THE CASE FOR EXPLICIT FINITE ELEMENT ANALYSIS OF FABRIC SYSTEMS, A PRESENTATION OF REAL WORLD APPLICATIONS

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This paper will present the application of Finite Element Analysis (FEA) to real world problems typically encountered in the Aerodynamic Decelerator Systems field, and to fabric engineering in general. All results are presented from the commercially available Explicit FEA package LS-DYNA, as this has been our most successful application. Our experience with the application of Implicit FEA, is that commercially available codes cannot handle the large deflections associated with fabric systems. The presentation of test to simulation comparisons, now available from several projects, is presented in an accompanying paper at this conference. These provide the reader with a feel for the level of precision/validation possible with today's simulation tools. Computational cost is also presented herein for most cases. Finally, we close with a discussion of where Irvin, and eventually our industry, will apply computational techniques in the coming years.

Nomenclature

FEA	- Finite Element Analysis
HOPEX	- H-II Orbiting Plane Experimental
HSFD	- High Speed Flight Demonstrator
PMA	- Pneumatic Muscle Actuator
RRDAS	- Rapid Rigging De-rigging Airdrop System

Introduction

The application of Explicit FEA, to fabric systems, began at Irvin in the mid-1990's, with the analysis of large airbag systems for the Kistler Aerospace Program (Ref. 2-4). Implicit FEA had been introduced earlier for metal parts (ANSYS), but proved virtually useless for airbag analysis, and fabric structures in general due to the large deflections involved.

Since that introduction, and subsequent assimilation of the Explicit simulation capability, we have applied this tool to multiple systems combining rigid, flexible, and fabric parts, dynamic and quasi-static problems, and continue to extend these applications.

Some of our current application areas include:

1) Airbags for aircraft/spacecraft recovery
   - Kistler Aerospace
   - NASDA/FHI HOPE-X HSFD
   - ESA Beagle II
   - US Army Natick, RRDAS Program
   - NAL Jet SSTS Program
2) Harness Deployment Simulations
   - Kistler
   - Coleman Aerospace
   - FHI HSFD
3) Fabric Retention Structures
   - Large Nets for Launch Stand Umbilical Impact
   - Retention Blankets for Missile Carriage Release
4) Other Unique Applications
   - A generic Pneumatic Muscle Actuator
   - Heavy Webbing Cutting Applications
5) Beam Buckling Problems
   - Irvin DLF – 3
   - Rapidly Installed Breakwater System (RIBS)
6) Parachute Stress Analysis
   - A substitute for Sandia's CALA/CANO
   - An emerging application
7) Fluid Structure Interaction
   - Water entry problems
   - Certain parachute problems

Herein, we will review several of these application areas, providing examples of the simulations results available, and how these data provided value by influencing configuration development, as this the ultimate goal of FEA and Computer Aided Engineering in general.

A comparison of (some of) these simulations to test data is presented in Reference 1. A discussion of potential simulation improvements is included.

Finally, we close with a discussion of developing applications, both in terms of Irvin expertise, and in emerging capabilities in the LS-DYNA tool and other simulation capabilities. The LS-DYNA code incorporates a significant fluids solver capability, and unique user friendly approaches to coupling of the Fluid and Structural Elements. This capability should lead to an eventual parachute simulation capability.

Airbag Applications

As indicated above, airbag simulations have been completed for several programs. Of these, the Kistler program is thoroughly covered in References 2-4., with new test results presented in Reference 1.

The Beagle II program (Ref. 6 and 7) is no longer active at Irvin, and the RRDAS program is thoroughly covered in Reference 5.

We will therefore concentrate on the NAL/NASDA/FHI High Speed Flight Demonstrator (HSFD) program in examining the application and its effect on configuration development.

Simulation to test comparisons are presented for Kistler, HSFD and RRDAS in the validation paper (Reference 1).

A Discussion of Airbag Simulations In LS-DYNA

One of the unique features of the LS-DYNA simulation tool is the inclusion of control volume and thermodynamic calculations for pressure vessels. These were originally developed for the simulation of automotive airbags. In recent years Irvin and others (Mars Pathfinder Program) have provided significant additional capability to allow the easy simulation – including control algorithms – of airbags more typical of the Aerodynamic Decelerator Systems community. Our close relationship with LSTC, and their rapid addition of features to the simulation, has been pivotal in making this work possible.

The airbag simulation within LS-DYNA allows the specification of a 'control volume' and the thermodynamic properties of the gas inside the control volume. Typically, this would be (in an airbag application) the outer structure of the airbag. Once the airbag definition is completed, the simulation automatically updates the thermodynamics calculations for airbag pressure, airbag in/out mass flow, etc., and applies the resulting gas pressure to the airbag structure. Airbag loading into a vehicle is accomplished through contact algorithms.

Multiple unique features allow control of the airbag initial pressure, inflation, and venting, by various means. These include venting as a function of airbag pressure, time, or constant orifice area venting. Additionally, algorithms for inflation control and vent control provide for time, pressure and body acceleration controlled events. Airbag to airbag venting is another option. As is the ability to model blockage of the vent as it comes in contact with another body.

High Speed Flight Demonstrator

Explicit FEA had a profound effect on configuration development for the HSFD airbag configuration. Figures 1 below presents several configurations, which were explored, by computer only. Once the initial simulation was built, models of these geometric modifications could typically be built in less than 8.0 engineering hours. Depending on the level of exploration required, a configuration could be explored and eliminated/morphed virtually over-night. Run times for these simulations were 2-10 hours, applicable computer details are provided in Appendix 1.

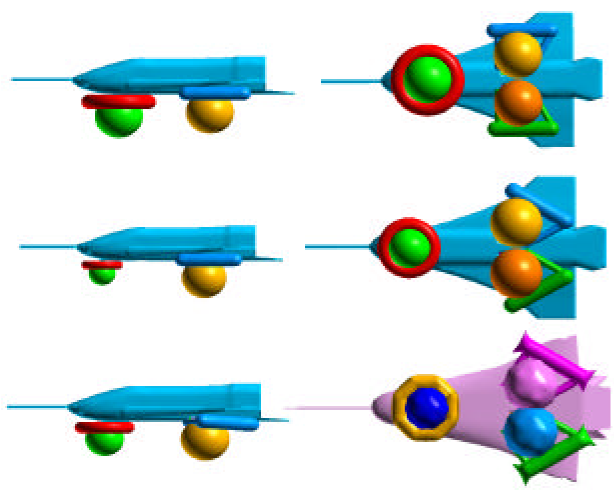

Figure 1 – Virtual Airbag Configurations

Figures 2 presents the final airbag configuration. Changes in the configuration included a stiffening of the anti-bottoming airbag arms, through diameter increase, optimization of landing control to minimize roll attitude departure/wing tip strike, and modeling of the airbag vents to account for ground obscuration of the vents.

Addition of the orifice blockage, already available in the simulation program (lucky), provided a significant tool for assessment of proper vent locations within the airbag.

As the vehicle landing attitude and resulting vent blockage was arbitrary, relative to the wind, this proved a challenging problem. However, a large database of landing simulations existed, where the orifice was present from the airbag control volume point of view, but not physically modeled in the finite element mesh. This allowed the investigation of candidate locations, including the potential for vent obscuration either through vehicle or ground contact.

Following initial candidate identification, a model with several candidate airbag locations was created. These could be turned on/off alternately. The final configuration demanded two vents per airbag, thus eliminating the potential for total obscuration of the venting of any one airbag. Figure 2 presents the final vent configuration.

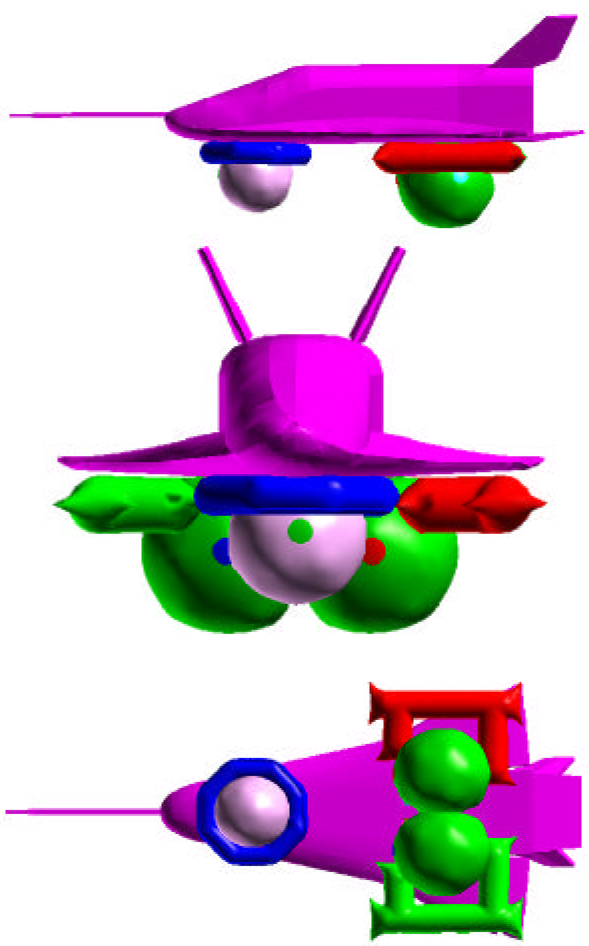

Figure 2 – Final Airbag Configurations

Harness Deployment Simulations

An interesting application of the LS-DYNA tool arrives for instances when harness deployments occur and aerodynamic forces are not relevant. These can include cases where; 1) harness aerodynamics are trivial (such as in the wake of a large vehicle), and vehicle motion is irrelevant (large vehicle/short time), or 2) when both aerodynamic forces are very low, such as in low speed deployments, under main canopy.

Herein, we present two such examples, the first a simulation of the Kistler upper stage (OV) first harness deployment. This simulation includes a representation of the parachute forces (deployment through inflation), but ignores harness aerodynamics – a good assumption due to the base flow region in which the harness deploys.

This simulation is presented in Figure 3. The large conical section represents the back end of the Kistler OV stage. Forces applied to the harness include the parachute force applied to the confluence fitting (deployment through inflation), harness contact with the harness tray, and harness break tie forces, including loading and eventual failure.

In the second simulation (Figure 4), we present a simulation of the re-orientation and harness deployment of the HSFD vehicle. As this maneuver occurs under main canopy descent, the dynamic pressure is extremely low, and aerodynamic forces are therefore, trivial. The LS-DYNA tool was selected for this simulation, as existing multi-body simulations (at Irvin) did not properly account for the single member between the main and terminal confluence fittings.

Figure 5 presents a plot of the harness forces for this maneuver. Peak forces approach that of parachute deployment/inflation. In fact, the harness storage was modified as a result of this simulation to reduce overall maneuver forces.

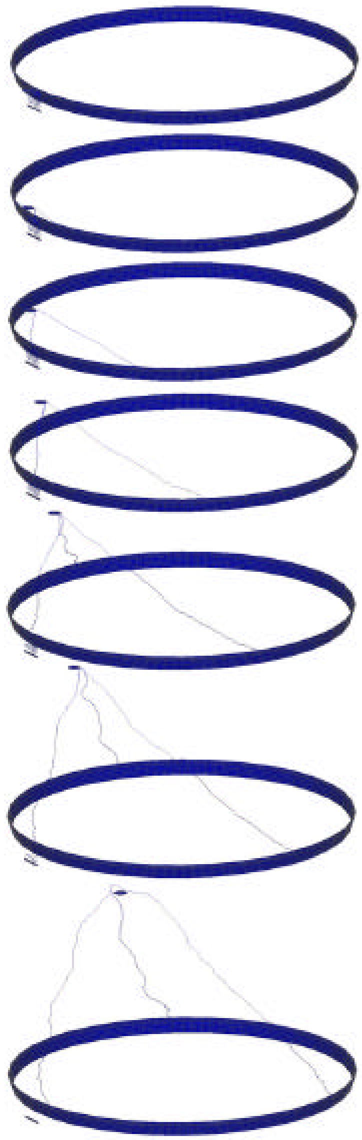

Figure 3 – Kistler OV Harness Deployment

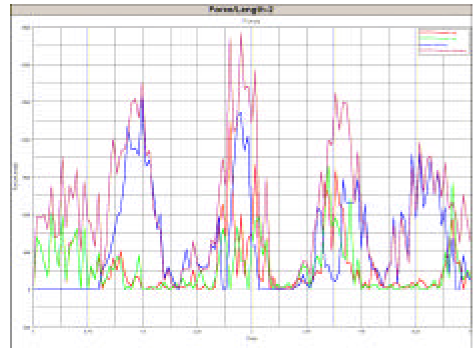

Figure 5 – Re-Orientation Harness Forces

A Generic PMA

The application of Pneumatic Muscle Actuators (PMAs) is well documented by Vertigo Inc, Reference 9 and others.

Herein we present a simple LS-DYNA model of a PMA, consisting of beam elements, which represent the fabric structure, and shell elements, which represent the PMA liner and the LS-DYNA control volume.

The top of the PMA is fixed, and the bottom is assigned a mass. Figure 6 presents a detailed view of the beam and shell elements which make up the FEA mesh.

In Figure 7 the PMA is inflated with an arbitrary gas flow rate. The resulting system contraction is demonstrated.

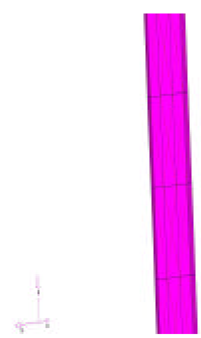

Figure 6

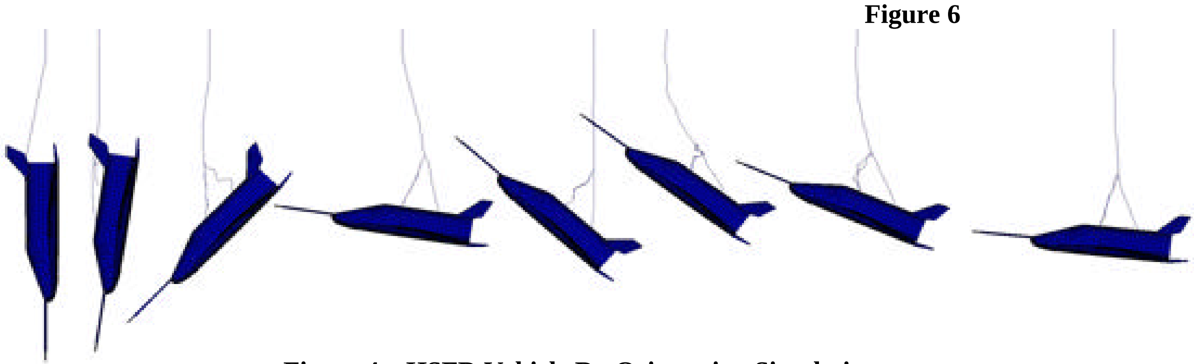

Figure 4 – HSFD Vehicle Re-Orientation Simulation

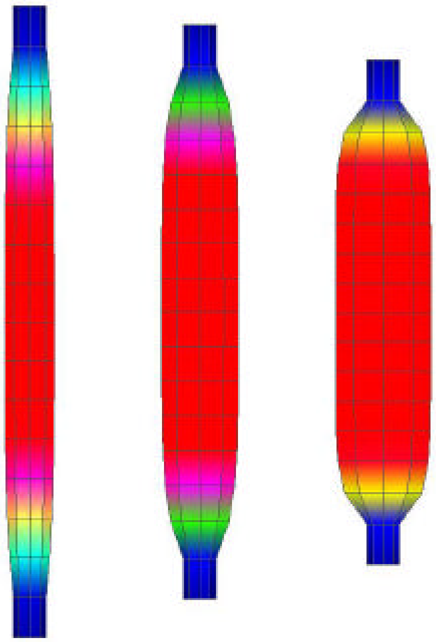

Figure 7

Umbilical Nets

Irvin was involved in the development of impact nets to decelerate umbilicals for a modern launch system. Performance criteria for the nets included the maximum force applied to the umbilical, maximum deflection of the net, and a required safety factor and re-use capability for the nets. These requirements for high performance, combined with the rather expensive and fragile nature of the impact item (umbilical), lead to the requirement to perform impact simulations (on the computer) to optimize the design.

Additionally, the high mass, and high velocity of these items dictated a level of detailed analysis prior to testing. The umbilicals (three different configurations) have weights in the 100 to 600 lb range, and as they are T0 umbilicals, are retracted at velocities up to 30.0 fps in order to clear the ascending launch vehicle. Three separate umbilical configurations were simulated, and multiple net configurations were constructed for each umbilical (in the virtual world), before arriving at a final design. Figure 8 presents a collage of impact frames for two of the umbilical configurations.

Key features of each of these models include:

1) Modeling frame and umbilical as rigid bodies with appropriate mass properties
2) Rotary joints at net frame top to model hinge
3) Non-linear discrete element models dash pot damper near frame bottom
4) Net modeled as fabric elements
5) Umbilical impact simulated at several locations on the net

Simulation outputs included:

1) Net Stress
2) Net Deflection
3) Net Force into Frame
4) Effect of Slack and Reuse in Net
5) Effect of Impact Variation
    a. High Impact
    b. Mid Impact
    c. Low Impact
    d. Impact Body CG and Rotation

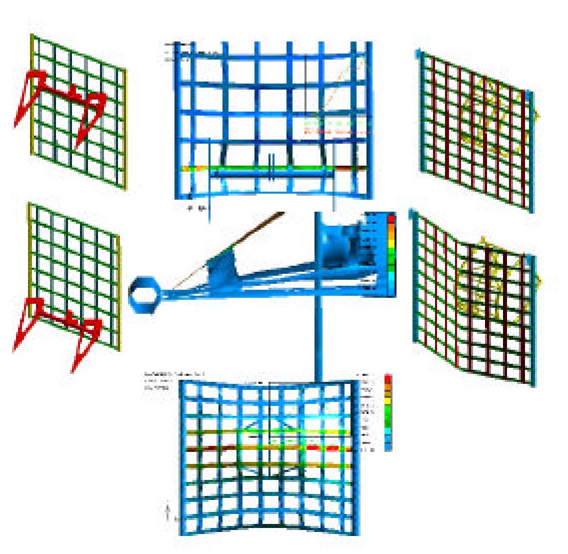

Figure 8

Beam Buckling Problems

Two beam buckling problems have been under investigation. The first is related to an inflatable decoy manufactured by Irvin Aerospace Ltd. In this application, the inflating beam can have multiple bend angles during the inflation process. LS-DYNA was used to assess the stress increase due to various buckling angles and inflation pressures. Figure 9 presents a graphic of one such result. In this analysis, the buckled stress is approximately 1.6 times the nominal tube stress, a significant increase over the basic tube stresses.

Another investigation involves the stress analysis of a large breakwater system constructed of pressurized fabric tubes. Irvin is working this analysis in partnership with Vertigo Inc. The application of current and wave loads allows the analysis of beam stress, required reinforcement, internal pressure, and beam deflection. The simulation of dynamic beam loading and potentially fluid representation is planned for the coming year. Figure 10 presents one such beam buckling result.

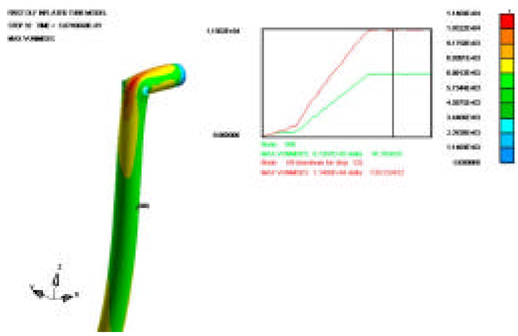

Figure 9

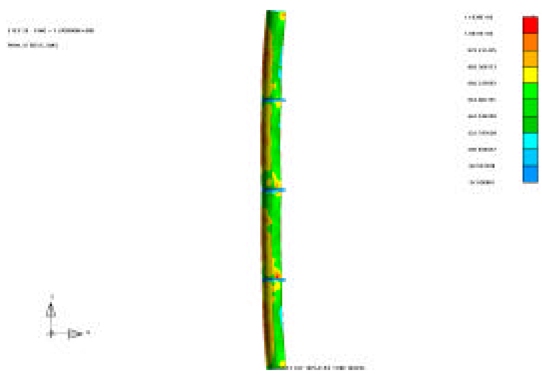

Figure 10

Summary

Finally, we present a brief discussion of the future of such simulations, as they might affect our industry. First, simulation improvements are almost daily. Irvin experiences excellent support from the software vendor (LSTC), with unique code improvements, to our specification happening often. Actually, we are typically, 1-2 releases ahead of the production release due to unique features, and often receive these updates in days (or less).

Secondly, computer resources continue to soar, making the level of problem per hour of computation proceed at the same rate. Additionally, improved turn around improves the model development time, as shorter runs shorten the mistake/correction cycle.

One coming technology will be the application of Massive Parallel Processing (MPP) to this simulation tool. LSTC is investing heavily in this area. Imagine all your high-end CAD stations working together on analysis programs overnight, instead of sitting idle. Standard network connections (10BaseT or 100BaseT are the planned interface between various computers). The light bill is easily balanced by the improved resource allocation.

Finally, the significant fluid capability currently available in this tool provides the ability to explore true Fluid Structure Interaction (FSI) problems. The current capability represents a Navier-Stokes solution with a moving mesh. The current fluid-structure coupling capabilities are impressive, allowing rather simple fluid to structure coupling, and are rapidly expanding.

Modeling of fabric porosity is currently being reviewed and the ability to model multiple materials within the same mesh (air and water) is currently available, Figure 11 presents a water entry problem, which utilizes these capabilities.

With regard to parachutes, the obvious early applications are not related to parachute inflation simulation. That will come with further computing advances, that is, these problems will be possible in a few years, at high speed computing centers. Industry application will require multiple years of advancement in both hardware and software, but it will come.

Rather, we believe that parachute design can benefit immediately from computer assistance to age-old problems such as:

1) Porosity optimization between drag and stability
    a. Single Canopy
    b. Clusters
2) Geometry optimization
    a. Line Length
    b. Pull down vent length
    c. Cluster riser length
3) Glide/drive optimization
    a. Venting/drive panel
    b. Riser slip condition

Figure 12 presents the inflated profile of a cross parachute (1/4 symmetry), as completed through an early attempt at FSI simulation of parachutes with LS-

DYNA. Figure 13 adds a view of the fluid flow field total velocity around the inflated parachute.

We believe that initial results, perhaps as significant as the airbag configuration data presented above, will be the subject of our paper at the next ADS conference, certainly, within the four (4) years between now and the 2005 conference.

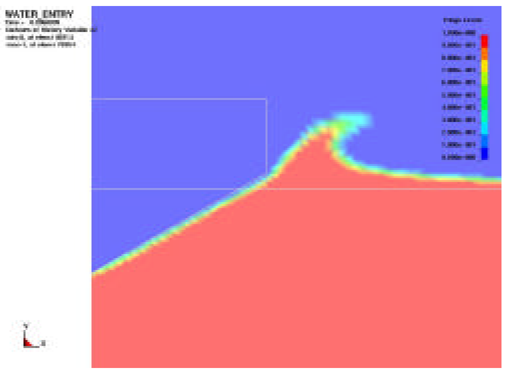

Figure 11 – Water Entry Problem

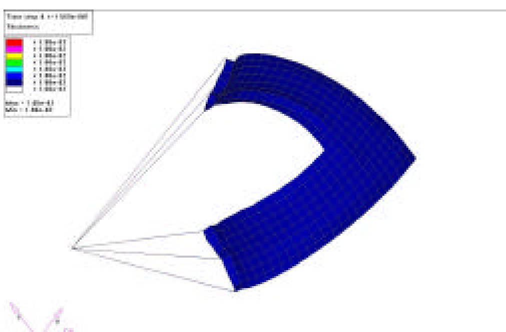

Figure 12

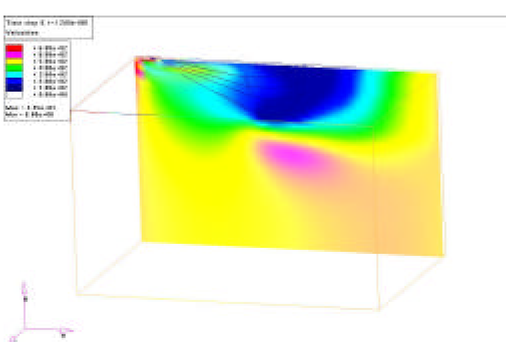

Figure 13

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Appendix 1 – Typical Computer Specification

Pentium III	900 Mhz
	Dual Processor
Memory	512 Mb
Graphics Card	64 Mb Frame
	64 Mb
Storage	36-54 Gb