Airbag Folding with JFOLD Latest Developments and Case Studies

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1 Abstract

JFOLD is a software tool for simulation based airbag folding in LS-DYNA®. Today's airbag deployment analysis demands accurate folding of complex designs, but this is often a very time consuming process requiring expert input. JFOLD's continuous development focuses on making the process simpler and quicker and to give the non-expert access to complex folding techniques. This is achieved through three core elements: intuitive user interface, built-in customisable tool libraries and realistic, state of the art examples and tutorials.

This paper describes a driver's airbag case study of two folding patterns with deployment validation using CPM. Two methods of folding a passenger airbag will also be shown, including and a novel way to quickly flatten the bag from 3D to 2D.

To further reduce airbag development cycle times and cost, a new airbag morphing application is under development to help the user optimise the design in a virtual environment. This and other new features will be presented.

2 Introducing JFOLD

JFOLD is a software tool developed by JSOL Corporation that helps the user perform simulation based airbag folding. It runs inside Oasys PRIMER as a JavaScript, and uses LS-DYNA® to simulate each folding step. The JFOLD graphics interface is designed to be easy to use and intuitive, so only a basic knowledge of LS-DYNA or PRIMER is needed.

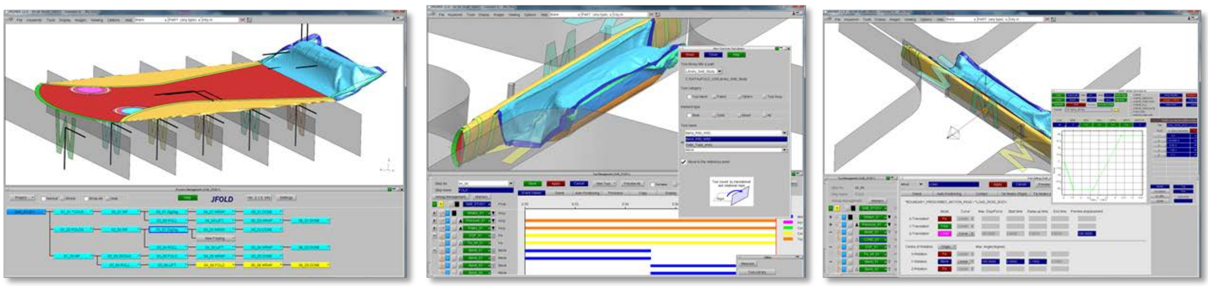

Fig.1: Figure 1: JFOLD's GUI: process management, tool management & tool setting panels

JFOLD's special benefits
- Folding steps managed using flow-chart graphics
- One-click auto-positioning of tools
- Reusability of tools
- Non-encrypted input files
- Free, state-of-the-art example models to use as templates

2.1 How it works

JFOLD manages the folding processes in a series of "steps". Each step uses one LS-DYNA analysis to deform the model like a real fold, stitch panels or relax fabric, etc. The airbag model is passed from step to step, using the deformed shape from the previous analysis. Folding steps can be modified, copied and branched off at any stage to investigate different folding patterns. "Tools" are used to deform the airbag and these can be copied across steps, imported from the built-in library or from the user's own.

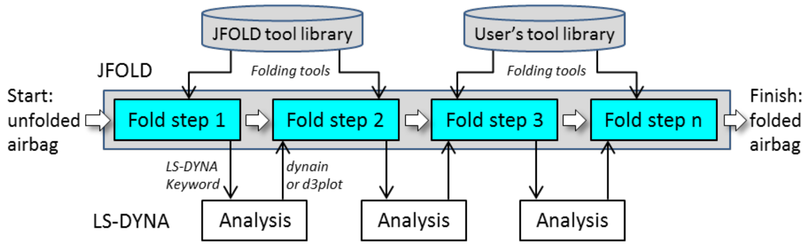

Fig.2: Schematic of one folding process using JFOLD

2.2 Tools available in JFOLD Version 3 Example Library

Category	Element Type	Characteristic (Action/tool type)	Extras
Tool Mesh	shell plates (11 sizes) solid plates (11 sizes) shell tubes (4 sizes)	Interchangeable action types: Move, Stationary, Load, Press, Roll, Fold, FinalGeom, dependent	Contact to airbag. Connected to airbag via extra nodes, rigid beams or tied contact.
Fabric	Non-mesh entities that are applied directly to airbag fabric	Pressure, LoadNodes, FoldLine (beams), Fix (SPC), Rigidify (NRB), Stitching (beams)	Many unique settings for each type.
Tool Assembly	Fold assy (3 sizes) Z-fold assy (4 sizes) DAB inflator	Special pre-defined action types	
Others	Inflator mesh examples (DAB, SAB, CAB, PAB) Cables	Inflators are FinalGeom type Cables are beams	

Table 1: Tools in JFOLD's example library are grouped into four categories

2.3 New Features in JFOLD Version 3

2.3.1 Moving tools using cables

With this capability cables pull a tool into a desired location by shrinking to zero-length over a defined time. Exact translations and rotations need not be defined. Tools move as a rigid body and can follow curved paths, as shown below.

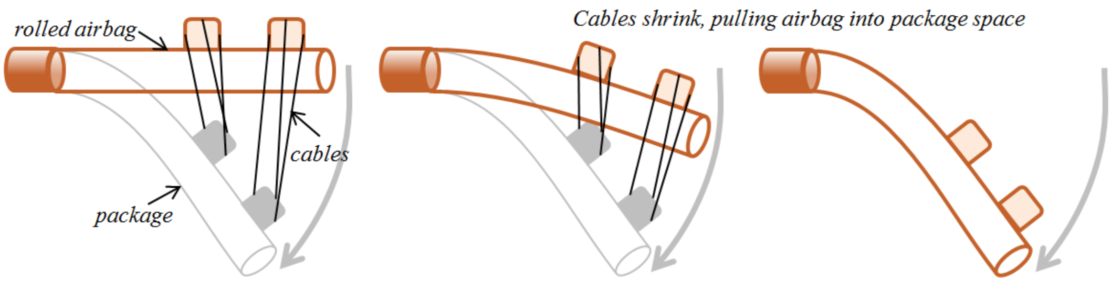

Fig.3: JFOLD Cables Tool can pull parts into position

2.3.2 Tying airbag fabric to a tool using tied contact

Tools can be "stuck" to airbag parts so that the fabric moves with the tool. The tied contact has the benefits of birth/death times for the sticking action, tools can be rigid or deformable and by default all airbag nodes within the adjustable contact thickness are tied to the tool.

2.3.3 Managing stress relaxation in the airbag fabric

Version 3 allows the user to control the timing of the stress-strain restoration ("relaxation") in ***MAT_FABRIC**. This feature can be used to "shrink" a wrapper or cover over the folded airbag at the end of the folding process, if the user imports the wrapper in an expanded condition with its own reference geometry. It can also be used to fit a curtain airbag into a complex package space as shown below.

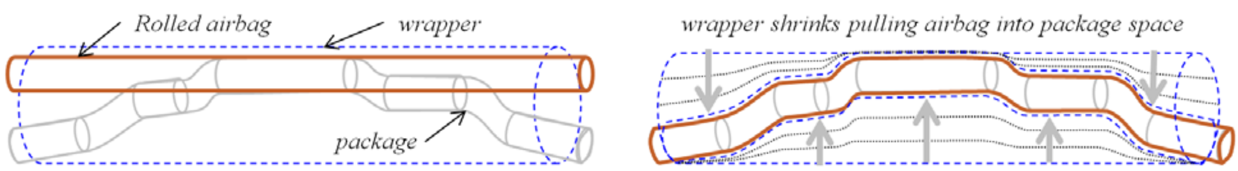

Fig.4: JFOLD shrink-wrap pulls a curtain airbag into position

2.4 Developments in JFOLD Version 4

The next version of JFOLD contains many user-interface and speed enhancements (copying tools is now 30% faster than v3). Other main additions include:

2.4.1 LS-DYNA submission to local processors

Each step can be submitted directly from within JFOLD's process management panel to LS-DYNA running on local processors. The analysis progress is tracked and the button changes colour according to the job and termination status. LS-DYNA executable and number of processors are defined in a new settings panel. (LS-DYNA license sold separately). In the future JFOLD will be able to run a chain of folding analyses automatically.

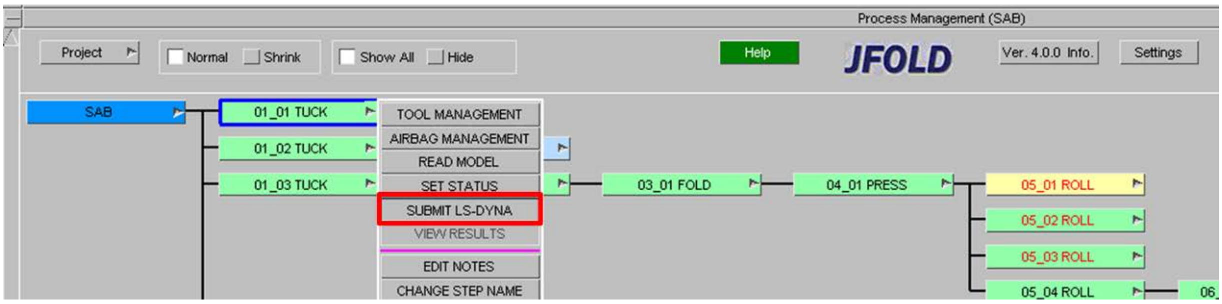

Fig.5: LS-DYNA submission to local processors available in JFOLD v4

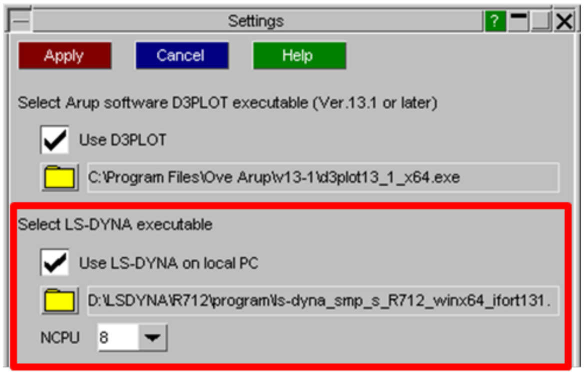

Fig.6: Local LS-DYNA executable and number of cores defined in the new settings panel

2.4.2 Deformable tool type

This addition to the tool mesh category supports **`*MAT_ELASTIC`**, **`*MAT_FABRIC`** and other deformable material types. For example a rigid tube is used to roll up a curtain airbag in one step, then changed to become a flexible core in the next step. This core keeps the rolled section of fabric stable when deformed to fit the vehicle. For **`*MAT_FABRIC`** tools JFOLD v4 can create and modify the ***`AIRBAG_REFERENCE_GEOMETRY`** for that tool, allowing "shrink tubes" shown earlier to be generated using tools rather than airbag components.

2.4.3 Folding Assessment Report

To help the user determine the success of the airbag folding analysis JFOLD v4 will report:
- The number of crossed edges (contact penetrations) that exist in the resulting airbag
- The % area change when compared to the reference geometry or previous state.

3 Case Study: Driver's Airbag (DAB)

In 2011 the Occupant Safety Research Partnership (OSRP), a division of the United States Council for Automotive Research LLC (USCAR), made available on-line their 2006 research "Benchmark Problems for Evaluating OOP Simulation Capabilities of Occupant Safety Simulation Codes".[1]

Test Set 1 comprised pendulum data for a generic driver's frontal airbag folded using two different folding patterns: zig-zag and top-roll. The set also included inflator data, simple wheel and pendulum models, and enough information to develop a DAB model using the corpuscular particle method (CPM) in LS-DYNA.

The differences in pendulum acceleration for the two folded patterns were only significant for test cases where the module lid is fitted. However accurate module geometry and material data were not available so for this study we just used the no-lid test data to validate a baseline DAB model.

3.1 Objectives

- JFOLD technical development – feedback to developers to improve future versions
- Create realistic examples to give to JFOLD customers to use as templates for their work
- Promote the capability of JFOLD using non-confidential real-world examples
- Create a realistic baseline DAB model with which we can develop out-of-position (OOP) countermeasures and research new capabilities in LS-DYNA

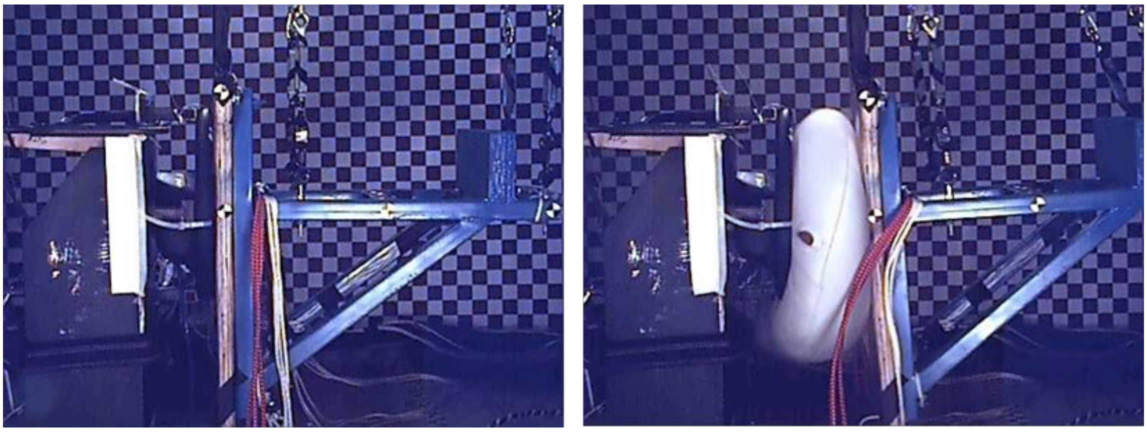

Fig.7: DAB Pendulum Tests from the USCAR Research

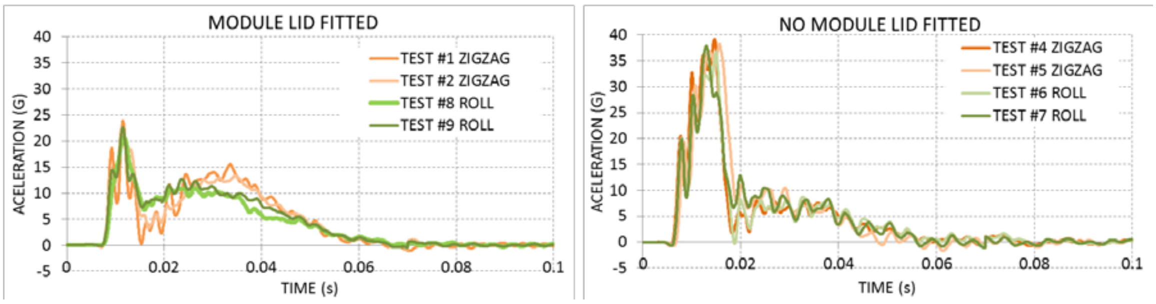

Fig.8: USCAR Pendulum accel. curves for tests with (left) and without (right) the module lid

3.2 Airbag Modelling & Folding

An existing generic DAB model was adjusted for size, 240mm tether length and vent diameter. The vents were not in the same location as seen in test film but considered good enough for this study.

3.2.1 Pattern 1: Top-Roll

The USCAR DAB used a "top-roll" pattern. (The more common reverse-roll pattern is shown later in this section.) A pressed, flat bag is first rolled up using JFOLD's Roll Tool assemblies, then pressed and rolled again into the middle. In both roll cases pressure is applied to the fabric to reduce wrinkling.

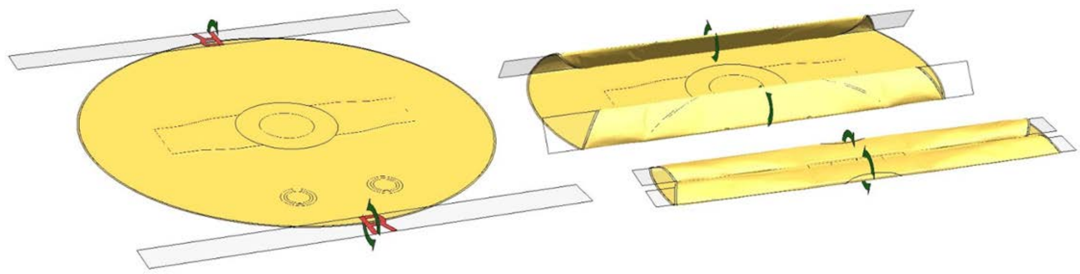

Fig.9: JFOLD Step 1 – roll folding using plates

For the second roll we use pairs of solid rods instead of plates – these provide a better contact surface and take up less space among the folded layers. The rods can be easily positioned to generate the correct roll width. Solid rods are available in JFOLD's example tool library from version 4.

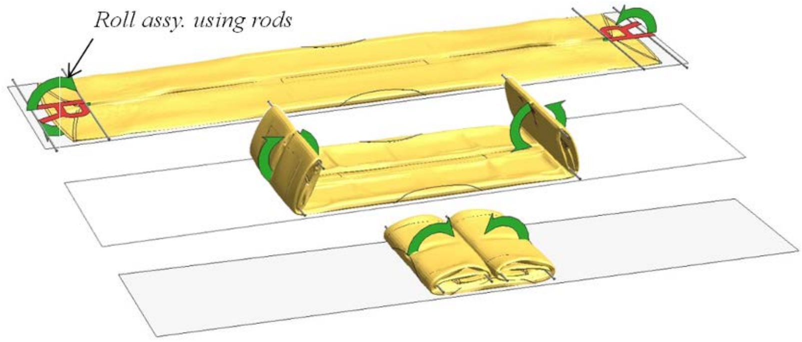

Fig.10: JFOLD Step 2 – roll folding using rods

The inflator is pushed into the folded bag while the wrapper is fitted. This combines two tasks and avoids premature unfolding. The user's own inflator model can be used here or the example model in JFOLD's tool library.

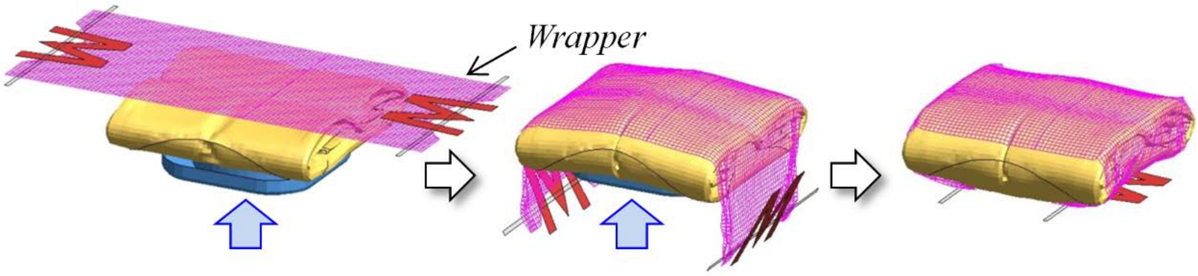

Fig.11: JFOLD Step 3 – wrapper and inflator fitting

Finally the module case is shrunk to real size, squashing the corners so the bag fits perfectly.

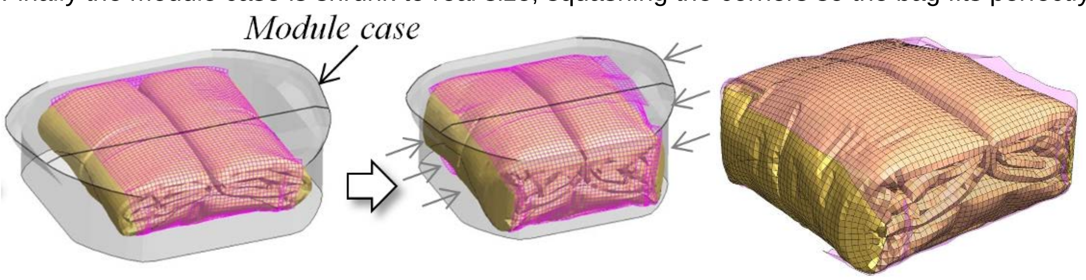

Fig.12: JFOLD Step 4 – fitting to the module case & final model (right)

JFOLD automatically creates reference geometry at the start of the process and stress relaxation is performed at every step, however high stresses and strains can still build up during folding, and these can cause severe wrinkles and distortion in the final model. The techniques shown in these examples have been refined to avoid high stresses from the start.

3.2.2 Pattern 2: Zig-Zag

The second pattern tested by USCAR involves two zig-zag folds. Both can be quickly executed using JFOLD's Z-Fold Tool Assembly. These tools use varying forces to move rather than prescribed motion so exact trajectories need not be calculated. In this example Fold Line Beams are used to fold the ends over cleanly.

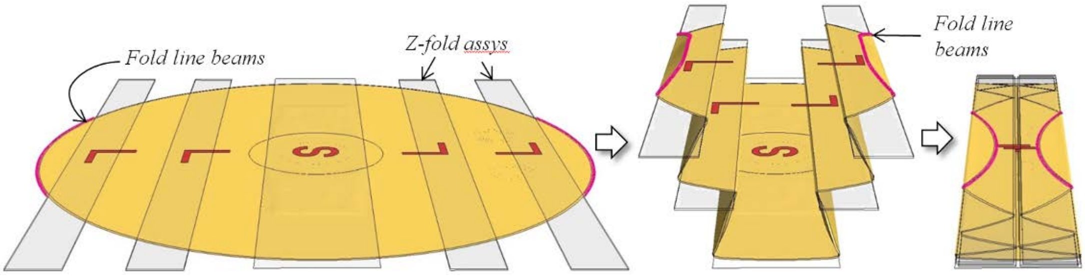

Fig.13: JFOLD Step 1 – zig-zag (Z-Fold) folding using plates & Fold Line Beams

For the second zig-zag fold solid rods are used again to cope with the thicker material. In this step a thicker portion of fabric must be folded at the ends, so Move Tools were used instead of Fold Line Beams. The Move Tools use the same forces as the Z-Fold Tools but also rotate 180^0.

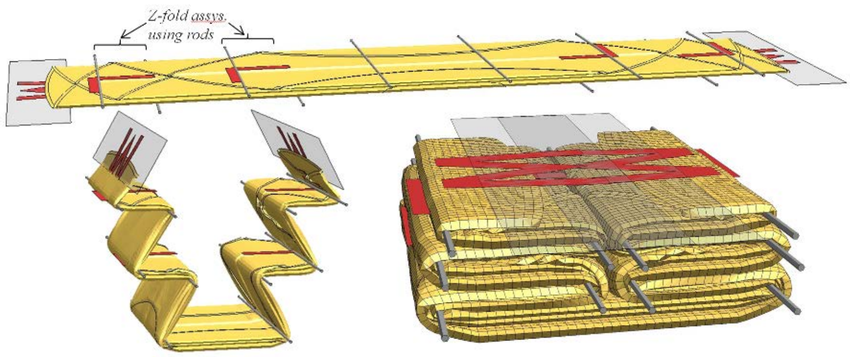

Fig.14: JFOLD Step 2 – zig-zag (Z-Fold) folding using rods

3.2.3 DAB Standard Reverse Roll

Although not used in the USCAR study this pattern is commonly found in production and is included in the data made available to JFOLD customers.

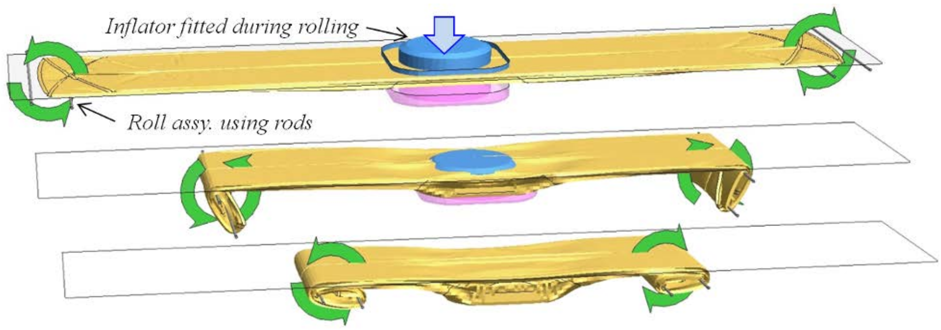

Fig.15: JFOLD Step 1 – roll folding using rods

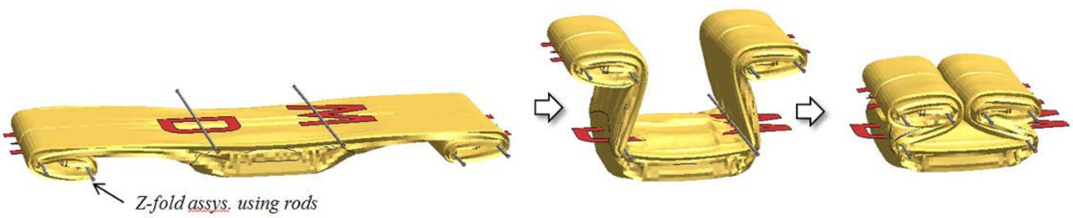

Fig.16: JFOLD Step 2 – Z-Fold using rods

3.2.4 Unfolded Airbag Model

The data set included pendulum tests performed on unfolded airbags so this geometry was also created using JFOLD. An inflator was pushed into the bag which was also in contact with a stationary steering wheel module.

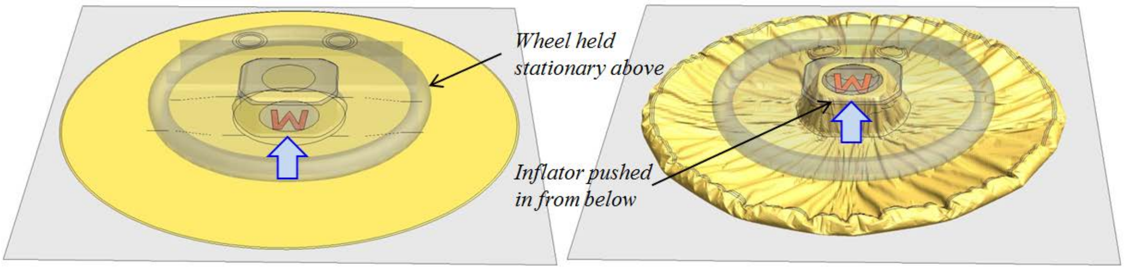

Fig.17: JFOLD generating the unfolded condition model

3.3 Deployment Analysis using the Corpuscular Particle Method (CPM)

3.3.1 Validation of venting & porosity

First task was to validate the vents and fabric porosity used in the model. This was done by correlating to static pendulum tests of unfolded airbags with and without vents and fabric coating.

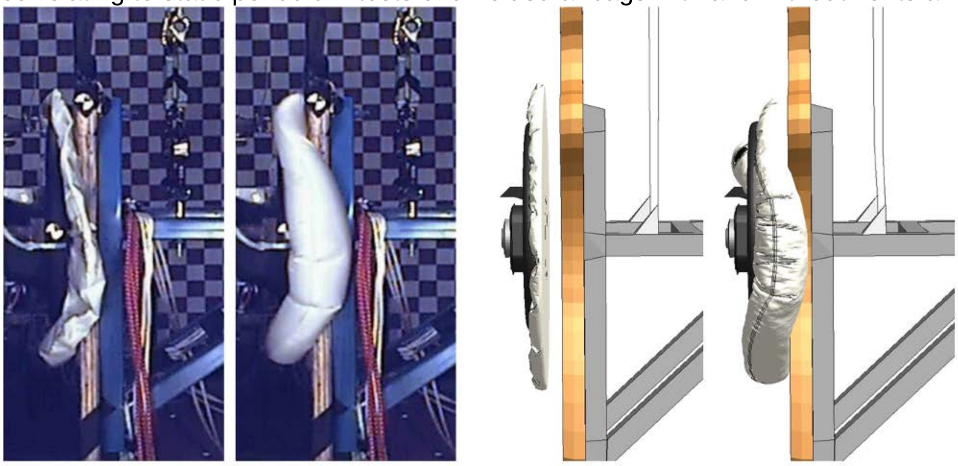

Fig.18: Static pendulum tests on unfolded airbags, test (left) and analysis (right)

Good correlation was achieved by tuning heat loss, leakage under the inflator and fabric porosity (all within realistic levels). Vent patches were assigned a soft material so they can stretch open under pressure. CPM's enhanced venting (ENHV=1) was also used.

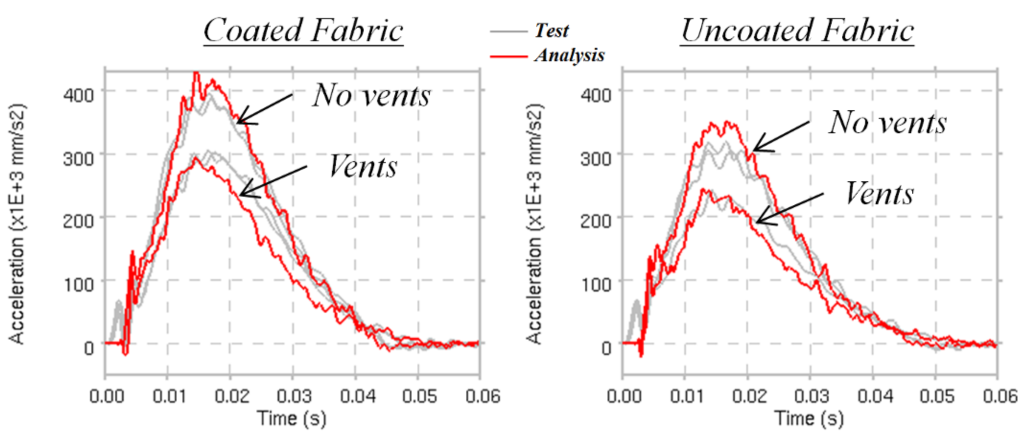

Fig.19: Pendulum acceleration for unfolded airbags

3.3.2 Static pendulum test correlation

The second task was to simulate the folded airbag pendulum tests without module cover lids.

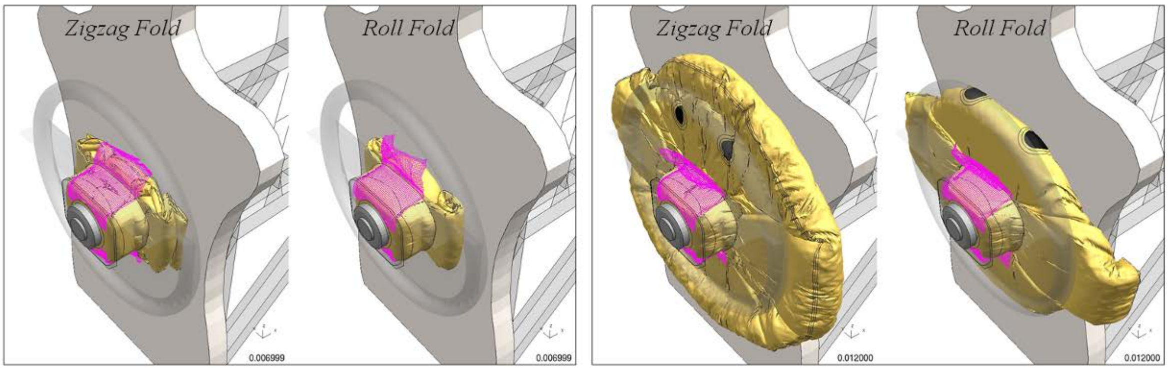

Fig.20: Deployment differences of zigzag and rolled airbags at 7ms (left) and 12ms (right)

Again, a reasonable correlation level was achieved with minimum tuning.

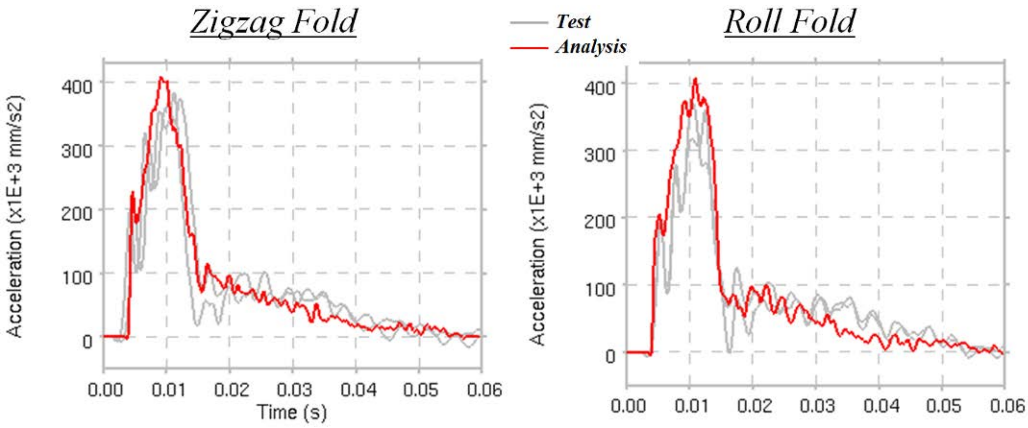

Fig.21: Pendulum acceleration for folded airbags (no lid)

3.4 DAB Case Study Summary

This well-tuned model has already been used for airbag research, aiding in the development of directional inner venting for CPM (VANG=-2, shown below). Further work will include improving CPM capabilities for OOP countermeasures (push-out vents, etc.), module rupture modelling techniques for break-out and enhancements to CPM gas flow field visualisation in D3PLOT.

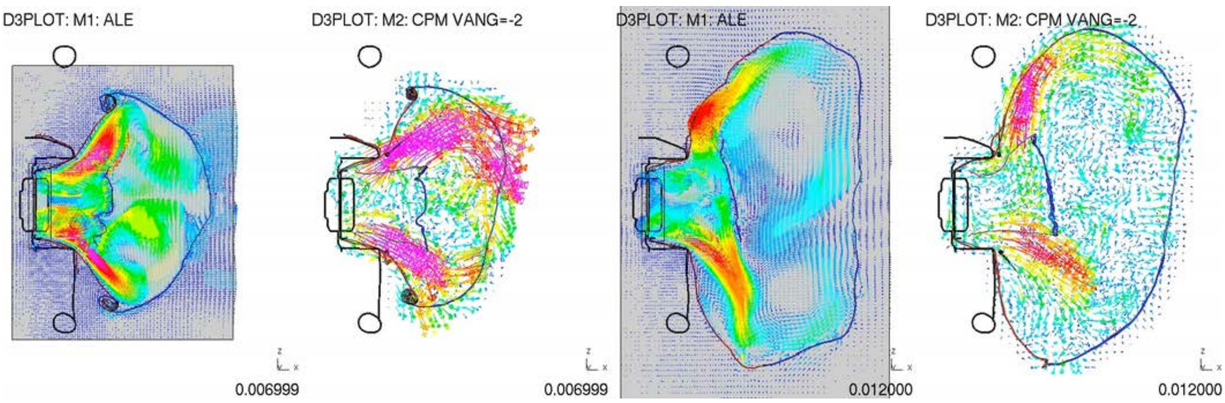

Fig.22: ALE gas flow (left) used to benchmark directional internal venting VANG=-2 for CPM (right)

4 Case Study: Passenger Airbag (PAB)

In the second case study two techniques for folding a passenger airbag (PAB) are presented. PABs are usually three dimensional in construction and must be flattened during the folding process, usually according to a complex pattern of tucks and folds. This 3D to 2D step is one of the biggest challenges in folding airbag models. In the following pages we present a classical way of 3D-2D flattening; using plates to tuck the front and sides, and also a new much faster method using beams to define the fold crease lines. The objectives of this study were very similar to the DAB research above.

4.1 Reference data

The same USCAR research mentioned previously[1] included in "Test Set 2" drop-tower and OOP test data for a typical passenger airbag. The airbag description and folding information was insufficient for accurate modelling but the overall dimensions and general folding pattern were used as a basis for this study.

Fig.23: Photos of the PAB from USCAR research in unfolded, partly-folded and folded states

4.2 Method 1: using plates and rollers (flattening process only)

As the shape of the PAB model was made up, no fold line information was available for collapsing the 3D structure to 2D. To get the inflated shape to fold flat without severe wrinkling a series of side tuck folds and stretching folds were performed. In all five steps (five analyses) were required. Previous experience guided the approach but still this process took a long time with much trial and error.

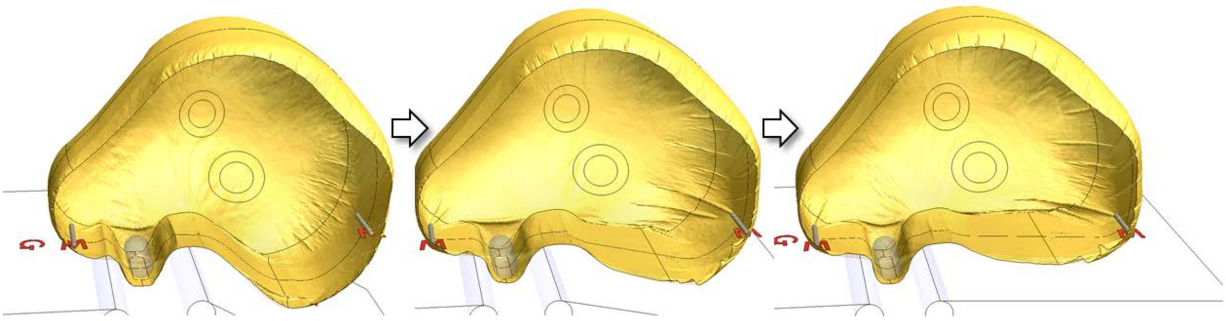

Fig.24: Step 1 – inner rollers & plates make the base flat

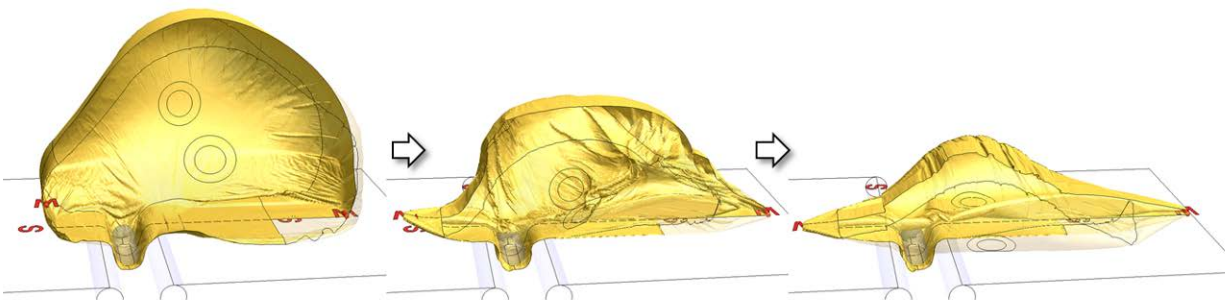

Fig.25: Step 2 – inner rollers stretch the bag while pressure pushes sides inwards

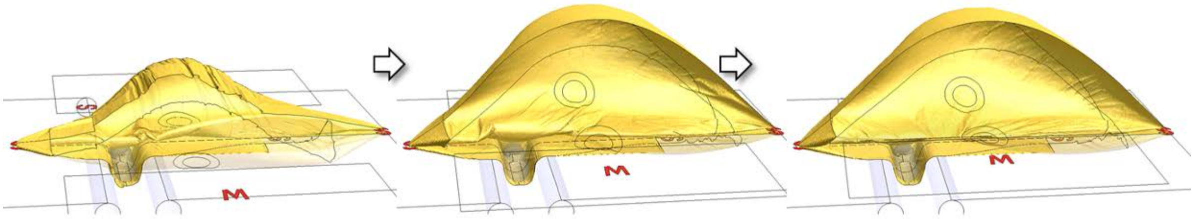

Fig.26: Step 3 – plates slide in to tuck the sides while pressure inflates the upper section

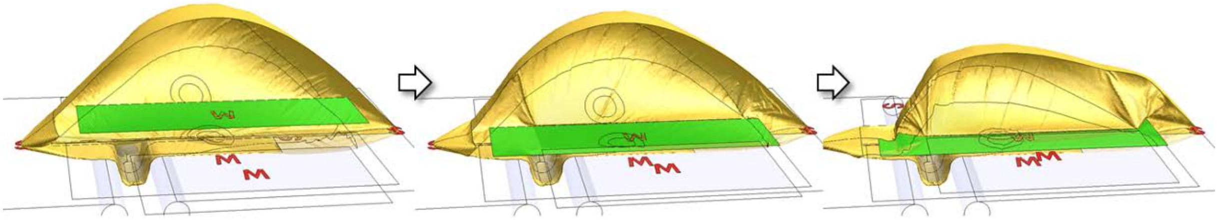

Fig.27: Step 4 – inner plate (green) presses the previous tuck while more plates slide in from the sides

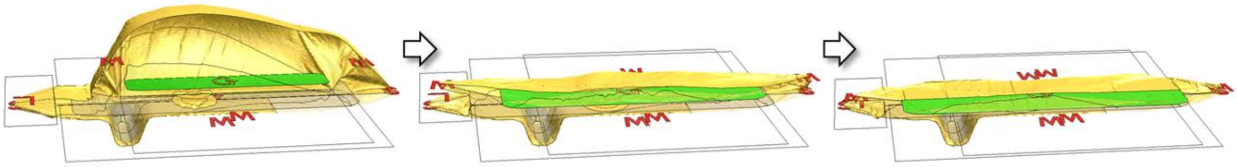

Fig.28: Step 5 – inner rollers used again to stretch the bag while pressure makes the last side tuck

4.3 Method 2: Using scanned fold lines (full folding process)

One objective of this study was to develop a faster and easier method of 3D-2D flattening. A new approach was considered that assumes most users have access to a real airbag with fold crease lines visible when unfolded. In our virtual model we took the crease lines from the example flattened in the steps shown earlier. The whole modelling process is included in this description.

4.3.1 Meshing from CAD

If the PAB geometry is very simple, CAD surfaces can be constructed in a 3D condition that enables the CAE modeller to mesh the parts already stitched up. However most PAB geometries are not simple and many users prefer to start by meshing 2D CAD surfaces of flat, separate fabric panels. In this method, seam lines are stitched together using beams between every node on matching perimeters. The mesh around the perimeter must therefore line up exactly for later merging of nodes. A good meshing pre-processor can achieve this without much effort.

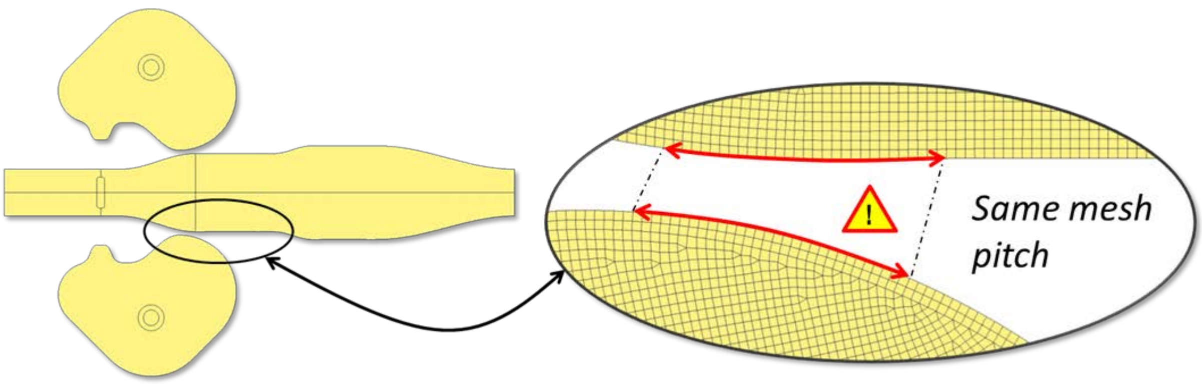

Fig.29: Creating the 2.5mm 2D mesh – perimeter mesh must match up

4.3.2 Transposing the fold line geometry

The next step is to open up the real airbag, scan the crease lines using a 3D measuring arm and convert those lines to beam elements of **MAT NULL** material. Again, good meshing software can achieve this very quickly. The beam elements can be independent of the fabric mesh, attached with a tied contact. Beam length should roughly equal the fabric shell mesh length.

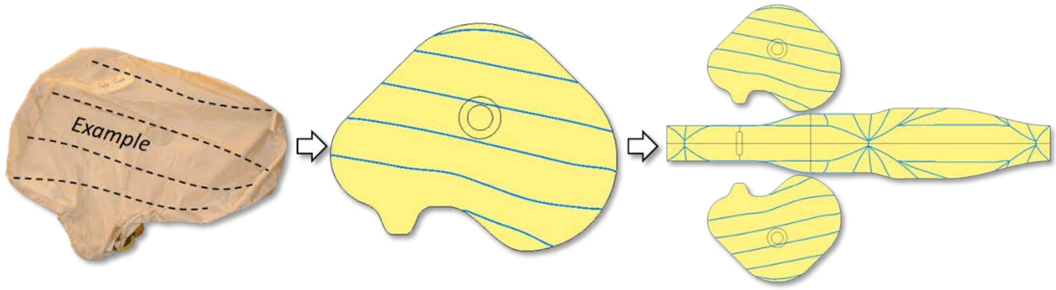

Fig.30: Transferring crease line geometry to the mesh surface as beam elements (example only)

4.3.3 Folding using JFOLD

Starting with the mesh of the flat panels marked up with the fold lines beams, the whole folding process can be performed in JFOLD very quickly with little trial and error.

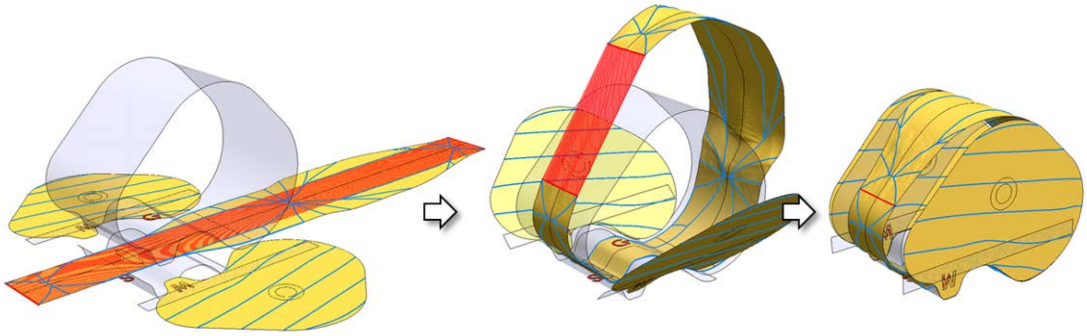

Fig.31: JFOLD Step 1 – Wrap and assemble the 3D shape from 2D meshed surfaces

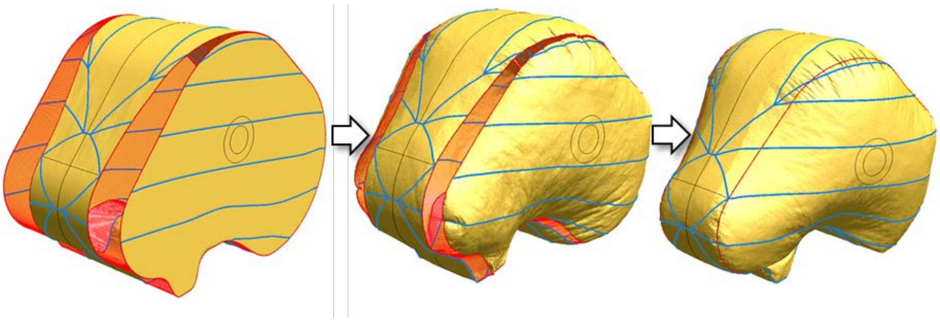

Fig.32: JFOLD Step 2 – Stitching the sides whist applying low pressure inflation

In Step 3 pressure is applied to fabric between the fold lines and load is applied to the fold-line beams so as to collapse the 3D shape. The simulation follows the established folding geometry of the real bag so requires only low pressures/forces and little wrinkling or stretching occurs.

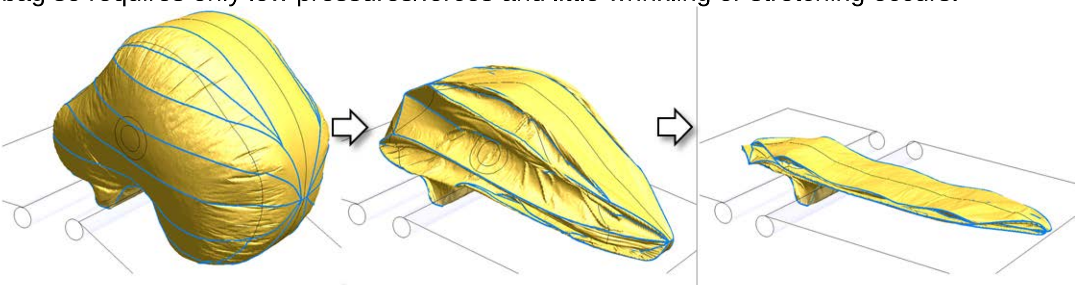

Fig.33: JFOLD Step 3 – Flattening the 3D bag into to a 2D folded shape

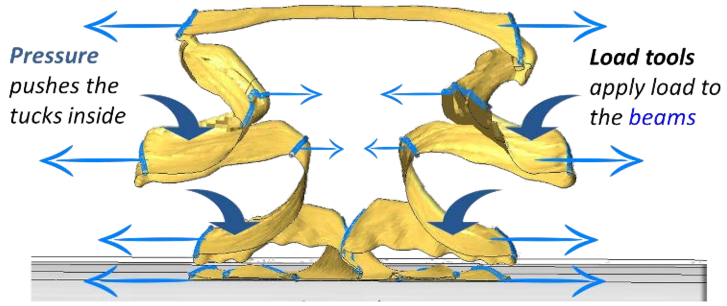

Fig.34: Cut section showing detail of the flattening process

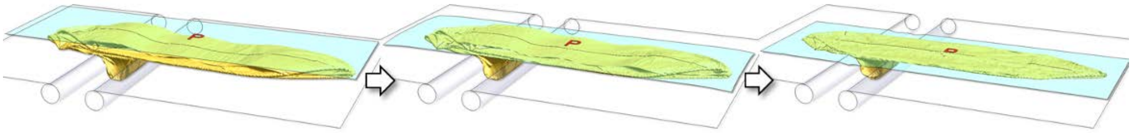

Fig.35: JFOLD Step 4 – Pressing to remove large gaps

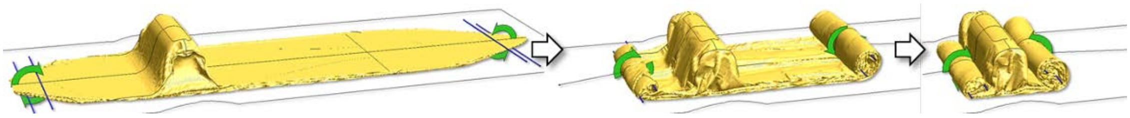

Fig.36: JFOLD Step 5 – Rolling up

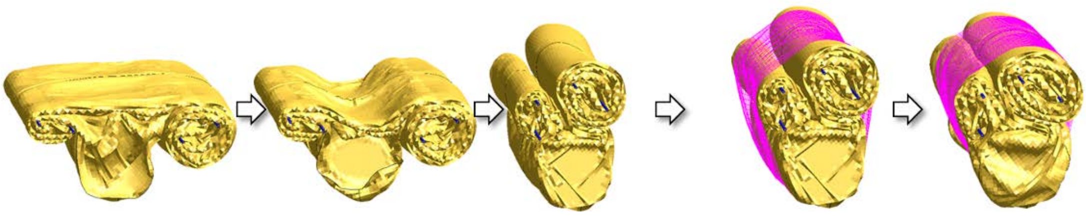

Fig.37: JFOLD Step 6 – Folding up the rolls and fitting the wrapper

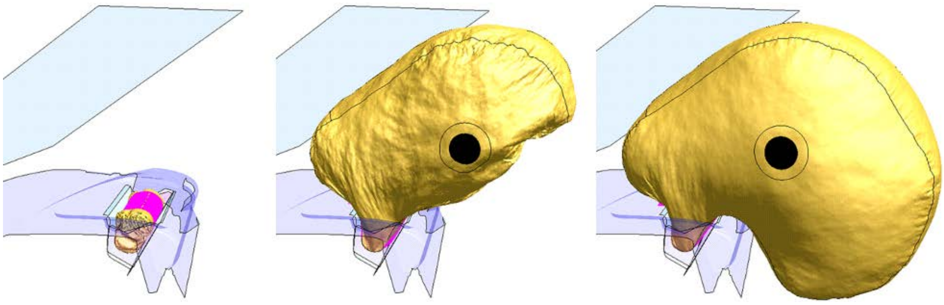

Fig.38: PAB deployment check using CPM

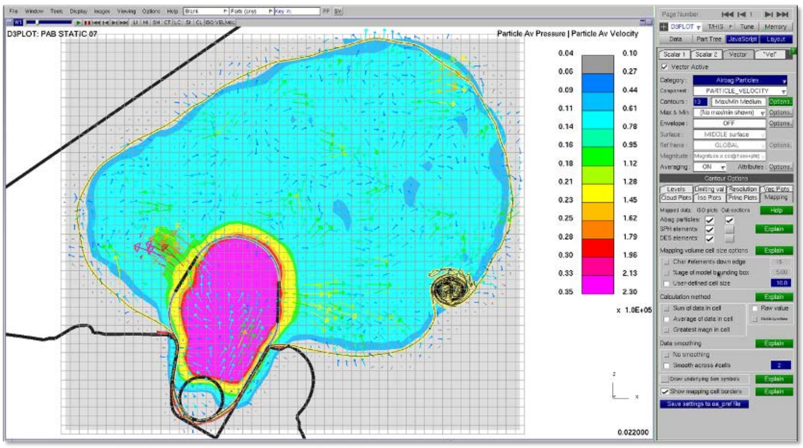

Fig.39: Visualising particle flow velocity and field pressure in a PAB with inner bag in Oasys D3PLOT

5 PAB Design Tool – Shape Morphing

Customers have requested the ability to morph the shape of the airbag to fulfil certain design criteria. This capability will be added to JFOLD in development phases spanning the next few releases.

5.1 Interactive shape morphing

After the stitching step in the previous folding process, models of the instrument panel, windshield and occupant can be imported as “tools” into a new JFOLD step. The user can then modify the shape of the inflated airbag interactively so as to make its deployed shape closer or further from the occupant or windshield.

This morphing process will use the interpolation feature of PRIMER’s scale & translate functions. The user selects an area of airbag to morph then drags the shape on the screen or inputs scale factors. The neighbouring area is stretched according to the selected interpolation function.

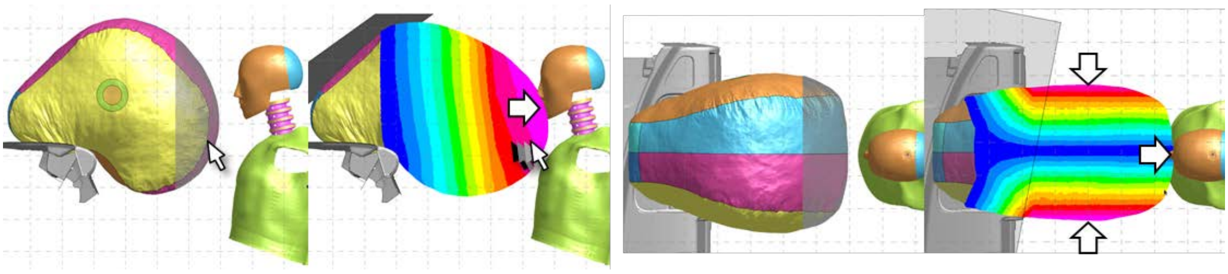

Fig.40: Shape modified by dragging or scale factor input in PRIMER’s orient interpolate function

JFOLD will calculate airbag volume and distance to the various “tools” (occupant head, chest, windshield etc.) and report the data during this process.

Once satisfied with the morphed shape the user can check that the deployed bag will achieve this condition by saving the step and running LS-DYNA. The results are then read into the next step where JFOLD again reports volume, distance to tools and also contact forces. The final deployed shape can also be visually inspected in JFOLD and results of the deployment in Oasys D3PLOT.

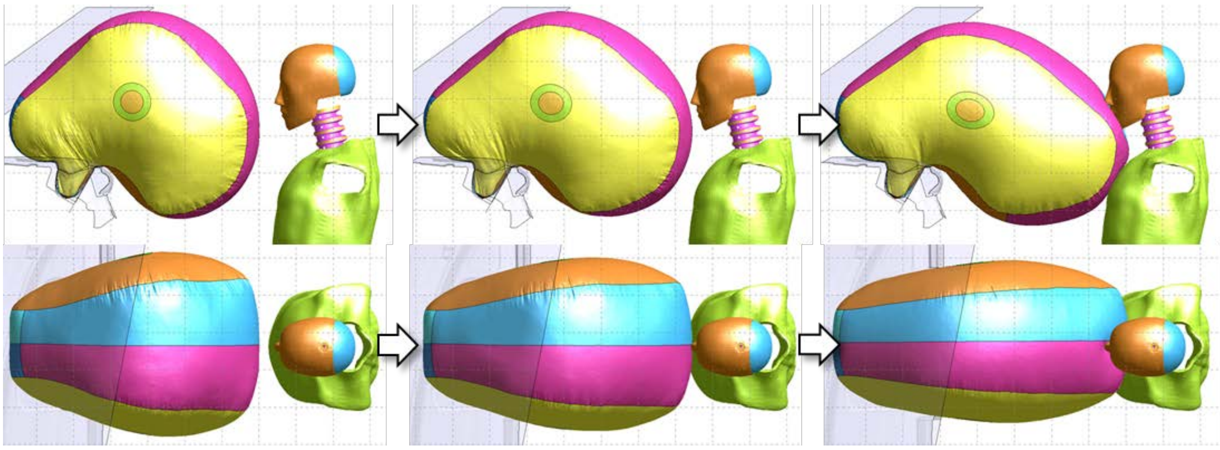

Fig.41: Checking the new shape using 20kPa inflation in LS-DYNA (Oasys D3PLOT)

If all criteria are not met the user can return to the previous step or easily copy the data to a separate new “branch” for further adjustment.

If all criteria are met, JFOLD can then generate new 2D reference geometry for the new PAB design using an LS-DYNA analysis to morph the fabric in a constrained 2D condition. Crease line beams can be included in this process and the panels do not need remeshing. However this approach will not work if the shells have been locally highly distorted out of the plane of the panels.

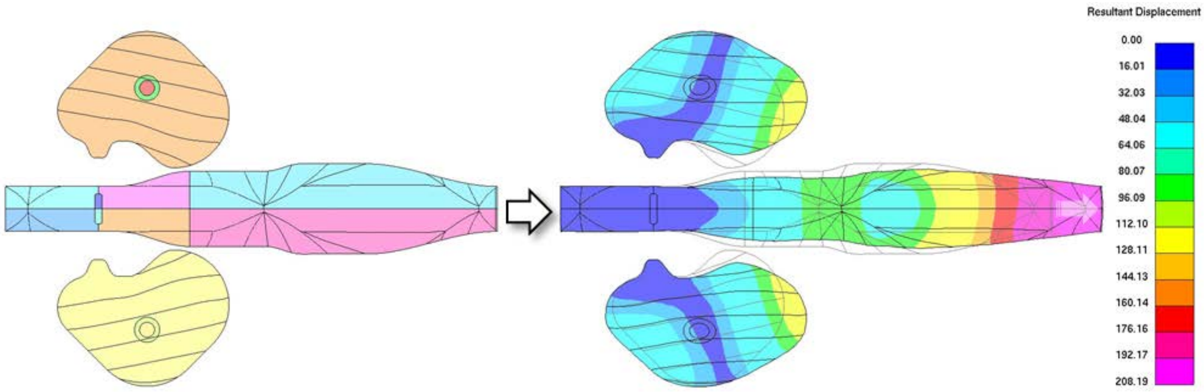

Fig.42: Using LS-DYNA to morph the 2D reference geometry into the new size/shape

The new 2D mesh can then be quickly refolded using the same tools and steps as performed earlier, albeit with adjustments for the new size/shape (e.g. one more roll may be needed if the airbag is longer than before).

This shape morphing capability will be gradually enhanced over time, for example options to avoid morphing the vents, or functions to scale the size of the vents.

6 JFOLD Examples & Tutorials

High quality realistic examples and tutorials are one of JFOLD's special benefits. As of March 2017 the following data is available free to JFOLD customers (supported in JFOLD v3):

Airbag Type	Example data	Tutorial
Side airbag (simple)	✓	✓
Side airbag (realistic)	✓	✓
Driver's airbag	✓	
Curtain airbag	✓	
Passenger airbag	✓	

Table 2: Example and tutorial data available for JFOLD v3

7 Summary

This paper has introduced JFOLD capabilities though two case studies and discussed new developments for future versions. The next release, Version 4, is scheduled for autumn 2017. Please ask your local Oasys distributor for a free trial version.

8 Literature

[1] USCAR OSRP Safety Simulation Working Group, "Benchmark Problems for Evaluating OOP Simulation Capabilities of Occupant Safety Simulation Codes", Problem version 8/15/2006
https://secure.uscarteams.org/secure/osrp/data/Test-HTML-Pendulum.html

The data used in this case study was provided by the Occupant Safety Research Partnership of USCAR (OSRP), which assumes no liability for its use, or for the analyses or conclusions that derive from its use.

[2] Taylor, R., Hayashi, S., Yagishita, S.,: "Introducing New Capabilities of JFOLD Version 3 and Airbag Folding Examples", 14th International LS-DYNA Conference 2016, Detroit, USA