Simulating Safe Landing : A Deep Dive into Parachute Inflation and Float with LS-DYNA

Suraj Dhomase[1], Chandra Sekhar Kattmuri[1], Rodrigo Paz[2], Karthik Chittepu[1]

[1]CADFEM India Private Limited
[2]Ansys, Inc

1. Abstract

Parachutes for aerospace application is a new research area in the current era of space science. The scope of our project includes parachute design and inflation techniques. The current research project focuses on the following application areas:

- Parachutes for Re-entry Capsule
- RLV Parachutes

Parachutes are used as aerodynamic decelerators in airdrop systems, so inflation is a significant fluid-structure interaction (FSI) phenomenon. New patterns of parachutes are constantly being developed and tested for airdrop systems but this research into parachute inflation is heavily reliant on historical experimental data. Till now, no parachute inflation model that is not based on this experimental data was developed. Material and instrumentation have changed significantly since the early experimental testing, yet the methods to develop the parachutes can still be traced to the same techniques used over ninety years ago. Rapid development of computational technology and modern computational mechanics combined with numerical simulation techniques have become more widespread in parachute research field and would enable us to develop the parachutes that are more optimized.

Simulating the landing of a vehicle on water using LS-DYNA is a complex task that involves the interaction between the fluid (water) and the structure of the vehicle. This type of simulation is crucial for vehicles designed to land on water. The process typically involves several steps and requires specialized techniques within LS-DYNA.

2. Introduction

Parachutes are used as aerodynamic decelerators in airdrop and planetary reentry missions. So, inflation is a significant fluid-structure interaction phenomenon. The parachutes should have low mass and high flexibility. The interaction forces between the parachute canopy and surrounding fluid have a significant effect on structural deformation. FSI technique should be developed for predicting parachute inflation performance. As new designs of parachutes have been developed and tested for various missions by the placement of gaps and slots in the surface of the canopy structure. This design implementation enhances parachute performance under high aerodynamic load. The traditional way of doing parachute deployment simulation is to first simulate structural deformation by solid mechanics solver and then taking this deformed structure into CFD solver for aerodynamic study. This way of doing parachute deployment simulation leads to inaccurate results. Hence design and development of parachute deployment simulation is important aspect of this thesis. This work will help aerospace and defense organizations to simulate parachute for airdrop and planetary reentry missions.

Figure 1 Fighter plane Decelerates Parachutes and Payload recovery Parachutes

3. Design of Drogue Parachutes

The drogue parachute must have reliable operation in the velocity range from 102 m/s at sea level to Mach 1.5 at 15240 m. Stability must be better than +-3 degrees.Minimum weight and volume are mandatory.The drogue chute must be able to decelerate the object to the permissible opening speed of the main parachute assemblies. The drogue chute must be suitable for the operational environment.

Table1 Dimensions of Parachute

Sr.No	Dimension	Symbol	Magnitude	Unit
01	Nominal diameter of parachute	D_0	2.9038	m
02	Disk Diameter of parachute	D_d	2.0616	m
03	Gap width	G	0.1161	m
04	Band width	B	0.3513	m
05	Suspension line length	L_s	4.3557	m
06	Number of gores	N_g	20	-
07	Length of Riser	L_R	0.4272	m
08	Vent diameter	D_v	0.2061	m

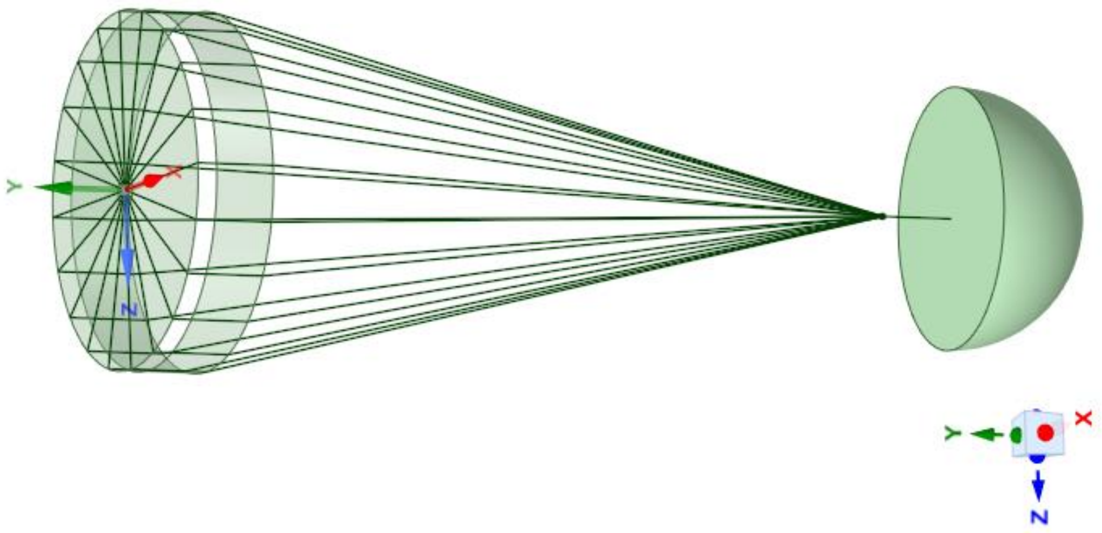


Figure 2 CAD of Parachute

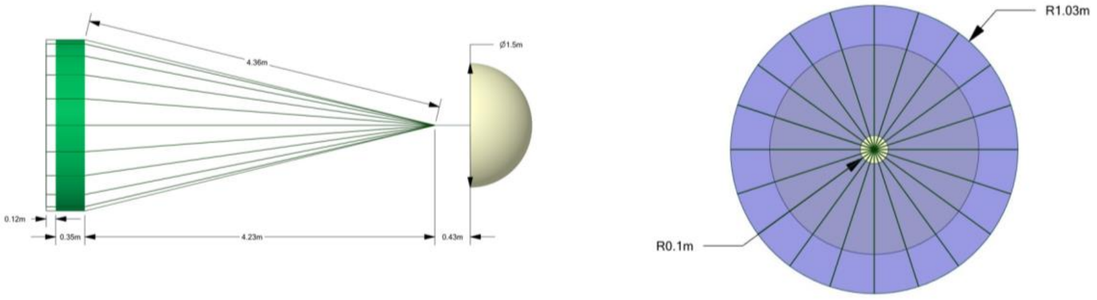


Abbildung 3 Dimensions of Parachute

4. Structural Analysis of Parachute

Structural structural analysis of parachutes is very important aspect of design and evaluation of structural components parachutes. The components of the parachute will be analysed for structural loads majorly comes from aerodynamic loads. The components of the parachutes are cables and fabric. Cables and fabrics are the main component which will be responsible for sustaining the aerodynamic load and stability of parachute. The structural analysis of parachute is nothing but deployment study of the parachute in Lagrangian dynamics.

All fabric parts are modeled by shell elements. Shell type 16 in LS-DYNA is a fully integrated shell with assumed strain Interpolants used to alleviate locking and enhance in plane bending behaviour. In LS-DYNA all shell elements include membrane, bending and shear deformation. The default Belytschko-Tsay formulation is the most economical and should be used unless features particular to other formulations are required.

The formulation 9 by calculating only member does not represent well the shell deformation when the fabric is subjected to the off-plane shear. The formulation 16 is fully integrated considering all stresses but requires the longer calculation time. The formulation 10 is good compromise between time calculation and representation of the fabric deformation.

The suspension lines and the reinforcement cables are modeled with the type 6 discrete beam. Discrete beam modelling is one of the first models of wire rope implemented in LS-DYNA consist of type 6 discrete beam defined with *MAT_CABLE_DISCRETE_BEAM material. The modulus of elasticity to be assigned to beam and the cable was treated as perfectly elastic member. It was observed that the discrete beam model underwear large amplitude dynamic oscillations and could not sustain a compressive load. Use of this model is limited due to reasons stated.

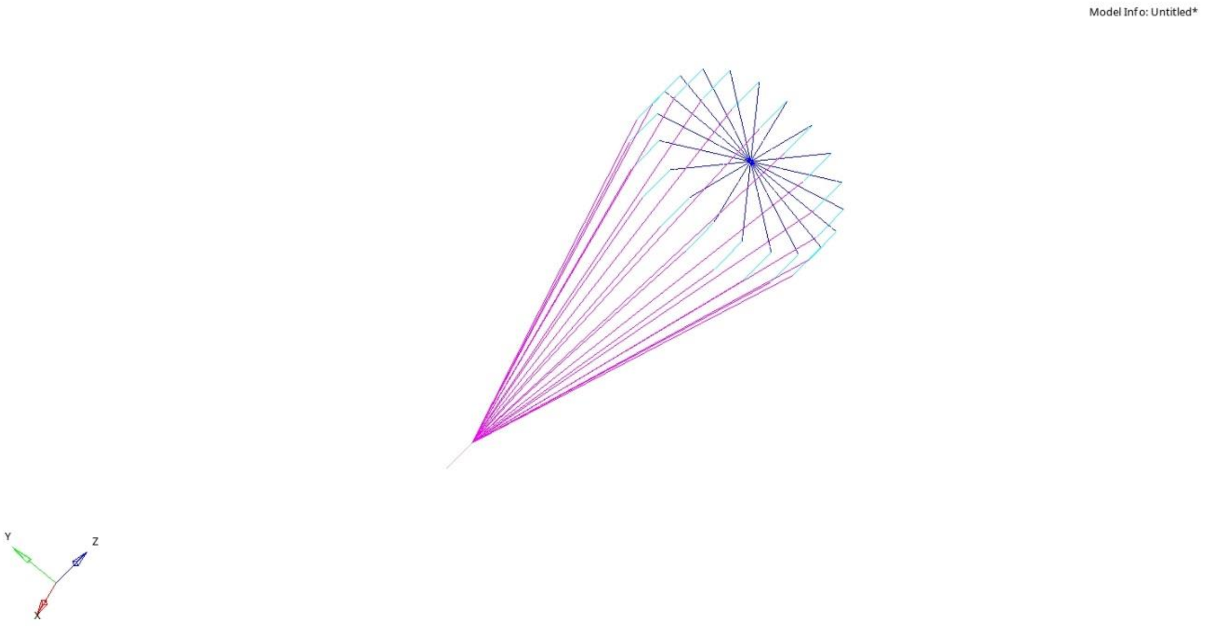


Figure 4 Suspension Cables (Beams)

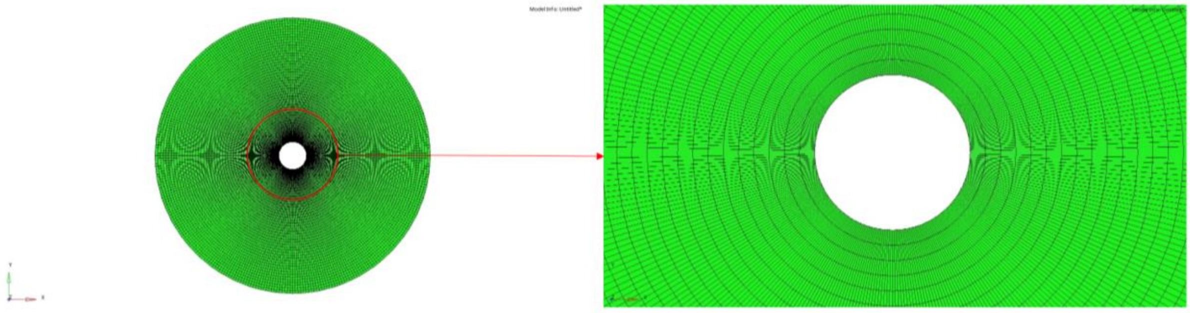


Figure 5 Fabric (shells)

5. Material Modelling

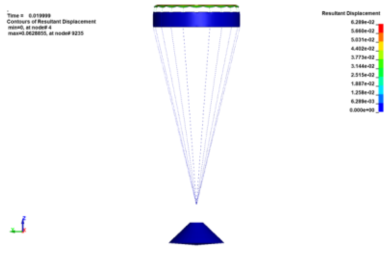
The fabric model is a variation on the Layered Orthotropic Composite material model (Material 22) and is valid for only 3 and 4 node membrane elements. This material model is strongly recommended for modeling airbags and seatbelts. In addition to being a constitutive model, this model also invokes a special membrane element formulation that is better suited to the large deformations experienced by fabrics. For thin fabrics, buckling (wrinkling) can occur with the associated inability of the structure to support compressive stresses. A linear elastic liner is also included which can be used to reduce the tendency for these material/elements to be crushed when the no-compression option is invoked.

If the airbag material is to be approximated as an isotropic elastic material, then only one young's modulus and Poisson's ratio should be defined. The elastic approximation is very efficient because the local transformations to the material coordinate system may be skipped. If orthotropic constants are defined, it is very important to consider the orientation of the local material system and use great care in setting up the finite element mesh. The parameters fabric leakage coefficient, FLC, fabric area coefficient, FAC, and effective leakage area, ELA, for the fabric in contact with the structure are optional for the Wang-Nefske and hybrid inflation models. It is possible for the airbag to be constructed of multiple fabrics having different values of porosity and permeability. The parameters, FLC and FAC, must be determined experimentally and their variation with time and pressure are optional inputs that allow for maximum modeling flexibility

The material modelling of suspension lines and reinforcement elements are modelled with type 71 i.e., *MAT_DESCRETE_CABLE in LS-DYNA. One of the first models of wire rope implemented in LS-DYNA consisted of type 6 discrete beam defined with *MAT_CABLE_DISCRETE_BEAM material. It was observed that the discrete cable model underwent large amplitude dynamic oscillation and could not be sustained a compressive load thus use of this model was limited. As discussed, there are various modelling techniques to model the cables in LS-DYNA. Parachute cables or suspension lines with reinforcement cables are majorly designed to sustain tensile load. So, we modelled suspension lines with *MAT_CABLE_DISCRETE_BEAM material model of LS-DYNA.

6. Results of structural Analysis

In dynamic analysis, there is effect of mass (inertia) or of damping. In dynamic analysis, nodal forces associated with mass/inertia and damping are included. Dynamic analysis can be done via the explicit time integration or the implicit time integration. In explicit analysis, no iteration is required as the nodal accelerations are solved directly. The time step in explicit analysis must be less than the Courant time step (time it takes a sound wave to travel across an element). Explicit does require this step. Explicit analysis handles nonlinearities with relative ease as compared to implicit analysis. This would include treatment of contact and material nonlinearities. In explicit dynamic analysis,



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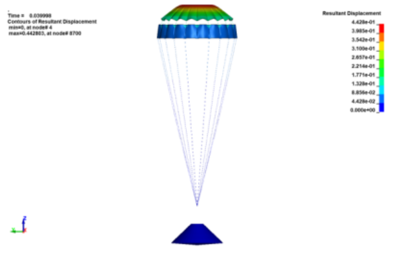

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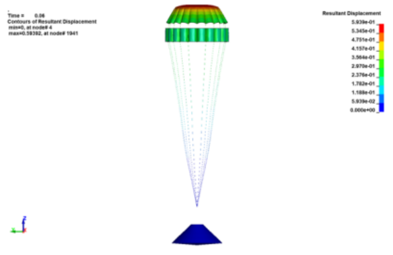

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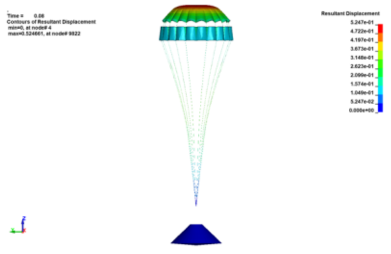

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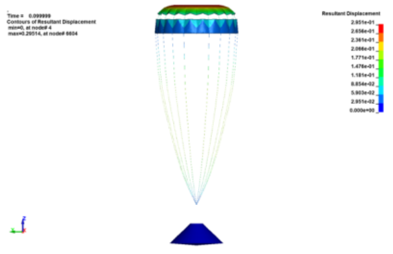

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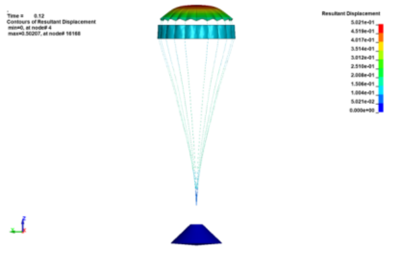

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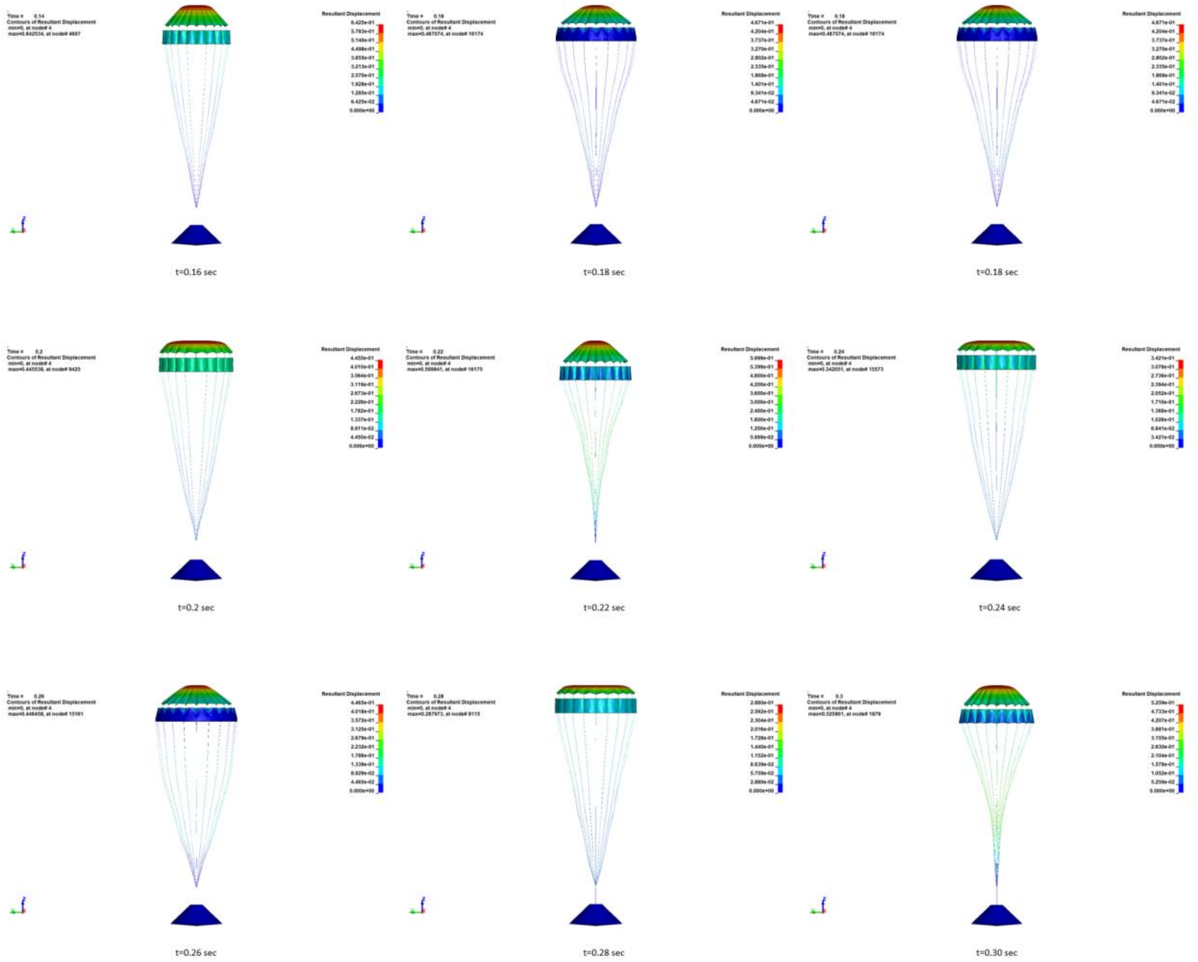


Figure 6 Inflation Process (Displacement Plot)

Table 2 Structural Results for Parachute

Component	Result	Value	Unit
Parachute	Maximum Displacement	0.68	m
Disc	Strain in a-direction	0.01349	-
	Strain in b-direction	0.01892	-
Band	Strain in a-direction	8.67e-3	-
	Strain in b-direction	0.0266	-
Suspension Lines	Axial Force	596.7	N
Riser	Axial Force	9190.8	N

7. Fluid Domain Modelling and Analysis

CFD can be through often FSI but with only one-way communication. Some insights into parachute aerodynamics can be gained from CFD analysis of flow around a rigid body that approximates the instantaneous geometry of a parachute in flight. However inherent instabilities associated with the bluff body of aerodynamics and uncertainty associated with inflated suggest that this technique has limited applicability when characterizing the performance of the parachute. The presence of recirculation and accompanied rivers flow in the wake of the proof body indicate the potential of such flow conditions to create symmetric instabilities. Prior experience suggested that CFD models can provide valuable insight into instantaneous parachute performance characteristics, especially for a parachute that cannot be fully analysed using FSI techniques due to high computational overhead. This technique has also proven beneficial when considering the wake of body particular concern for interplanetary missions.

The Eulerian fluid is modelled in a spatially fixed cartesian coordinate system. This kind of Eulerian fluid domain often refers to the wind tunnel class model. The air is forced into and around the parachute at known velocity and density. The dimension of fluid domain must be as large as possible considering the computational limitation and pressure reaching to free slip boundary condition.

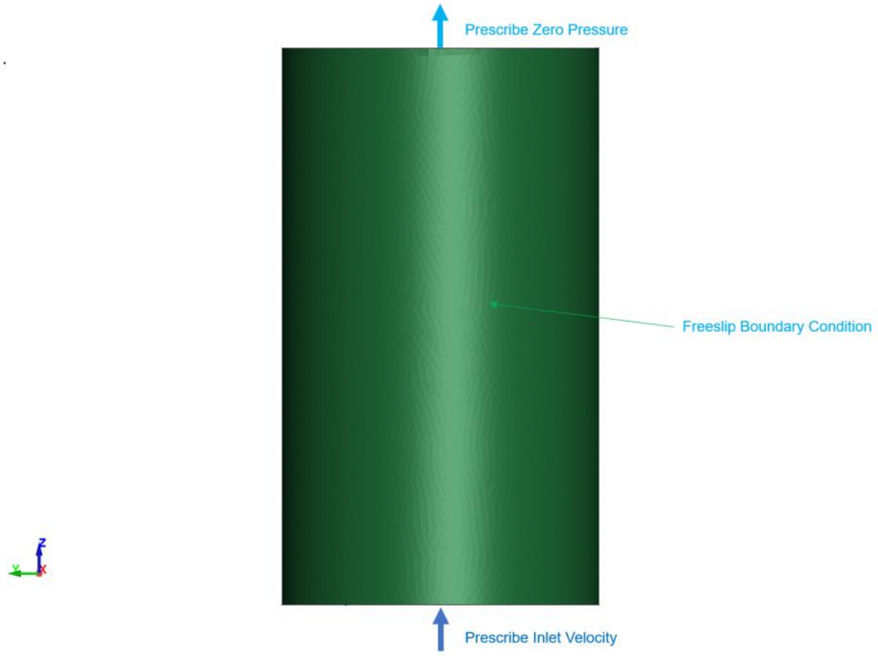


Figure 7 Boundary Conditions

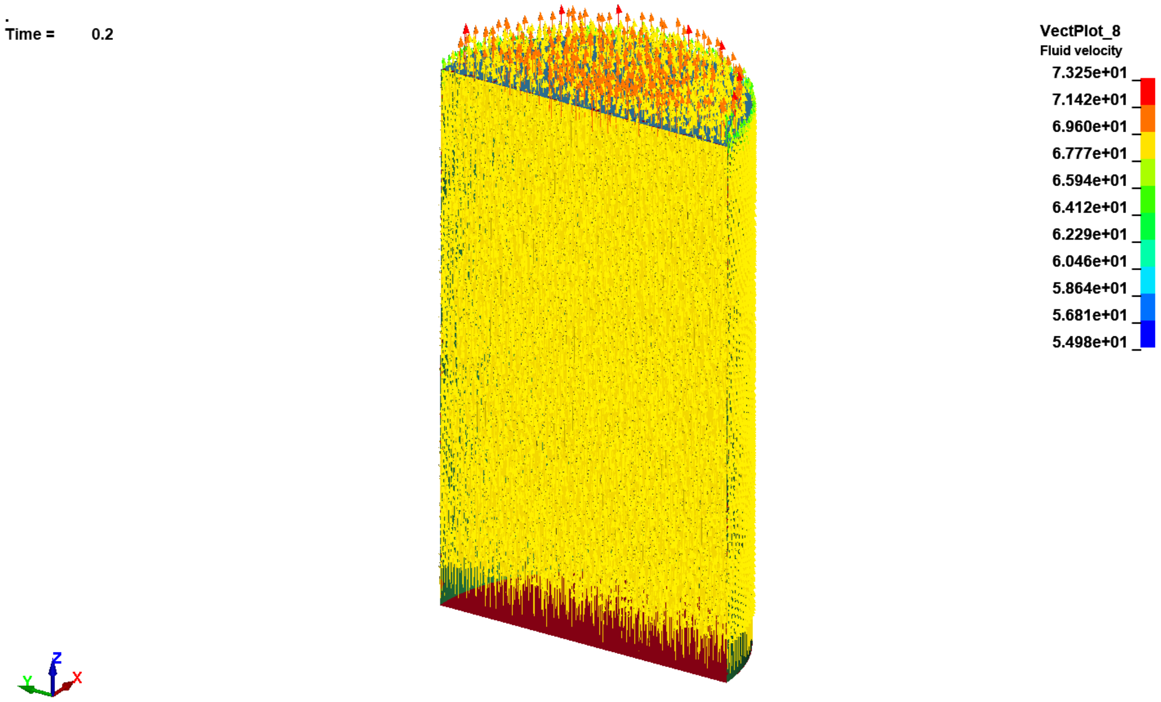


Figure 8 Velocity Vector Plot

8. Porosity Modelling of Fabric Material

To understand the behavior of porous media models in LS-DYNA one porous shell element with structural properties discussed is conducted. The material permeability already exists in penalty coupling method utilized for fluid structure interaction models within LS-DYNA. To define porous material property in LS-DYNA *ICFD_MODEL_POROUS.

Area (m2)	Numerical Pressure Δp (Pa)	Analytical Pressure Δp (Pa)	%Error
1	1001.6	1010	0.83

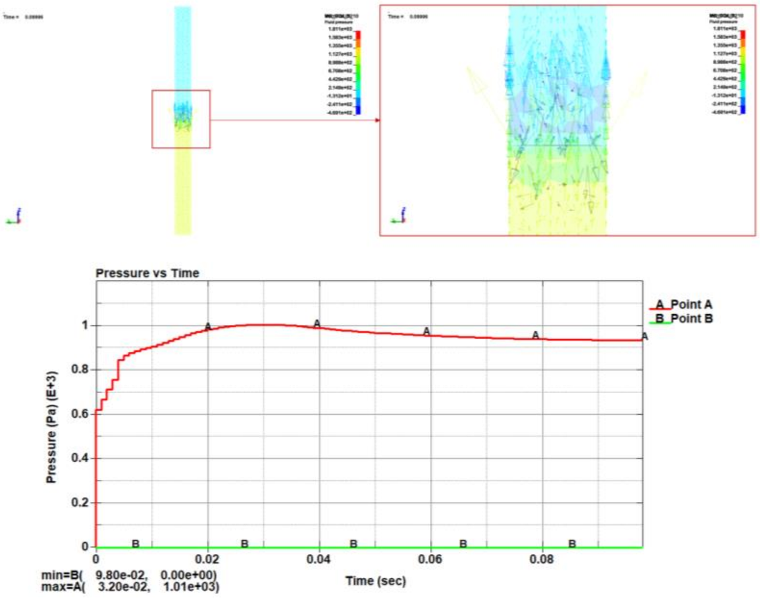


Figure 9 Pressure Drop Across One Fabric Element Test

9. FSI Analysis of Semi Deployed Parachute

A common approach in the industry when dealing with FSI problems is to use an indirect coupling method. First, the flow field is solved using a CFD code. Then, the pressure loads are extracted and mapped into a format compatible with a solid mechanics code which then performs a static or dynamic vibration analysis. This approach can in some cases save computational time but will only yield inaccurate results if the interaction between the fluid and structure can be considered linear i.e. the displacements of the structure do not affect significantly the fluid flow. Linear coupling between the ICFD solver and the LS-DYNA solid mechanics solvers is possible, either indirectly through the output of the pressure loads in a format compatible with the keyword format or directly if the steady state or potential flow solvers are used. When the steady state or potential flow solvers are used and a FSI problem is defined, the solver will automatically apply the loads on the structure once steady state has been reached and allow the solid mechanics problem to proceed. In this study we have applied two-way coupling. In this coupling Loads and displacements are transferred across the FSI interface and the full non-linear problem is solved.

Fluid structure interaction for highly deformable structures has brought them to describe several modelling approaches each of which has computational and operational differences. In general terms, FSI technique involves the coupling of structures and fluid dynamics the method utilized to achieve coupling depends upon the code used into some extent analysis application. They approved the use by list to perform Model structural and fluid computation with the same code. Data still must be transferred between the structure and the fluid. Obvious benefit of FSI scheme is that no inter code data transfer is necessary.

To start with it is possible to use FSI in several alternative ways to simulate this highly dynamic fluid and structural event. However, missions associated with parachute behaviour limit the applicability of the language formulation for both parachute and flow field, and in our experience the runtime requirement of Smooth Particle Hydrodynamics (SPH) or mesh free methods currently limit their efficiency.[13]

FSI model comprises a fluid which is solved by using Eulerian formulation on Cartesian coordinate mesh, that overlay a parachute structural mesh that is discretised by Lagrangian 4-node shell element based on type 16 formulation and 2 node cable element in LS-DYNA. The multilateral Eulerian formulation permits material flow through mesh which is fixed in space. Individual elements are allowed to contain a mixture of different materials. The incorporation of Eulerian Langrangian coupling algorithm permits the interaction of flow field.

In an explicit time, integration solution, the calculation of nodal forces is the primary procedure within each time step. When considering the simulation of parachute nodal forces are calculated for both the fluid structure interaction. The forces due to coupling are then computed, these forces only affect the nodes that are on the fluid-porous structure interface. Fluid-structure interaction problems involving an incompressible viscous flow and elastic nonlinear-structure have been solved in the past using different methods. The monolithic approach considers the fluid and the solid as a single domain with the fluid and solid equations solved together in a coupled way. However, solving the pressure together with the rest of the unknowns (typically velocities or displacements) is too expensive from the computational point of view.

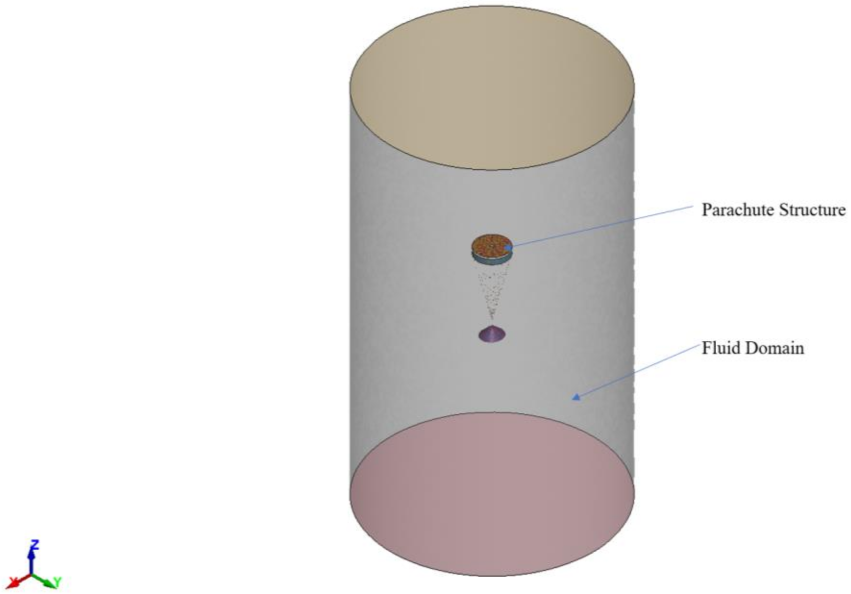
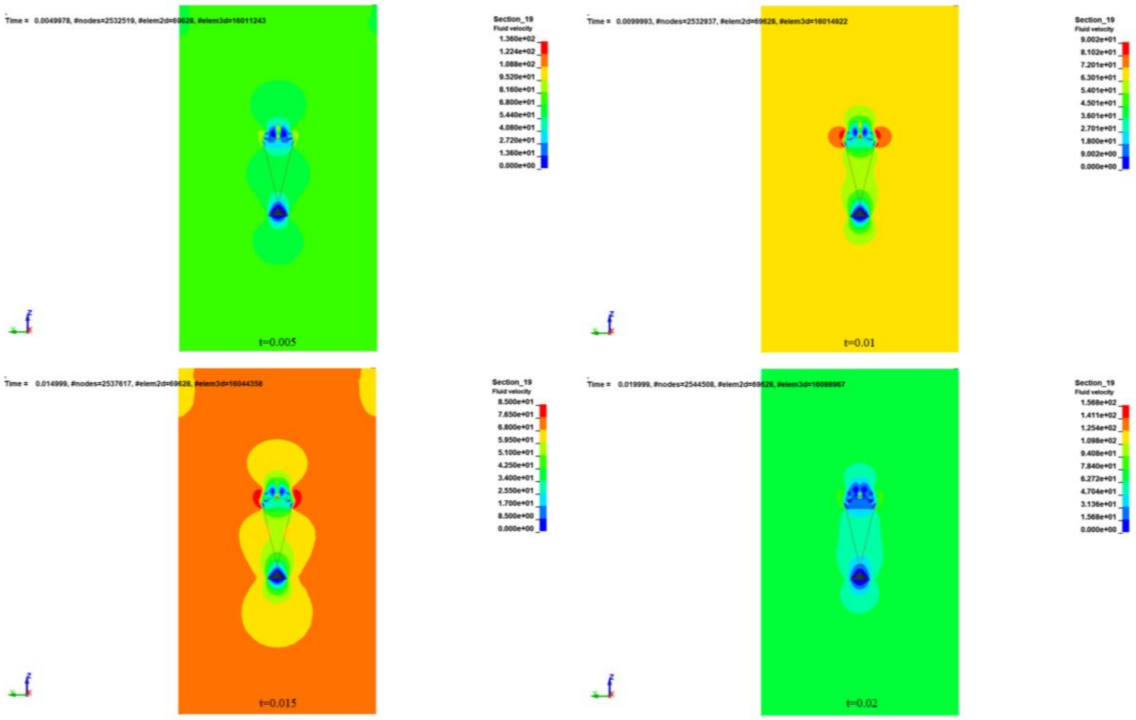


Figure 10 Boundary Condition for FSI



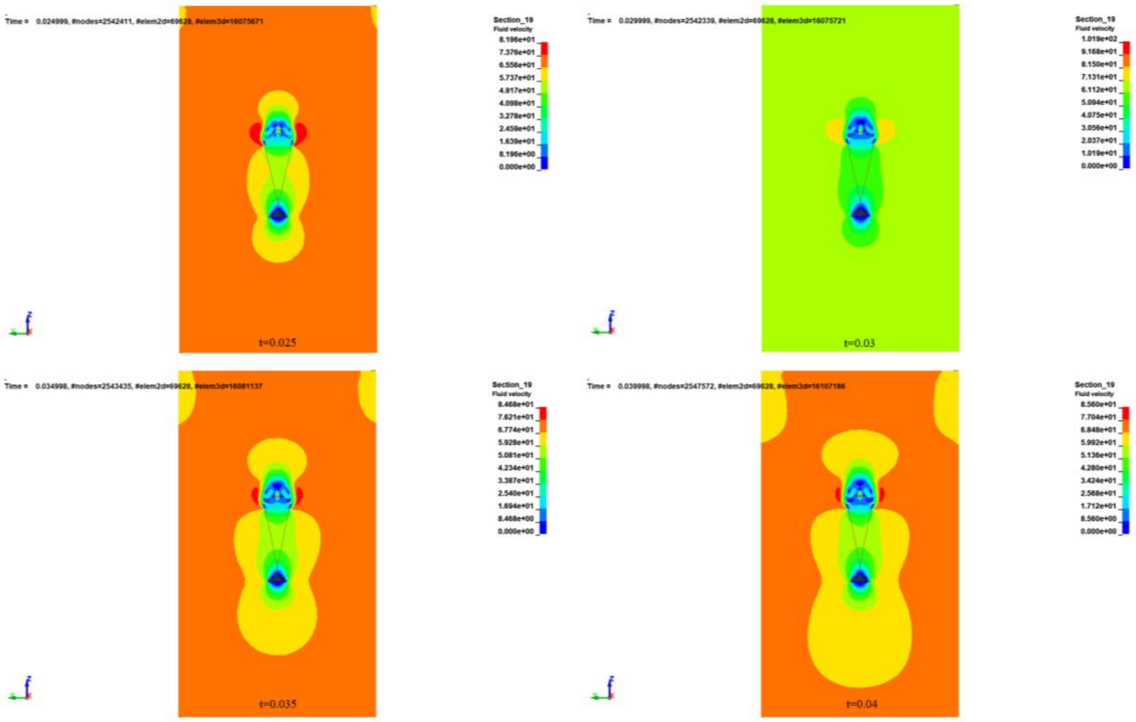


Figure 11 FSI Inflation Process with Fluid Velocity Plot

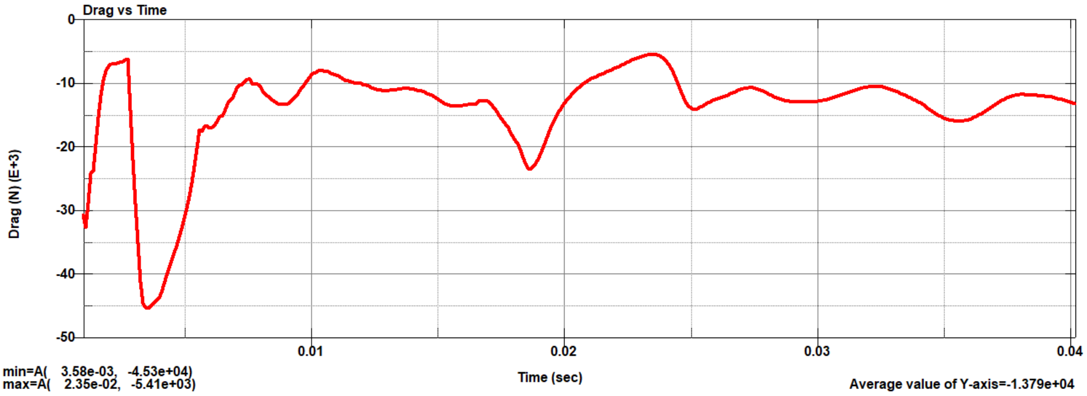


Figure 12 Drag Force versus Time

10. Analysis of Floats with FSI

Fluid-Structure Interaction (FSI) simulations are essential in understanding the behavior of floats used in aerospace applications. Floats are designed to provide buoyancy and stability in water, making them critical components in various engineering systems. This research paper explores the application of LS-DYNA, a multiphysics simulation software, to analyze the interaction between fluids and float structures under various conditions. The study involves the use of advanced FSI techniques within LS-DYNA (Structural+ICFD) to simulate the response of float structures to fluid forces, with a focus on the accurate modeling of materials, structural deformations, and fluid flow.

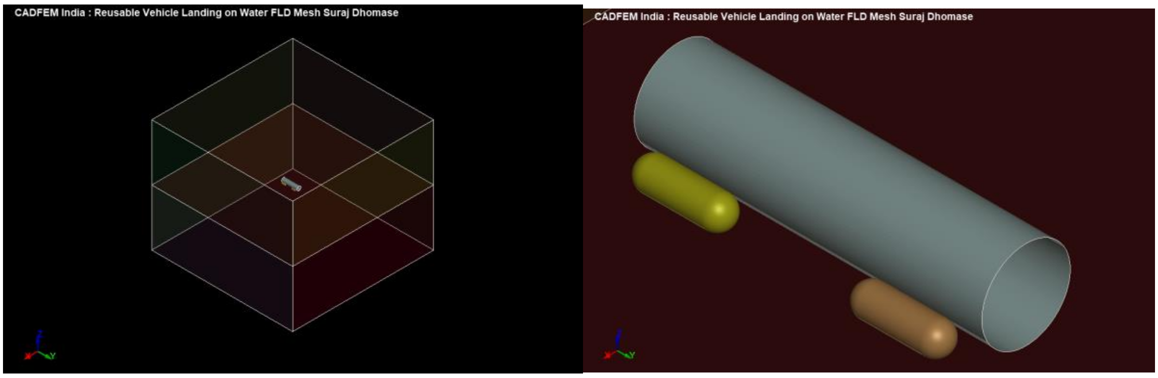


Figure 13 Float Impact on Water

This study demonstrates the effectiveness of using LS-DYNA for FSI analysis of floats. The ability to simulate the complex interaction between fluid and structure in a detailed and accurate manner makes LS-DYNA a valuable tool for engineers designing floats for aerospace applications. Future work could involve the integration of more advanced material models and the study of FSI in more complex fluid environments, such as turbulent or multiphase flows.

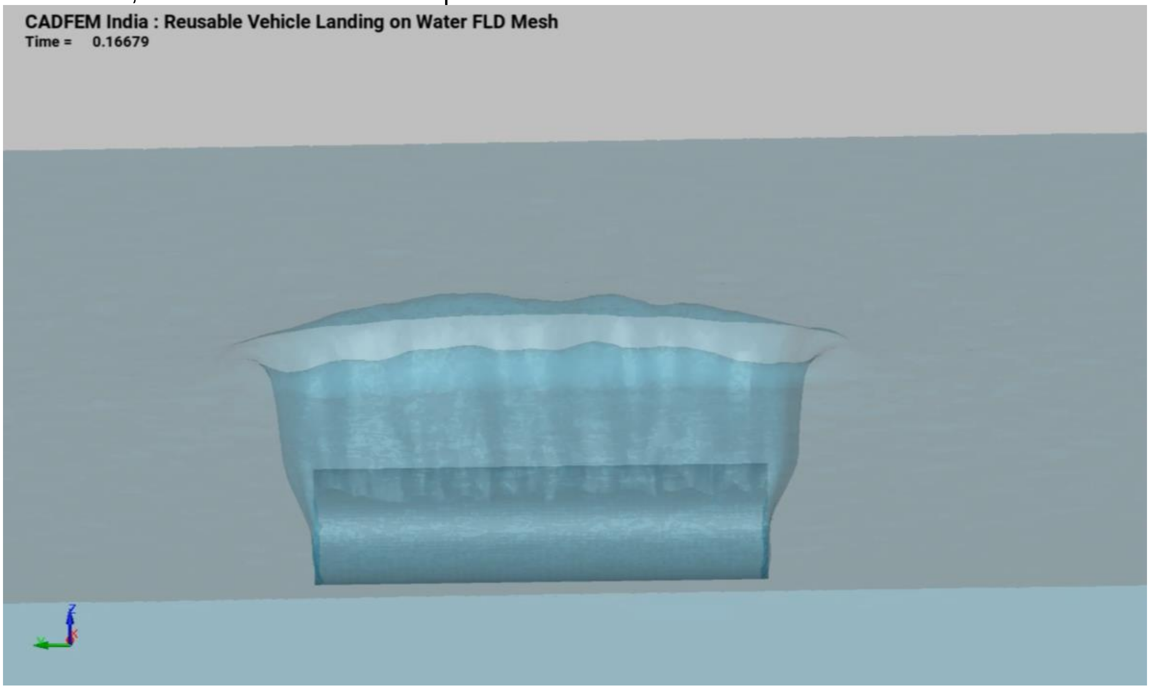


Figure 14 Floats Slashing in Water

11. Conclusions and Recommendations

The parachute deployment is a very complex physics, having the interaction of highly deformable thin structures with a fast-moving fluid. Successful development of the methodology for this highly nonlinear application using LS-DYNA was presented in this thesis. This thesis accurately captures the general behavior of parachute in terms of opening forces and breathing.

This study covers the complete process of discretization, element formulations, material modeling of fabrics & suspension lines, fluid domain modelling for ICFD analysis, porous media modelling, FSI analysis of parachute inflation, parachute folding procedures, and structural analysis versus FSI analysis. Strong and loose coupling methodologies for FSI analysis of parachute are discussed and loose coupling methodology was demonstrated for parachute inflation in this thesis. This methodology was successfully applied to a 2.0616 m disc-gap-band type parachute, with various complexity involved. The Robust ICFD solver gave us the flexibility to predict the rapid deformation of parachute structure along with the air dynamics around it to capture the inflation accurately. Flat folded parachute was considered in this thesis for demonstrating FSI simulation in LS-DYNA with fully coupled ICFD simulation. This study also concludes the simulation of fluid permeability through the thin, porous fabric materials.

For the more realistic tightly folded configuration, the improvements in the modeling are necessary. The volume mesh generation in complex and tight fabric folding is critical, care needs to be taken at the time of setting up adapting mesh size-shape during modelling stage for precise pressure field calculation. Fluid mesh generation in small fabric folds leads to very small elements, which leads to huge reduction in computational efficiency. This requires huge computational resource for taking advantage of the MPP LS-DYNA scalability. For more advanced study, coupling of ICFD and DEM solvers can be carried out for the study of fluid interaction with 1D beams of parachute suspension lines. Furthermore, methodology to deploy a parachute from the canister of the re-entry module can be developed with the help of *AIRBAG in combination with currently developed workflow shown in figure 141 is open for future research. Also, all these finding are to be validated with accurate physical test, with appropriate test measurements.

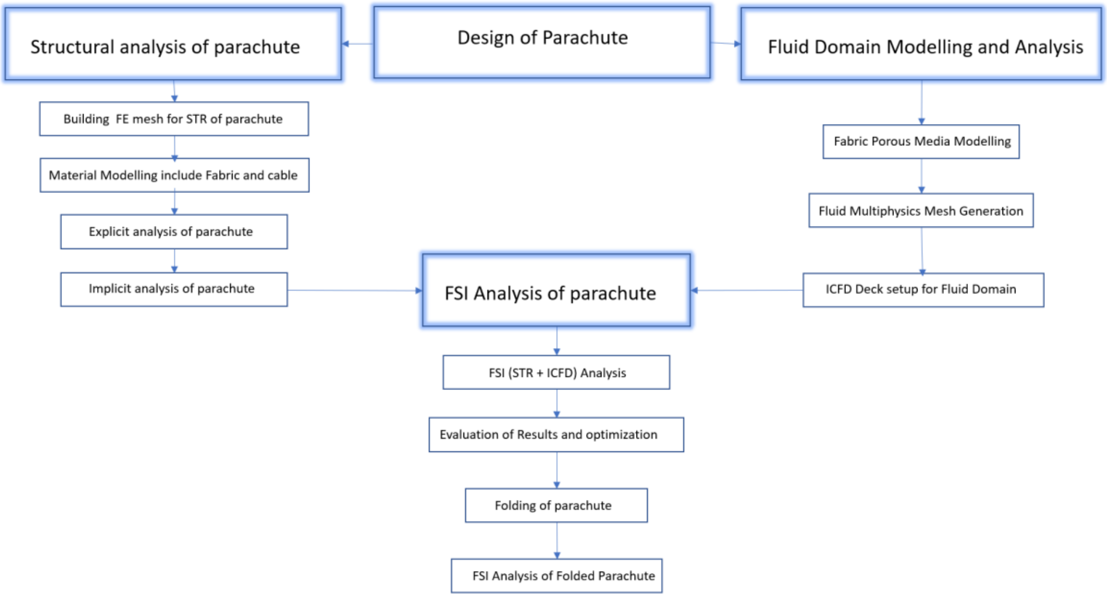


Figure 15 Flow Chart of Process of Parachute FSI Analysis

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