Design of Soft Recovery Facility for Artillery Testing

User Manual for CFD Simulation for Design of SRS Sections

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Content

Objective

- A ballistic compression type SRS utilizes compressed air bounded by diaphragm to increase projectile drag & get desired deceleration.
- The use of compressed air provides an increased ramming pressure ahead of projectile, thus helping with higher deceleration.
- However, significantly higher pressure ahead of projectile can be achieved if shock is reflected few times between projectile & diaphragm.
- This phenomena can be simulated by solving time dependent governing equations for fluid domain. Since it involves moving body, adaptive mesh & diaphragm modelling, a special purpose CFD scheme is required

Input File Description

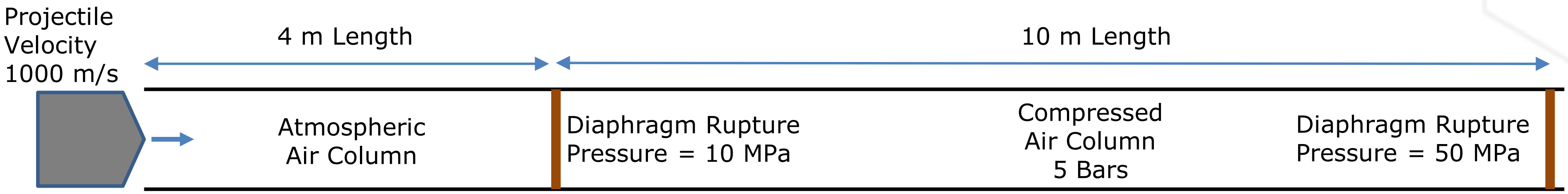
- Diameter of Barrel (Recovery Tube) = 155 (mm)
- Length of Section 1 of Barrel = 4000 (mm)
- Length of Section 2 of Barrel = 10000 (mm)
- Initial Shell Velocity (When Entering Recovery Barrel) = 1000 (m/s)
- Initial Pressure in Section 1 of Barrel = 1.000 (Bar)
- Initial Pressure in Section 2 of Barrel = 5.000 (Bar)
- Initial Temperature of Air inside Barrel Tube = 30 (^{o}C)
- Mass of Shell = 43 (Kg)
- Rupture Pressure of Diaphragm 1 = 10 (MPa)
- Rupture Pressure of Diaphragm 2 = 50 (MPa)
- Gamma (Ratio of Specific Heat) for Air = 1.4
- Molecular Mass of Air = 28 (g/mol)
- Number of Cell (Discretization) = 1000
- Time Instant for Output Generation = 3.0E-03 (sec)

Output File Description

- There are three output files:
- Output Location:
  - Presents time varying data on shell i.e. its location, velocity, deceleration and pressure on shell nose. Also, generated is pressure on the diaphragm
- Output Instant:
  - For the time instant specified by user, it presents density, velocity, pressure & temperature for the air trapped between shell & diaphragm
- Output First Rupture:
  - For the time instant when first diaphragm ruptures, the file presents density, velocity, pressure & temperature for the air trapped between shell & diaphragm

Problem Statement

- A partial SRS like setup is designed as sample problem statement for development & demonstration of CFD method
- It comprises of two sections: section 1 (4m) contains atmospheric air bounded by a diaphragm that breaks at 10 MPa; followed by, section 2 (10m) that contains compressed air at 5 Bar bounded by diaphragm that breaks at 50 MPa. Schematic is shown below:
- The projectile weighing 43 kg enter the atmospheric section at 1000 m/s.

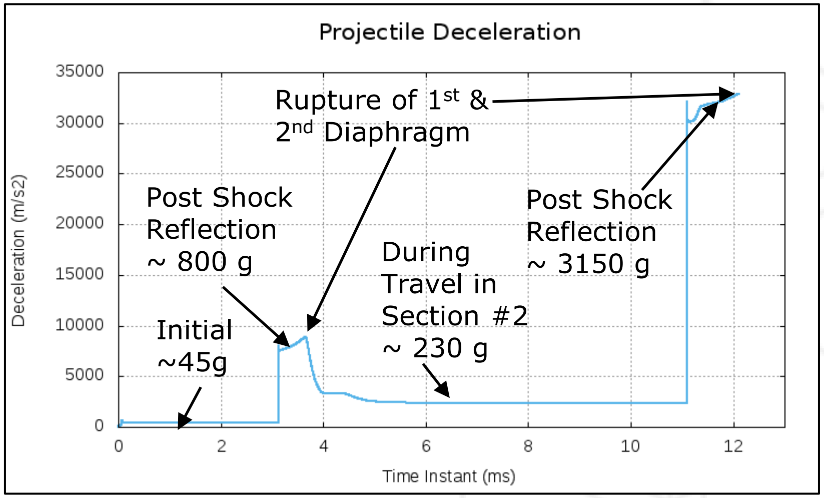


CFD Methodology

- A one dimensional CFD solver is implemented that solves for transient compressible flow equations in presence of moving boundary.
- The scheme adopted is AUSM-ALE that adapts the mesh size depending upon the change in fluid domain length. The scheme is marched in time with explicit integration with appropriate CFL number
- The solver is further customized to incorporate rupture of diaphragm and instantaneous extension of domain to account for next section of compressed air.
- The solver is implemented using ‘C’ on Linux platform. Simulation stops on rupture of second diaphragm.

Simulation Results

- Attached are time history plot of projectile motion (travel, velocity & deceleration) during its movement inside a representative SRS setup


Projectile Deceleration

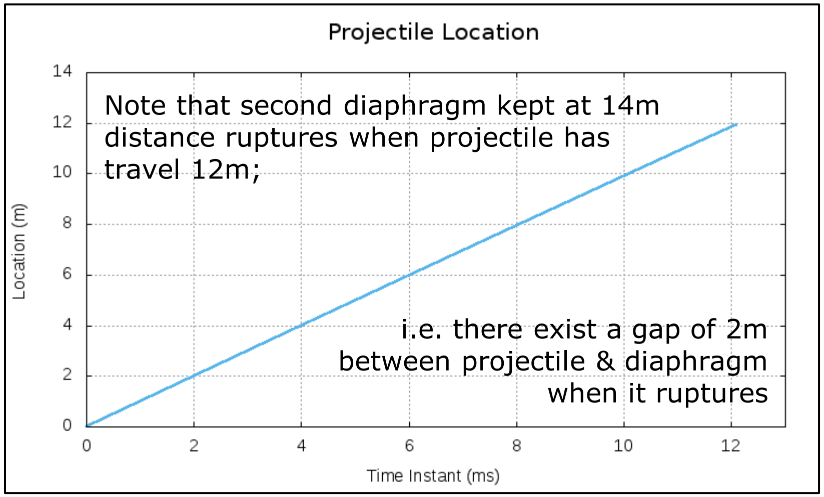
Rupture of 1st & 2nd Diaphragm

Post Shock Reflection ~ 800 g

Post Shock Reflection ~ 3150 g

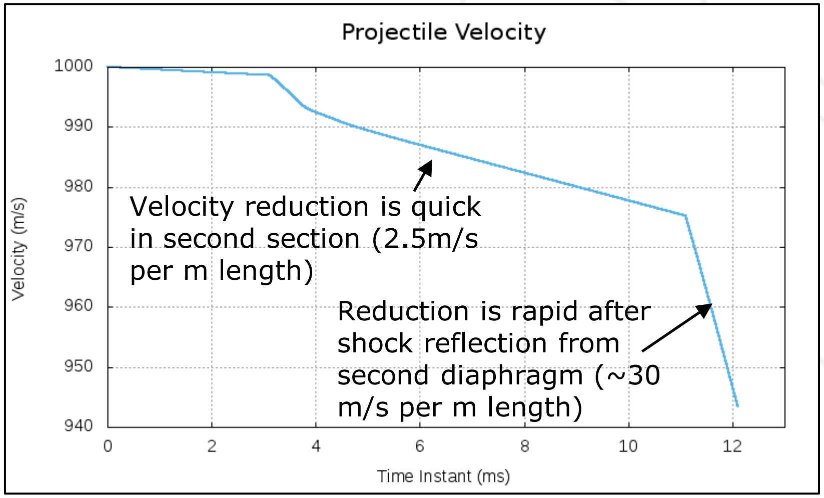
During Travel in Section #2 ~ 230 g

Initial ~45g


Projectile Location

Note that second diaphragm kept at 14m distance ruptures when projectile has travel 12m;

i.e. there exist a gap of 2m between projectile & diaphragm when it ruptures

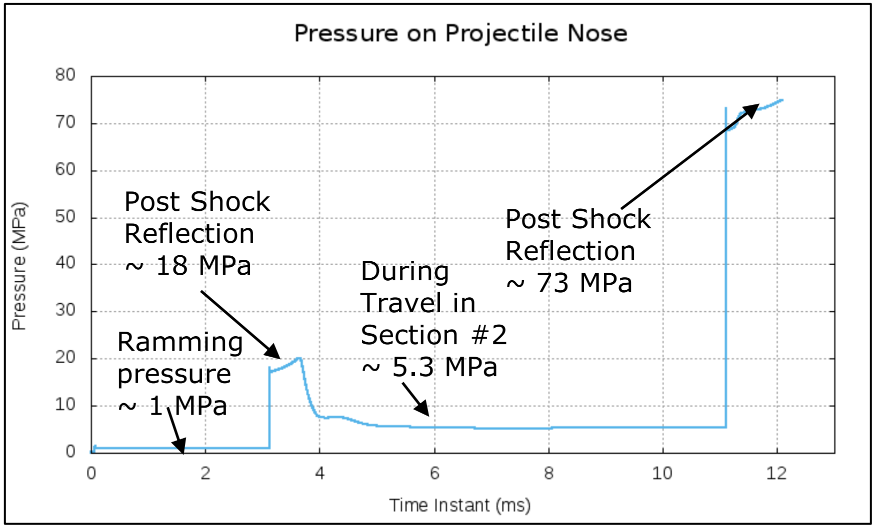

Projectile Velocity

Velocity reduction is quick in second section (2.5m/s per m length)

Reduction is rapid after shock reflection from second diaphragm (~30 m/s per m length)

Simulation Results (Contd..)

- The plots below show development of pressure with time at two locations (i) on projectile nose & (ii) on diaphragm
- Pressure of projectile nose determines the deceleration of projectile where pressure on diaphragm determines time of its rupture.

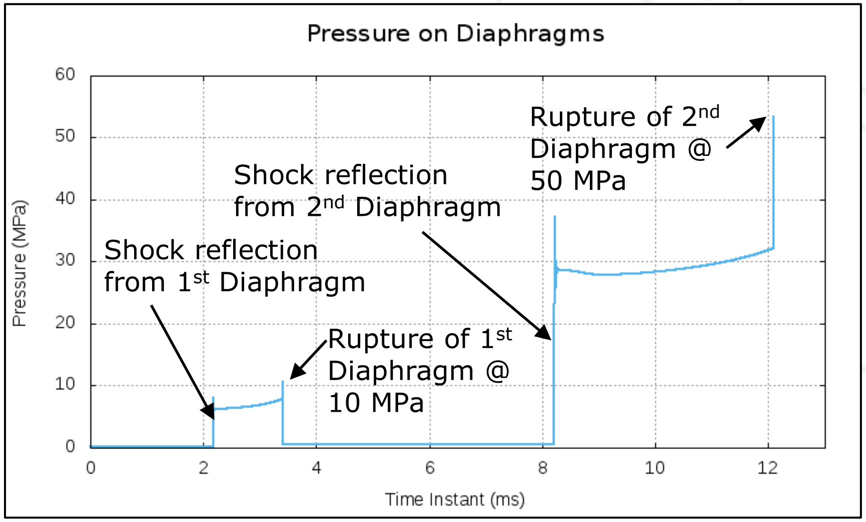

Pressure on Projectile Nose

Post Shock Reflection ~ 18 MPa

Ramming pressure ~ 1 MPa

During Travel in Section #2 ~ 5.3 MPa

Post Shock Reflection ~ 73 MPa


Pressure on Diaphragms

Rupture of 2nd Diaphragm @ 50 MPa

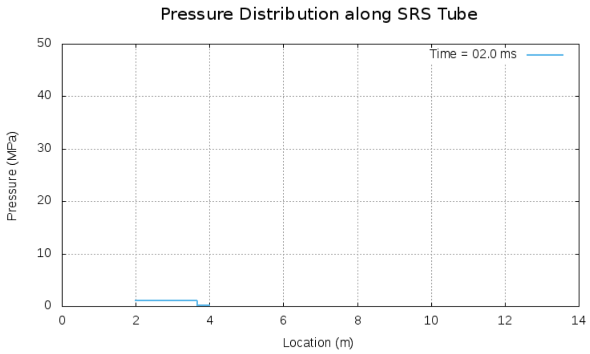
Shock reflection from 2nd Diaphragm

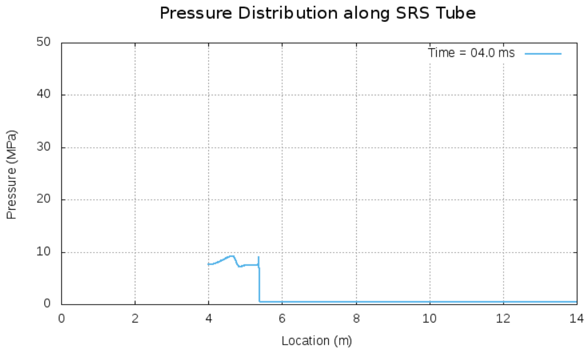
Shock reflection from 1st Diaphragm

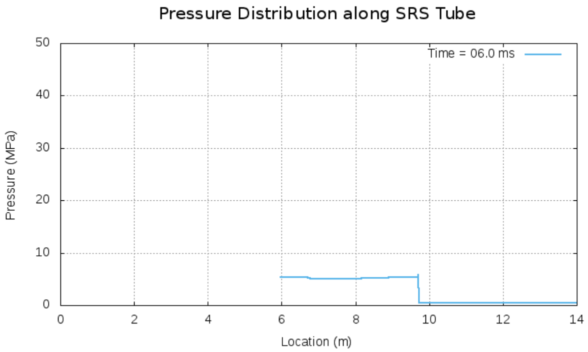
Rupture of 1st Diaphragm @ 10 MPa

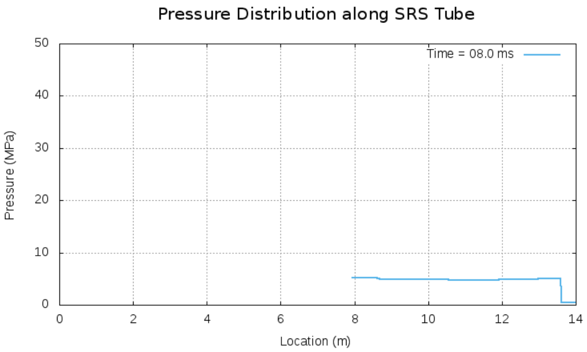
Simulation Results (Contd..)

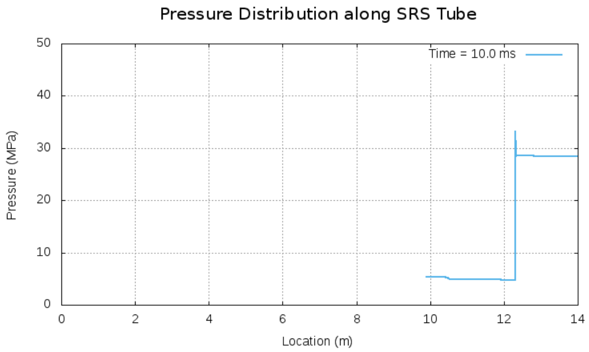
- The animation shows pressure in the SRS tube. The moving left end of curve signifies moving projectile nose. Observe increase in pressure post shock reflection;

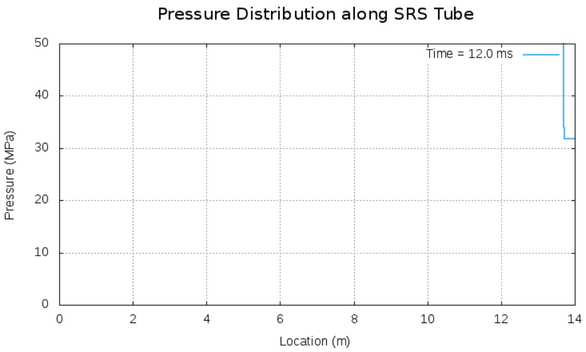

Pressure Distribution along SRS Tube


Pressure Distribution along SRS Tube


Pressure Distribution along SRS Tube

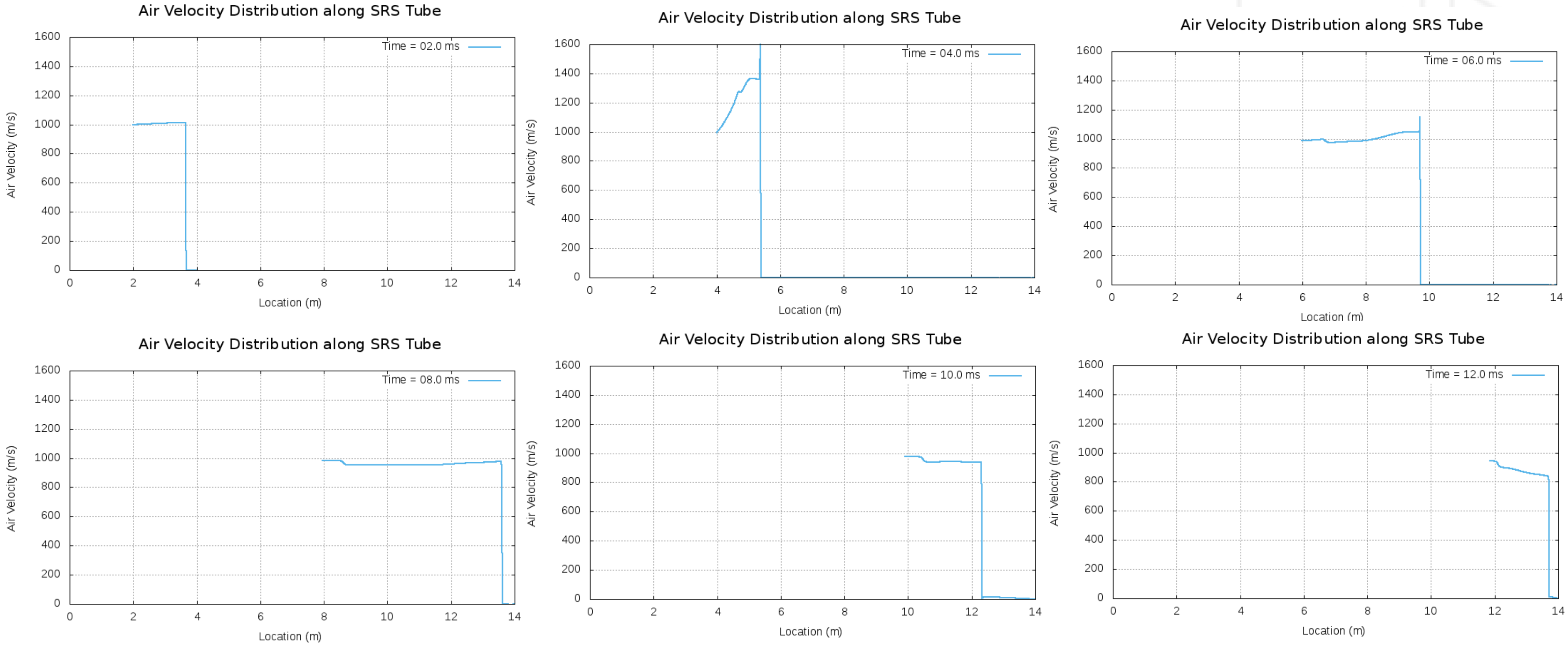

Pressure Distribution along SRS Tube


Pressure Distribution along SRS Tube


Pressure Distribution along SRS Tube

Simulation Results (Contd..)

- Due to compressible nature of fluid, only a limited column of air ahead of projectile attains velocity; Rest of tube remains at static condition;



Conclusion

- The shock dynamics due to movement of supersonic projectile inside an enclosed air column is demonstrated using a custom CFD solver.
- We find that reflected shock generate significantly higher pressure which when interacts with projectile causes sudden drop in its velocity.
- The demonstrated CFD technique can be employed for design optimization of full scale SRS system. Objective would be to arrive at section length, pressure of compressed air & rupture pressure of diaphragm.

Thank You!

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