Thermo-Structural Analysis of the HIBACHI-Foil

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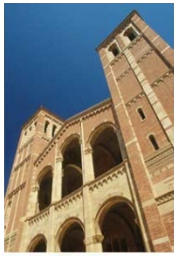

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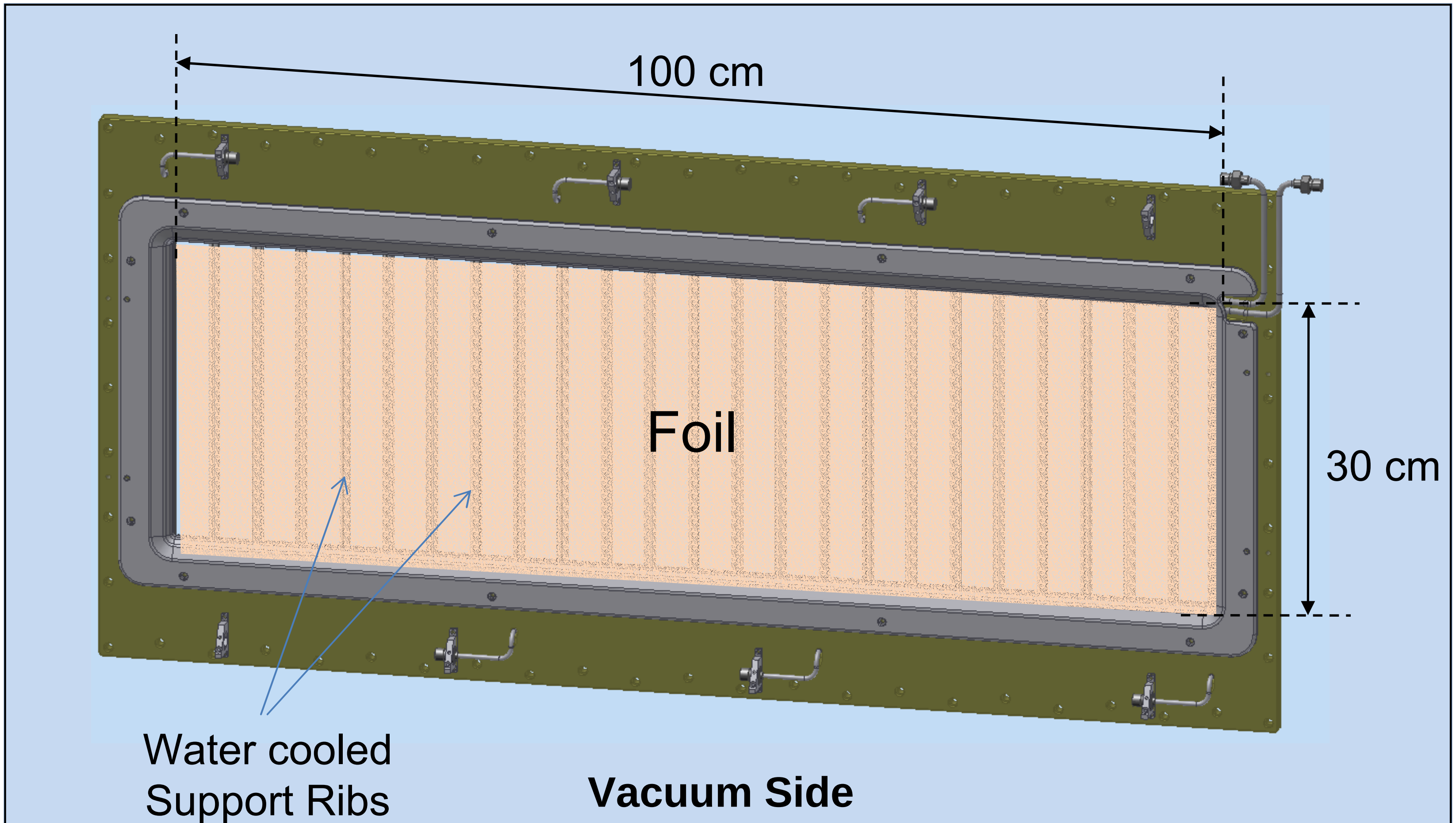
OUTLINE

- Geometry and Loads
- Exp. Performance Statistics
- Thermo-Structural Analysis
- Summary

Hibachi Foil Geometry



Commonwealth Technology, Inc.
J. Parish – 2008

Foil: 304 SS; 25 μm thick

Loading

Temperatures:

$T_{foil} \approx 180\ ^oC - 450\ ^oC$

$\Delta T_{foil} \approx 30\ ^oC$ (swing/shot)

Laser Gas Pressure:

P $\approx$ 20 psi (0.138 MPa)

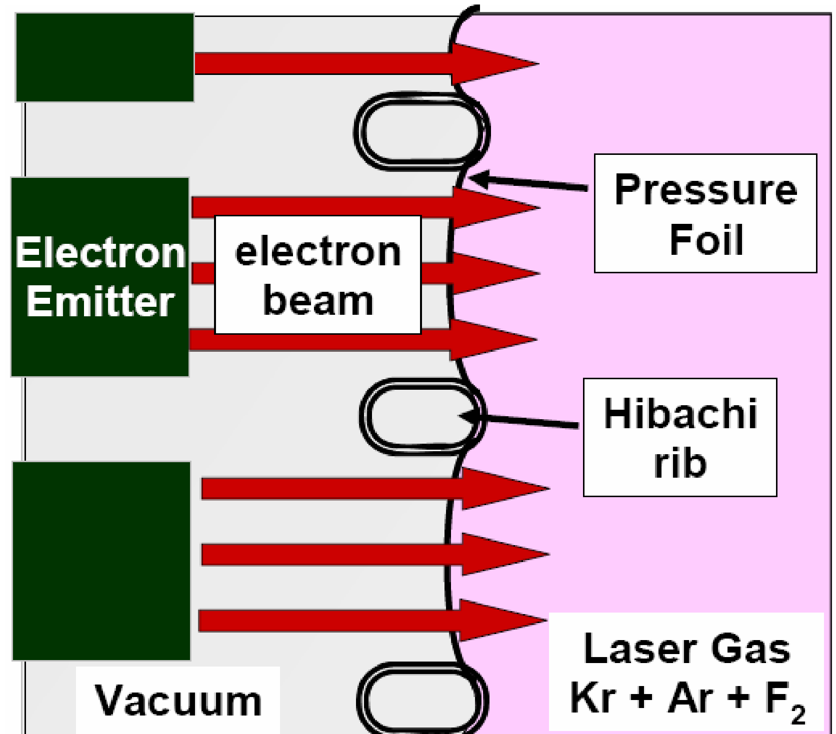
Load Duration:

f = 5 Hz

$\Delta t_{heat} \approx 140$ ns (heating)

$\Delta t_{mech} \approx 10\ \mu s$ (mechanical)

Hibachi Configuration



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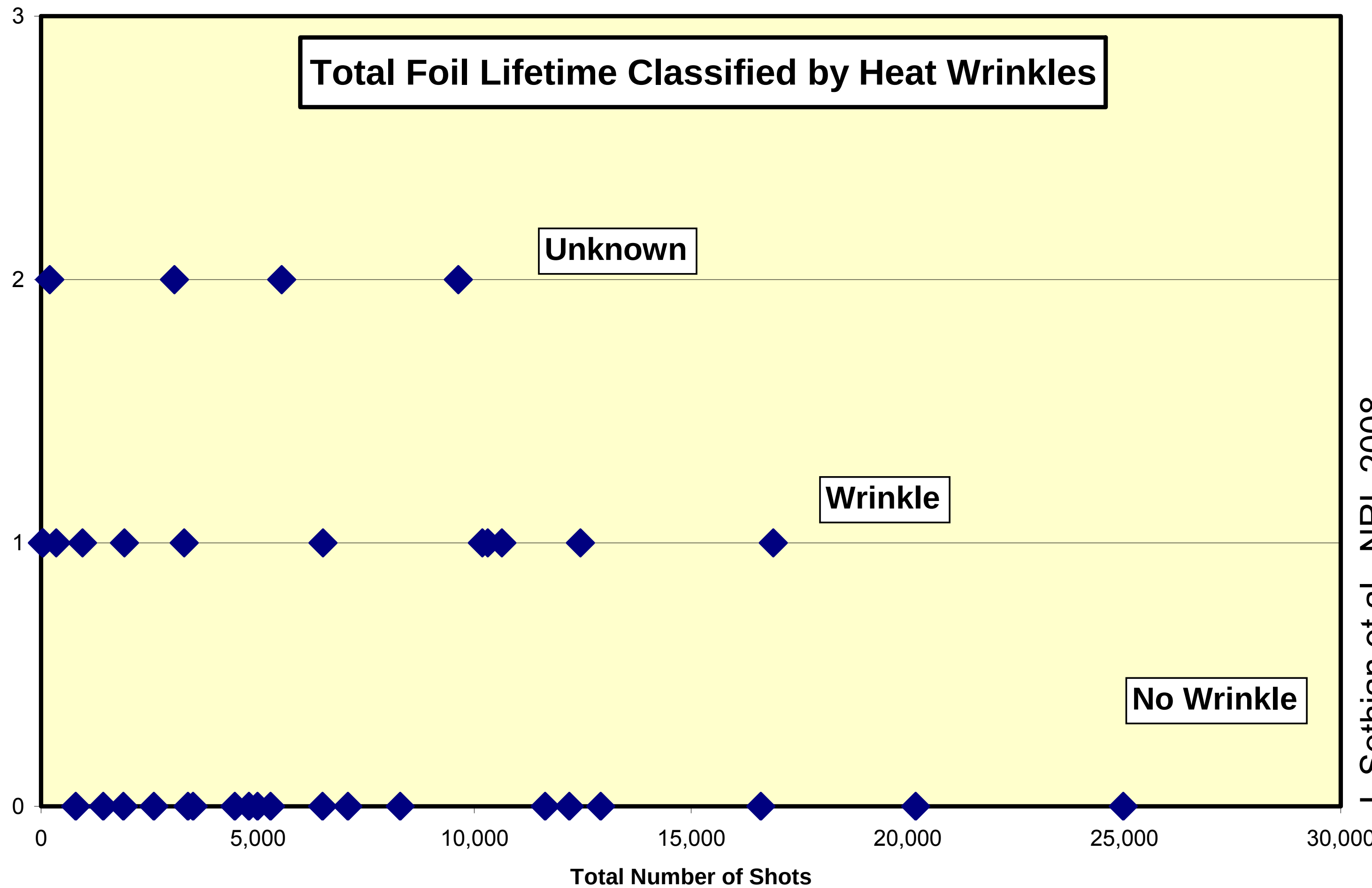
Global Performance Statistics

For runs: 5/13/04 to 1/16/08

- 447,963 shots
- 63 different foils
- 33 foil failures
- 18 failures due to holes
- 15 failures due to “blows”
- Max : ~25,000 shots (no wrinkles)



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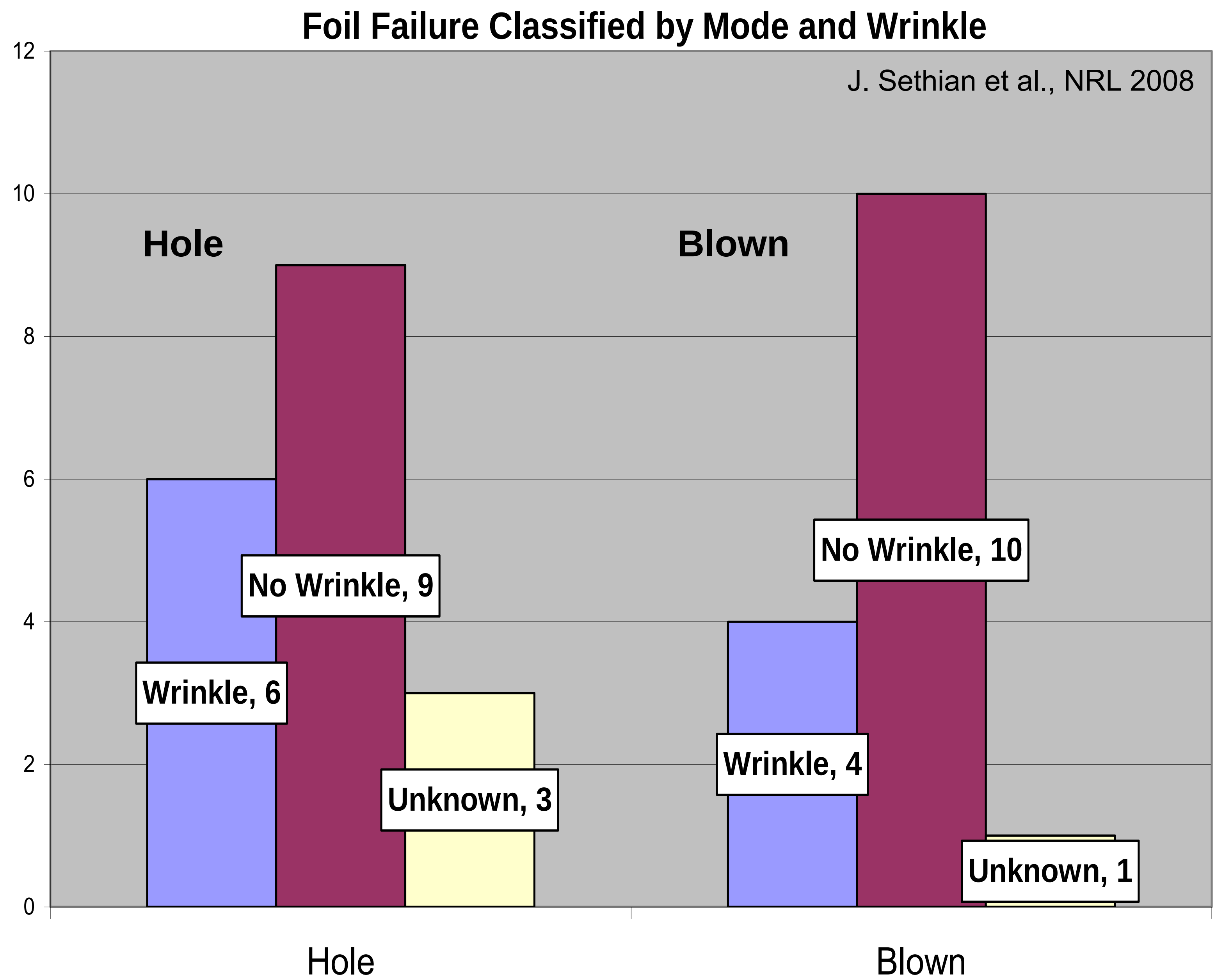
Global Performance Statistics



Thermo-Structural Analysis

Four Models:

(1)Flat foil

(2)Curved foil

(3)Flat foil+ Curved Rib

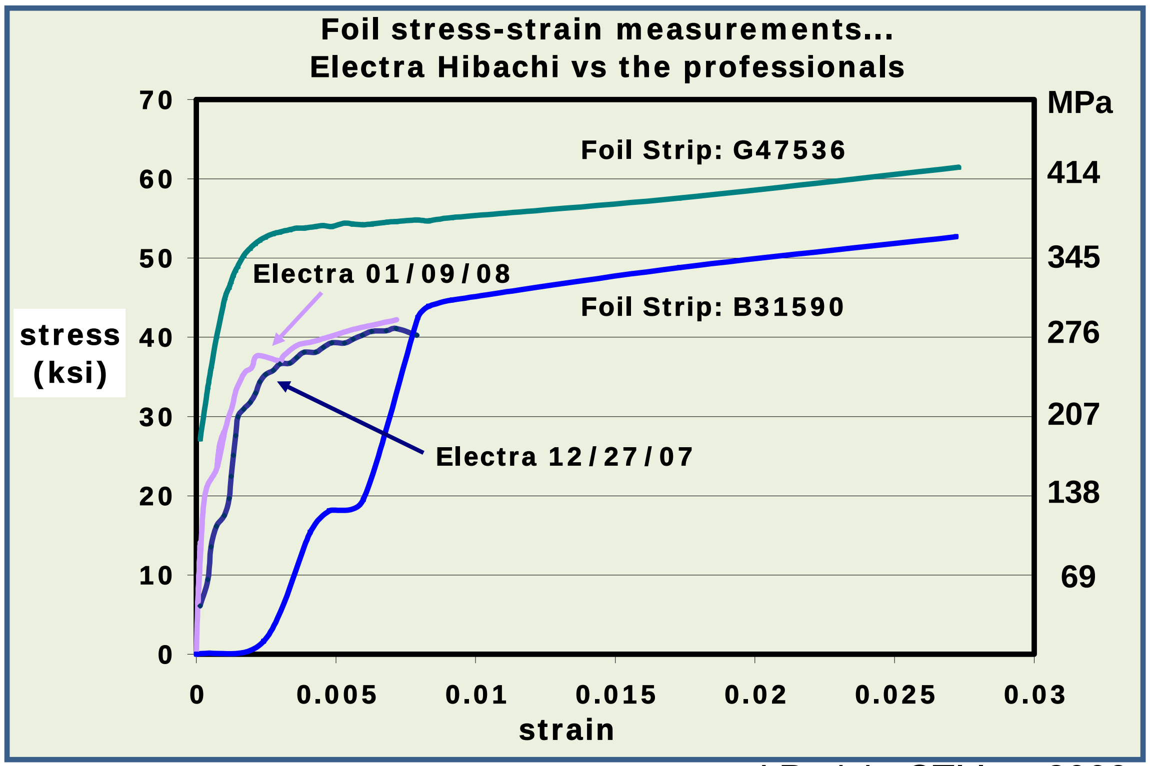
(4)Scalloped

Properties:

Temperature	20 °C	400 °C
Young's Modulus	200 GPa	170 GPa
Tangential Modulus	1.8 Gpa	1.8 GPa
Yield Strength	310 MPa	207 MPa

Analysis

- Shell Elements
- Pressure Load
- Pressure +Thermal
- Linear/Non-linear



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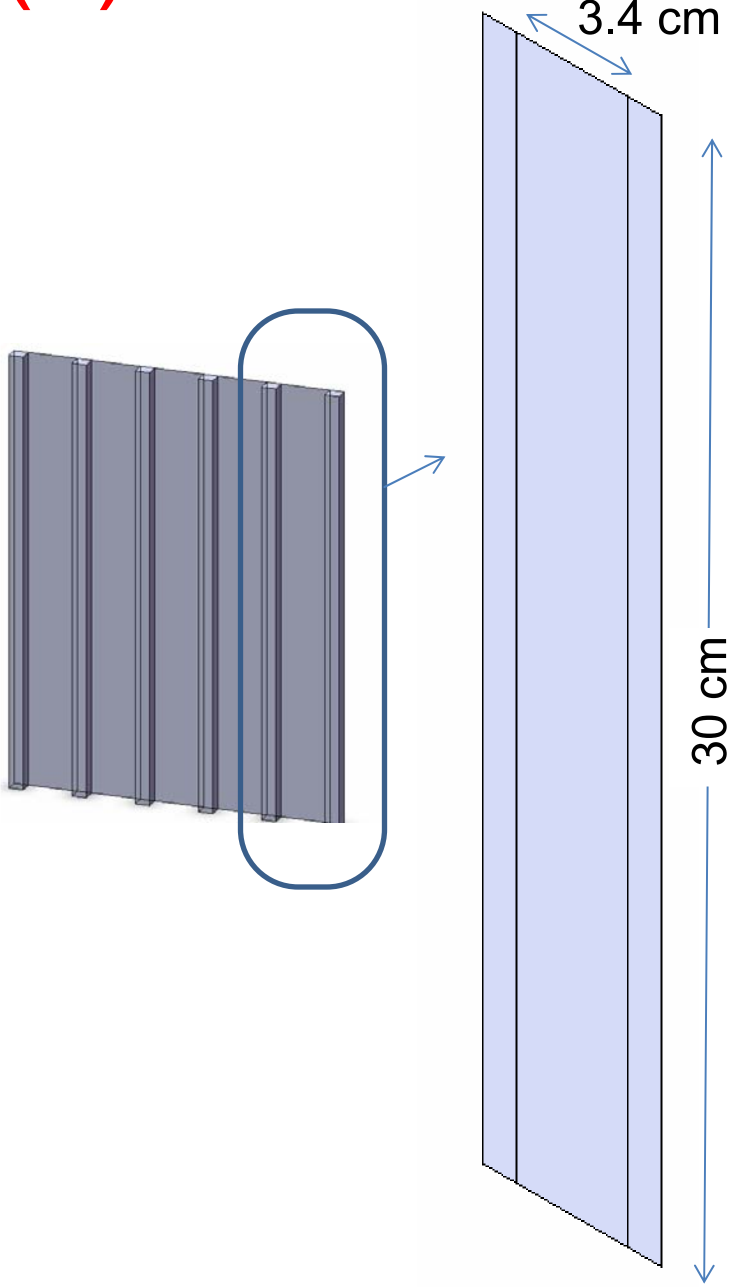
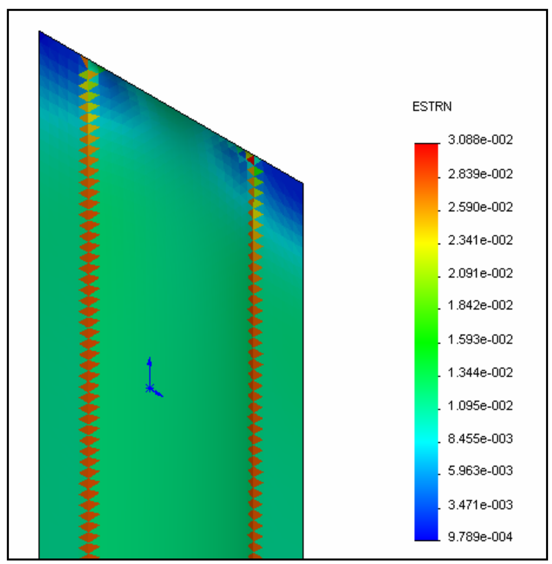
(1) Flat Model: Pressure Only

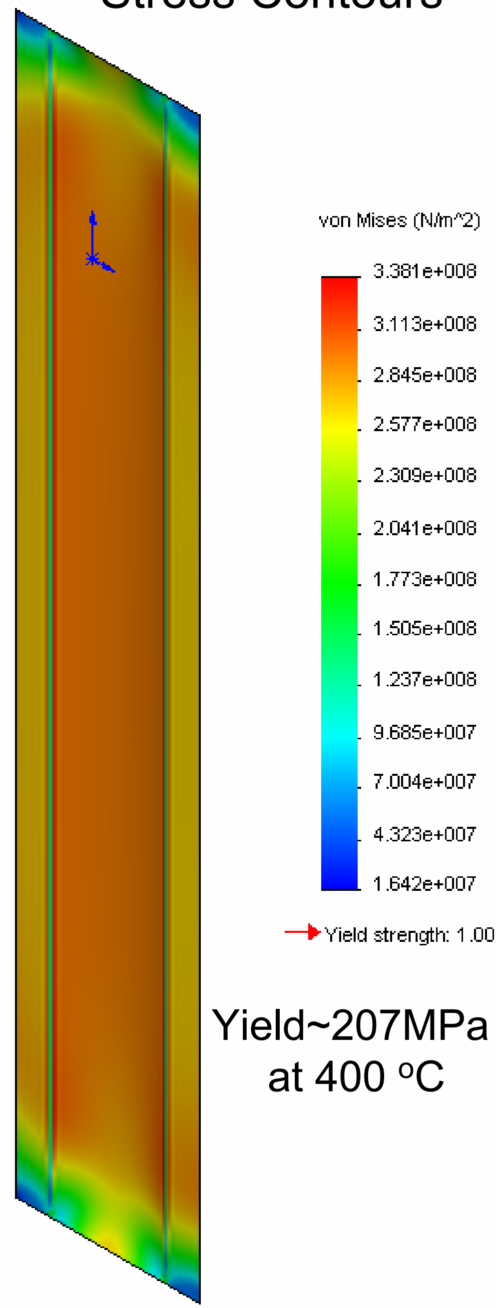


With all four outer edges fixed, and pressure applied, the model deforms **plastically**.

<u>5 Cycles at 400 °C:</u>
Stress ~ 340 MPa
Strain ~ 3.9 %
(**max along rib edges**)



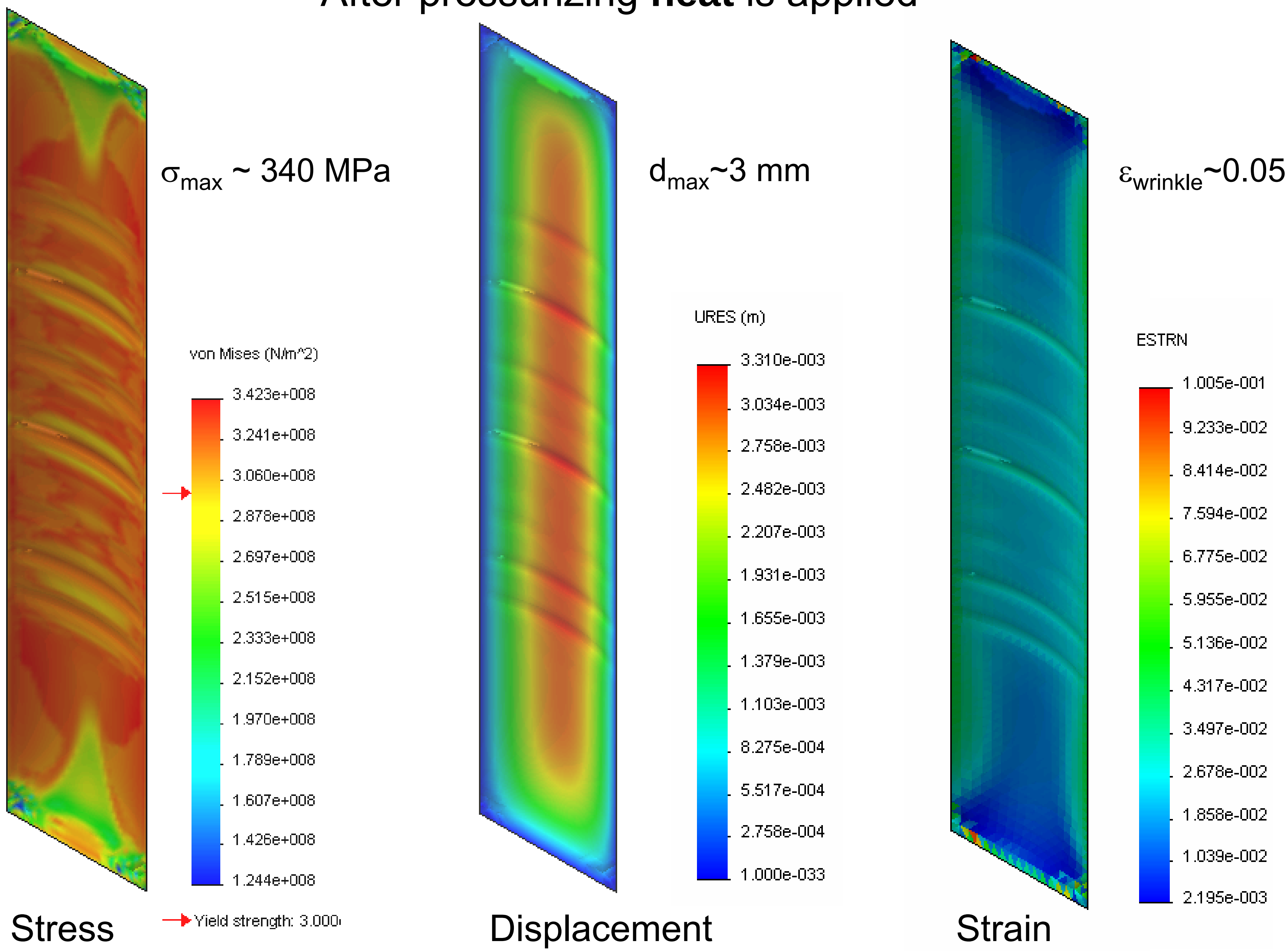
Stress Contours



Yield~207MPa at 400 °C

Model 1: Flat Foil – Pressure & Temp.

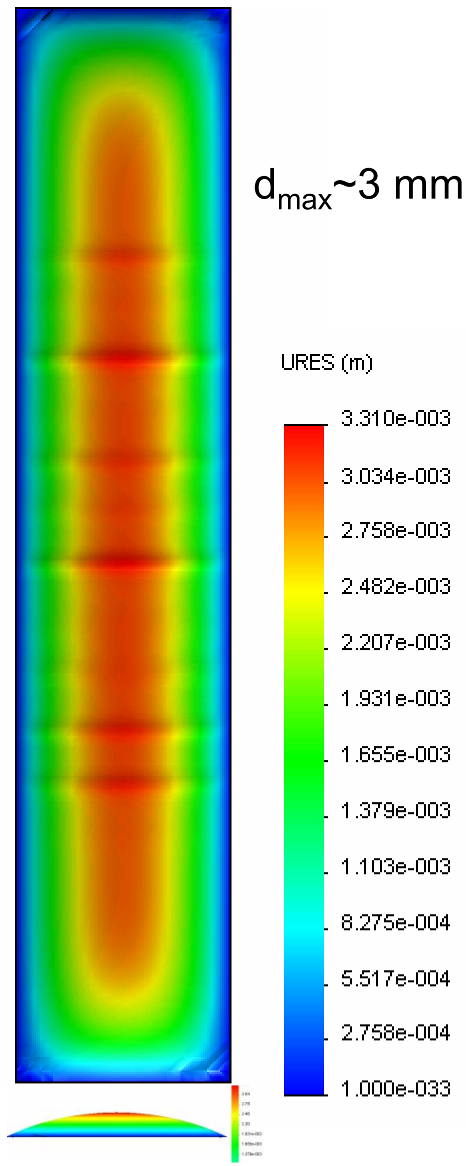
After pressurizing **heat** is applied



Flat Model: Pressure & Temperature

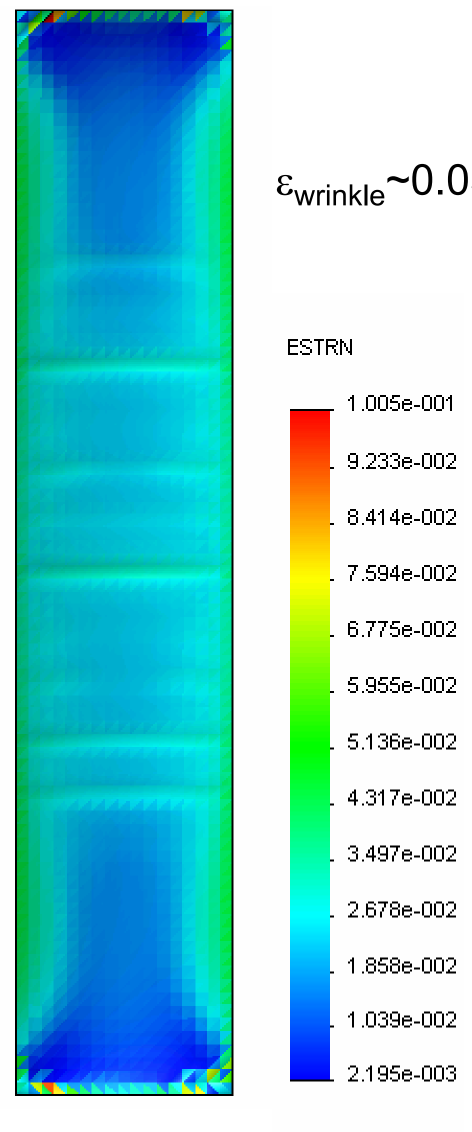
Displacement

d_{max}~3 mm



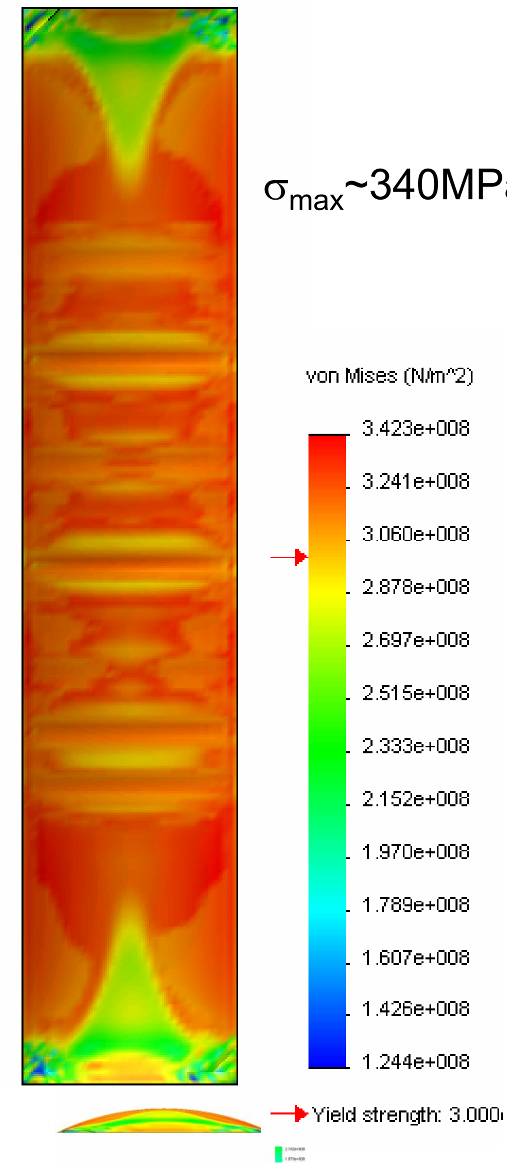
Strain

$\varepsilon_{wrinkle}$~0.05



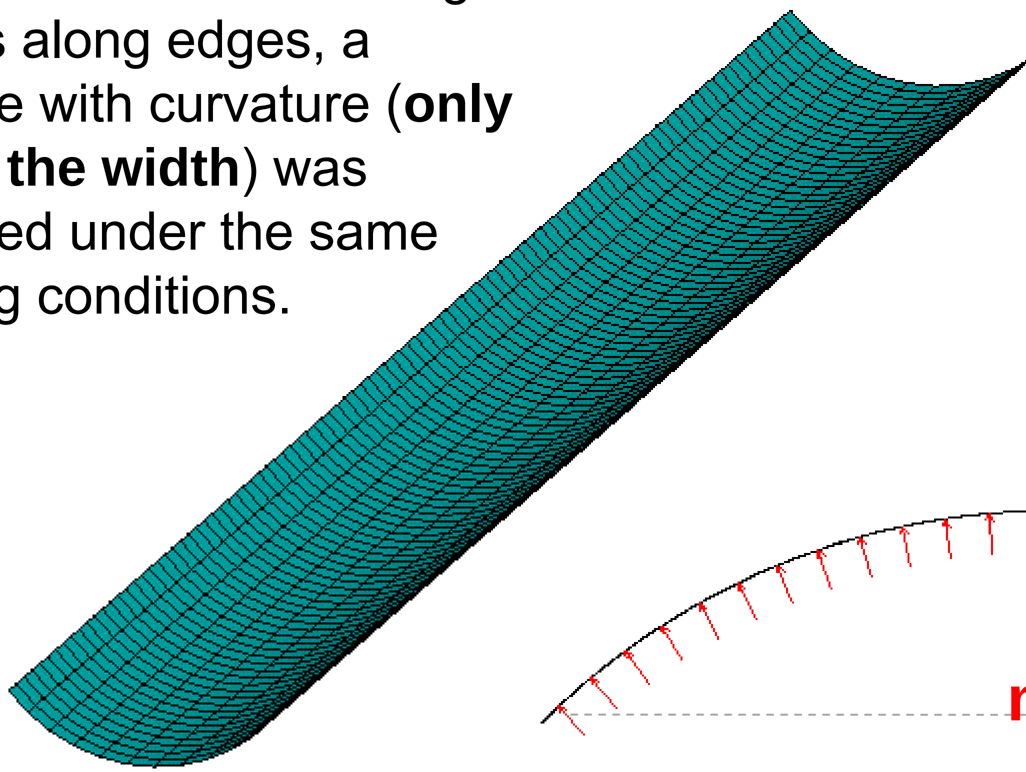
Stress

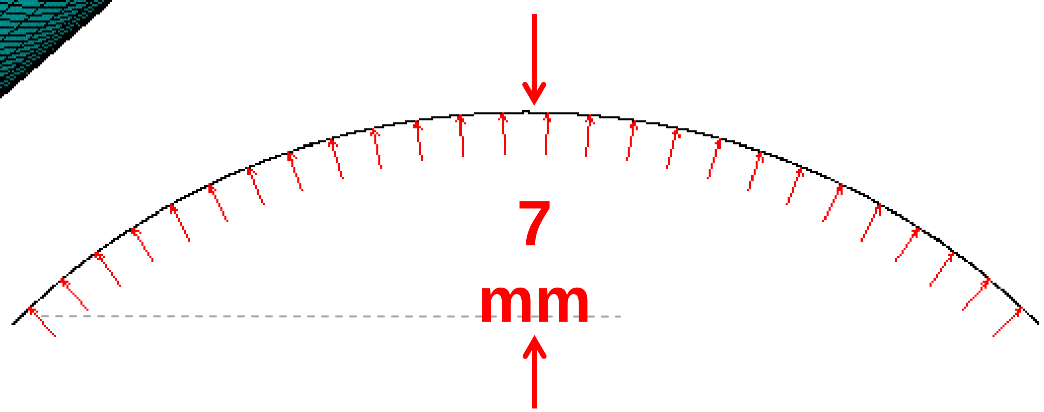
σ_{max}~340MPa



Model 2: Curved Foil Before Loading

To further examine the high strains along edges, a surface with curvature (**only along the width**) was modeled under the same loading conditions.

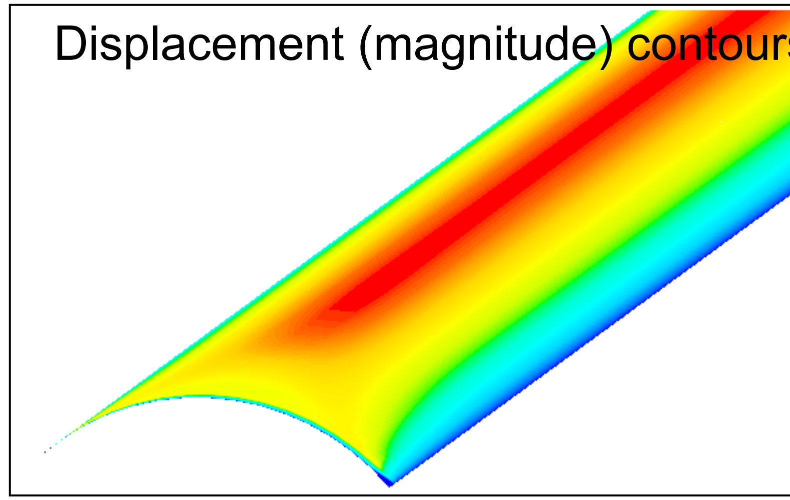




Cross-section view

Pressure Loading

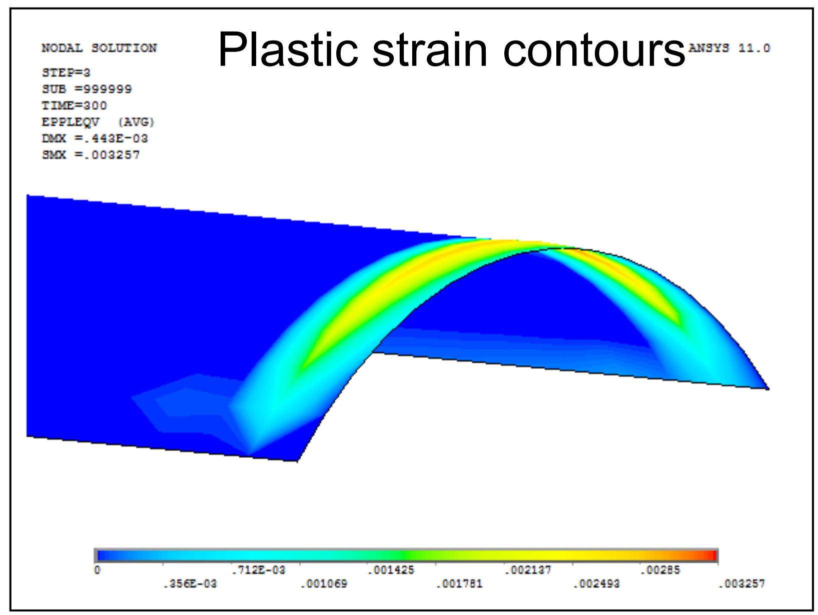
With all four edges fixed, and pressure applied, the model deforms **elastically**.



Pressure & Temperature

In this case, the “wrinkle” caused by thermal expansion is **very** localized.

Is the foil buckling?



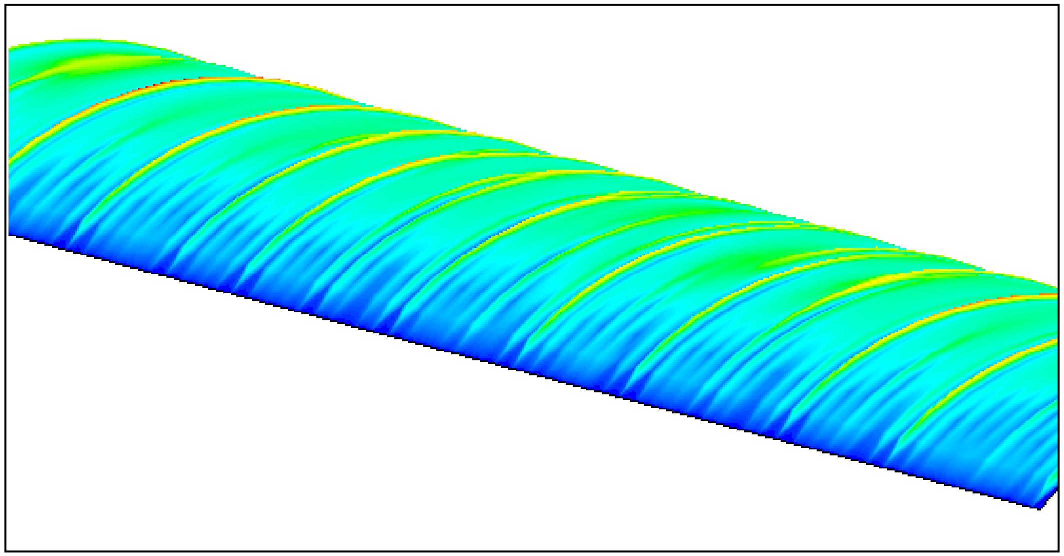
Nonlinear Buckling Analysis

A more conservative approach is to use a nonlinear buckling analysis.

In this case, the temperature load is increased until the solution begins to diverge.

Then, an ANSYS nonlinear stabilization option adds an **artificial damper** to maintain a stable state.

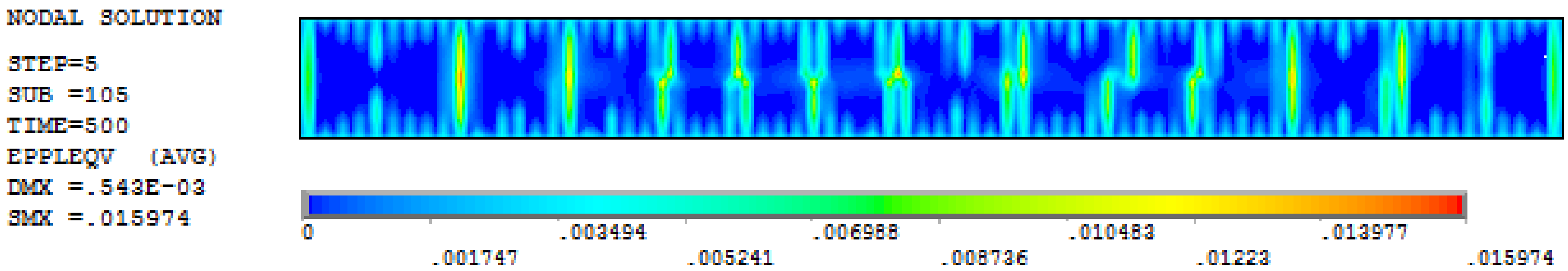
The damping coefficients are tracked and are used to make corrections to the results.



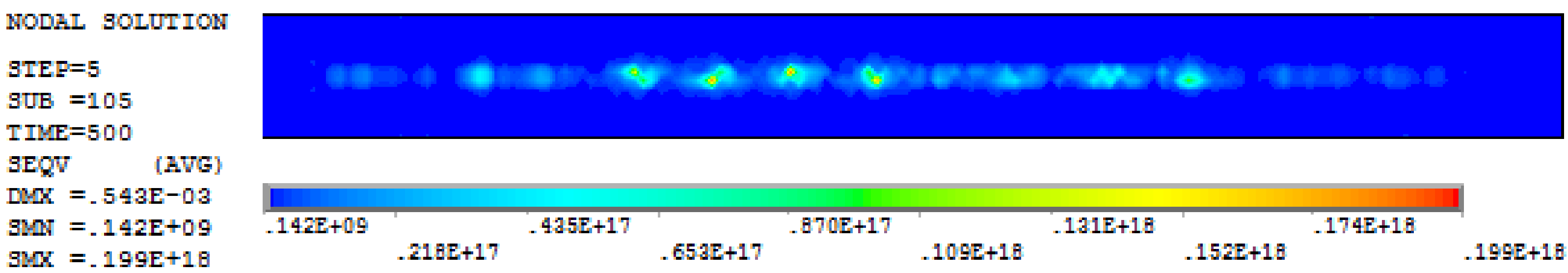
Displacement (magnitude) contours

Model 2: Curved Foil Non-linear Buckling

Plastic Strain Contours



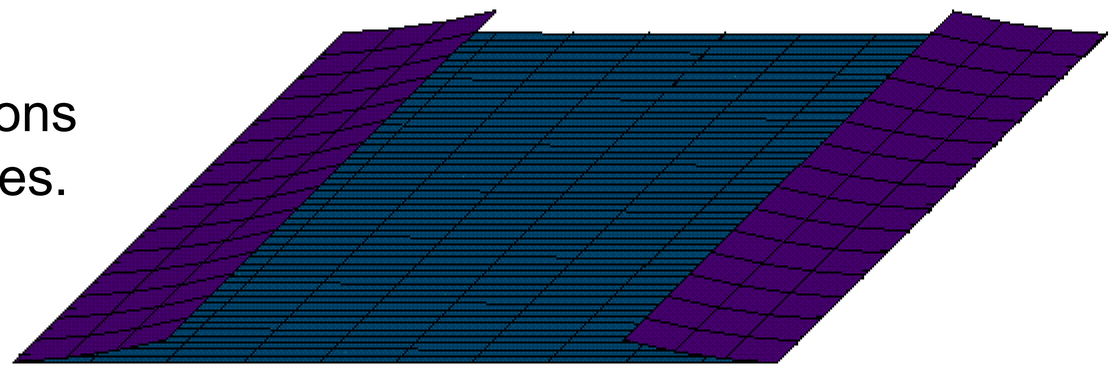
Von Mises Stress Contours

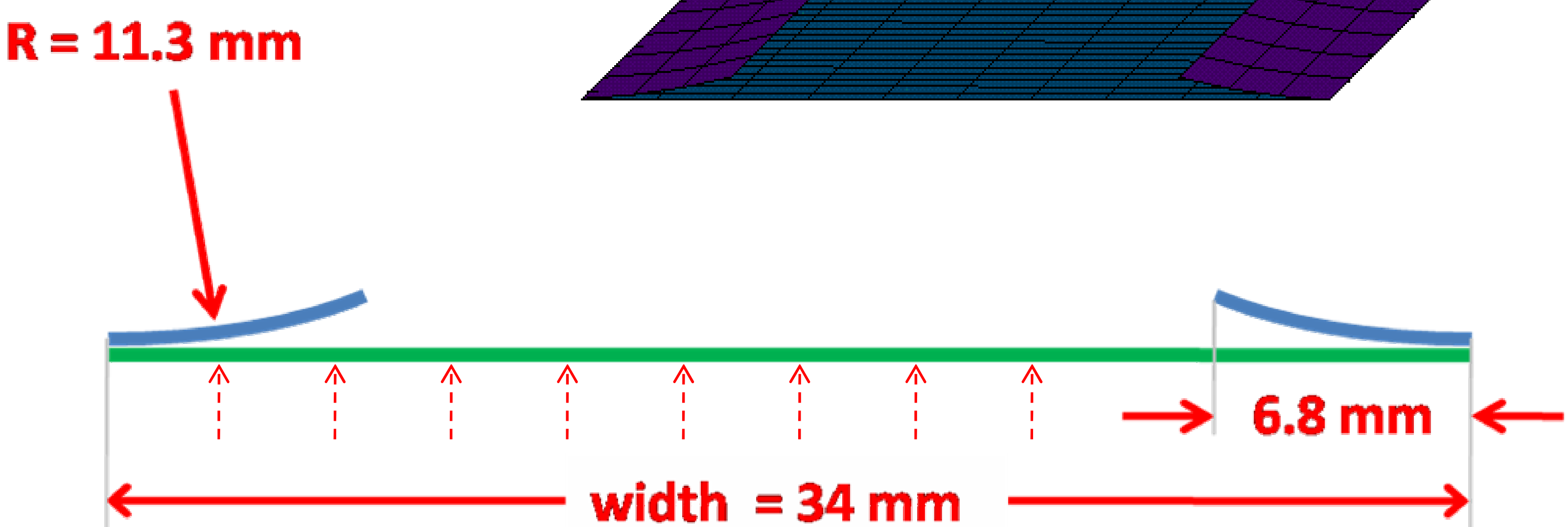


Model 3: Flat Foil, Curved Support

This analysis examined the effects of **curving the supports** that hold the foil in place.

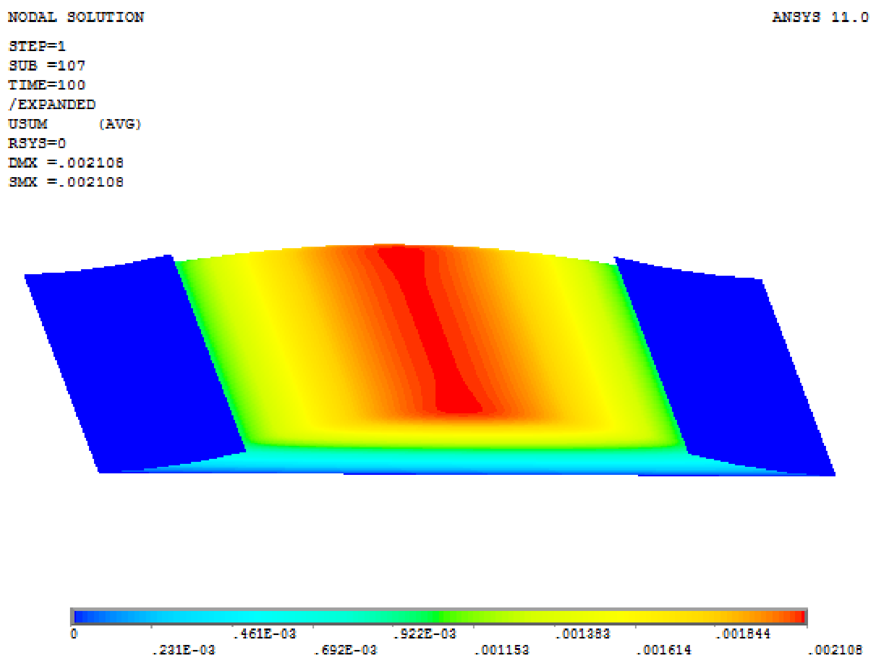
This is done to attempt to alleviate the very large rotations of the foil about the long edges.

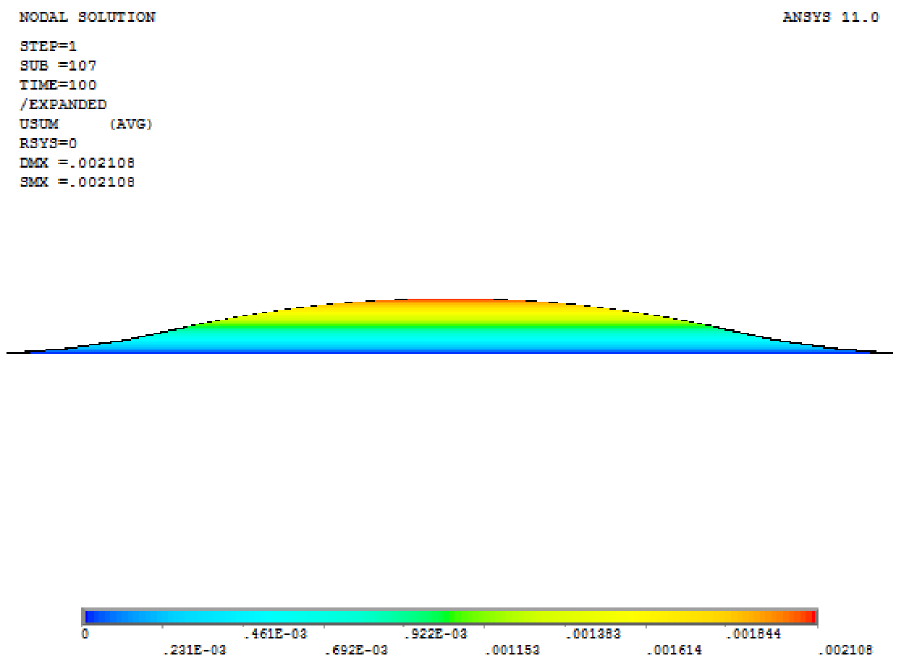




Front View

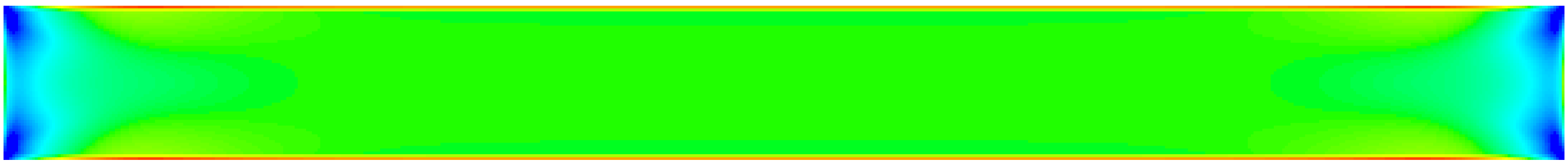
It is immediately apparent that the shape of these rigid supports *ease* the transition to the foil's equilibrium state.





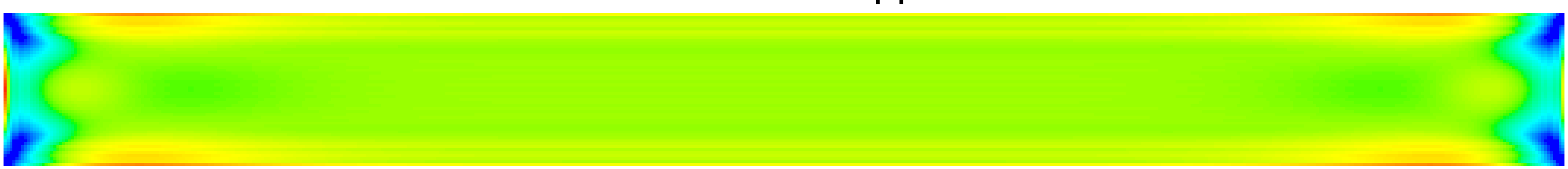
Compared to the original flat model (Case 1) with a similar mesh density, there is a significant **decrease in plastic strain.**

Original Flat Foil



Max Plastic Strain:
0.039

With Curved Supports



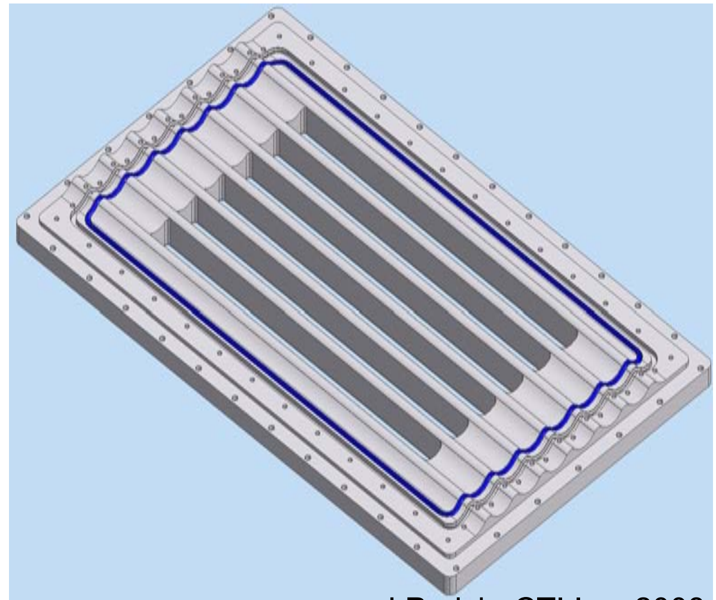
Max Plastic Strain:
0.016

Model 4: Scalloped Foil

This analysis examined the effects of **curving the supports** and **curving the foil**.

This is done to attempt to further alleviate the rotations of the foil about the long edges.

Scalloped Foil Test Section



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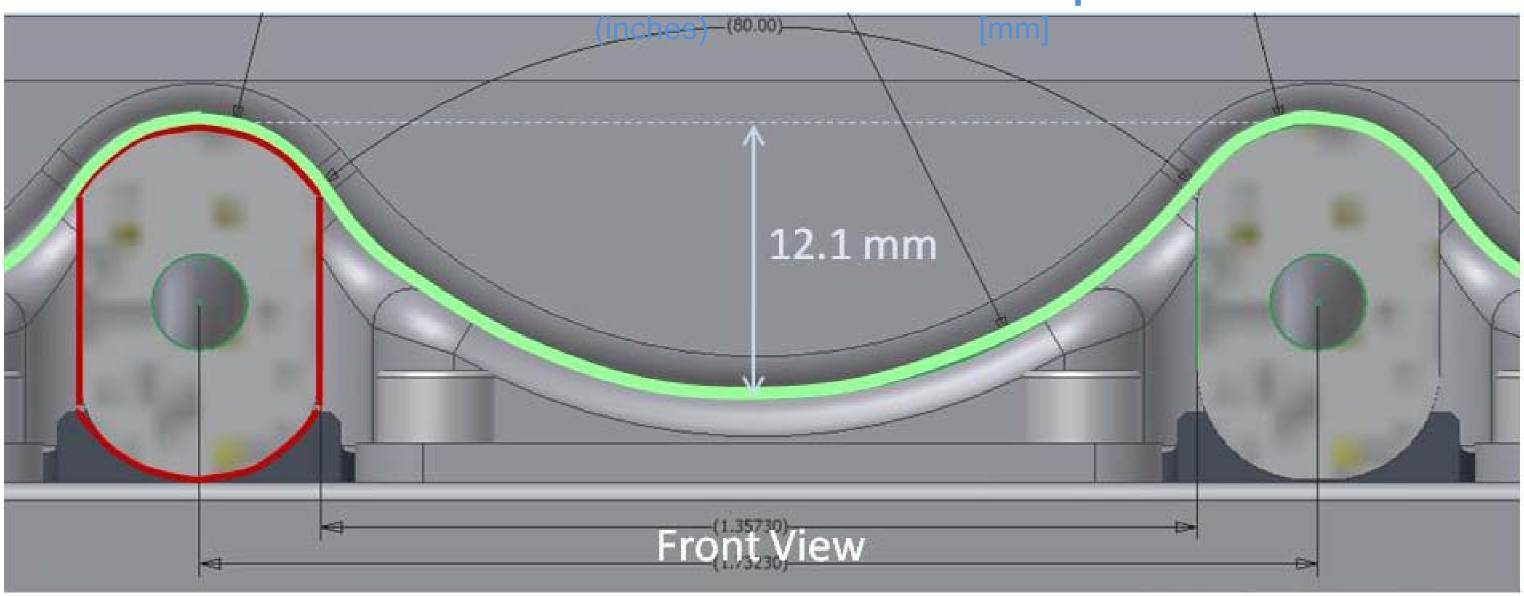
Details of the Scallops



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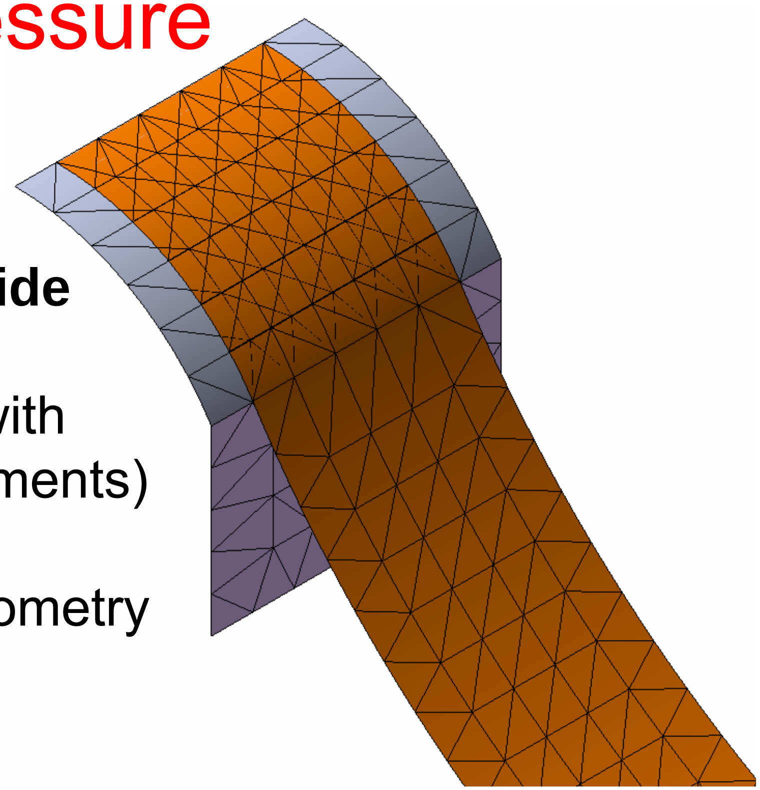
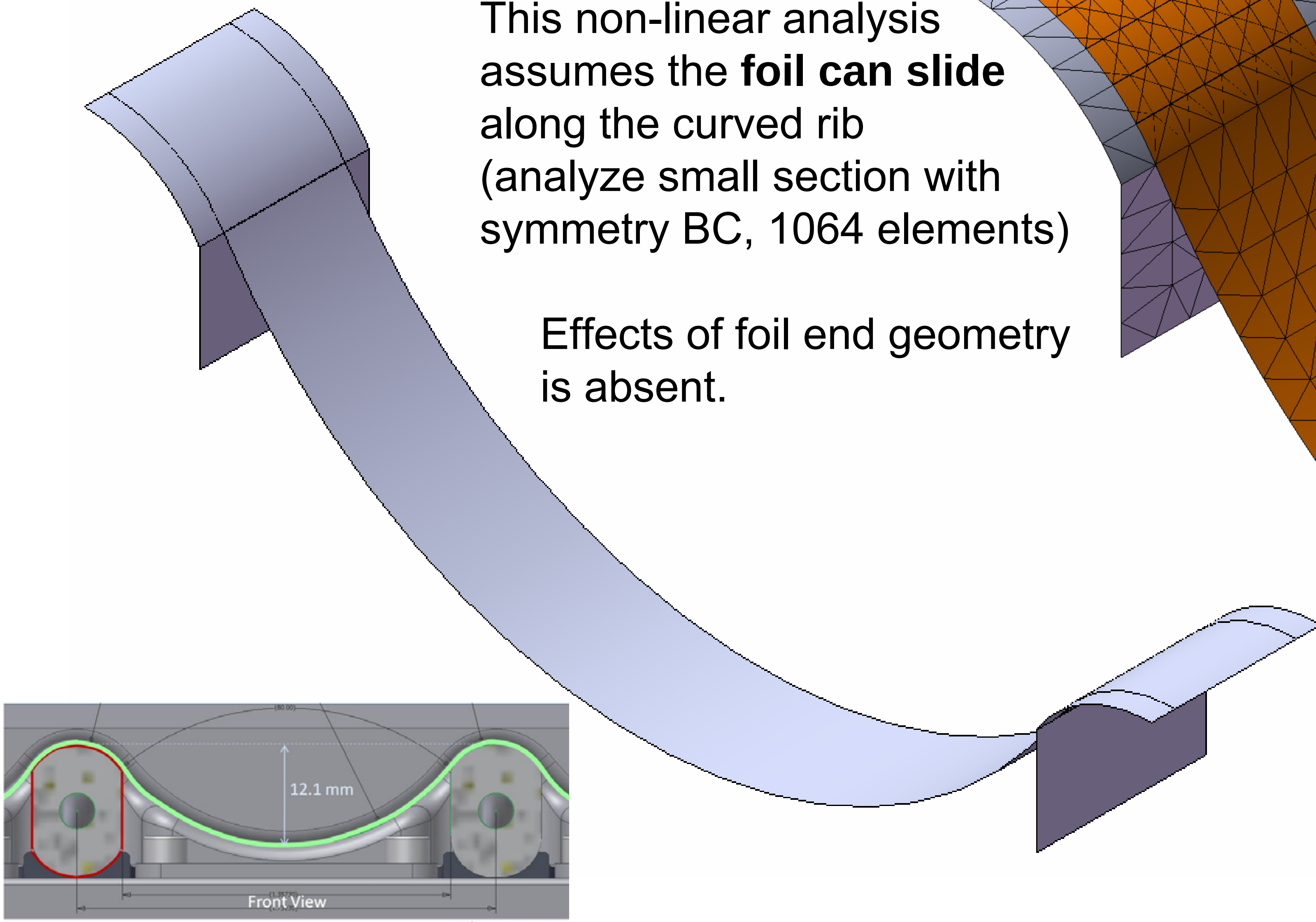
Model 4: Scalloped Foil – Pressure



This non-linear analysis assumes the **foil can slide** along the curved rib (analyze small section with symmetry BC, 1064 elements)

Effects of foil end geometry is absent.



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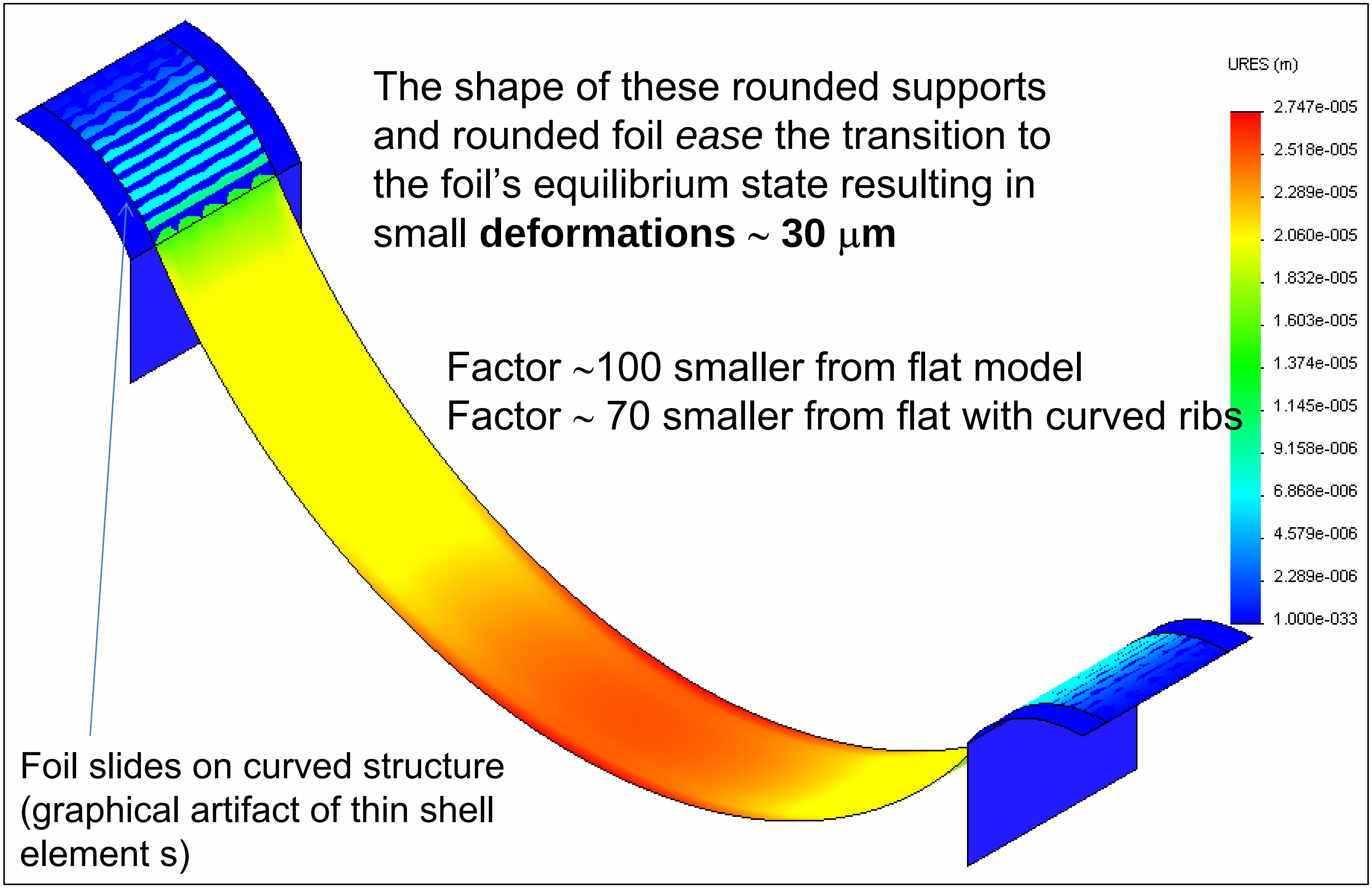
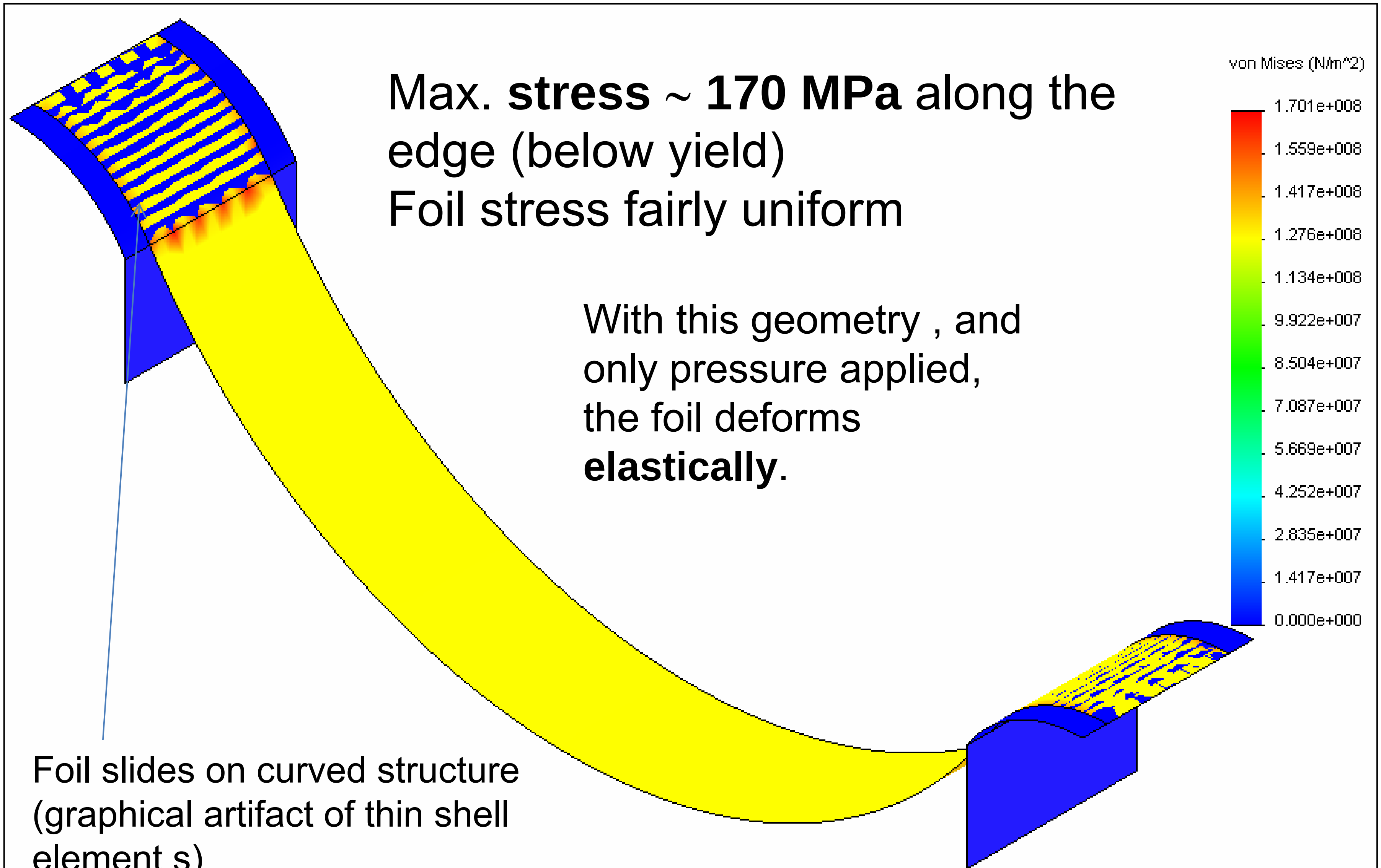
Displacement Contours



At max. pressure: 26.6 psi

Stress Contours



Max. **stress ~ 170 MPa** along the edge (below yield)
Foil stress fairly uniform

With this geometry , and only pressure applied, the foil deforms **elastically**.

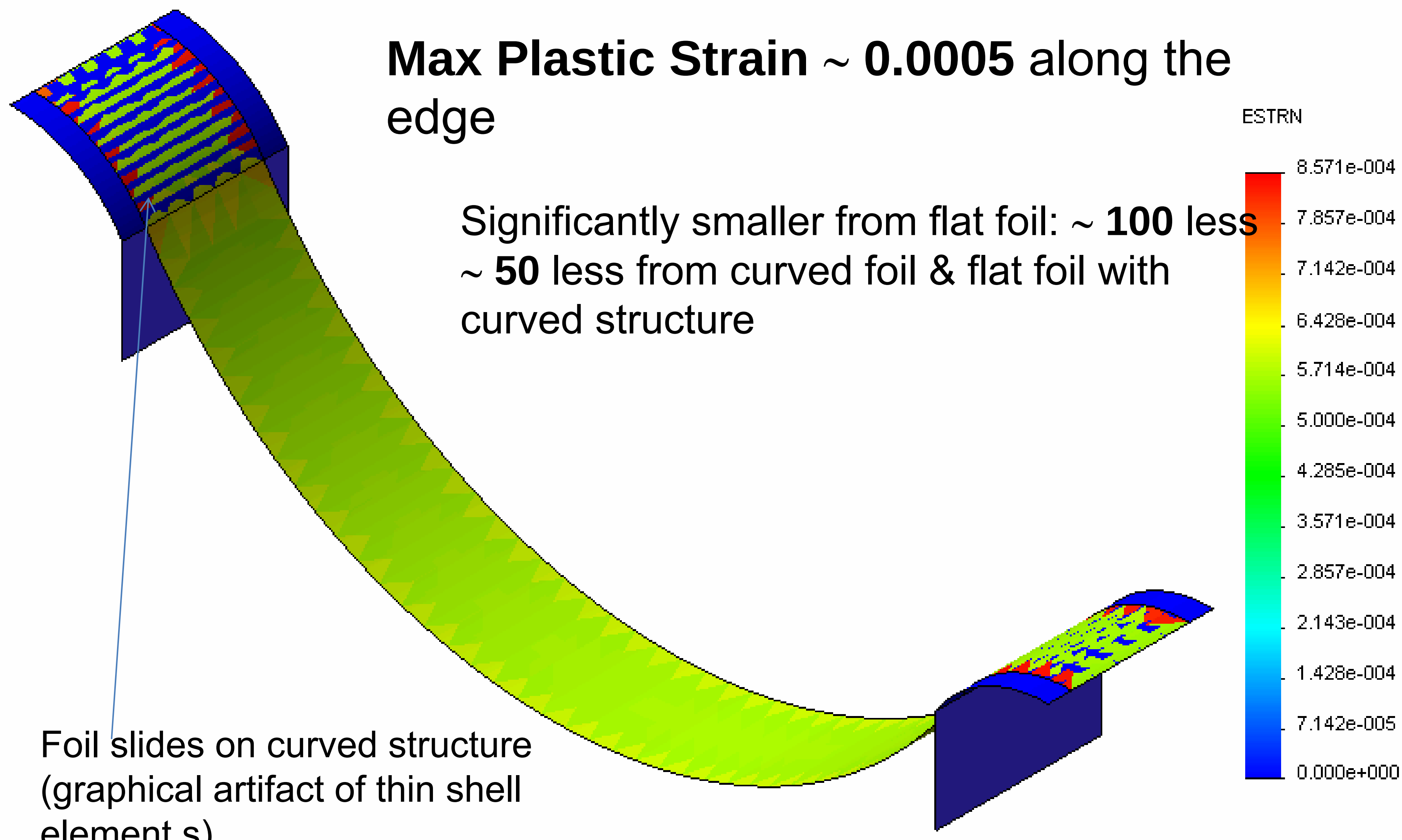
Foil slides on curved structure (graphical artifact of thin shell element s)

At max. pressure: 26.6 psi

Strain Contours

Max Plastic Strain ~ 0.0005 along the edge

Significantly smaller from flat foil: ~ **100** less
~ **50** less from curved foil & flat foil with curved structure

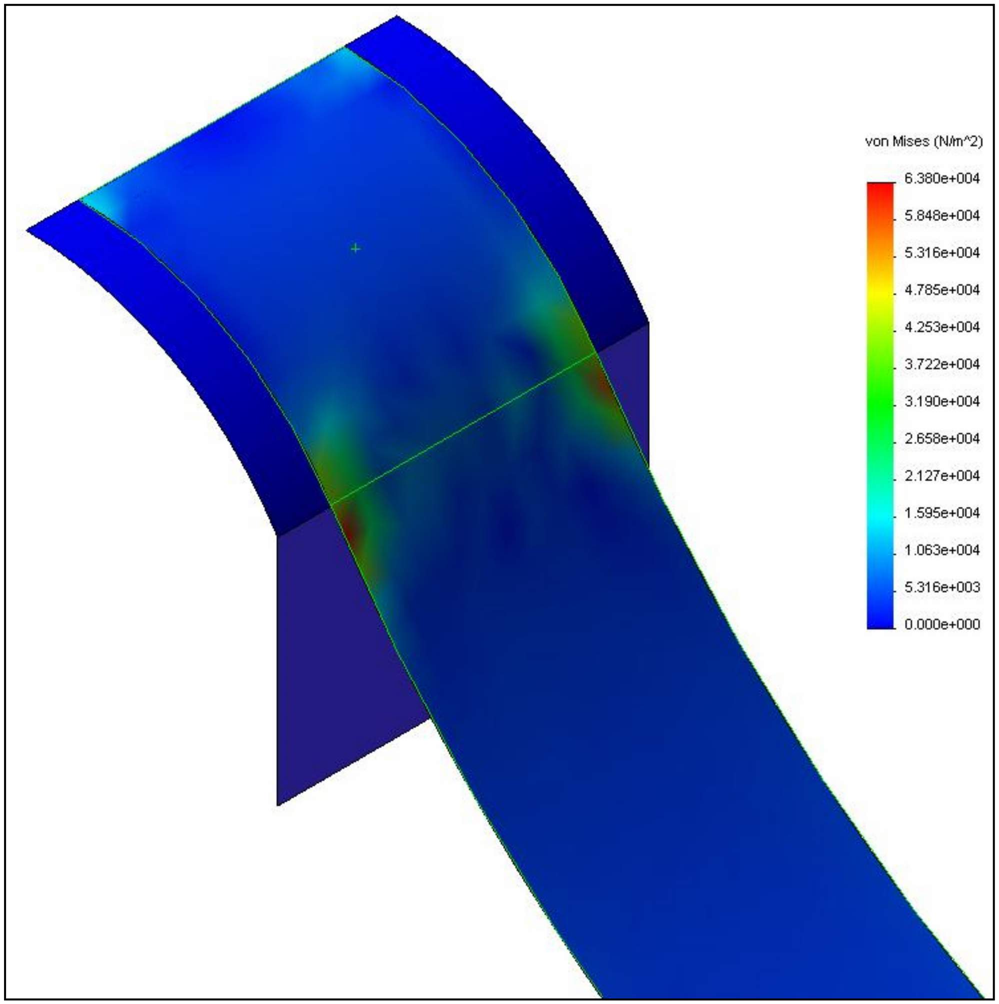


Foil slides on curved structure (graphical artifact of thin shell element s)

At max. pressure: 26.6 psi

Residual Stress: Unload from 26.6 psi to 0 psi

Residual stress levels are low: 0.065 MPa (pressure only)



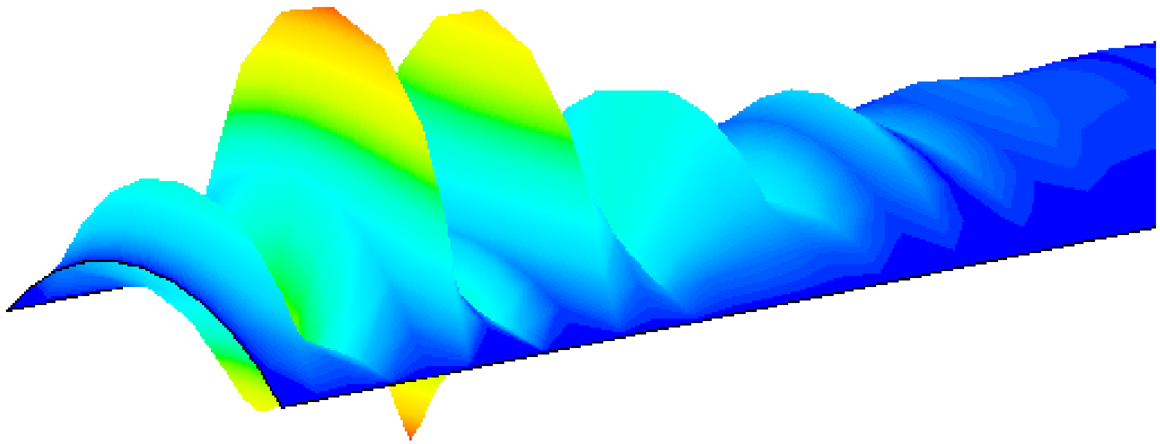
Summary

- Four Models were investigated:
  (1) Flat foil
  (2) Curved foil
  (3) Flat foil & curved support
  (4) Scalloped foil
  – Pressure + Thermal loads of (1) shows wrinkle formation
  – Pressure + Thermal load of **(2)** inconclusive (pressure alone shows ½ strain of flat; wrinkles using non-linear buckling)
  – Pressure (only) of (3) shows ½ strain of flat
  – **Pressure (only) analysis for Scalloped (4) shows:**
    - **Max. Displacement factor of 100 less than (1)**
    - **Max. Stress factor of 2 less than (1)**
    - **Max. Plastic strain ~100 X less than (1) and 40 X less than (2) & (3)**
- Effects of thermal load and “end-geometry” for scalloped foil remains to be analyzed

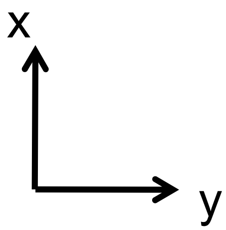
Additional Slides

Buckling Analysis

An conservative eigenvalue buckling analysis was performed to determine an approximate **first buckling mode.**



From this preliminary analysis, it appears that under temperature loading, when the foil buckles, the **largest deflections are near the ends.**



X-Component Plastic Strain

$\varepsilon_{x,max}$ = 0.013

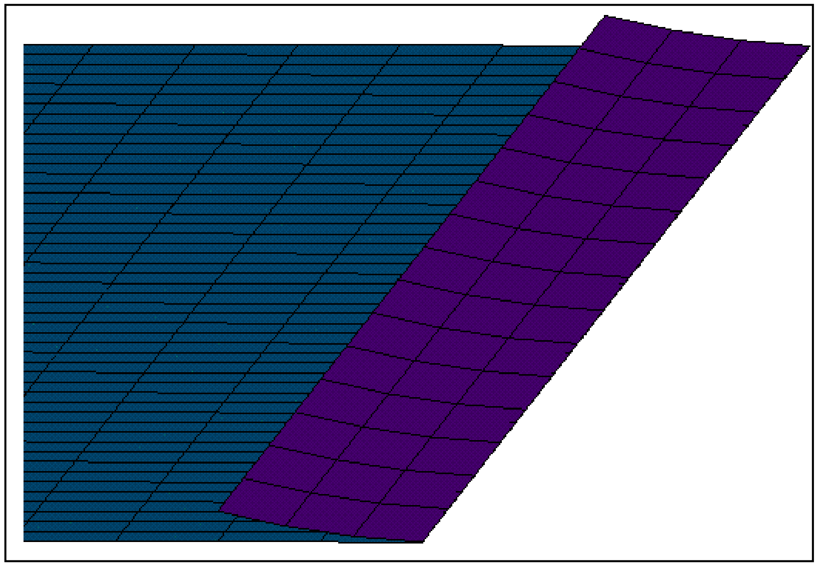
Y-Component Plastic Strain

$\varepsilon_{y,max}$ = 0.012

Nonlinear Contact Analysis

Foil Mesh

- SHELL181 (4 node quad): shell elements that support large displacements, membrane stresses, and account for change in shell thickness
- CONTA174: contact surface elements



Support Mesh

- TARGE170: rigid target surface elements

Loading

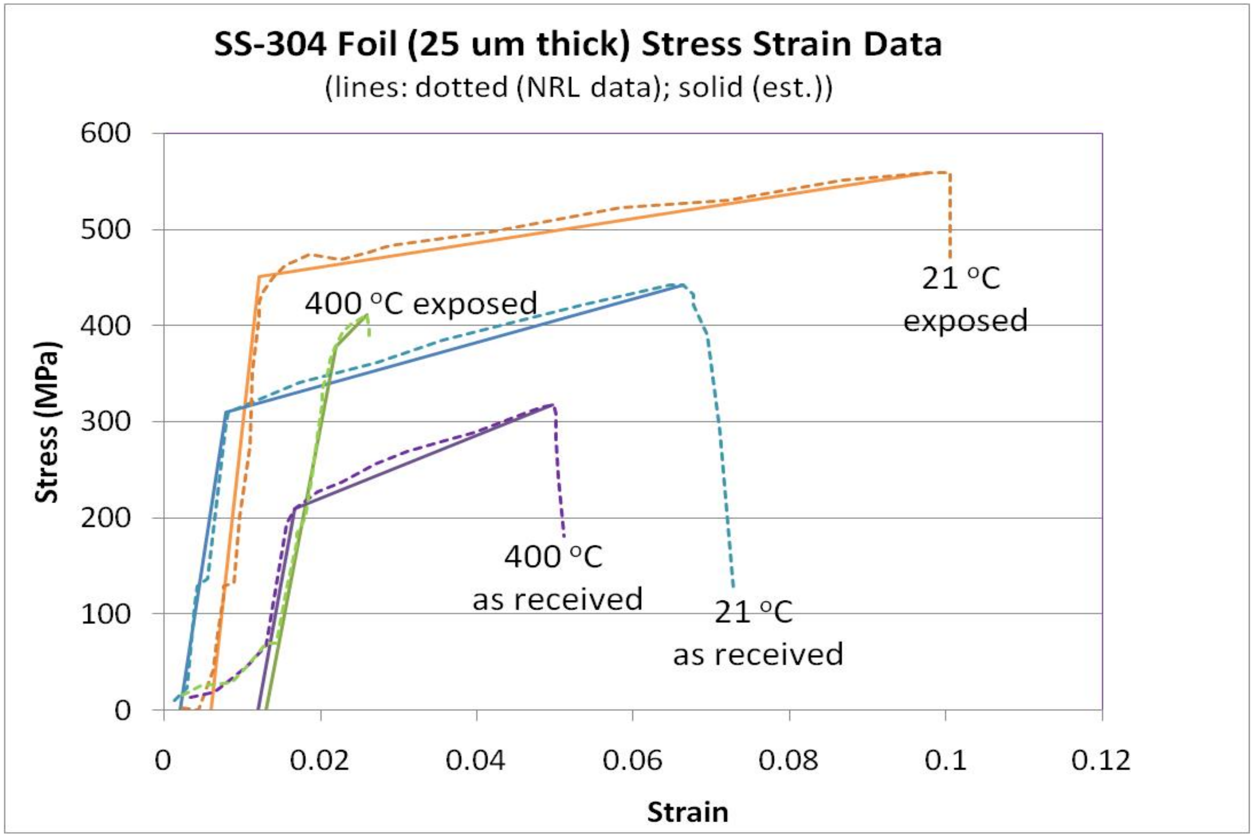
- 3-edge fixed
- Modeled one side – 1 symmetry B.C.
- Pressurized

Solution

- Adjusts small gap to bring surface to initial contact
- Solved for 4000 and 16000 nodes

Mechanical Analysis

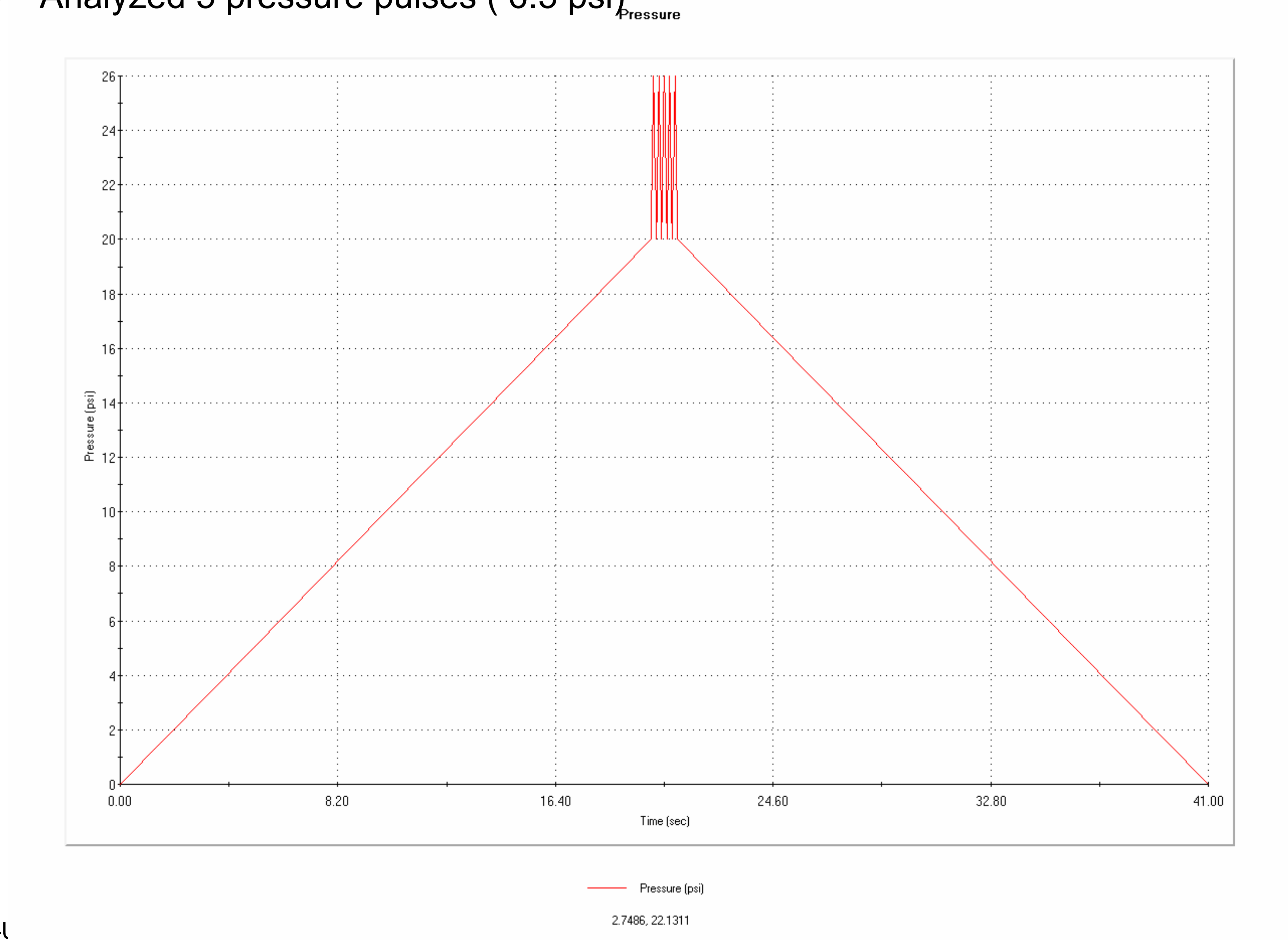
- Made a six-rib section of the Hibachi foil
- Used shell elements for elastic and plastic analysis
- Estimated Young's Modulus (E) and Tangent Modulus (E_{tan}) based on NRL Data.



Test Temp. & Condition	E (GPa)	E_{tan} (GPa)	Yield (MPa)NRL Data
21 °C as received	39.16	2.26	310
21 °C exposed	36.82	1.27	434
400 °C as received	12.59	3.29	209
400 °C exposed	17.22	8.41	365

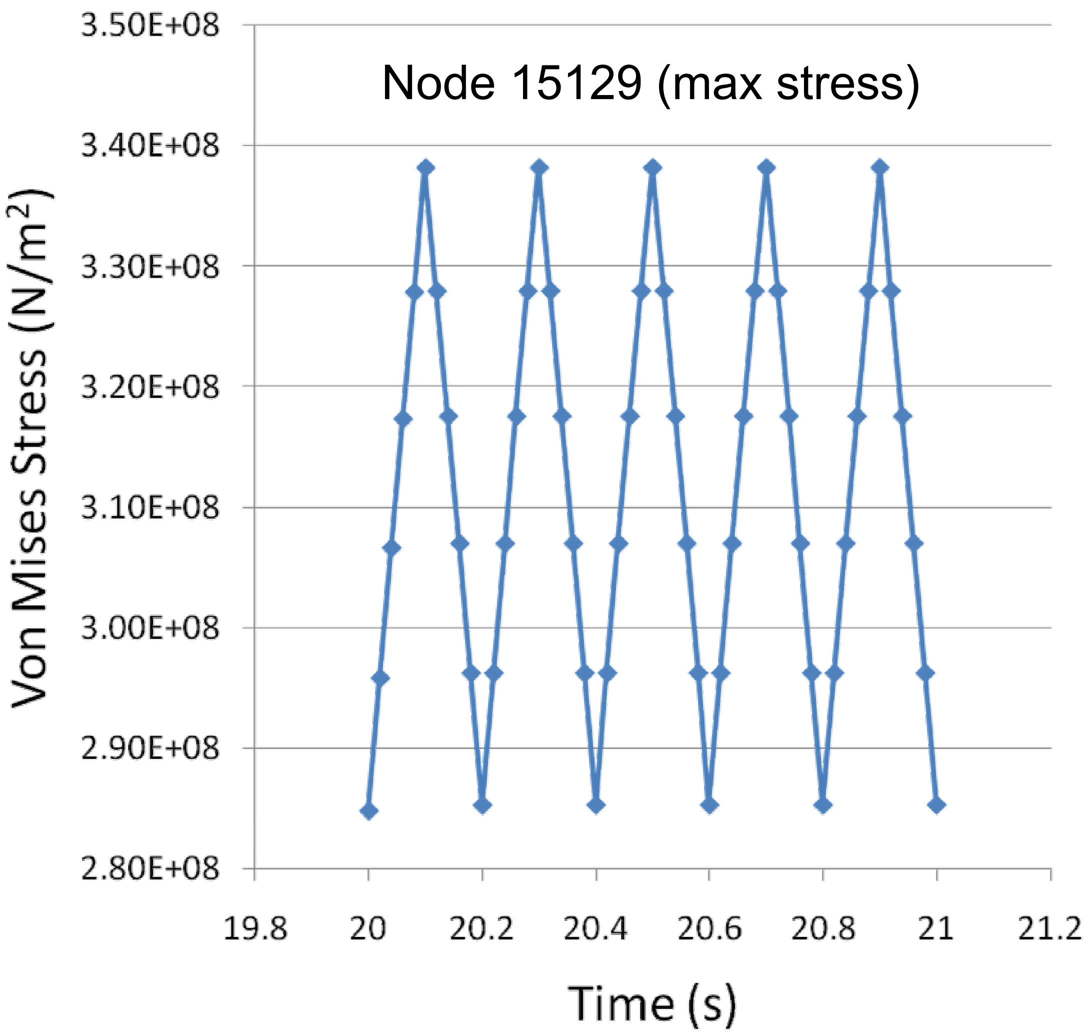
Pressure Loads

- Analyzed 5 pressure pulses (6.5 psi)



Stress for 5 Pulses (400 C exposed)

- Residual stress following first pulse: 0.47 MPa



Pulse	Residual Stress*
1	0.47
2	0.30
3	0.20
4	0.30
5	0.30

*assumes constant material properties