. Figure 10 represents the flow velocity using water. In this case, the capsule does not present rotation and translation in X or Y direction. However, when this setup is applied with glycerine, the solver cannot converge the results.

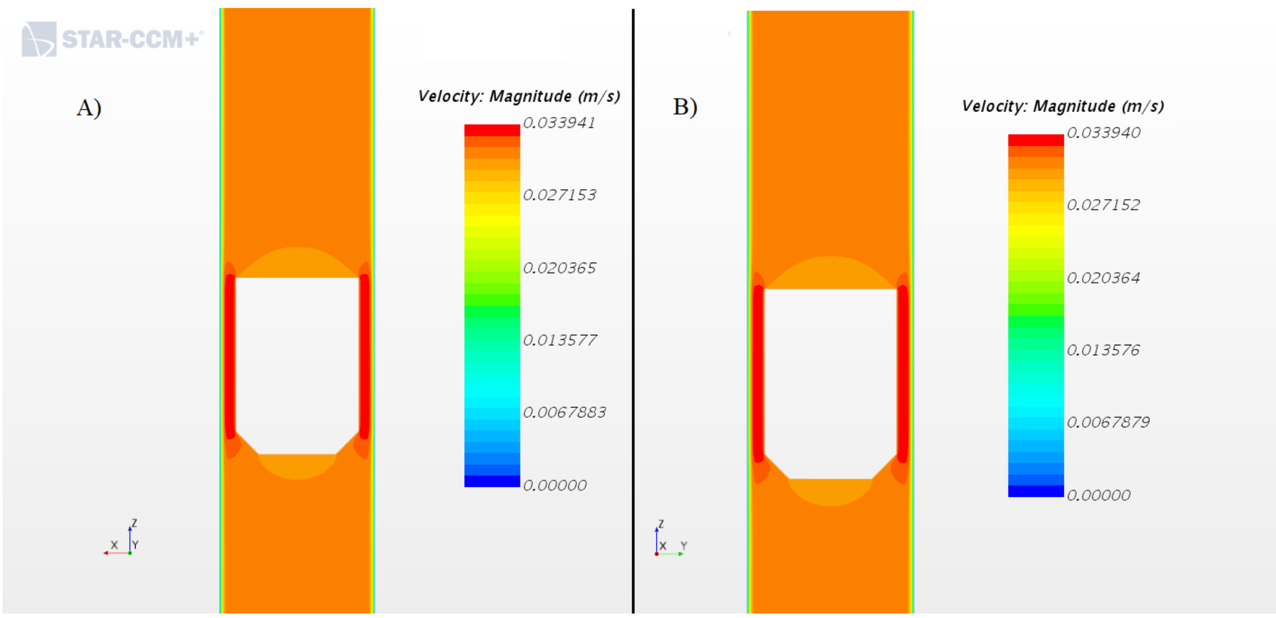

Figure 10. Flow velocity using water as fluid and imposed inlet velocity at top. A) Plane X. B)Plane Y.

To study the effect of viscosity, other two simulations were performed with the same velocity setup verified in Fig. 10, with other interaction fluids: alcohol and a higher viscosity water, but with the same density of the previously considered one. The comparison of forces in these cases are presented in Fig. 11 and 12. The first one is a comparison of resultant forces in X and Y directions and the second one is the resultant force in Z direction. Note that forces in X and Y directions are elevated to the minus four order, which is the residuals scale of the simulation. One interesting behaviour in relation to the force in Z direction is that the viscous forces becomes irrelevant when compared with the fluid density, which is the parameter that influences more the resultant forces.

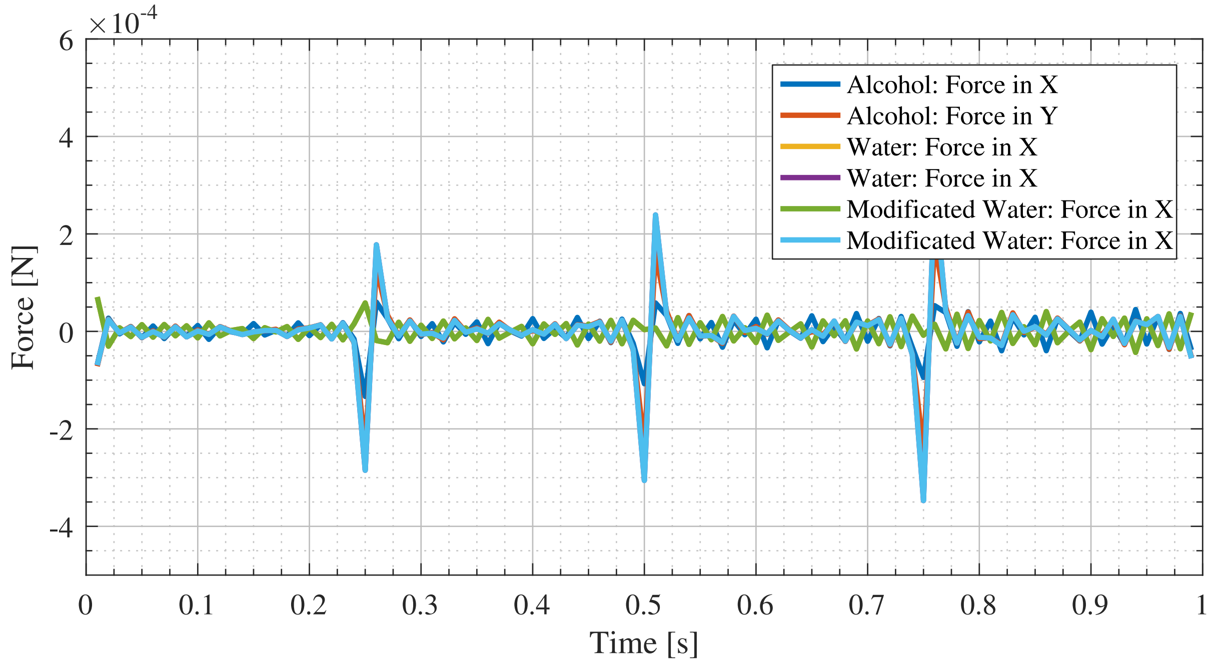

Figure 11. Comparison between resultant forces in X and Y directions using imposed inlet velocity at top.

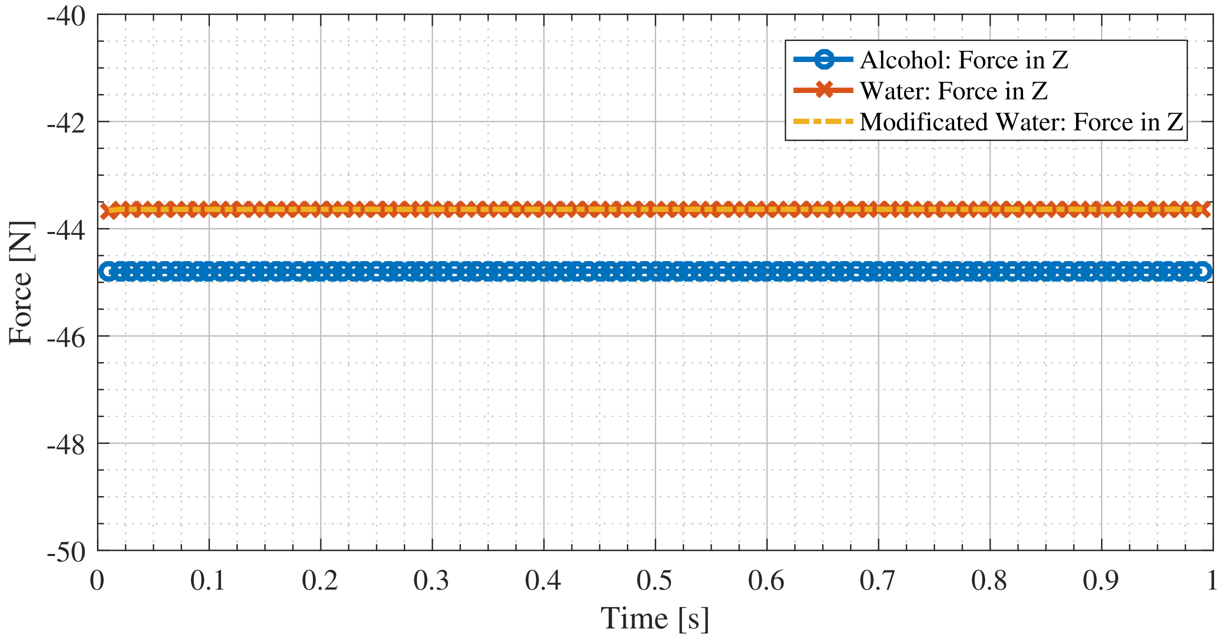

Figure 12. Comparison between resultant forces in Z direction using imposed inlet velocity at top.

4. CONCLUSION

This work studies a parametric analysis between two different fluids interacting with a moving structure. By doing so, a specific computational fluid dynamics method was proposed to achieve important conclusions about fluid-structure phenomena. A trimmed mesh is used along with a chimeric mesh in order to save computational efforts and hence save costs. Initially, two fluids are compared and, in addition, two other fluids were necessary to perform a complementary task, since initial results led to simulation issues.

In the first case is observed that the weight of the capsule can make their motion along the duct without the need of a down pulling force. In second case, is observed the translation and rotation of the capsule due to its motion, caused by the resistance of the static fluid. Lastly, in the third case, it was identified that for a motion without shocks between the capsule and the duct, a condition for inlet velocity of the fluid is required, resulting in smoothing the viscosity effects where the density of fluid starts to be more representative in terms of the resultant force.

For future work a few studies about mesh independence and a deeper analysis of the shock effects between the capsule and the duct will both be performed.

Therefore, this study demonstrates that capsule transportation inside ducts is facilitated when a flux of fluid in the same direction of the object motion is applied. Furthermore, it is important to know the physical particularities of each fluid when in interaction with the capsule, since its motion will be influenced by fluid density and viscosity.

5. ACKNOWLEDGEMENTS

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