

Improving Parachute Efficiency: The Function of LS-Dyna in Fluid-structure Interaction Simulation

Chang Song Kim^{1*}, Kun Song Kim², Sol Song Pak³, Kum Gwon Choe⁴, Hyong Gyu Jon⁵

Abstract

As an accompaniment to assessment of DGA Aeronautical Systems created a simulation and model-building capability to gain a better understanding of the parachute dynamic behavior and to maximize the parachute systems flight tests. This work reports on the latest developments in Arbitrary Lagrangian mathematical (ALE) methods for analyzing the properties of the quasi-steady state descent phases and canopy inflation. Thus far, none of the simulations of the endless mass type have been created by restricting the parachute confluence point and forcing a specific airflow through the body of water. Its flight will be simulated through testing of these code changes, which should enable more precise analysis of the canopy's dynamics and the materials' structural dynamics. There is also discussion of these upcoming characteristics.

Keywords: Ringsail parachute, Orion space vehicle, fluid–structure interaction, CFD, DGA

INTRODUCTION

Originally, parachute evaluations based on experimental data have frequently necessitated many flight tests, which can be expensive, take a while, and sometimes prevent a thorough knowledge of the changing characteristics of the parachute.

DGA created a modeling and simulation capability to support the monitoring operation.

The dynamics under analysis, particularly the inflated state of a very thin spongy deformable fabric membrane coupled with the surround flow of fluids, is what makes skydiving flight modeling a challenging subject. There are several numerical techniques available for this purpose, such as the use of the computational fluid dynamics (CFD) method or the computationally structural dynamics (CSD) approach, which study the fluid flow behavior.

The ability to analyze the interaction between a moveable and malleable paratrooper structure that the surrounding air flow makes the FSI (Fluid Structure Interaction) method more appropriate [1].

First-generation FSI parachutist simulators were created at DGA in the 1990s.

The architecture allowed to allow the coupling of two implicit commercial finite element computational codes, a fluid solver named N3S and a structural solvers named SAMCEF, to analyze fluid arrangement interactions1-3. SINPA is a French acronym for the numerical modeling of parachutes to This coupling technique—often referred to as the partitioned approach—calculates preserving the structural and fluid responses independently in two codes.

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The lift-to-drag ratio and the in-flight canopy form of a ram-air parachute, for example, could be found using this coupling approach, which produced good results but was difficult to use since it needed a robust connection algorithm [2].

Due to flexible re-zoning and re-meshing as well as the duration it took for data to move between codes, this method was also computationally expensive. The combined technique—often referred to as the partitioned approach—calculates both the structural and flow responses independently in two codes.

The ratio of drag to lift and the in-flight canopy form of a ram-air parachute, for example, could be found using this coupling approach, which produced satisfactory outcomes but was difficult to use since it needed a robust linking methodology.

In addition to fluid re-zoning and re-meshing as well as the time it took for data to move between codes, this method was also computationally expensive. Since 2003, DGA in order has supported inspection and assessment by doing FSI simulations of parachutes using LS-Dyna.

The LS-Dyna solver, version 971, was used to do the computations reported in this study.

A PC with four 64-bit bi-core processors and 24GB of RAM was used as the workplace. Only six cores of an MPP (Massively Parallel Processor) were used to execute the modeling tasks.

LS-Prepost version 2.4 or 3.0 was used for both the before and after processing tasks.

Modeling Techniques

A Lagrangian formulation is used to simulate the parachute structure, which is generated from the profile geometry provided by the parachute.

The four-node membranous elements that make up the parachute fabric are simplified shell elements that can only support loads that are allowed to occur in-plane (such as no resistance to bending).

Seatbelt elements, which are essentially simplified cables or beams without any flexion firmness, make up the ribbons, suspension lines, and risers, as illustrated in Figure 1(A,B).

Because the fabric is the orthotropic system and stretchy, it can be used in multiple directions for the warp and fill.

The parachute's leaders can be fastened to the dummy's shoulders in two places if a dummy representing a paratrooper's uniform is needed.

The model of the cadaver is a solid structure. Thus, no stress or strain is calculated in the dummy.

The movement of water is built of ALE (Arbitrary Lagrangian Eulerian) solid elements and is represented using an Eulerian formulation.

In contrast to the Lagrangian formulation, this one permits the separation of the lattice and material movements.

Following the component's and mesh's common motion during a simulation time step, the mesh returns to its initial or user-defined position as well and the material data proceed via an advection process.

As a result of this, volumetric mesh instabilities are prevented, preventing inaccurate results or longer processing times. As seen by the bright pink hue in Figure 2, ambient elements with constant pressure

inflow are positioned at the bottom of the fluid volume when contemplating an infinite mass type simulation. The publication will go into further detail about this approach later on [3].

The LS-Prepost mesher's caterpillar block options create a parallelepiped or cylinder-shaped reservoir of fluid around the parachute structure.

The fluid is coarser around the fluid volume borders in which the fluid is not disturbed by the parachute and finer meshed in the center of the volume, near the parachute fabrics where the detailed study of the hydraulic structure connection behavior is required.

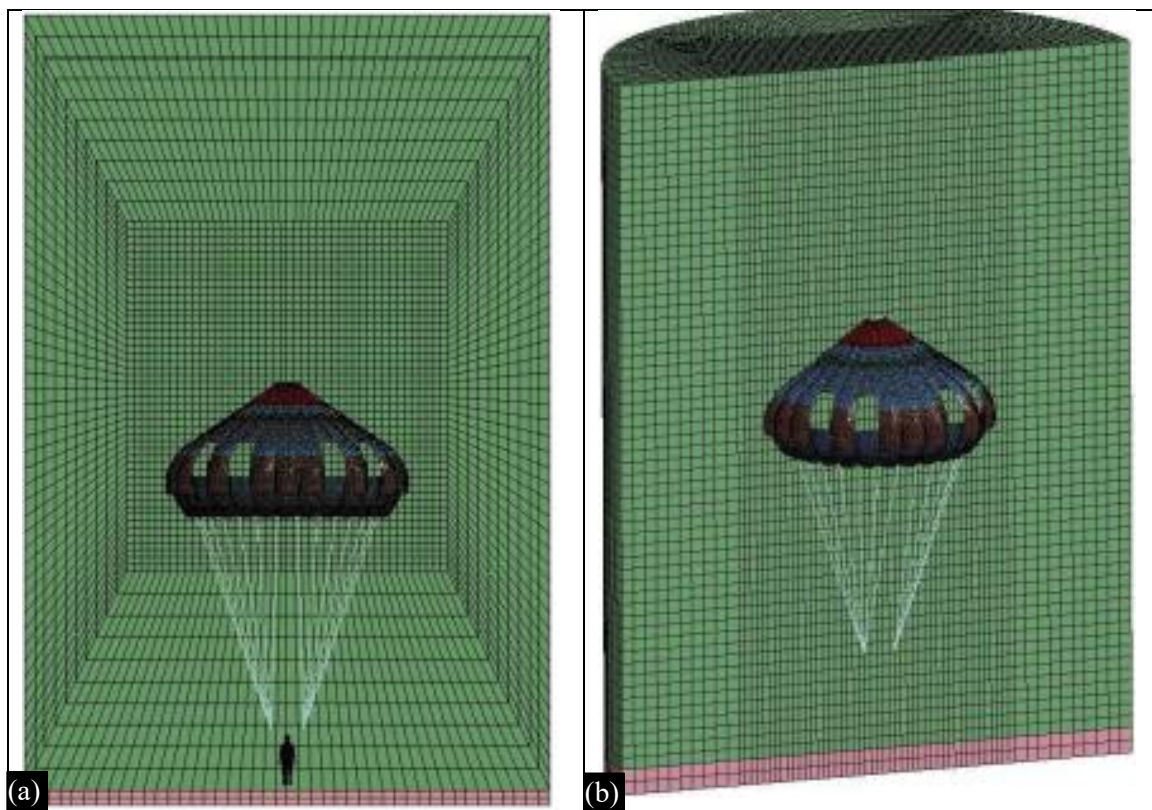


Figure 1. Parallelepiped, (a) and cylindrical, (b) fluid volume modelling.

The Eulerian fluid is described using the equation of state and material attributes.

The cylindrical component in the model shown in portion b) of Figure 1 is about 25 m high and 10 m in diameter, and the fluid volume is coarsely meshed [4].

Using an interactions methodology based on the penalty method, the ALE method provided in LS-Dyna is used to model the fluid structure interaction.

The association method^{16,17} also uses an Ergun law-based permeability algorithm. To prevent excessive computation time, the fluid and suspender lines/risers were not linked.

Simulation

By restricting a parachute's confluence point (or the dummy) and introducing a predetermined airflow through the fluid, simulations of the infinite mass kind were created.

This kind of modelling is similar to experiments conducted in wind tunnels [5].

Steady-state Descent Phase Analysis

The built character model is inserted into the fluid flow at the chosen velocities if only an equilibrium descent phase analysis is needed.

The chute's drag force can be determined with regard to in-flight observations once the point of steady state is reached.

The cross parachutes that were employed as extracting parachutes were the subject of the earliest examinations of the chutes in flight. As seen in Fig. 2, the making of this type of parachutes is extremely straightforward and consists of sewing together two cloth strips. Moreover, the fluid framework coupling feasibility was clearly shown because the swollen profile differed greatly from the designed profile. Under the assumption of a steady laminar stream behind the aircraft, the calculated fluid flow rate in this mathematical example is the airplane speed [6–8]. This straightforward method does enable analysis of the quasi-steady state descent parameters, such as the drag that results from the swollen profile. As seen in Fig. 3, it is simple to examine the differences between a porous and non-porous fabric on the inflated profile. The porosity method was added to LS-Dyna, which has greatly increased the calculations' accuracy and precision over the past few years. With the not permeable fabric, the drag force that resulted was 20% greater than the drag force that was predicted. For an empirically determined drag force of 2400daN, the resultant drag force after adding the permeable fabric modeling is 2370daN [9–11].

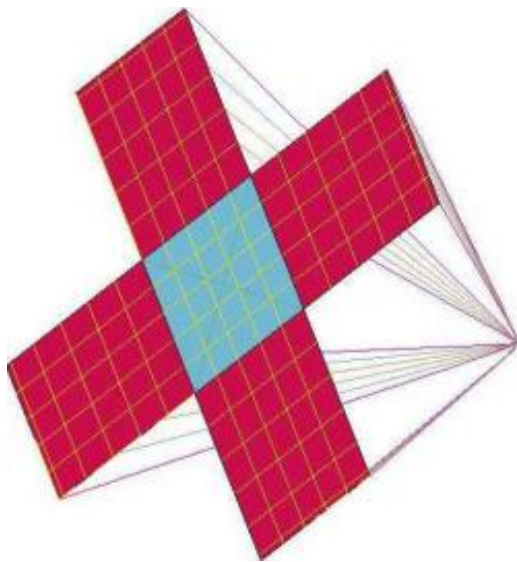


Figure 2. Constructed profile of a cross parachute.

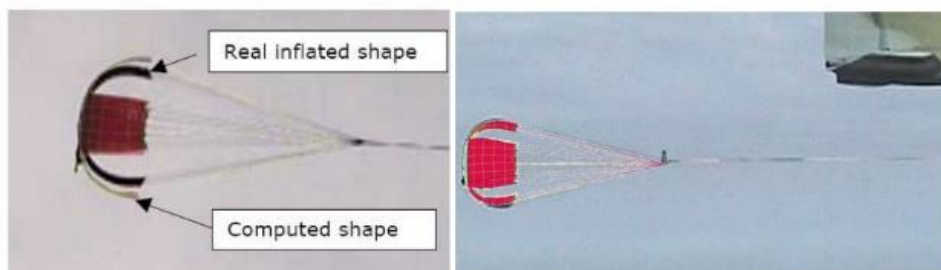


Figure 3. Superimposition of the in-flight inflated profile with the computed one for a non-porous fabric on the left and the correct porous fabric on the right.

Following the procedure's successful demonstration on straightforward challenges, person parachutes were used.

Modeled after the new EPC (Ensemble de Parachutage du Combattant) static line parachute used by the French Army.

For personnel parachutes, the dummy is confined and the specified airflow velocity is the depth of fall ascertained by in-flight measures when employing infinite mass subtype simulation.

The calculated and in-flight inflated profiles of the EPC parachute are displayed in Figure 4.

To establish the relevant drag forces, many simulations were run with applied rates of fall according to the paratrooper mass range. After analysis, the pressures and flow velocities fields produced the anticipated worldwide outcomes [12].

After a preliminary simulation with a significant fluid volume, this volume can be easily changed in accordance with the fluid flow disturbances surrounding the parachute to reduce computational run time.



Figure 4. Real and simulated inflated profiles of the EPC.

Furthermore, in order to maximize simulation time, simulations on a $\frac{1}{4}$ symmetry model—illustrated in Figure 5—were carried out following the validation of the numerical methods on a full-size parachute.

Results from the gigantic model and the $\frac{1}{4}$ symmetry model have been compared based on a few selected factors, yielding complete satisfaction [13].

Because of the time savings, it is possible to increase the number of elements and still evaluate the accuracy and quality gain within a suitable simulation period.

The fake body was combined with the fluid for the initial steady state descent investigation to assess its impact on zipper function [14].

In various other experiments, the fluid-dummy coupling was eliminated since the fluid disturbances caused by the dummy did not affect the parachute's descent.

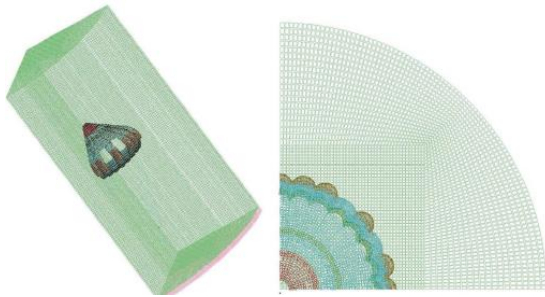


Figure 5. A $\frac{1}{4}$ symmetry model of the EPC parachute.

The fluid velocity vectors in Figures 6 and 7 are displayed in various parts, with colors corresponding to the intensity of the velocity and points indicating the pattern of travel. Figure 6 allows for the visualization of the fluid flow through the vents, demonstrating a spike in fluid velocity at these places [15].

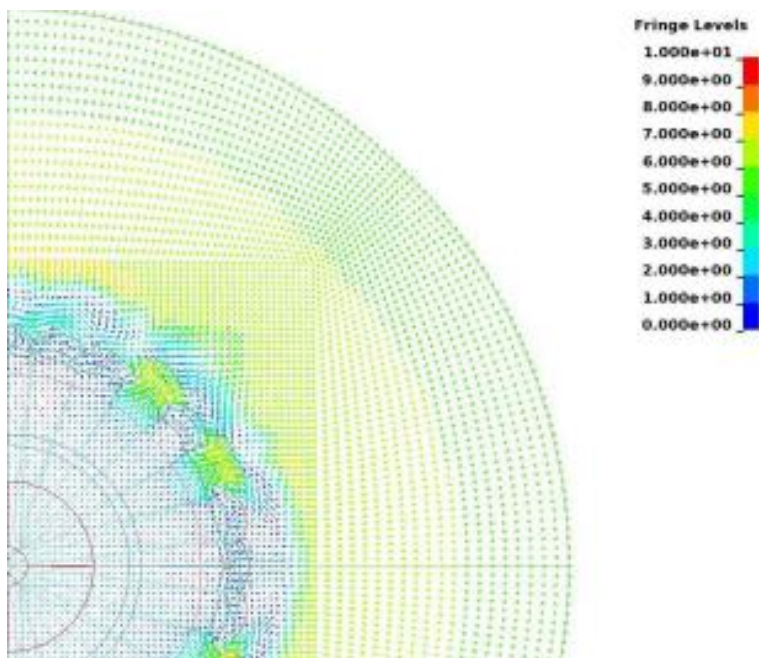


Figure 6. Fluid velocity vectors on a horizontal section through vents.

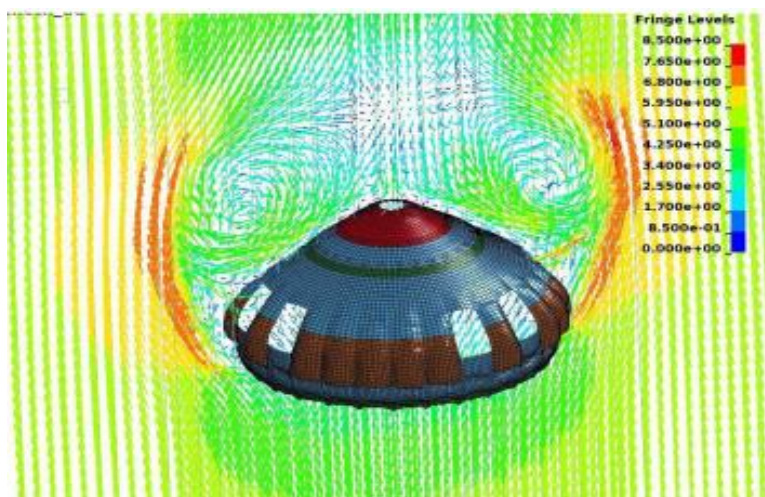


Figure 7. Fluid velocity vectors on a vertical section.

Inflation phase analysis

In order to replicate the inflating phase, the starting geometry of the parachute cannot be the manufactured profile, but rather a vertically compressed straight line profile that matches the shape of the parachute immediately after it exits the inflation bag.

The study did not model the morphology of fold and packed parachutes; in contrast, the pumping simulation's initial condition is substantially simpler.

However, there is a computer-aided technique for folding cloth that can be done with LS-Dyna.

For instance, the car industry today frequently uses folding airbags [18], a feature that has been proven for many years. Nevertheless, it is challenging to mimic because of the size difference that exists between an umbrella and a parachute as well as the distinct challenges of folding and compressing a parachute, especially given the constraints on technological resources. Moisture is not used during the canopy generating phase in order to obtain the initial geometry prior to inflation [16].

The method is to ensure there is no strain in the fabric or the suspension lines/risers via applying dynamic traction to the parachute apex until it reaches the desired geometry in Figure 8.

Additional methods were implemented as well, such as limiting the apex and imparting gravity to the structure.

Since effective folded geometry that results has a significant impact on the final result of the subsequent computational inflation phase, the primary issue to consider during this phase of the process is the interaction control. A number of nodes on the leading edge have little mass added to them because it's important to have a well-done geometry and to make contact control difficulties easier.

Only within the parachute-forming phase immediately these mathematical masses introduced, and they were deleted prior to the inflated phase.

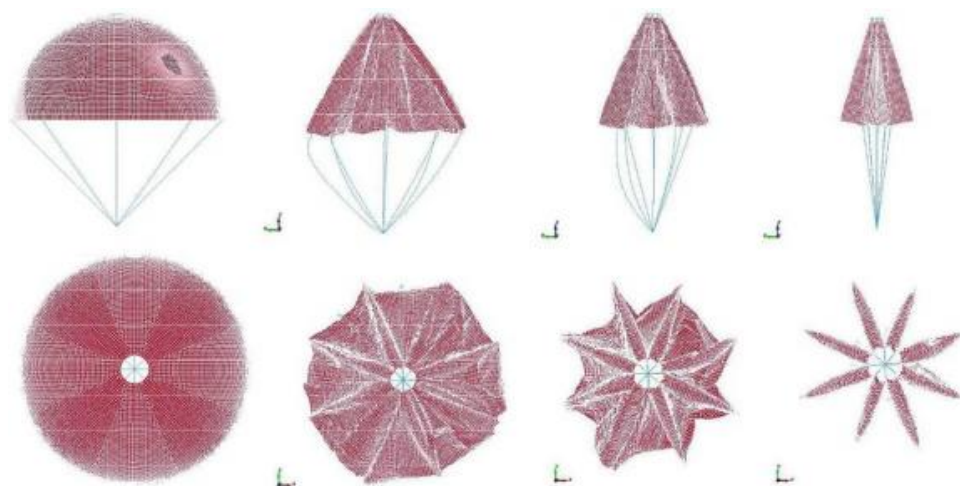


Figure 8. Parachute forming process using added mass.

Figure 9 depicts several stages of this parachute formation procedure on a tiny, homemade hemispherical parachute.

The purpose of this 4.2 m² hemispherical parachute was to perform a number of test falls from the tower shown in Figure 9. The payload was heavily configured for assessing flight test results with prediction and assess strain detectors for drop fabric.



Figure 9. Drop of a small hemispherical parachute.

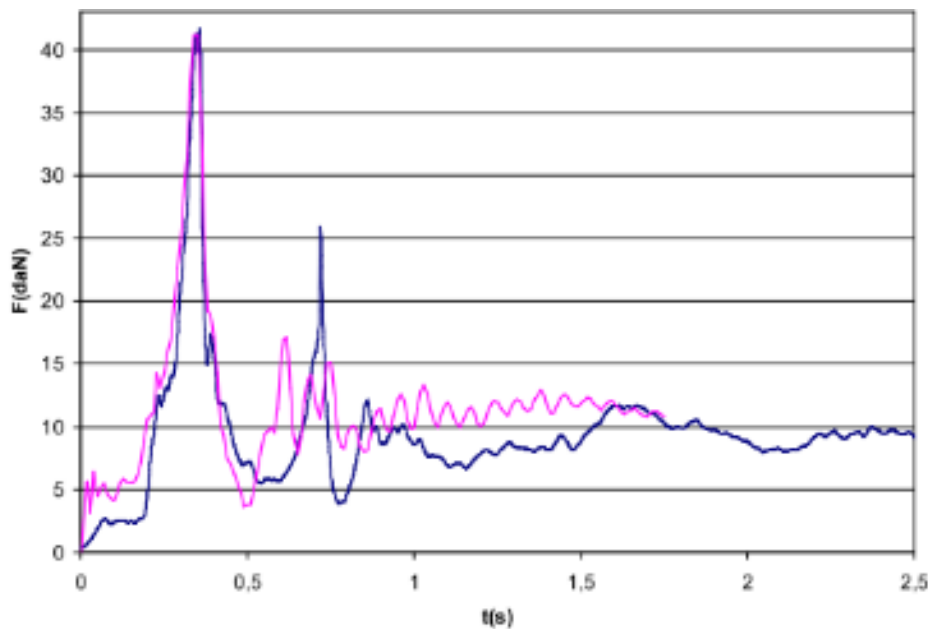


Figure 10. Drag force at the confluence point versus time.

Simulation (in pink)
and flight test (in blue).

The configuration that appears folded vertically in Figure 10. The parachute was inflated using.

Metrics using the acquisition system, which was synced with the camera, and rapid connectivity pictures taken by the camera are juxtaposed with the findings of the simulated inflation.

As seen in Figure 9, the inflating time and the maximum drag force were verified.



Figure 11. The folded geometry.

Higher than expected was the subsequent drag force peak, which corresponded to the parachute breathing.

The material stress mapping within the fill and warp directions at the opening shock time is shown in Figure 11.

Regretfully, there hasn't been a strain comparison between simulation and testing done as of this writing.

The EPC paratrooper was also subjected to deflation analysis depicts the geometry that was folded vertically before inflation.

The numerically folded structure has a maximum diameter of 1,6 m.

Validation of the inflation scenario was achieved through flight testing on the EPC parachute from a balloon.

Through the analysis of both flight path measurement and in-flight video, the parachute's descent speed at the end of the deployment phase was determined.

Before prices, this velocity was used as the starting condition for the vertically folded geometry.

The predicted profile and the real in-flight profile at various points throughout the inflation are compared in Figures 12, 13.

Analysis has been done on the conveyance of fluid using vents undergoing inflated. The acquired outcomes from comparison are really promising.

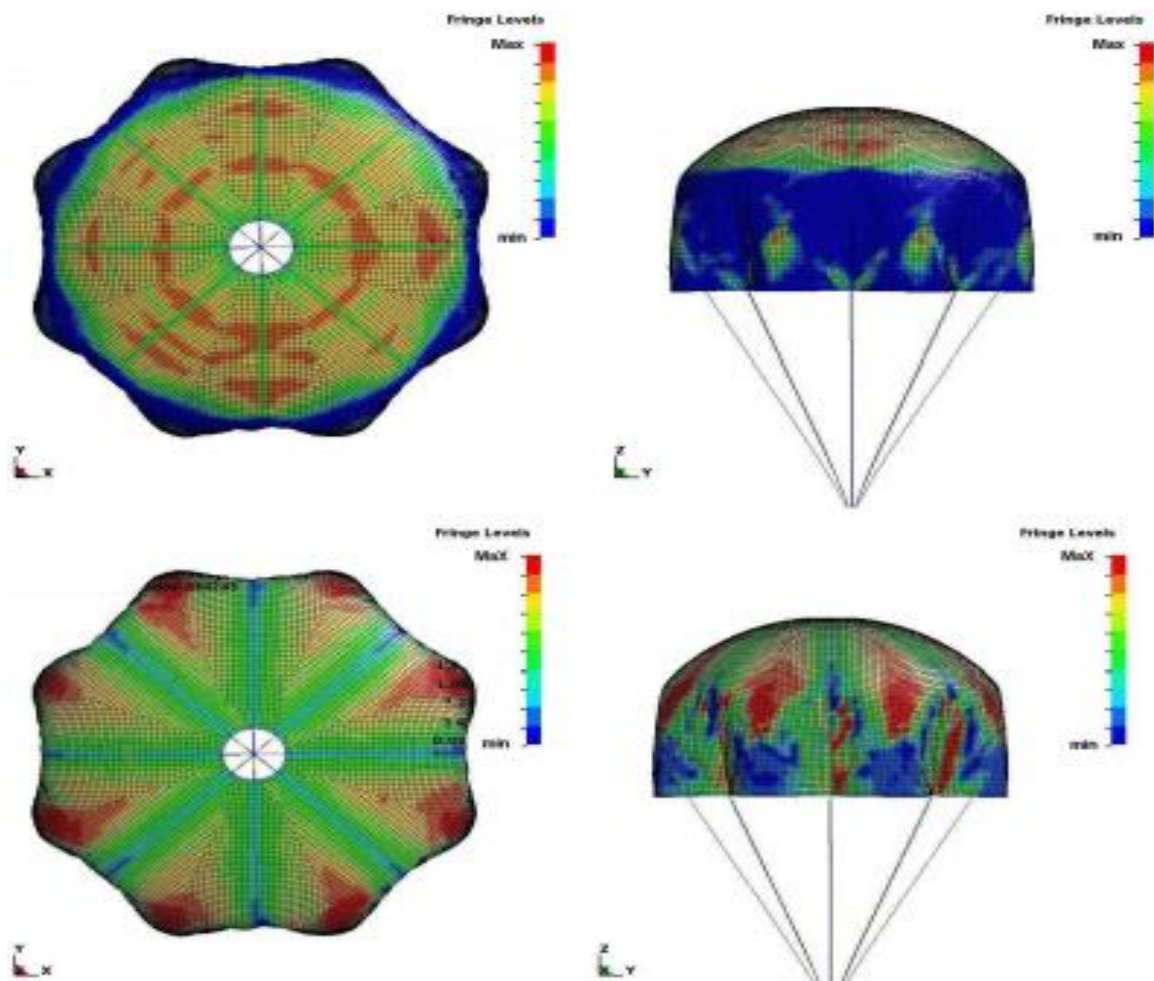


Figure 12. Stress mapping, in fill and warp directions, at the opening shock time.



Figure 13. Real and computed profiles compared at different times during the opening.

Finite Mass Type Simulations

The process of modeling was enhanced with the increase in parachute geometry complexity.

Predictions of the parachute drop were created using finite masses.

The parachute system and the dummy are subjected to gravity as part of the method.

The state of constant descend and inflation can be examined with a particular paratrooper mass.

Fixed velocity is not needed during the simulation period, in contrast to the infinite bulk subtype simulation.

All that has to be supplied is the initial velocity.

The ALE construction permits the separation of the material movement from the mesh movement, as earlier mentioned.

The water-based mesh is moveable in finite mass style simulations, though it is fixed in dimension for infinite mass type predictions. Put differently, the fluid Eulerian mesh moves with the fluid material through one particular step and then returns to a location based on the position of the Lagrangian mesh.

In LS-Dyna, there are various ways to regulate the classical mesh relaxation.

In this investigation, the simulated motion governs the fluid mesh.

On scaled models, Tutt and his associates demonstrate the technique's initial application¹¹.

Finite load analyses were performed using the built profile and the vertically folded profile, first on the small hemispherical parachute and subsequently on the EPC parachute.

The EPC parachute's inflation prediction is shown in Figure 14 from the folded position shown in the preceding figure.

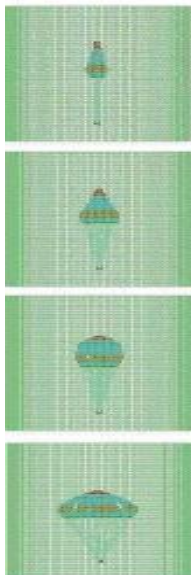


Figure 14. Finite mass simulation of the EPC parachute.\

CONCLUSIONS

In this study, we examined the ALE approach for simulating a parachute.

During the opening process, we computed the drag force and velocity vector.

The simulation and real parachute inflating processes were also compared.

However, we failed to take sidewind's deviation into account.

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