APPLICATIONS OF LS-DYNA TO STRUCTURAL PROBLEMS RELATED TO RECOVERY SYSTEMS AND OTHER FABRIC STRUCTURES

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ABSTRACT

Irvin Aerospace Inc., has used the LS-DYNA Explicit Finite Element Analysis (FEA) tool for over five years for the analysis of static and dynamic fabric problems. The References provide many examples of this previous work. Our first application was the analysis of airbag landings for several spacecraft programs, including Reusable Launch Vehicles (RLV's), various Unmanned Air Vehicles (UAV's), Military Airdrop Systems, and planetary exploration systems. These are all covered in the references.

This paper presents some current results along the lines of the above, and other recent developments. These include an air beam supported structure, which was evaluated for both snow and wind loads, and a fabric blanket system that was somewhat optimized by a combination of FEA analysis and testing.

While these applications appear rather bland, the air beam structure is designed to house military fighter and rotary aircraft and must withstand significant snow and wind loads. The blanket system is used to constrain a target-missile that performs a unique 'Air Launch' mission, involving extracting the target from a cargo aircraft and allowing it to stabilize prior to release and ignition.

INTRODUCTION

The aim of this paper is to discuss the use of the LS-DYNA Explicit Finite Element Analysis (FEA) tool for a selection of diverse fabric-based applications currently being undertaken by Irvin.

One such application is the use of LS-DYNA to simulate environmental loads on high-pressure inflatable structures. The Vertigo Aviation Inflatable Maintenance Shelter (AIMS) is an example of a structure that relies on high-pressure air beams to support a fabric skin. An erected view of the AIMS prototype is presented in Figure 1.
The advantages of these types of structure over conventional rigid structures are numerous. One of the primary benefits of an air beam structure is the ease of erection and disassembly (strike); an entire shelter can be erected with limited personnel and a compressor. Clearly, an inflatable structure is relatively lightweight, compared to a rigid shelter, and can be packed and transported with far less logistical support.

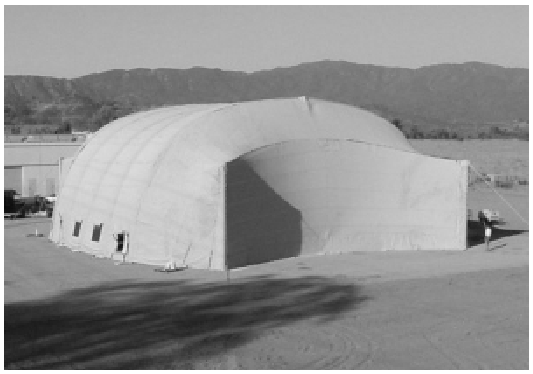

Figure 1. Vertigo AIMS Structure

Another application for which the LS-DYNA tool has been utilized was a fabric blanket support system. This work, carried out under contract to Coleman Aerospace Corp., involved analysis and optimization of a fabric blanket system used to constrain a target missile during its extraction from a cargo aircraft and airborne stabilization. A similar blanket system is shown covering a different missile in Figure 2.

Figure 2. An Example of a Fabric Blanket Constraining a Missile

Both applications could be simplified and reasonable assumptions made that would have in the past turned these systems into Implicit FEA problems. Due to the static nature of these class of problems, a first analysis approach might be to apply implicit solutions and membrane elements to simulate the fabric structures. However, our experience with commercial implicit solvers is that they are poorly suited to the large deformations of fabric problems, ABACUS being the only exception we have encountered.

Not possessing that tool, our approach is to use the LS-DYNA explicit solution in a quasi-steady state approach. Additionally, the recent anisotropic enhancement to the *mat_fabric material model has had bearing on this work.

APPROACH

Irvin has recently simulated wind and snow loads on a pair of Eurovinil (EV) developmental shelters, one of which is similar to the Vertigo geometry shown in Figure 1.

The method used to analyze these shelters was quasi two-dimensional. The approach involved reducing the structure to a section containing one air beam and the outer shell that it was required to support. Boundary conditions could then be applied to the edges of the shelter to simulate the neighboring air beams.

Figure 3 presents views of this section for the larger EV/Vertigo shelter, an Aircraft Maintenance Hanger (MH). The internal width and height of the hanger is approximately 26m and 10m respectively, and the air beams are 0.8m in diameter.

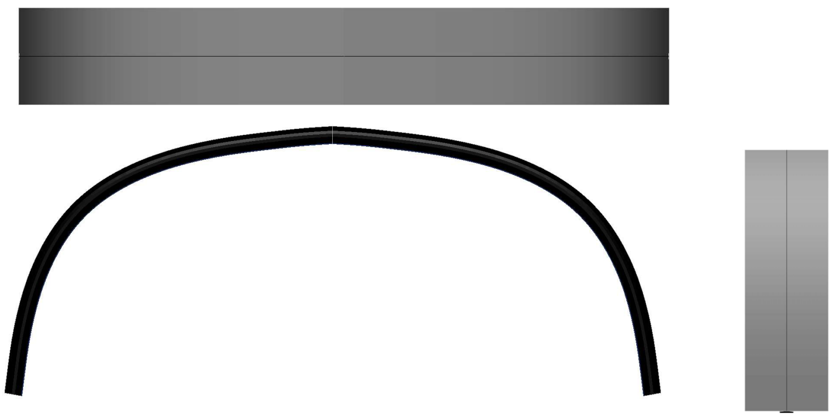

Figure 3. Model of Aircraft Maintenance Hanger

Fabric material definitions include a low modulus fabric, polyester or similar, for the shelter's external skin and a high modulus, high bias braid for the air beam. The braid is completed with a nominal 15 degree bias from the hoop direction of the beam. Figure 4 gives examples of fabric pattern for a material with orthogonal material axis and for a typical high bias anisotropic braid.

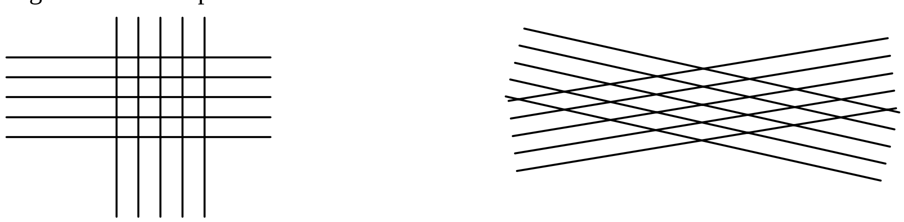

Figure 4. Orthogonal and Anisotropic Material Patterns

The ability to incorporate non-orthogonal material axis, which requires the *mat_fabric anisotropic card, is a unique capability introduced in the 960 release of LS-DYNA. The FORM variable available within the *mat_fabric card allows large strain with non-orthogonal material axis to be defined. This then provides for offset angles, offset from the AOPT definition of the material axis, to be defined in the *section_shell card. These approaches were used during our work.

The high bias angle in the braid produces an air beam that would tend to expand in length when pressurized. This is the fundamental process that gives the shelter its strength. Figure 5 illustrates the result of a simulation where a high bias braided air beam was pressurized without the presence of anything to constrain this suggested expansion.

Figure 5. High Bias Air Beam without Spar Caps

The actual beam construction includes high modulus straps, termed spar caps, which are bonded to the braided air beams. Two of these Vectran spar caps are bonded to the underside of the beam, each offset from the beam's centerline to provide a level of lateral stability. Another higher strength strap runs the length of the beam at its attachment point to the shelter's skin. These spar caps resist the air beam's natural tendency to expand and therefore a preload is created in the spar caps. This preload then provides bending moment resistance and delays the onset of buckling.

The model used for this simulation was created and meshed using Altair's HyperMesh. The spar caps are modeled as beam (seatbelt) elements; this allows for non-linear load elongation characteristics to be assigned to the Vectran spar caps. Figure 6 presents a view of the beam elements used in this FEA.

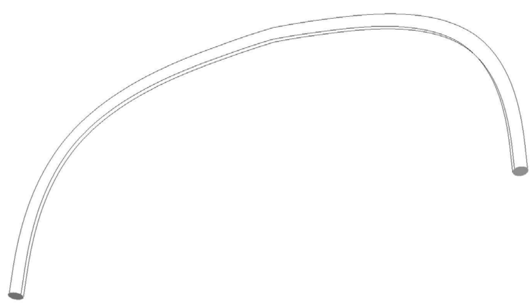

Figure 6. Air Beam Spar Caps and End Caps

The next step involved applying loads to this structure. Both 50m/s winds and snow loads of 100kg/m^2 were analyzed.

The wind load was simulated as a pressure applied normal to the elements of the shelter's skin. Pressure distributions for a broadside wind were obtained from wind tunnel work previously completed by Vertigo. The snow load was applied over an area to the point of a 45 degree or higher local slope, which is consistent with U.S. Civil Engineer Code for such structures. Preliminary analysis also applied the snow load as a pressure normal to the skin elements, however, when viewed graphically it was clear that snow could not apply a force at an angle normal to each element. The only force that the snow could exert is one in a vertical direction under the influence of gravity. For this reason, the snow load was modeled as a layer of elements sharing the same nodes as the shelter's skin. These elements have little strength/stiffness, but possess an element mass that reflects the required snow load.

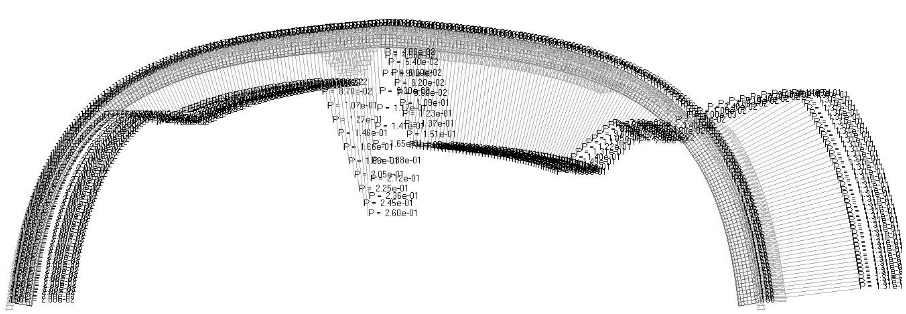

Figure 7 Wind Load Vectors.

Figures 7 and 8 illustrate the environmental loading of the MH.

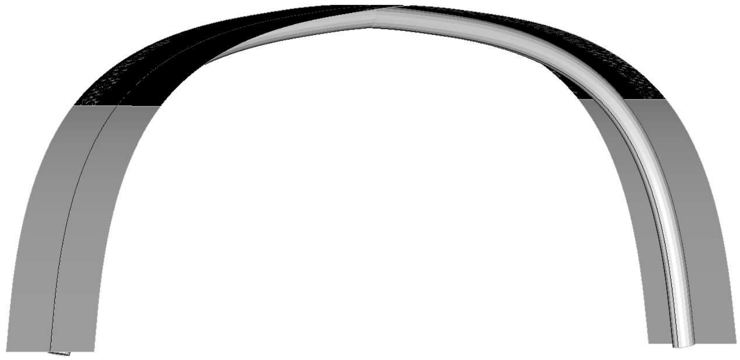

Figure 8. Snow Load Elements

In both loading cases, the air beams were allowed to inflate and settle before the environmental load was ramped in over a period of time. Clearly, the actual period of time required for a snow load of 100kg/m^2 to accumulate on the roof of the shelter could not be simulated. A series of simulations with differing load ramping periods were conducted in order to assess a reasonable timescale that would closely simulate the load but would also meet our run-time requirements.

Calculations were conducted on a PC using a Pentium III processor with a clock speed of approximately 900 MHz. Final simulation times were on the order of 12 hours for a 3 second solution.

For the second application, the fabric blanket system, LS-DYNA was initially used as an analysis tool. Following the success of those simulations and the accuracy of their results, it was decided that LS-DYNA would be used to aid modification of the blanket design.

Previous attempts (by Irvin) to complete this analysis with ANSYS led to frustration both at Irvin and the ANSYS VAR.

Again, the mesh generator HyperMesh was used, this time to mesh a CAD drawing of a test blanket. Figure 9 shows the actual test specimen.

Figure 9. Test Blanket

The method used to simulate the various layers of webbing and blanket was to overlay extra elements on the simple CAD drawing mesh. Coincident elements would then share common corner nodes, as if the fabrics were perfectly glued or stitched together. Figure 10 is the complete, stacked mesh; the separate colors depict the separate fabric components within the blanket. These different components can then be assigned individual material properties and principle material axes. In the case of the diagonal members, the principle material axes needed to be rotated 21 degrees from the global axes.

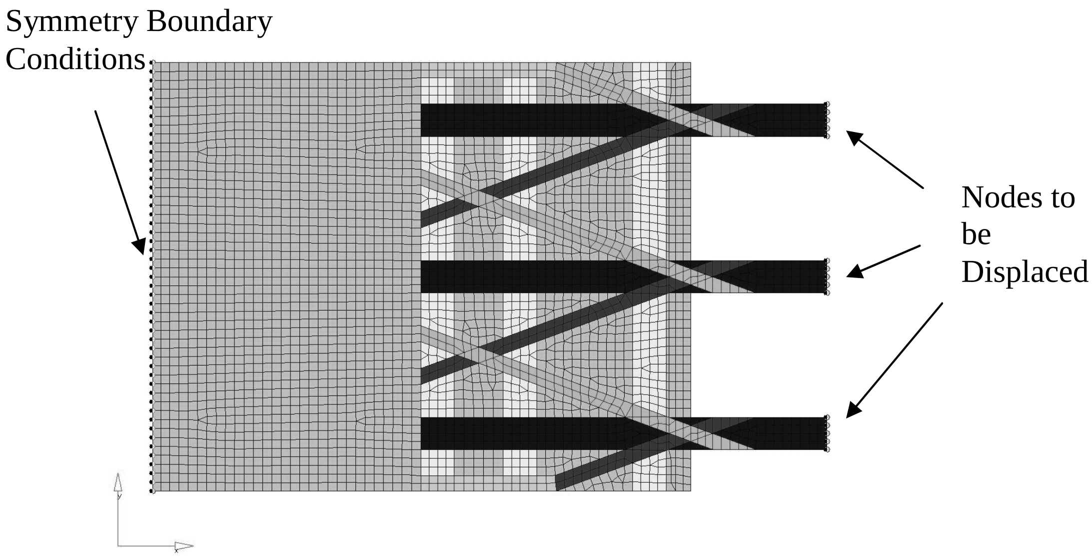

Figure 10. Blanket Mesh

The primary challenge in this type of explicit problem is to prevent local element distortion and obtain a quasi steady-state solution.

Our approach at Irvin in order to overcome this problem has involved the following:

- Ramp the total load seen by the blanket over a period of time.
- Beam elements are attached to the sides of the main load-bearing straps. These elements can then be assigned a small amount of tensile and compressive stiffness, which is enough to suppress the tendency of those elements to wrinkle when loaded. The beam elements mimic the edge bead to be modeled.
- Nodal displacements, rather than forces, were used to load the straps.
- Additionally, the *damping_global function was activated to continually damp the solution to a quasi steady-state condition.

The combination of these processes produces a stable model that accurately handles large fabric deformations.

The method chosen to simulate loading of the blanket was based on the fact that test data was available. The approach taken was to displace the nodes at the end of the main straps until the blanket experienced a load equal to the failure load. Analysis of the stress levels experienced by the separate fabric components could then be used to identify the modes and areas of failure.

As shown by Figure 10, symmetry boundary conditions were applied to one edge of the blanket. This helped reduce run-times to four hours for a one second solution. These calculations were also completed on a 900 MHz Pentium III processor.

DISCUSSION OF RESULTS

The work undertaken to analyze the air beam structures has demonstrated that the unique features in LS-DYNA, non-orthogonal fiber axis and airbag control volumes, have enabled a complex structure to be relatively simply modeled using existing finite element tools. A significant number of configurations and loading cases were completed in 80-100 engineering hours.

Initial concern over the reduced time span that the snow load was applied to the shelter, compared to that existing in reality, were removed when the sbtout file was investigated. Figure 11 presents force time history data for a single spar cap element on the underside of the air beam. The data can be clearly broken down into different beam responses. The first half of a second depicts the airbags undergoing inflation and settling. The deformation of the beam is then illustrated by the gradual increase in the force experienced by the element. The leveling out of the load is then observed, representing the beam's response to the load and eventual support of the load.

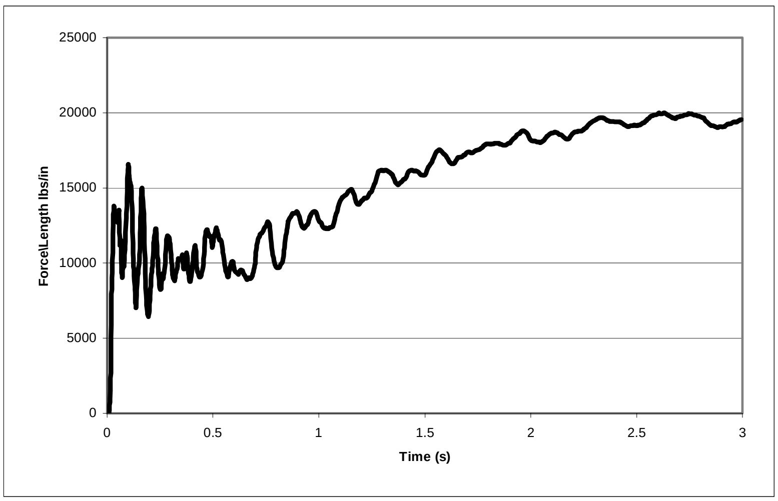

Figure 11. Spar Cap Element Force Time History

Final beam deflection is illustrated in Figure 12. The results of this study indicated that the shelter design was well suited to withstand the specified loads. This result was expected, as it had been previously demonstrated with other tools, proprietary fabric structural codes, and hand calculations.

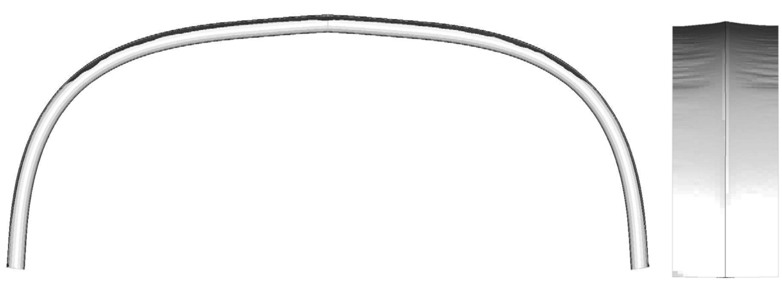

Figure 12. Steady State Shelter Deflection

Future analysis will incorporate the full shelter, including the aircraft entrance at both ends. It will also investigate methods of anchoring the shelter. The study highlighted that the snow load was the force responsible for beam collapse and that the wind load would contribute primarily to anchor requirements. Shelter lift reduction techniques will be pursued through use of the LS-DYNA fluid solvers.

Thorough investigation of the wind loading would be ideally suited to another LS-DYNA capability that is currently being explored at Irvin, the field of fluid structure interaction. Here, the tool could be used to improve the understanding of wind loading, study the dynamic response of structures to gusts of wind, and to reduce the lift co-efficient of inflatable structures.

The fabric blanket presented our first opportunity to utilize LS-DYNA's non-orthogonal material axis capability and the results were impressive. Two sets of test data were available, qualitative and somewhat quantitative, for model validation in this study. The first represented an existing design and the second represented an expected design improvement. Testing demonstrated that the failure load of the improved design was reduced when compared to the original design. Figure 13 presents a comparison of test and simulation in the area of failure.

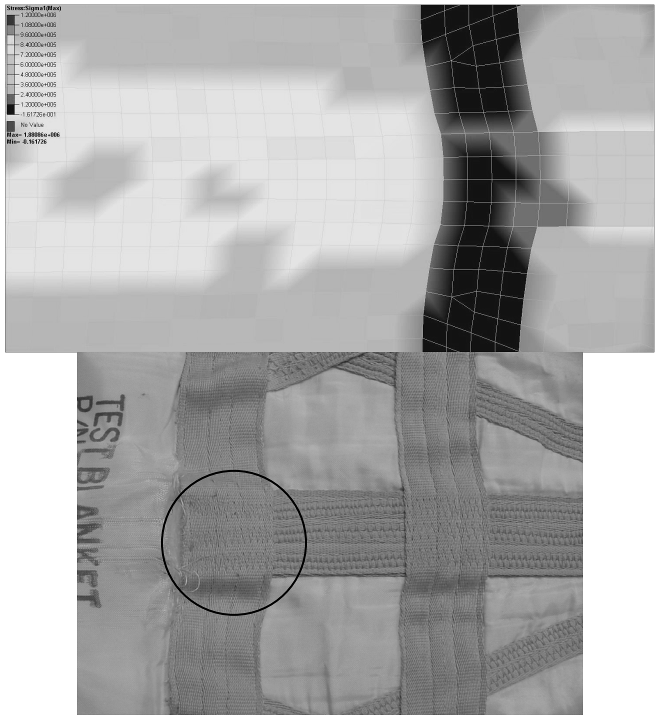

Figure 13. Simulation and Test Results

LS-DYNA correctly predicted this reduction in strength of the blanket and this provided confidence that the tool could be used to aid modification of the blanket's design. A series of iterations lead to an improved simulation design that was later manufactured and tested. The iterations concentrated on trying to disperse the distribution of load transfer more evenly over the webbing blanket interface. This involved further rotation of principle material axes and increasing/reducing the number of ply used in the straps. The enhanced design exhibited the 10% increase in load bearing capability predicted by simulations.

CONCLUSIONS

Previously and in the references, we have presented the value of LS-DYNA in supporting analysis and design direction for fabric systems under dynamic loading.

Herein, we have presented the use of LS-DYNA for static load events through quasi-static analysis approach. The work presented has influenced structure design and, in the blanket case, has been validated through test. This work has exploited and benefited from some of the newest LS-DYNA features, particularly the anisotropic option in the *mat_fabric constitutive model.

We look forward to future LS-DYNA enhancements further expanding our modeling capabilities and continue to explore and exploit the current capabilities- the coupling of fluids and structures being a significant example.

REFERENCES

1. McKINNEY, J. (Virtual Engineering) and TAYLOR, A. (Irvin Aerospace Inc.). "Use of LS-DYNA to Simulate the Airbag Landing Impact Attenuation of the Kistler K-1 Reusable Launch Vehicle", LS-DYNA Users Conference.
2. TAYLOR, A., GARDINIER, D. and SABBERTON, A. "Design Optimization of the Beagle II Mars Lander Airbags through Explicit Finite Element Analysis", LS-DYNA Users Conference.
3. TAYLOR, A "Design Optimization of the Beagle II Mars Lander Airbags through Explicit Finite Element Analysis- An Update", LS-DYNA Users Conference.
4. TAYLOR, A "The Case for Explicit Finite Element Analysis of Fabric Systems, A Presentation of Real World Applications", AIAA Paper.
5. TAYLOR, A "The Case for Explicit Finite Element Analysis of Fabric Systems, A Comparison to Test Data", AIAA Paper.