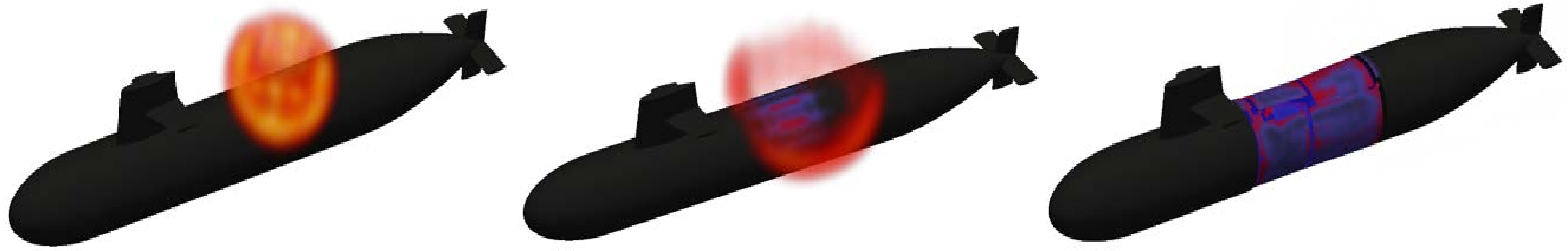
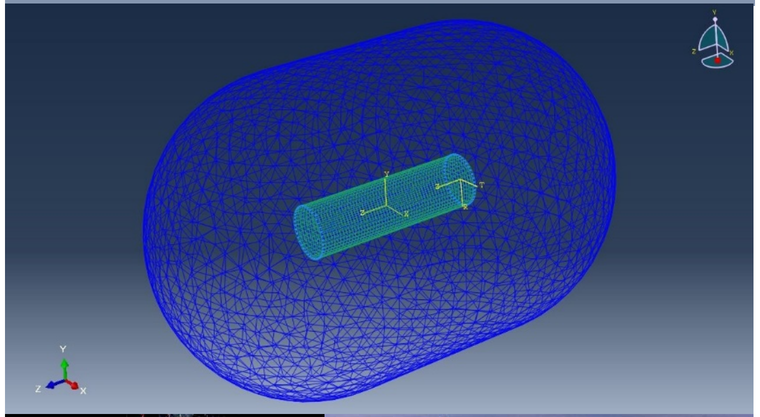
Numerical Analysis of Immersed Steel & Composite Cylindrical Shell Structures Submitted to Underwater Explosion (UNDEX).

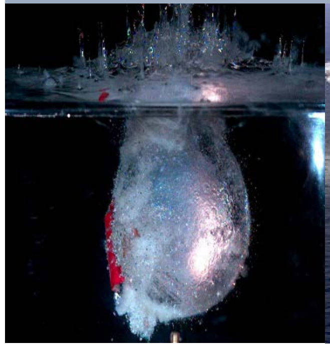


Master Thesis Presentation by Md Mahabub Hasan Mousum
Supervised by Prof. Hervé Le Sourne
Developed in Calcul meca & ICAM, France

Motivations

- **Structural Survivability to close-in non-contact UNDEX from Typical weapons (such as torpedo and mine)**
  - Understand the physics of UNDEX to carry out realistic numerical analysis
  - Understand the physics of Fluid Structure Interaction (FSI)
  - Effect of Radiation Damping in the fluid domain
  - Influence of Cavitation
  - Implementing different material model for fluid domain
  - Another perspective to compare with Analytical calculation results





Objective

- ***First***, evaluation of an appropriate *theoretical or analytical methodology* to calculate,
  - i. The pressure evolution
  - ii. The distribution of the primary shock wave

  Here the side-on UNDEX with respect to time (*Neglecting subsequent pressure pulsations from the bubbles*)

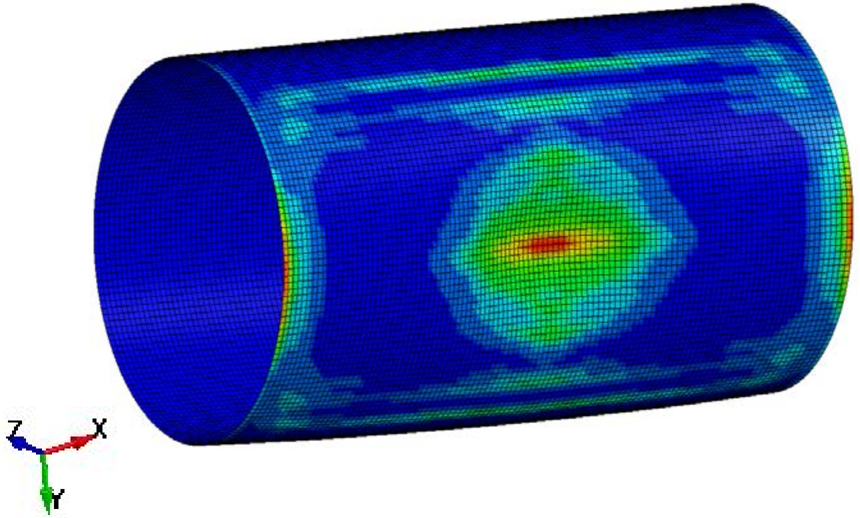
$$P_I = P_S\, e^{-t/T_S}$$

$$P_S = K_P \left(\frac{C^{1/3}}{D}\right)^{A_P}; \quad T_S = K_T C^{1/3} \left(\frac{C^{1/3}}{D}\right)^{A_T}$$

$$P_{element}(t) = 2P_I(t) - \frac{2\rho c T_s P_S}{m(1-\beta_i)}\left(e^{-\beta_i t/T_s} - e^{-t/T_s}\right)$$

$$P_{element}(t) = 2p_I(t)\left(\frac{1+\cos\alpha}{2}\right)$$

- ***Secondly***, to perform a *non-linear dynamic finite element analysis* of the Structure,
  - i. Immersed
  - ii. Non-stiffened
  - iii. Cylindrical shell structure
  - iv. Pressure load distributed over the one side of the cylindrical shell.



Background

❑ **Physical Phenomena UNDEX**[1]

Sequence of events,

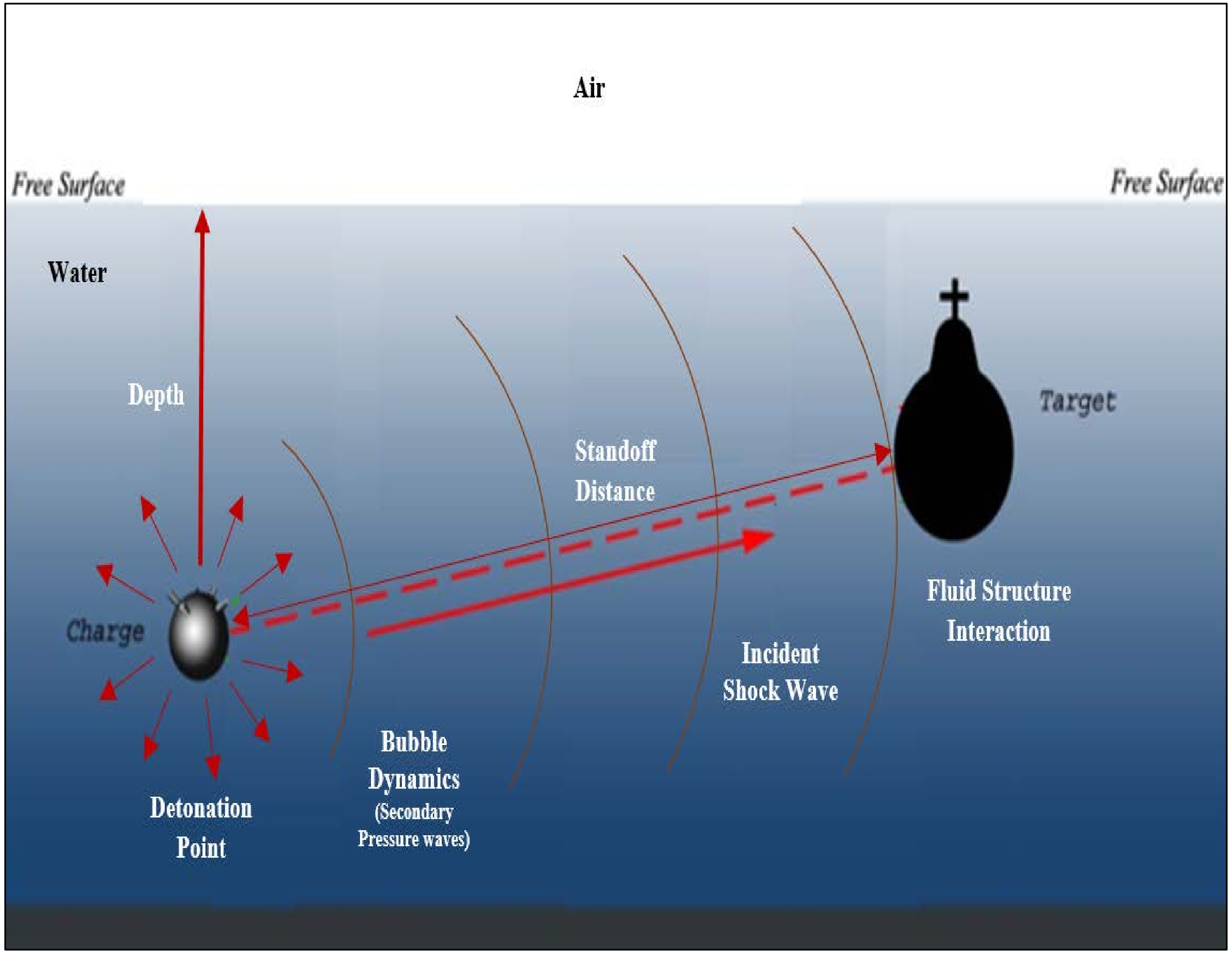
- **Detonation of Explosive** : Highly energetic thermo-chemical reaction Superheated, Highly compressed gas bubbles are formed

- **Shock-wave released :** A rapid event (in milliseconds)

- **Evolution of bubble pulsations** occurs over a slower time period

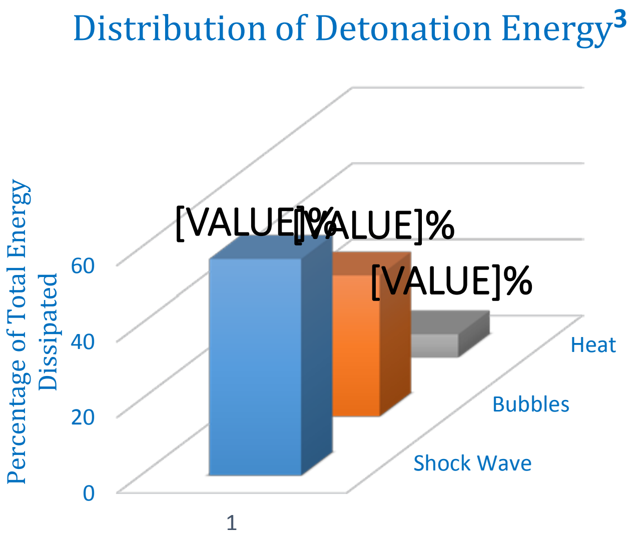
- **Fluid Structure Interaction(FSI):** Impact of the primary Shock wave

- **Dynamic response of the Structure:** Plastic deformation



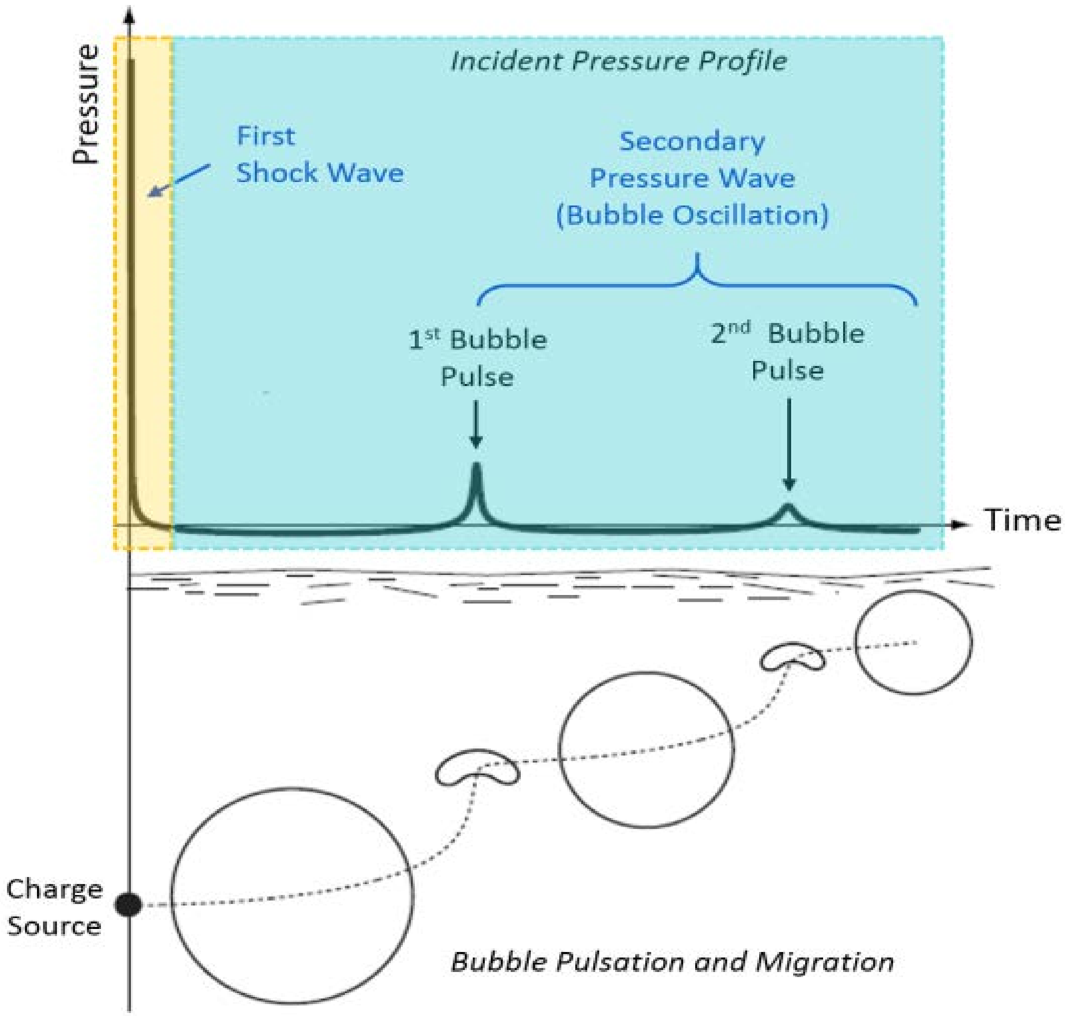
[1.] Cole, RH. (1965) Underwater Explosions, Dover Publication

Background



- **Shock Wave:**
- Dissipated 57% of total detonation Energy
- A rapid event compared to Bubbles
- Peak pressure exponentially decays up to oscillation phase and propagates much faster than the sound speed.
- Propagates as a spherical pressure wave

[3]Arons, AB., Yennie, DR. (1948). Energy partition in underwater explosion phenomena. Rev Mod Phys



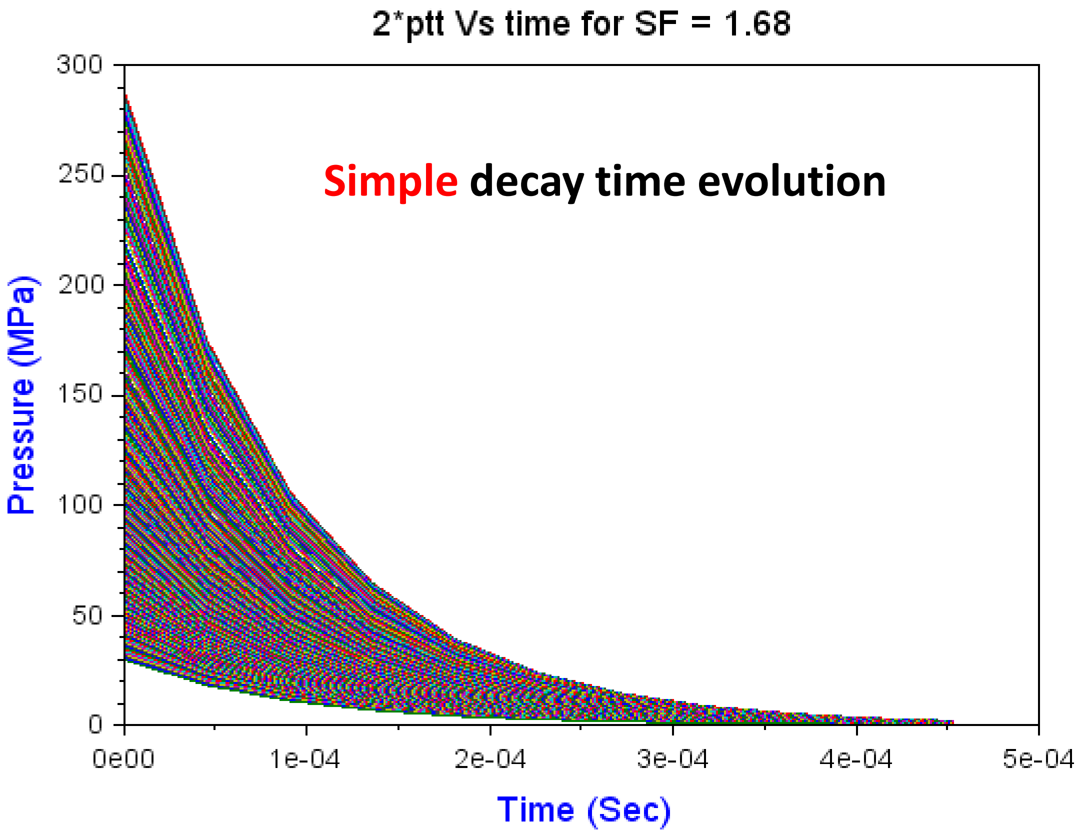
[2] Keil, A.H. (1961). The response of ships to underwater explosions, Proceedings of Annual Meeting of the Society of Naval Architects and Marine Engineers

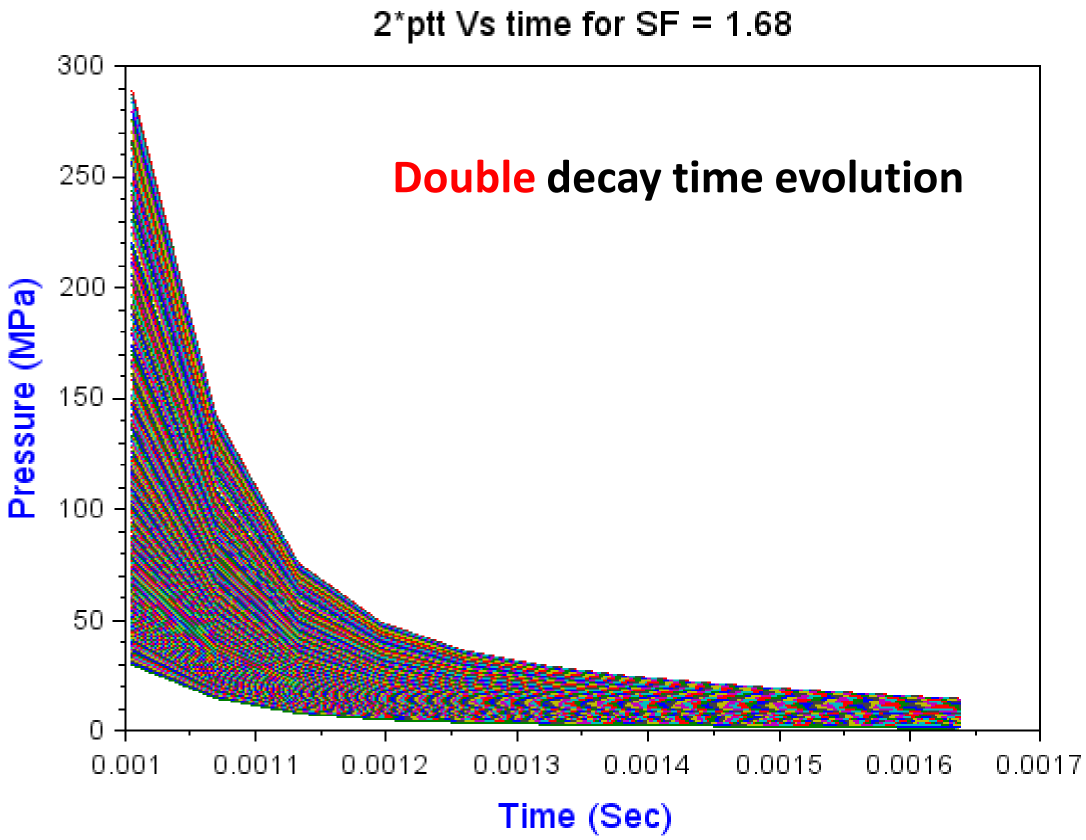
UNDEX Loading

- **Developed code in Scilab:**

I. For High & Low Shock Factor (SF)
II. Loading Hypothesis: Simple & Double Decay

The SF can be determine as: $SF = W^{1/2}/R$
R = Standoff distance 0.42 m, SF 2.5 is for charge weight W = 1.1kg and SF 1.68 is for W = 0.5kg





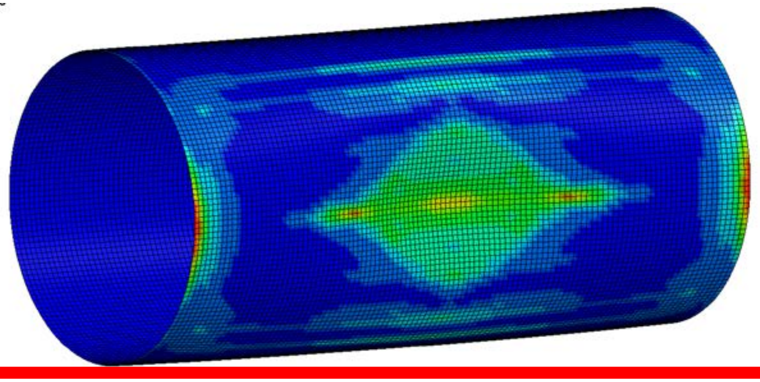
Response Analysis - Isotropic Material (Steel) Structure

- **Deformed Shape**

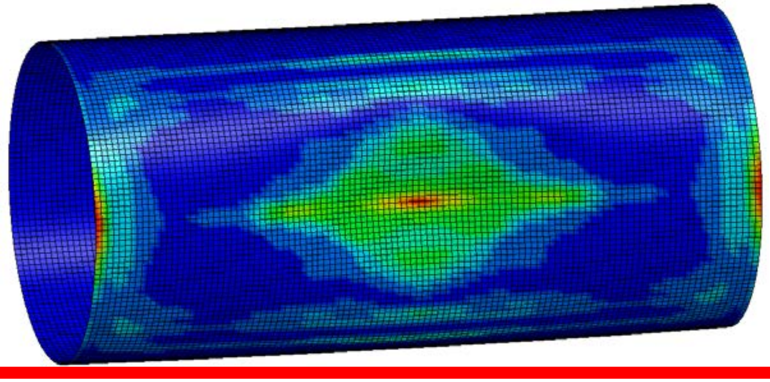
- Dished hull plating submitted to one sided noncontact UNDEX

High Shock Factor

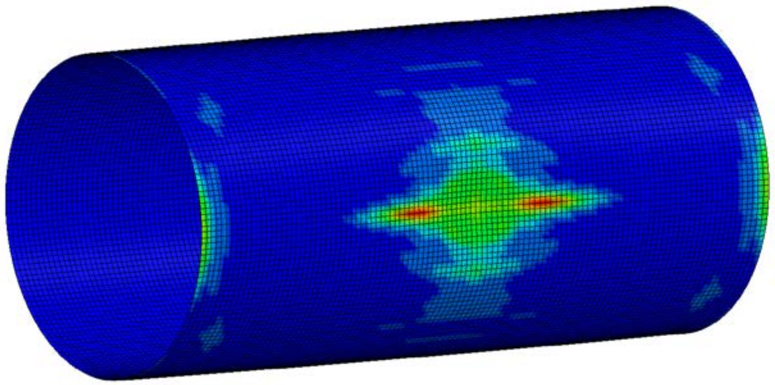
Fluid Modelled with ACOUSTIC Element

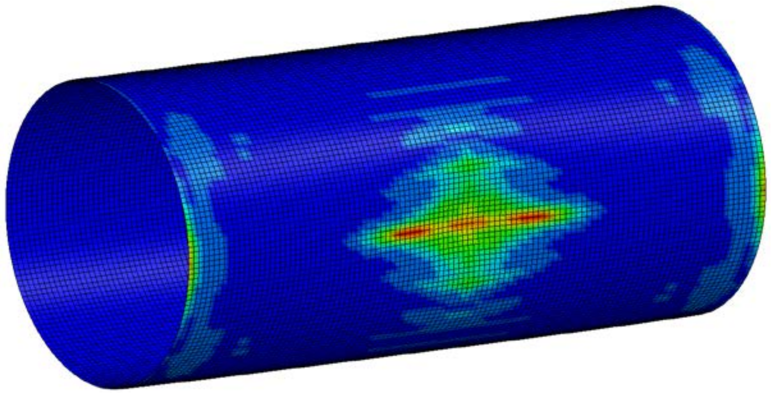


Fluid Modelled with ELASTIC_Fluid Element



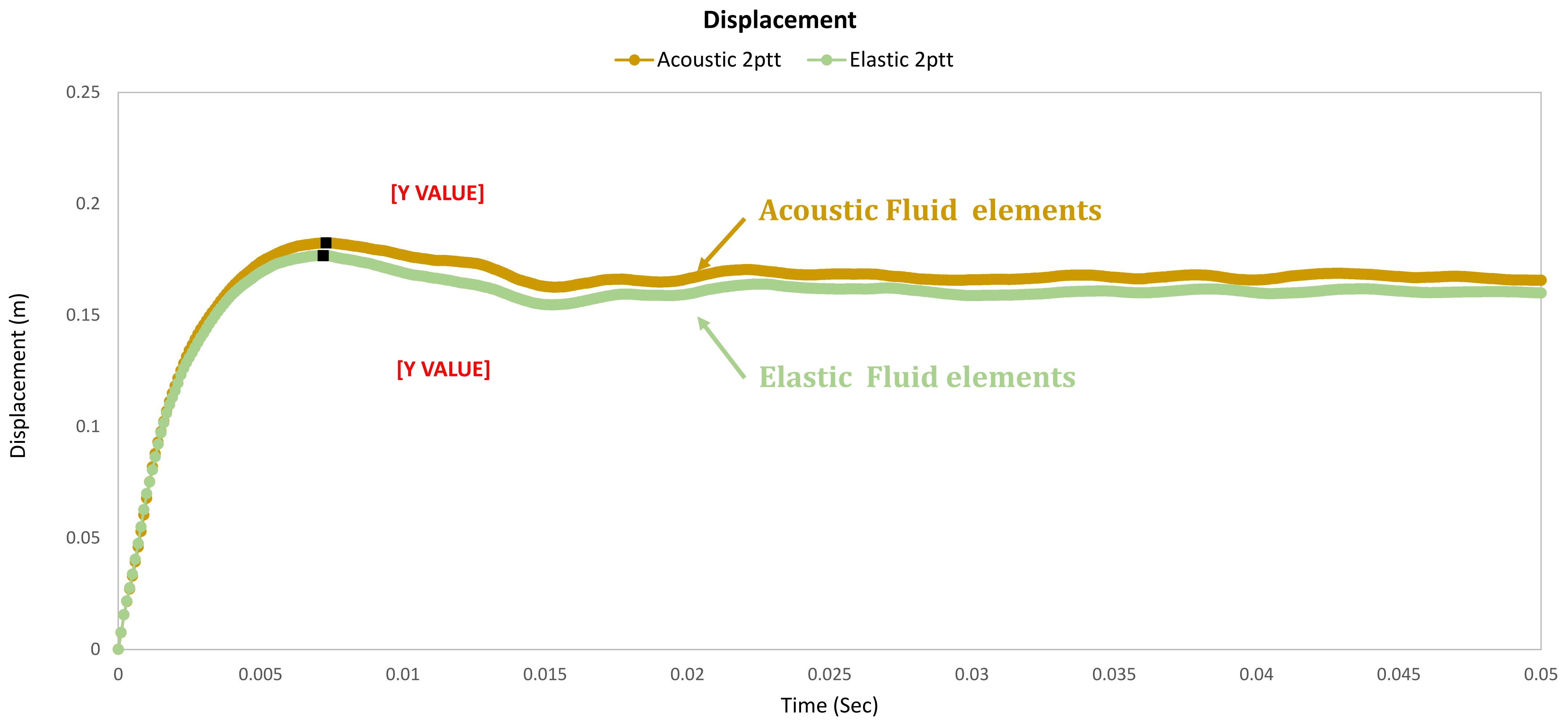
Low Shock Factor



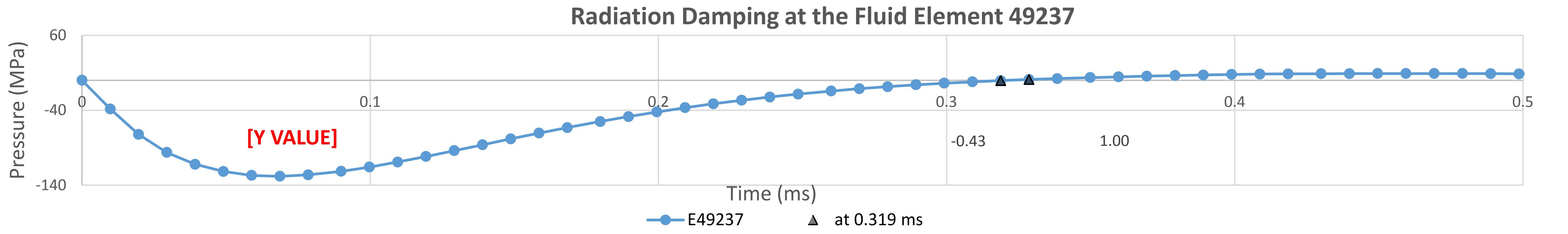


Response Analysis - Isotropic Material (Steel) Structure

- **Structural Displacement :** *High Shock Factor* – ACOUSTIC & ELASTIC Fluid Model

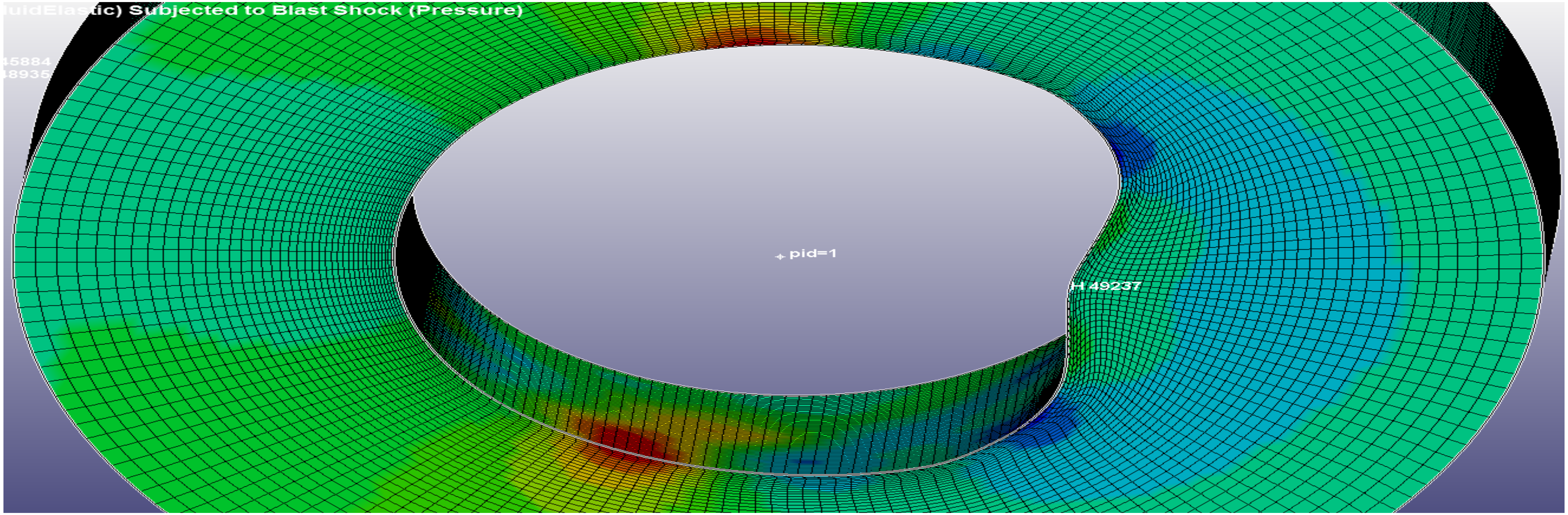


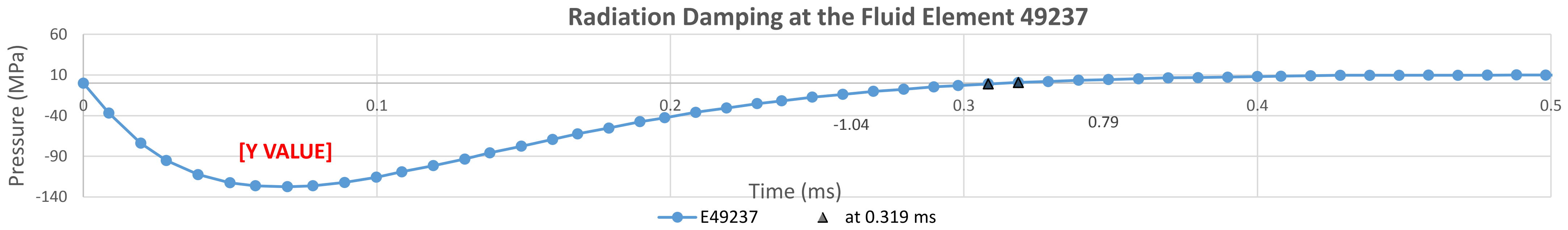
- **Pressure inside the Fluid Domain :** Acoustic Fluid Element



Response Analysis - Isotropic Material (Steel) Structure

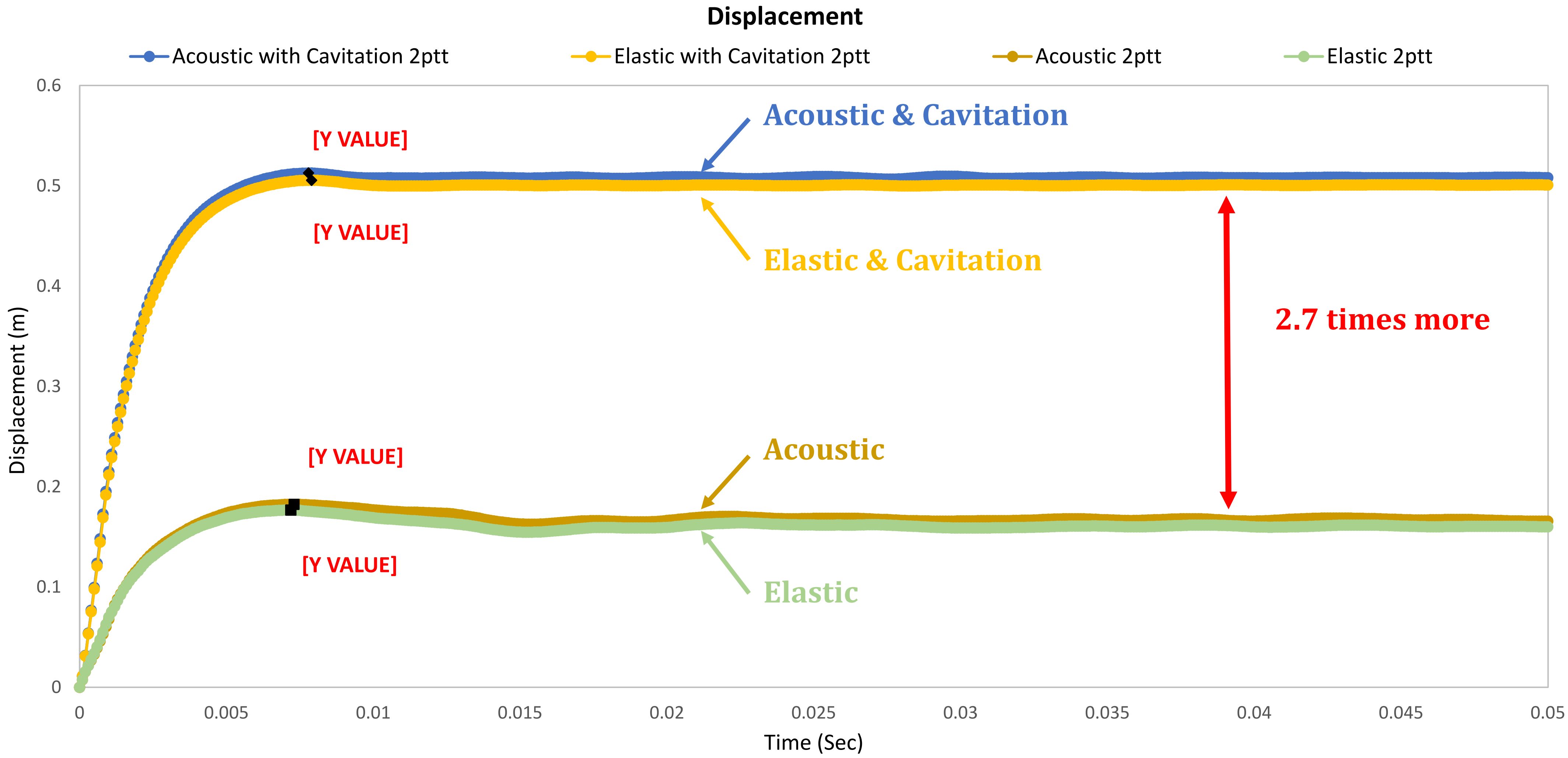
- **Pressure inside the Fluid Domain :** Elastic Fluid Element





Response Analysis - Isotropic Material (Steel) Structure

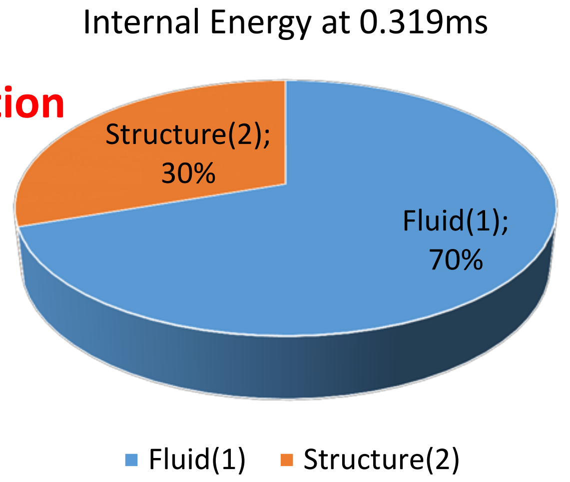
- **Structural Displacement :** *High Shock Factor* - Fluid Model with Cavitation

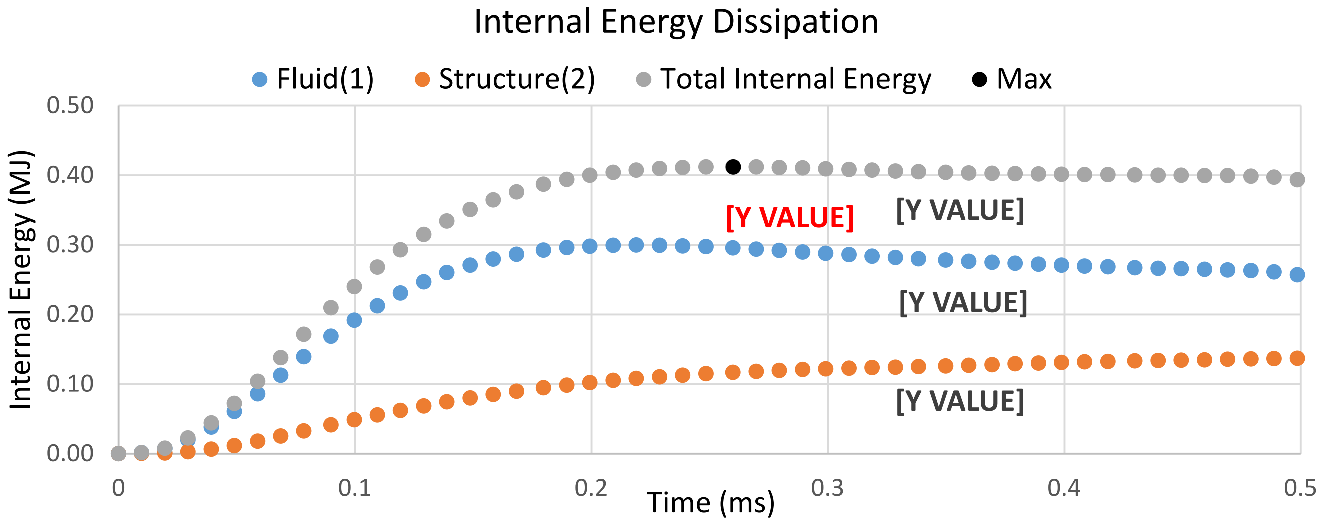


Response Analysis - Isotropic Material (Steel) Structure

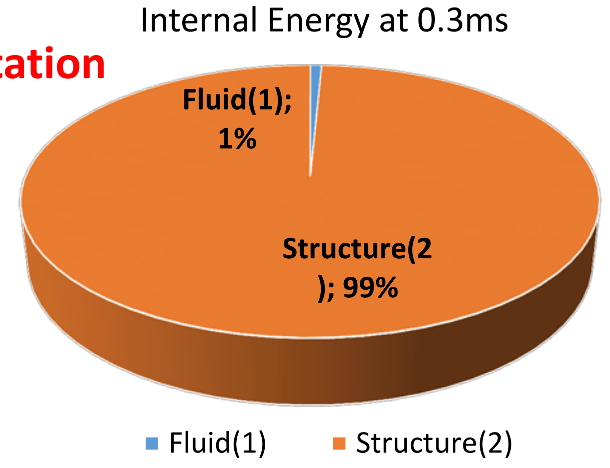
- **Structure Energy Absorption :** *High Shock Factor* – ACOUSTIC Fluid Model & Cavitation

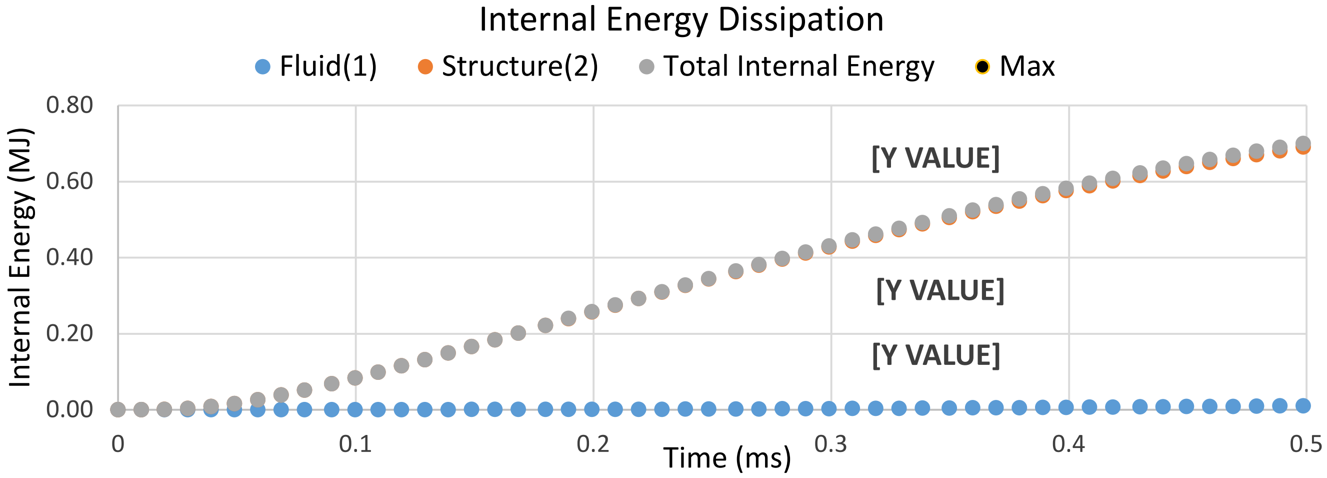
W.O. cavitation





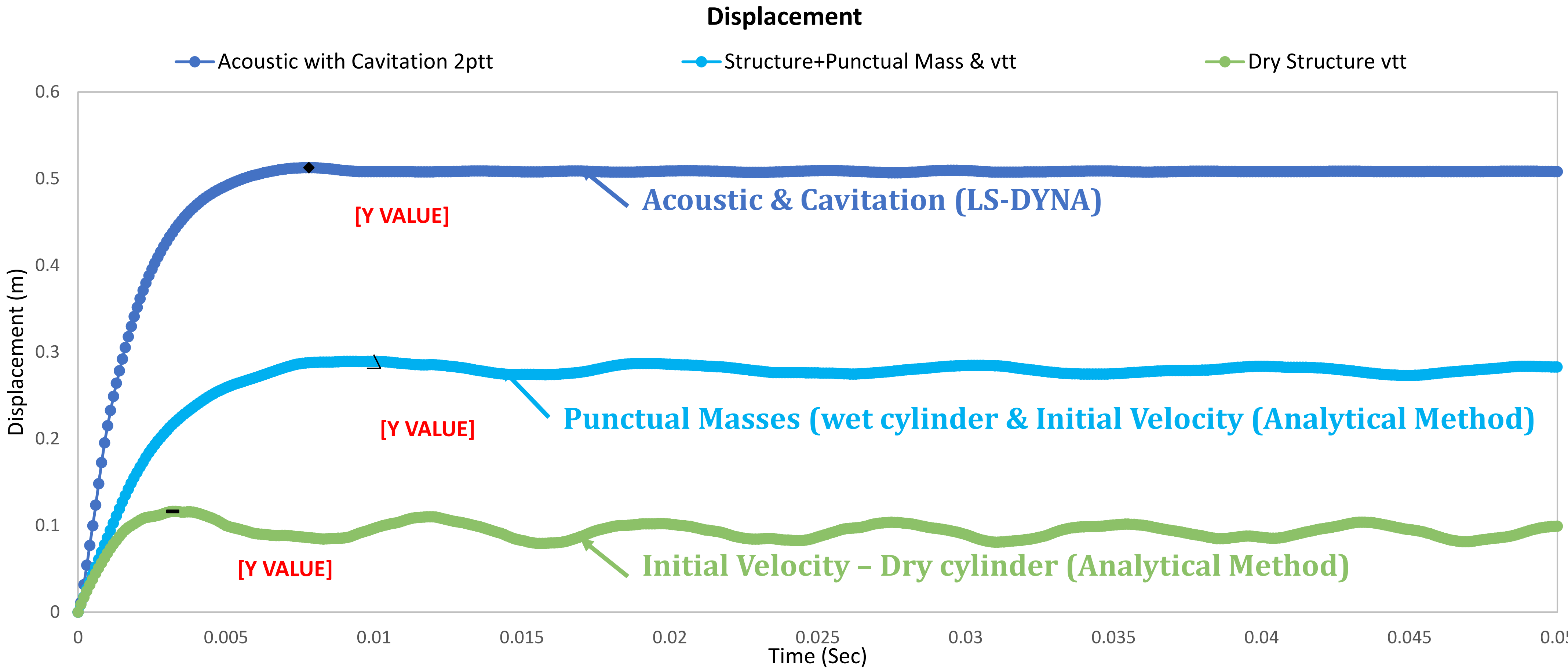
With cavitation





Response Analysis - Isotropic Material (Steel) Structure

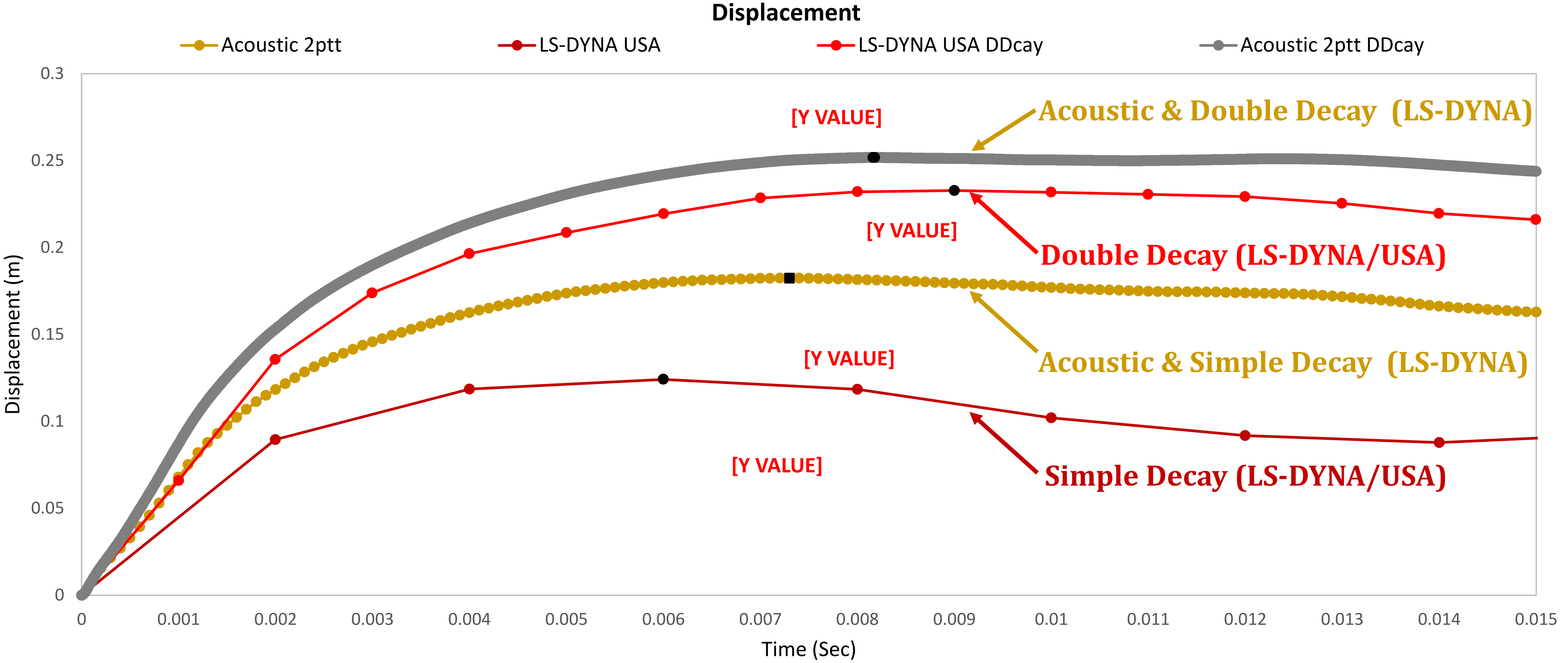
- **Structural Displacement :** *High Shock Factor* - ACOUSTIC Fluid Model **with Cavitation Treatment**
- Comparison with *Analytical Method* (Initial Velocity (Vtt) & Added Mass Effect)[4] and LS-DYNA



[4] Brochard, K., Sourne, H.L. and Barras, G. (2018). Extension of the string-on-foundation method to study the shock wave response of an immersed cylinder. Journal of Impact Energy

Response Analysis - Isotropic Material (Steel) Structure

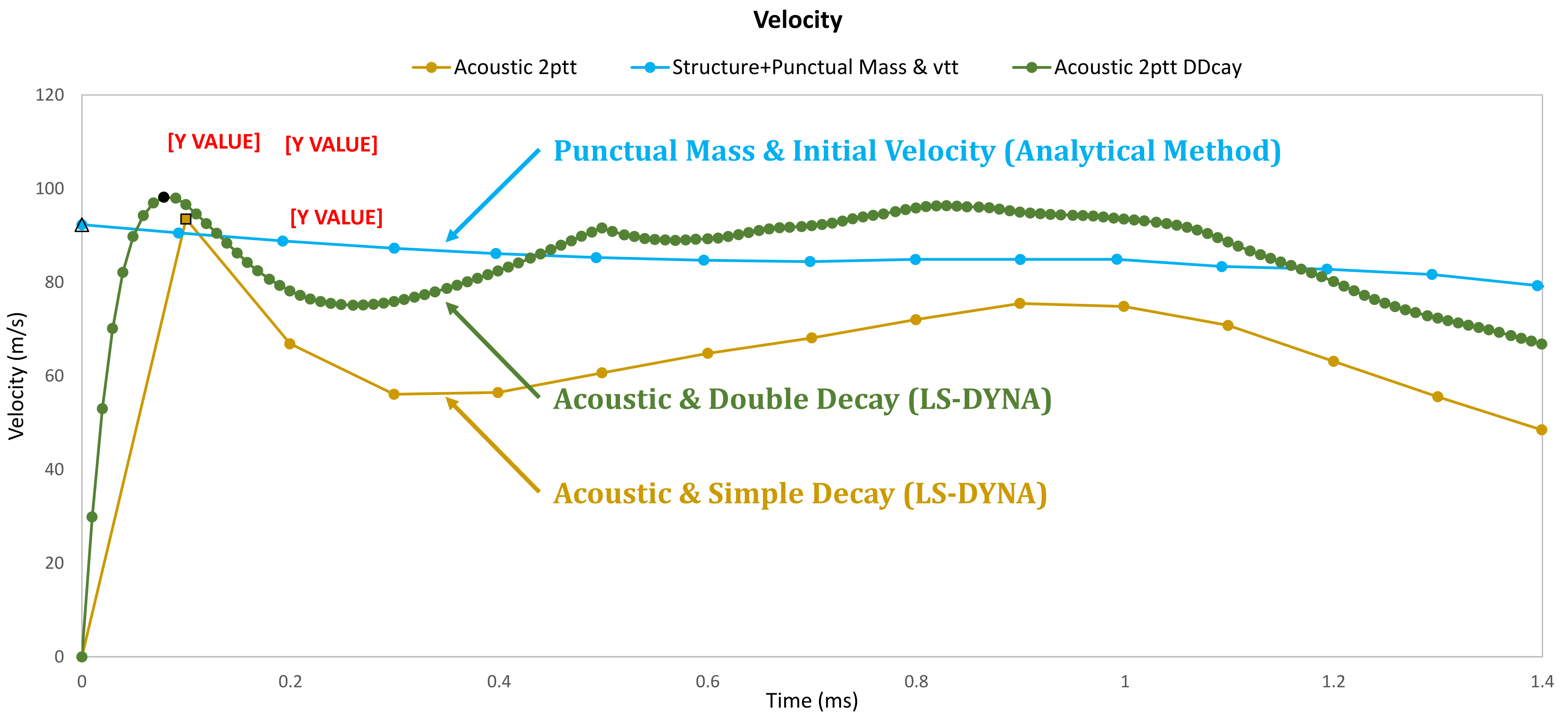
- **Structural Displacement :** *High Shock Factor*
- Loading Hypothesis Single & Double Decay and Comparison With LS-DYNA/USA[5] and LS-DYNA



[5] Results LS-DYNA/USA collected from DGA (Direction générale de l'armament), Toulon, FRANCE

Response Analysis - Isotropic Material (Steel) Structure

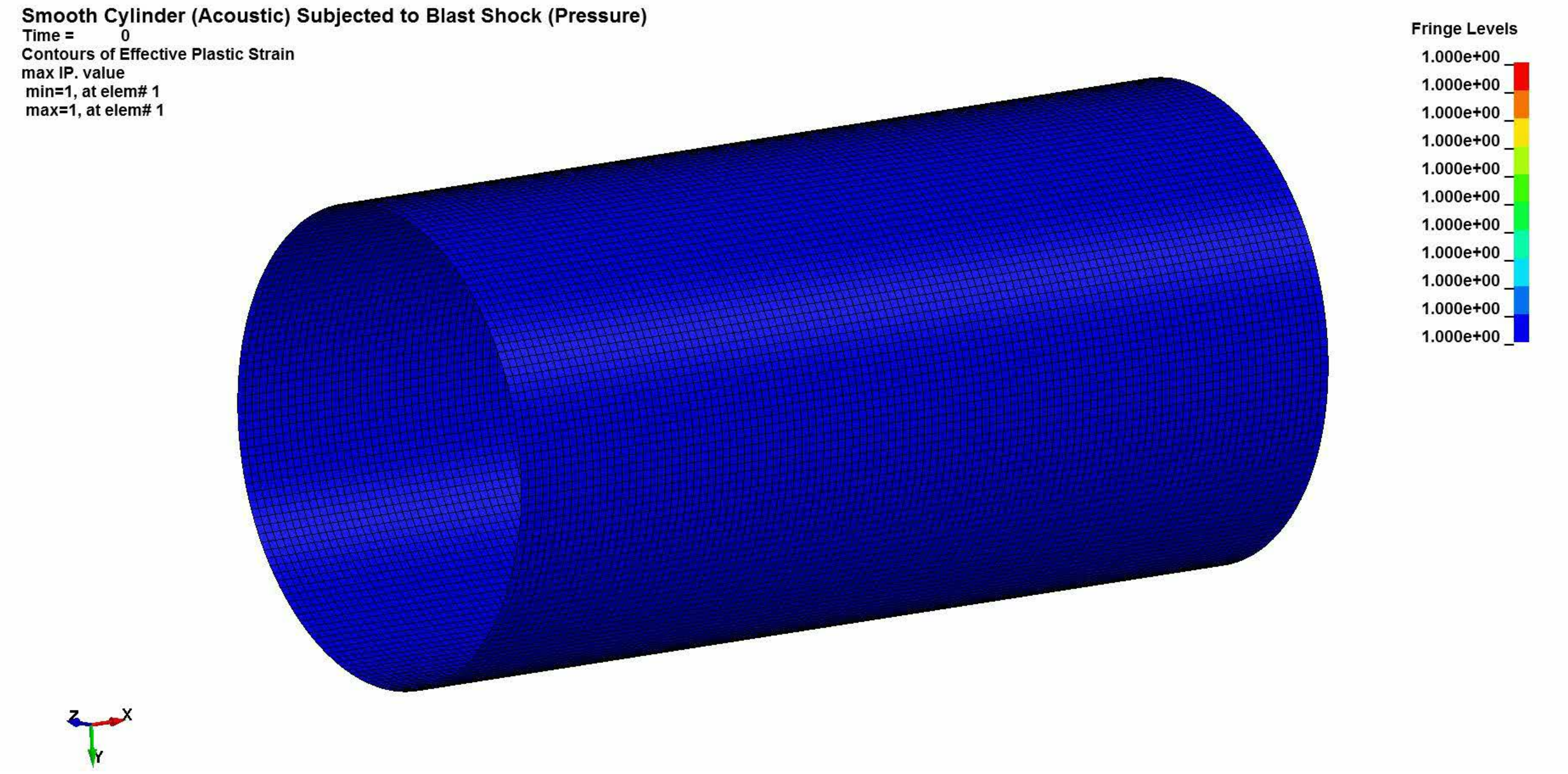
- **Structural Velocity :** *High Shock Factor* - ACOUSTIC Fluid Model
- Comparison with Analytical Method (Initial Velocity (Vtt) & Added Mass Effect)[4] and LS-DYNA



Conclusion & Discussion

1. The results are realistic whatever the fluid behaviour law.
2. Acoustic behaviour law can be used with confidence for modelling fluid domain.
3. During FSI, pressure reaches negative values, which is not realistic. So when cavitation is accounted for, cylinder hull deflection is more than twice => accounting for cavitation is recommended.
4. Submerged structure is damaged in the form of dished hull plating.
5. Findings **are** nowadays being used for validating and developing analytical formulations for **steel** immersed cylinders (Kevin Brochard's PhD work[4]).
6. Findings **will** be used for developing **future** analytical formulations for **composite** plates and cylinders (Ye Pyae Sone Oo's PhD work).

Future Work - Orthotropic Material (Carbon Fibre/Epoxy) Structure



Thank you for your Attention