

2D-3D methodology

Project done by:

CMT (UBC) and Boeing Phantom Works

Project funded by:

AFMRL (Processing for Dimensional Control)

Summary:

Although the main COMPRO offering is a 2D code, a methodology has been developed to predict the behaviour of realistic 3D structures using COMPRO 2D together with a standard 3D structural FE code.

It can be shown that typical aerospace structures can be very efficiently and effectively modelled in this fashion. Given the very long run times of 3D models, this is often a desirable strategy.

References:

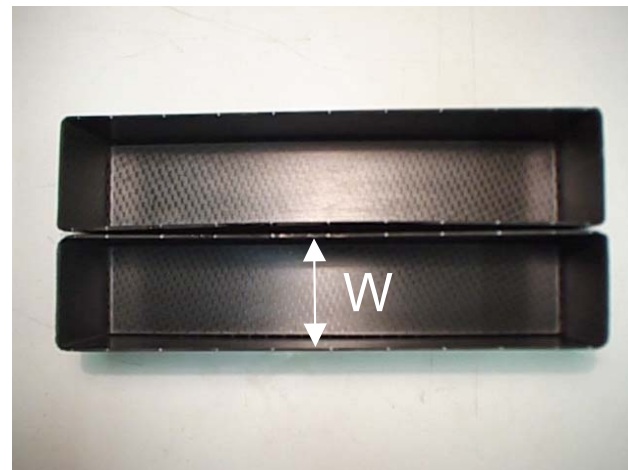
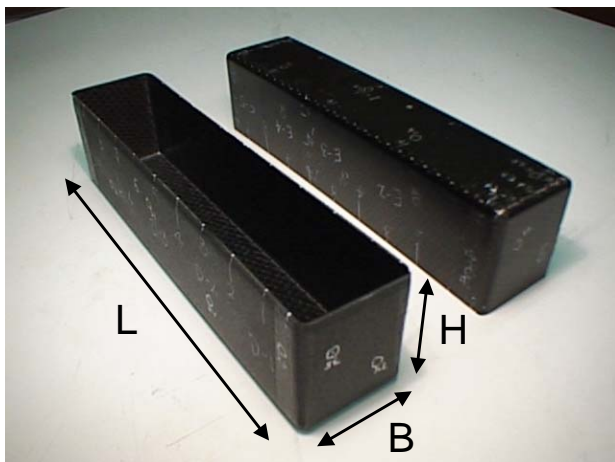
* Fernlund G, Osooly A, Poursartip A, Vaziri R, Courdji R, Nelson K, George P, Hendrickson L, Griffith J. [Finite Element Based Prediction of Process-Induced Deformation of Autoclaved Composite Structures Using 2D Process Analysis and 3D Structural Analysis](#). Comp Struc 2003; 62: 223-234

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Modeling of 3D structures

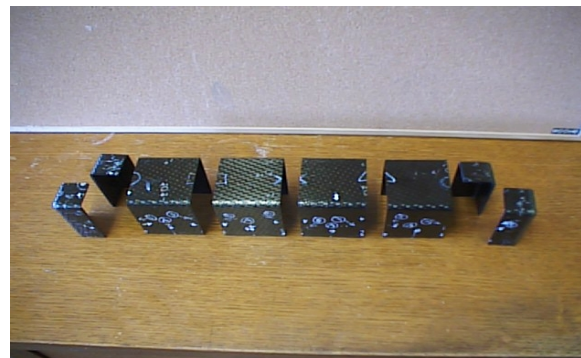
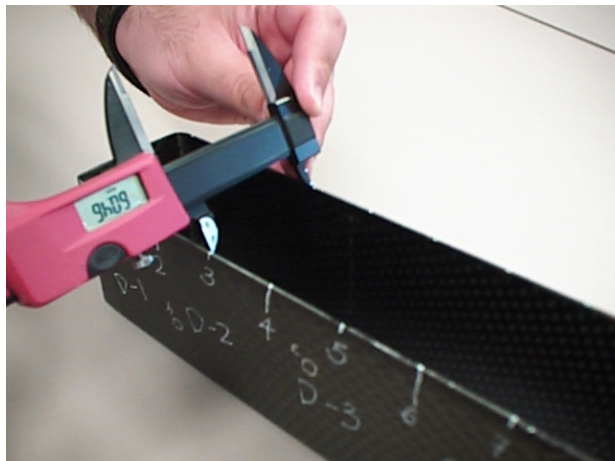
Assumptions:

- Process induced stresses are not 3D (residual stresses at different cross-sections are not dependent on each other)
- The 3D effect is due to elastic interactions after tool removal

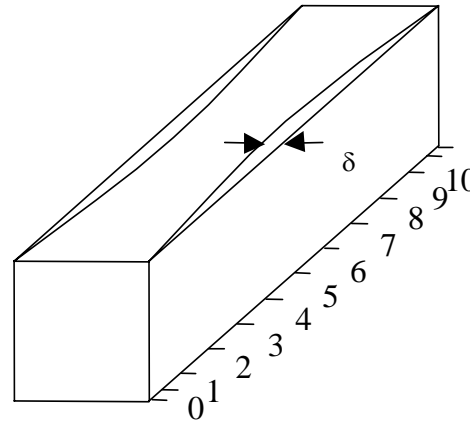


Verification of assumptions

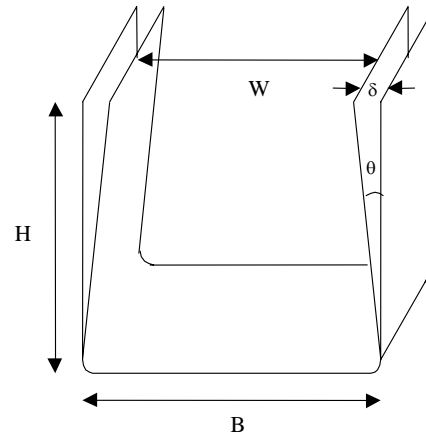
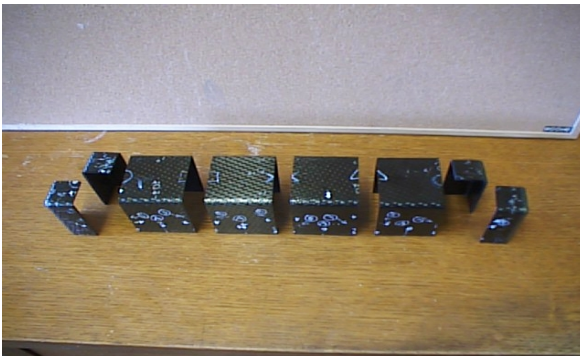
- Part studied: a “shoe-box” (rib on the T-45) made of AS4/977-3 fabric
- Deformations (flange spring-in) of the cured part were measured before and after sectioning of the part using a digital caliper



Measurement of flange spring-in

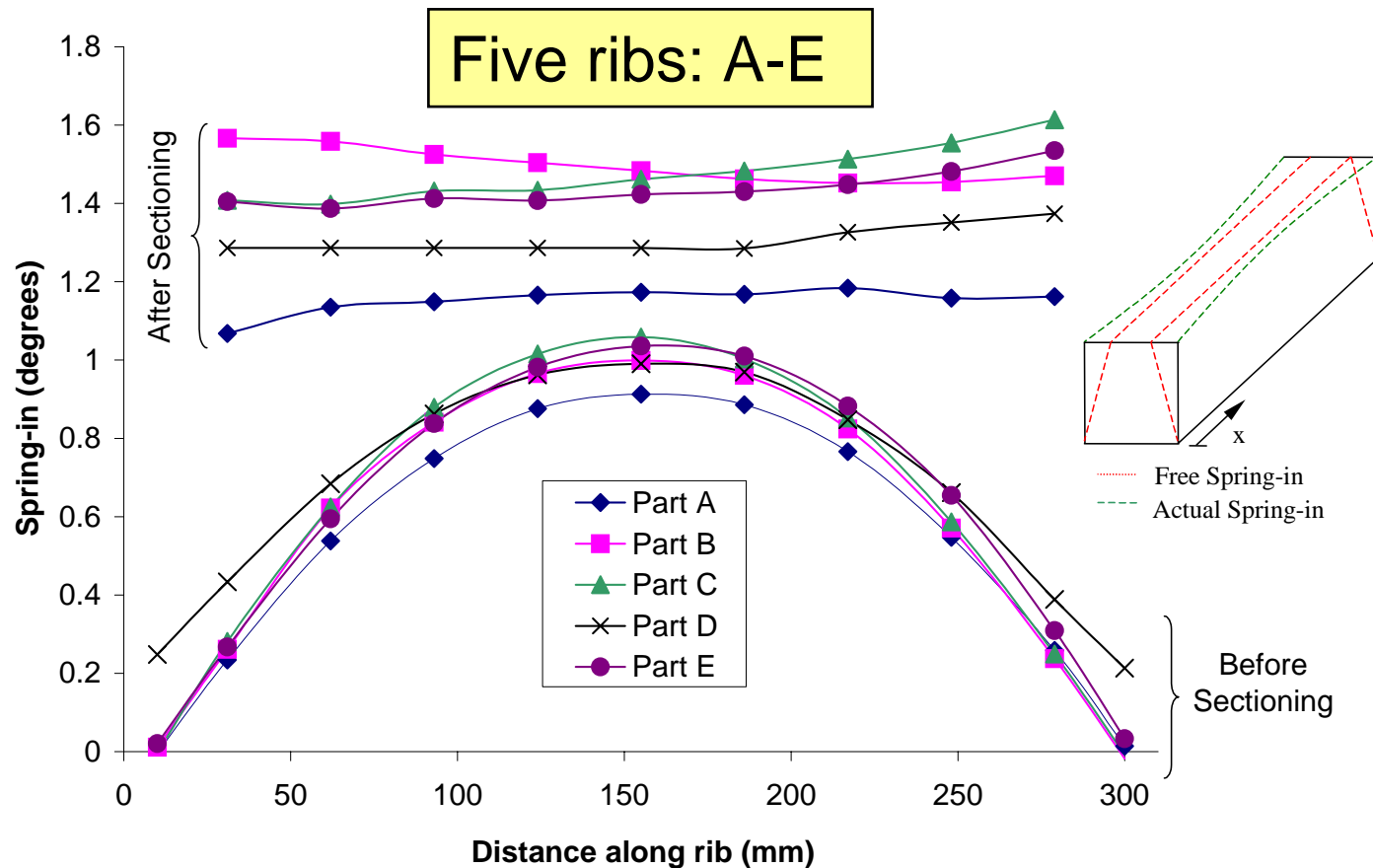


Initial and deformed shape



Definition of spring-in (θ)

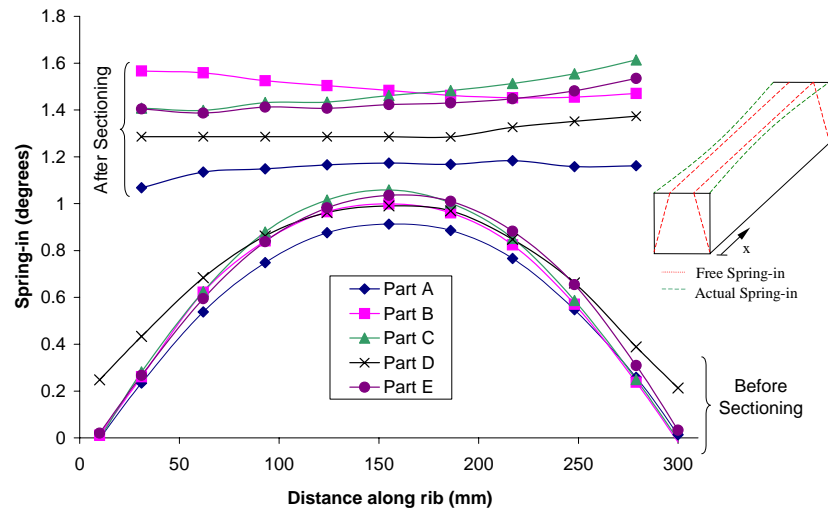
Spring-in before and after sectioning (1)



Spring-in before and after sectioning (2)

Measurements show that:

- Spring-in of the sectioned ribs is constant along the length of the rib
- Spring-in of the un-sectioned ribs are zero at the ends and maximum at the middle



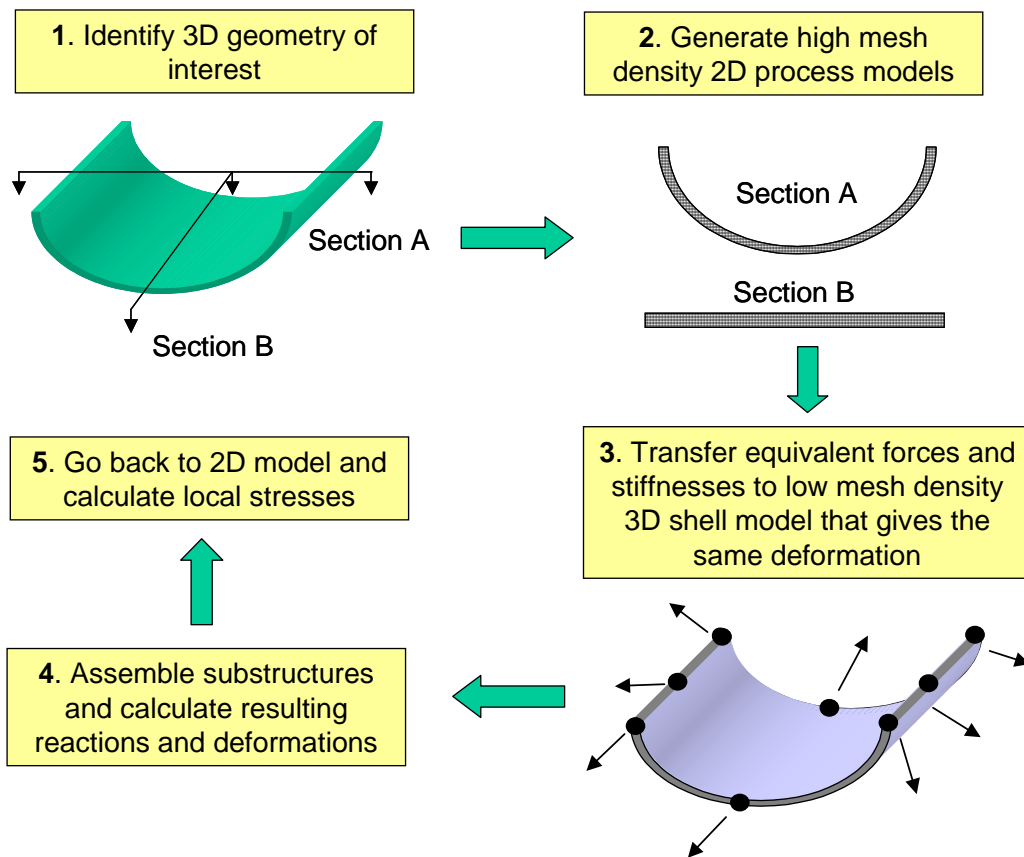
This shows that the 3D effect (variation of spring-in along the length of the rib) is due to the geometric 3D constraint, i.e., the ends of the shoe-box are constraining the spring-in of the flanges

Modeling of 3D deformations

Approach:

- Compute deformations of selected cross-sections of the part using a 2D process model (COMPRO 2D)
- Create a 3D elastic model of the part in a general purpose FE package and subject it to loads consistent with the predictions from the 2D model

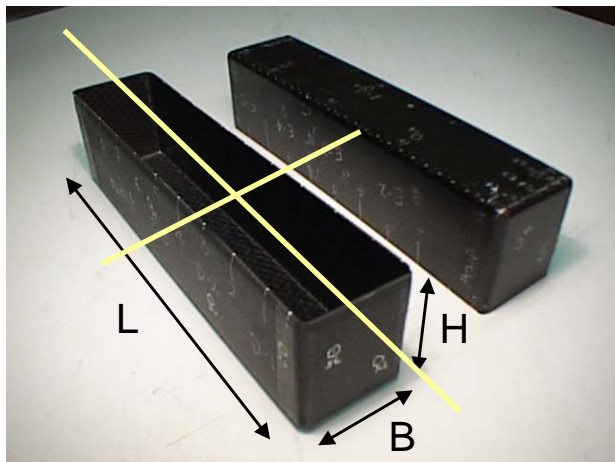
Schematic of 2D-3D approach



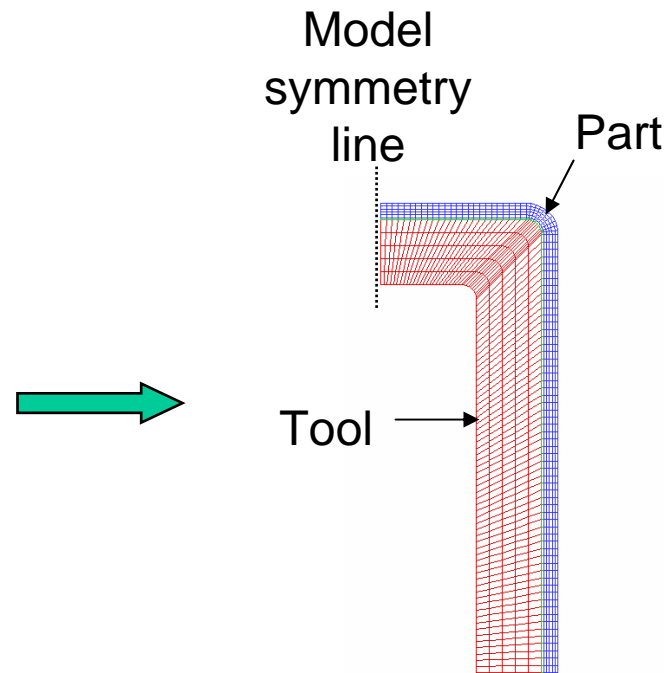
Modeling of composite ribs (1)

Create 2D process models of select cross-sections

Part with cross-sections to be modeled identified



2D FE model of cross-section

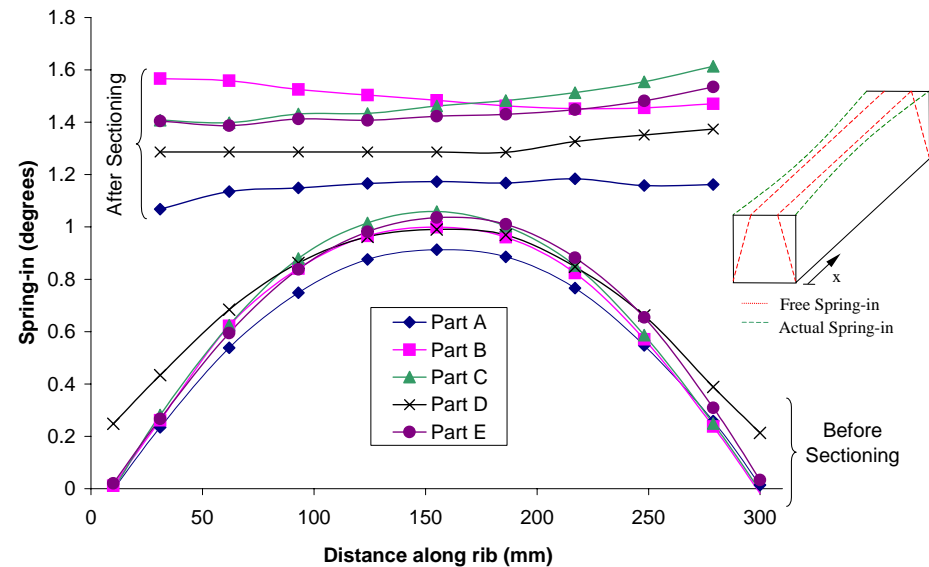


Modeling of composite ribs (2)

At the time of the project, no process material properties for the rib material (AS4/977-3) were available, and properties of a similar material was used

Model results:

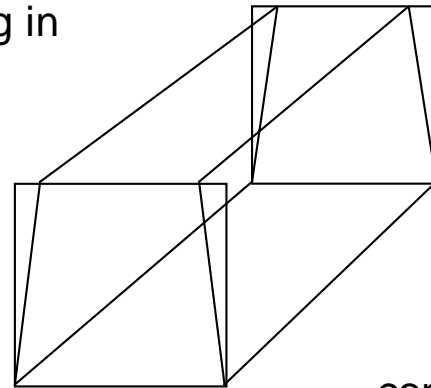
- Predicted spring-in: 1.6° (material properties estimated)
- Measured average spring-in: 1.4°



Modeling of composite ribs (3)

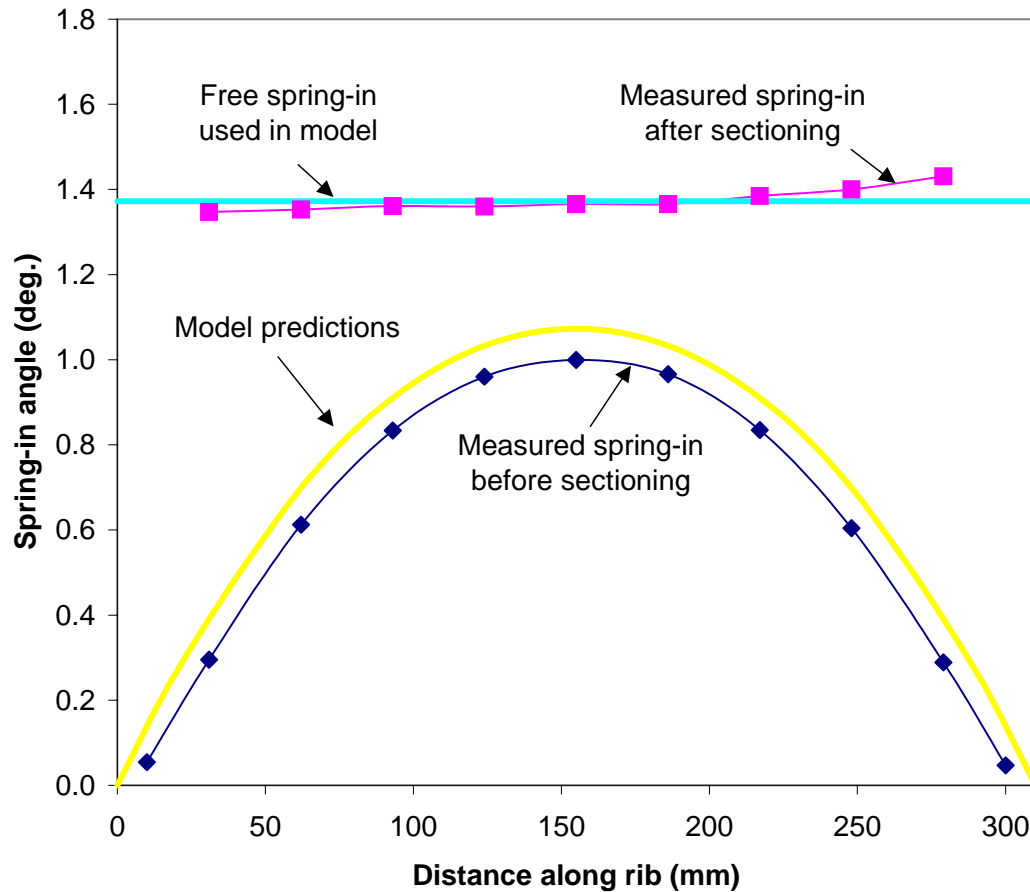
- A simple 3D model of the rib was created using orthotropic shell elements in ANSYS
- Model was set up with flanges sprung in 1.4°
- Edges then connected

A) Flanges modeled as freely sprung in



B) Edges connected to give 3D shape

Model results

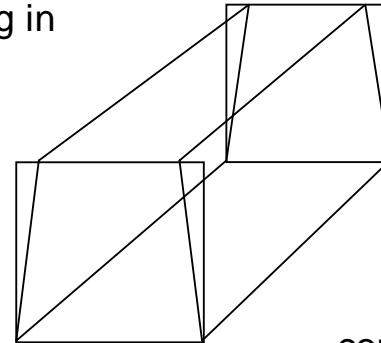


Predictions in good agreement with experimental data

Comments on model

- Only spring-in of the long flanges accounted for
- Spring-in of ends neglected (not significant)
- Warpage of web neglected (not significant)

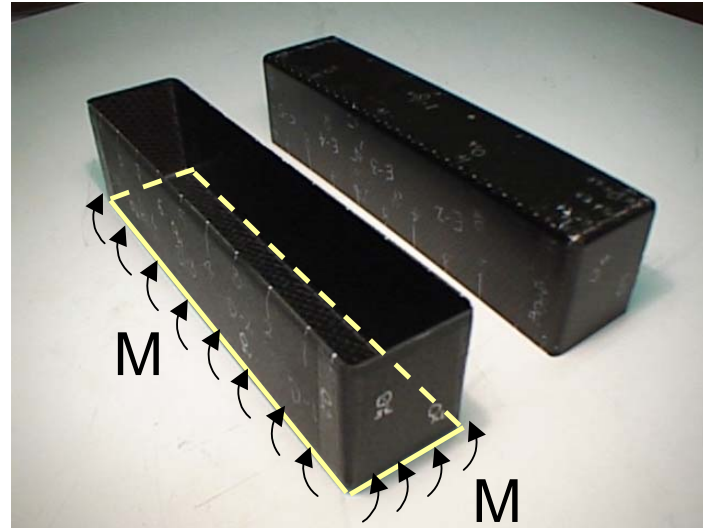
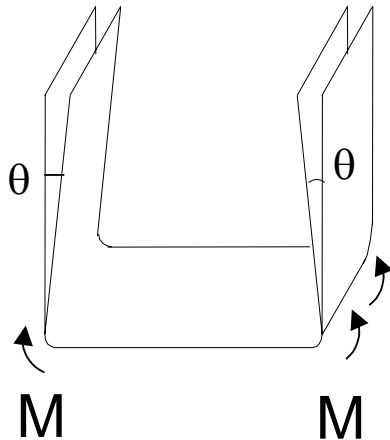
A) Flanges modeled as freely sprung in



B) Edges connected to give 3D shape

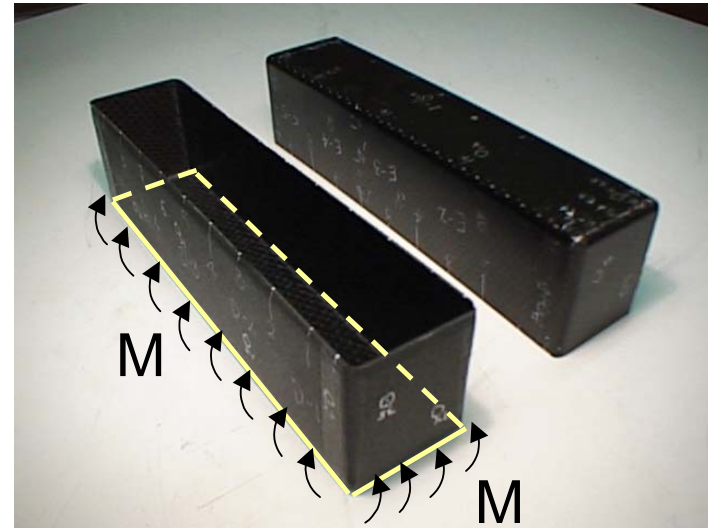
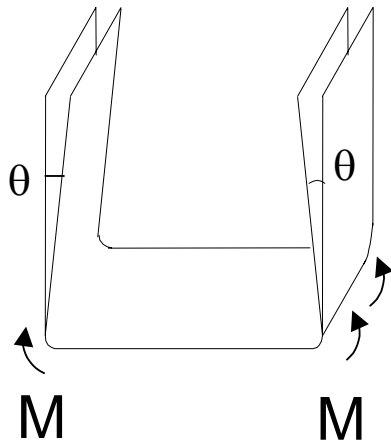
Refined analysis of the rib

- Compute the mechanical moment, M , required to cause the predicted spring-in of the sectioned parts
- Apply that moment as a distributed moment on the 3D model

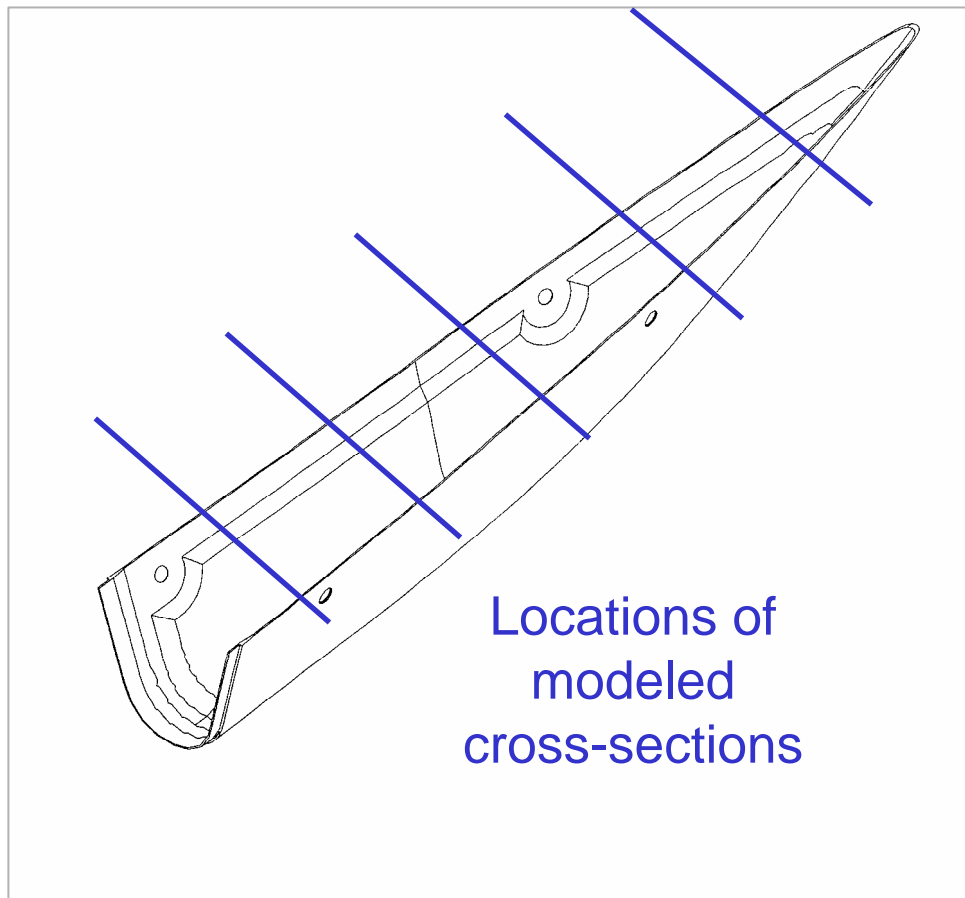


Predictions from refined analysis

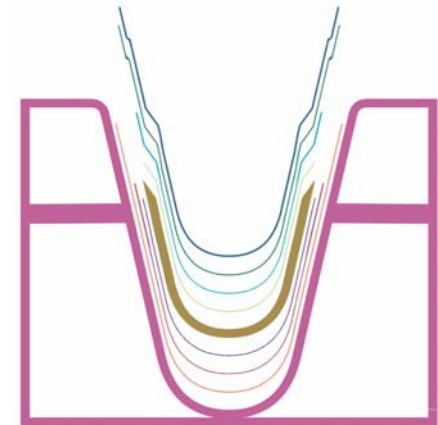
- Predictions of flange spring-in almost identical to 1st approach
- Refined analysis predicts observed 2nd order effects such as warpage of the web



2D-3D approach applied to the Boeing 777 Aft Strut Fairing

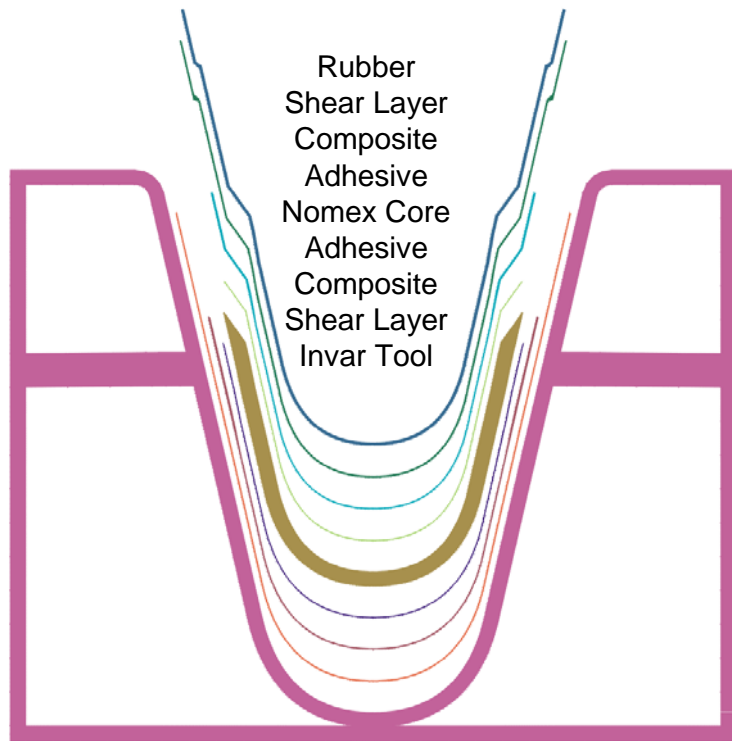


Side view of cross-section including tool

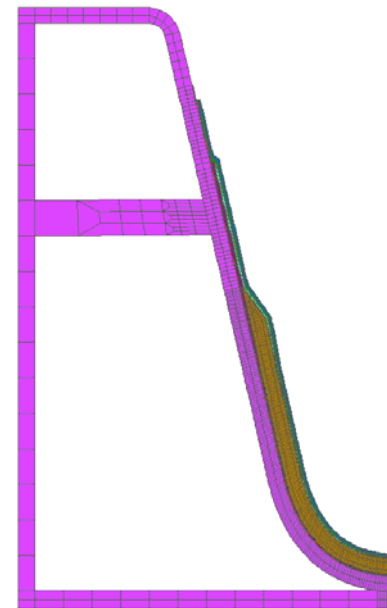


FE mesh of 777 Aft Strut Fairing

FE model includes process tool and all layers in the lay-up



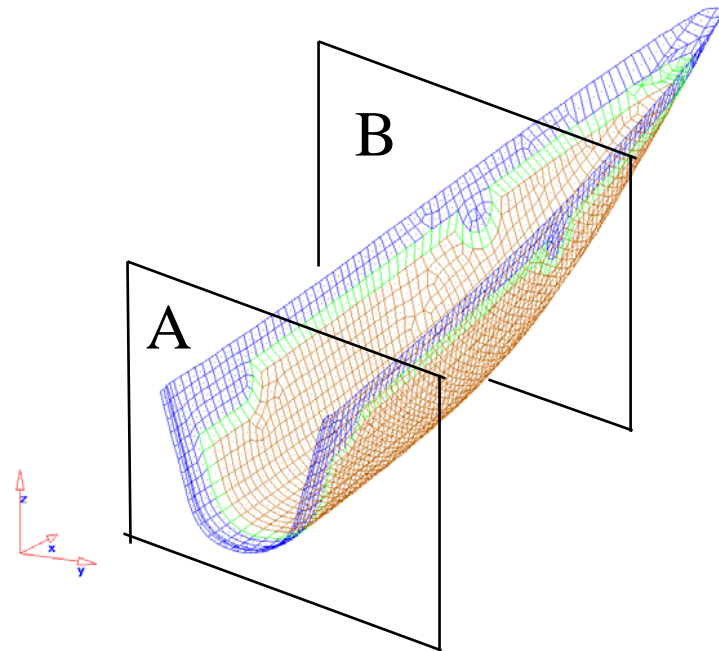
FE mesh



2D-3D approach

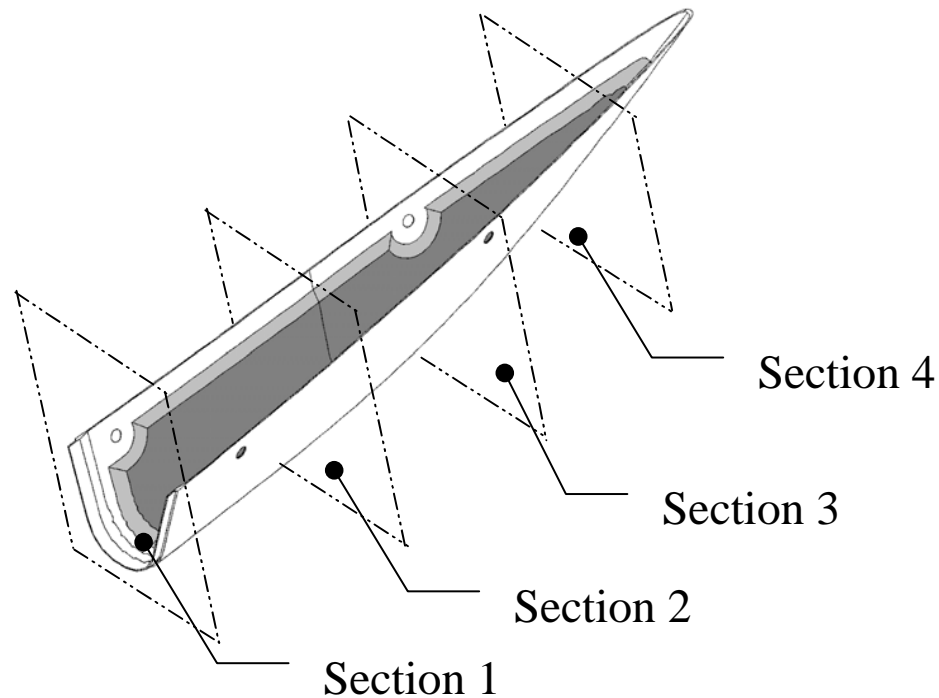
Justification of 2D-3D approach

- The tool is massive and the part will not move away from the tool during processing
- There is little stress transfer between sections (A and B) during processing
- Stress transfer between sections (A and B) will mainly occur when the part is fully cured, removed from the tool, and allowed to deform



2D-3D approach applied to the fairing

1. Select appropriate 2D sections (4 sections chosen)



2. Create and run 2D models

FE mesh of half cross-section (symmetry)

Materials

Composite

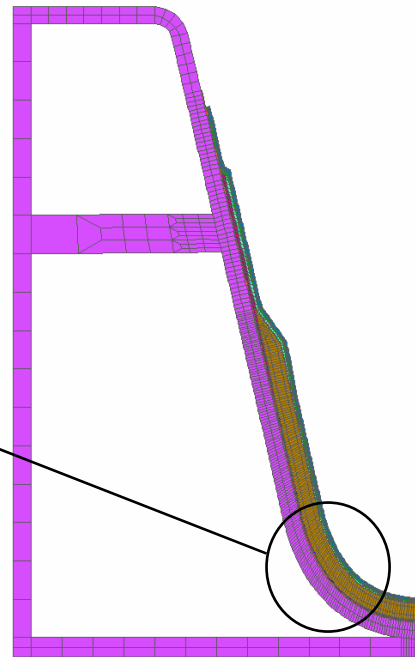
Adhesive

Nomex core

Adhesive

Composite

Invar tool



FE model

FE mesh

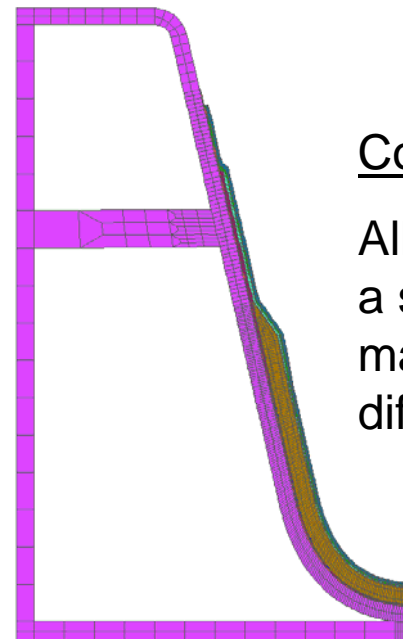
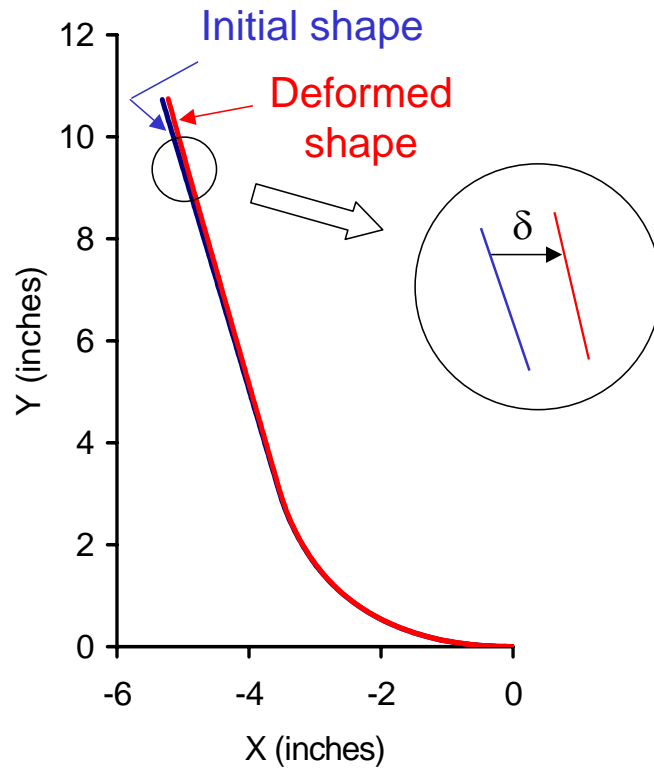
Boundary conditions

Material properties

Cure cycle

3. Study deformations of 2D models

Predicted tool-side deformations of part when removed from tool

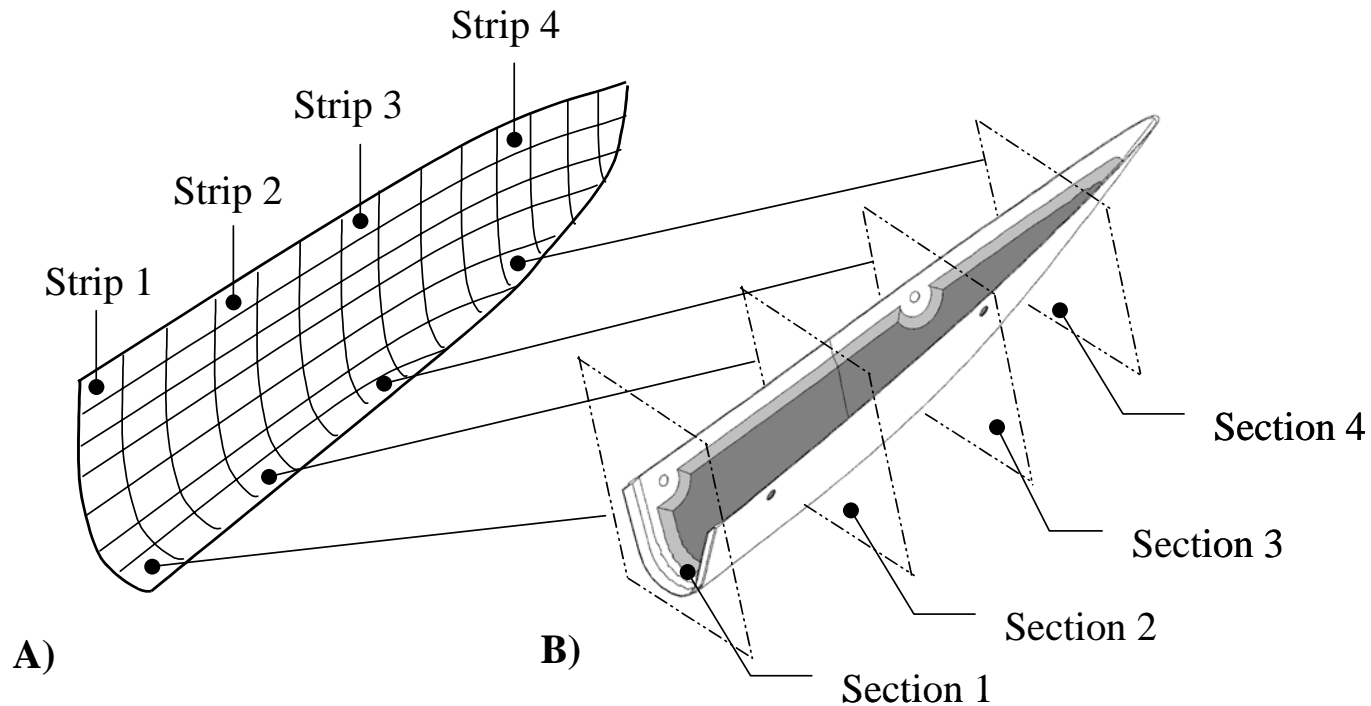


Comment on predictions

All 4 sections deformed in a similar fashion although magnitudes were different

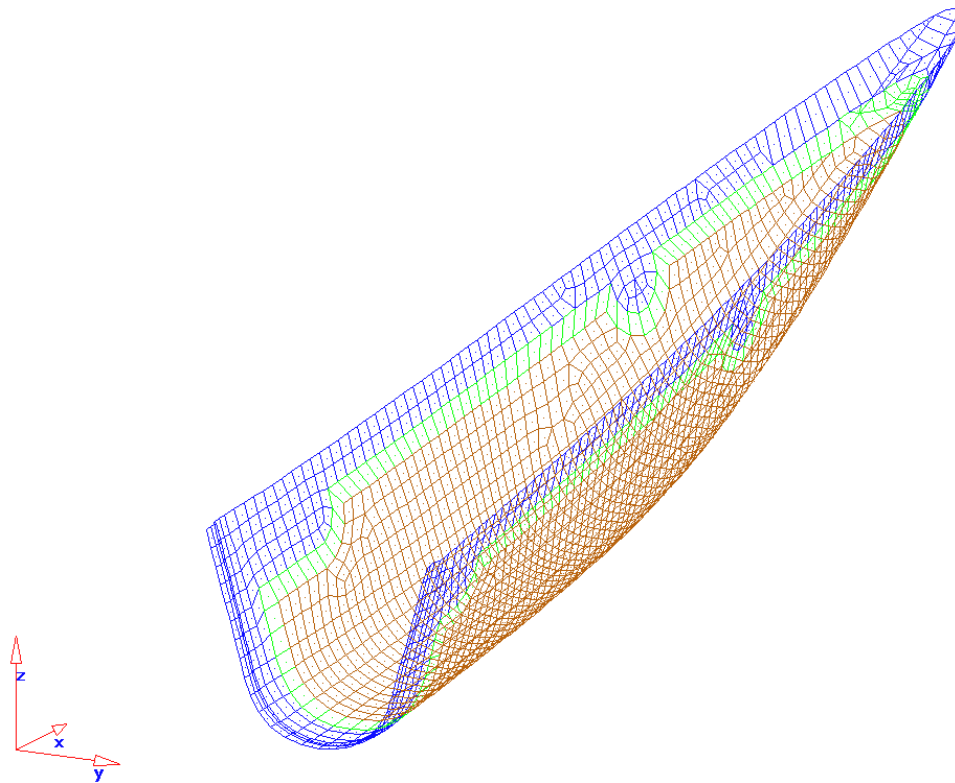
4. Create 3D model of the part

3D model simple elastic shell model generated in ABAQUS (tooling not modeled)



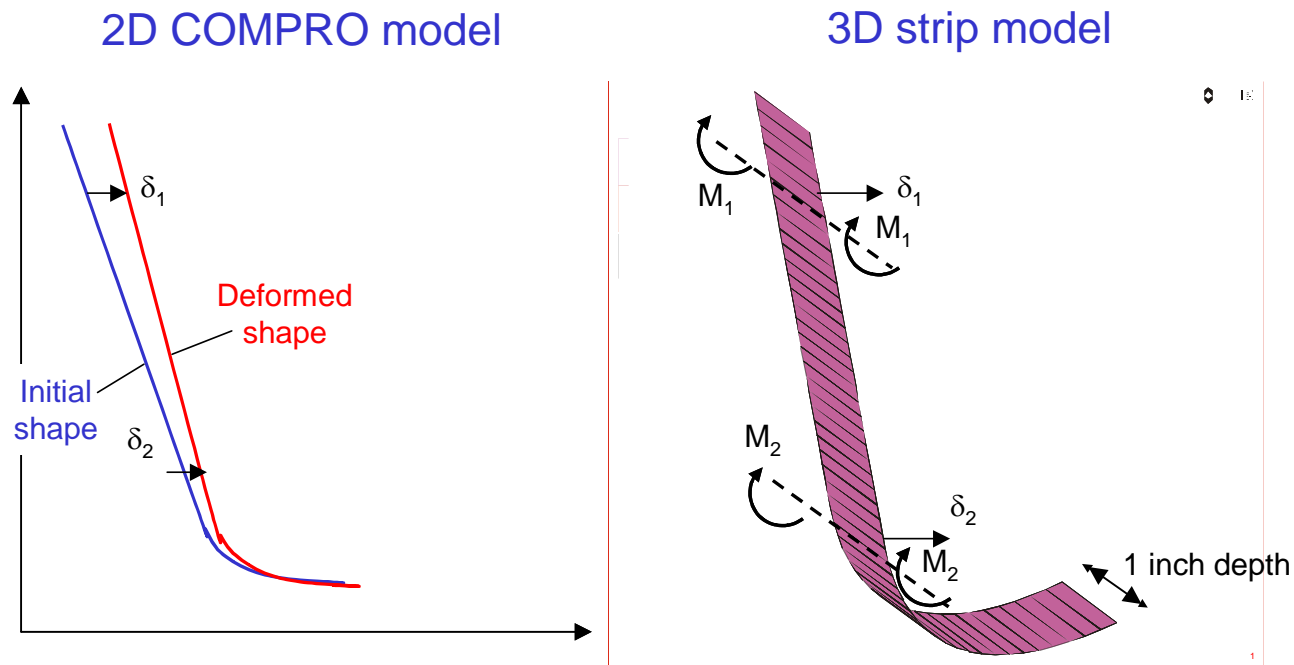
Actual 3D FE mesh

FE mesh created based on CATIA description



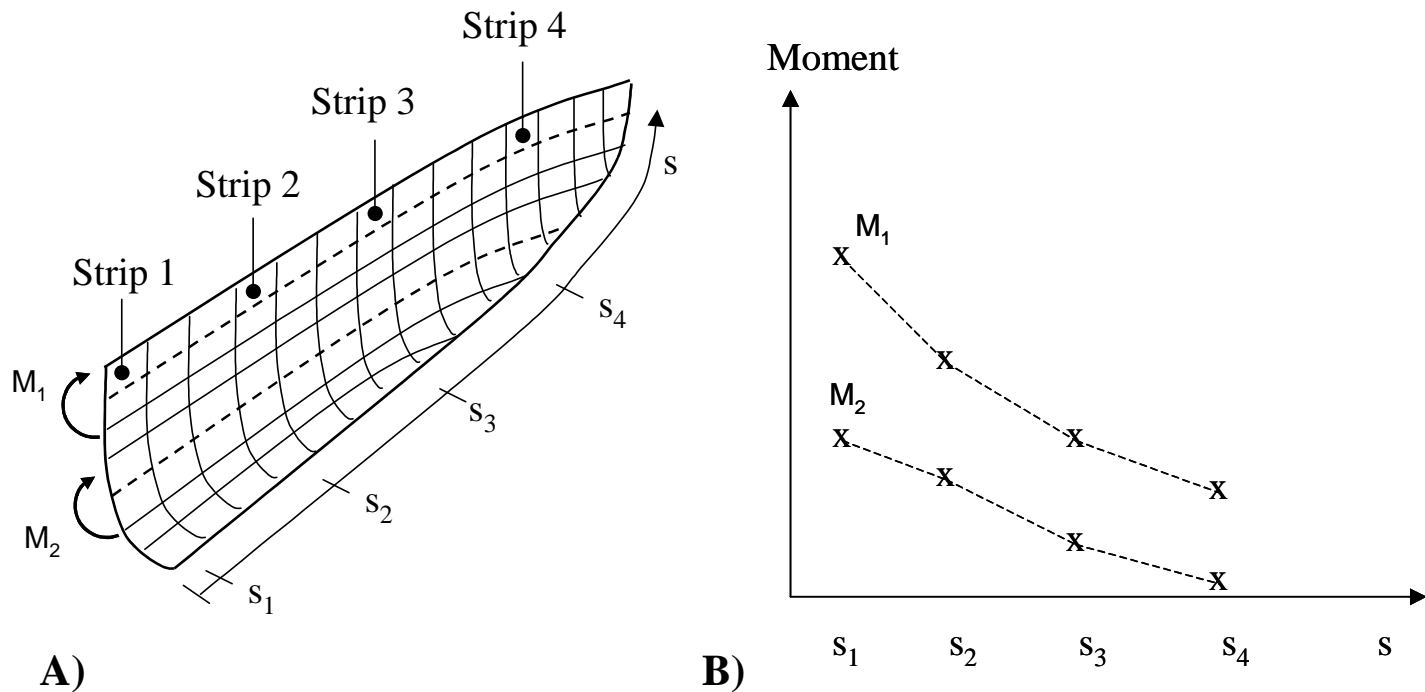
5. Isolate cross-sections in 3D model and match deformations

Use the principle of superposition to determine the mechanical moments, M_1 and M_2 , required to obtain the same deformations as the 2D process model

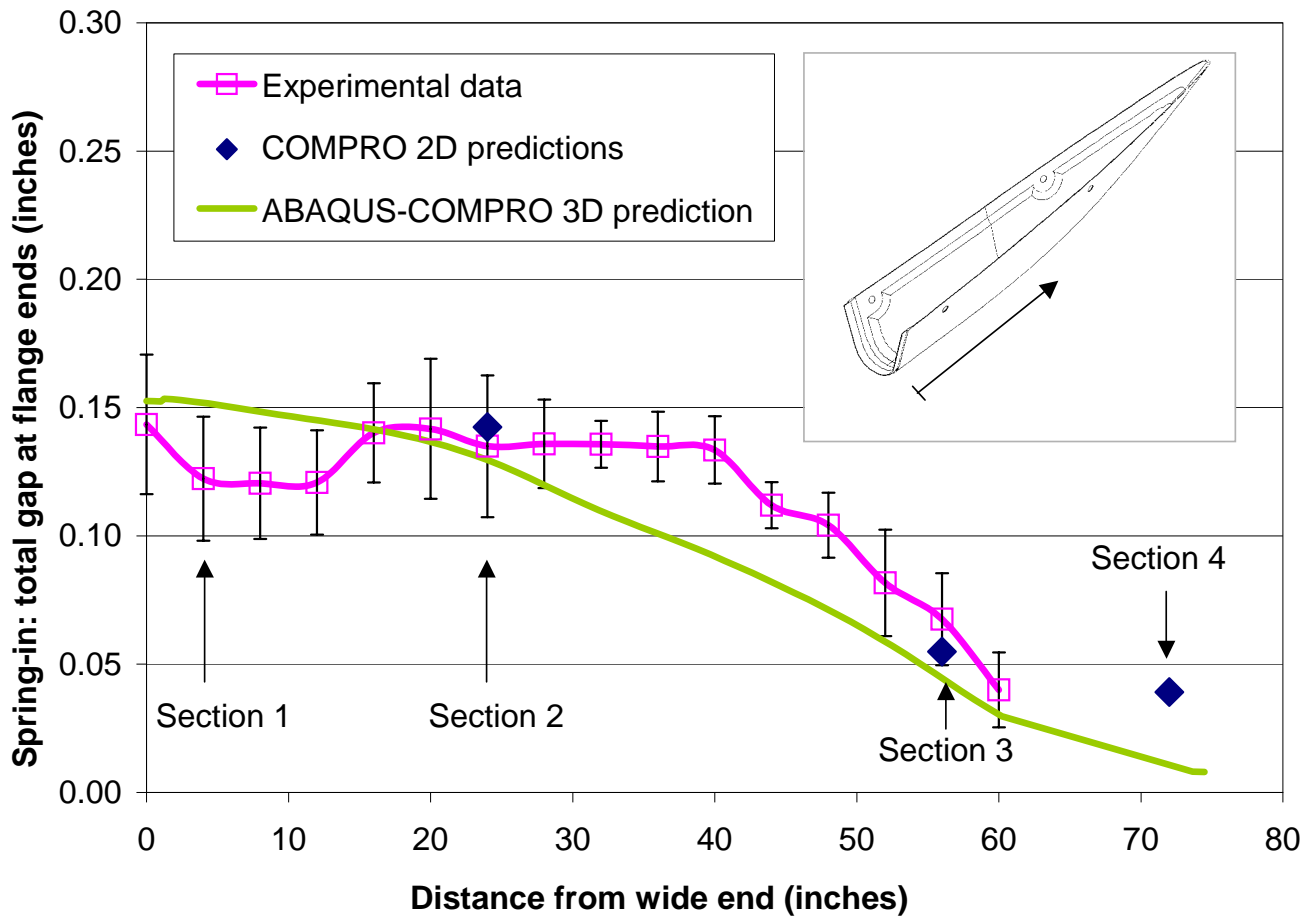


6. Perform 3D interaction analysis

Apply the moments, M_1 and M_2 , as line loads on 3D shell model



Comparison of predicted and measured spring-in



Note:

Moments applied to 3D model vary linearly between cross-sections

Local variations in honeycomb thickness not accounted for

Conclusions

- Comparison of predicted and measured spring-in for the two case-studies, the T-45 rib and the 777 aft strut fairing, showed good agreement. The agreement was better for the T-45 rib than for the aft strut fairing mainly due to some geometric complexity of the aft strut fairing that was not included in the models
- It is possible to model many 3-D structures by
 - (a) using 2-D sections to determine local residual stress build-up and then
 - (b) combining the 2-D sections into the 3-D structure
- Sufficient detail must be built into the model(s) to capture important effects

Summary:

Although the main COMPRO offering is a 2D code, a methodology has been developed to predict the behaviour of realistic 3D structures using COMPRO 2D together with a standard 3D structural FE code.

It can be shown that typical aerospace structures can be very efficiently and effectively modelled in this fashion. Given the very long run times of 3D models, this is often a desirable strategy.

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