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Sandia National Laboratories

# A Simplified Finite Element Model for Design of a Resonant Plate

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U.S. DEPARTMENT OF ENERGY NNSA

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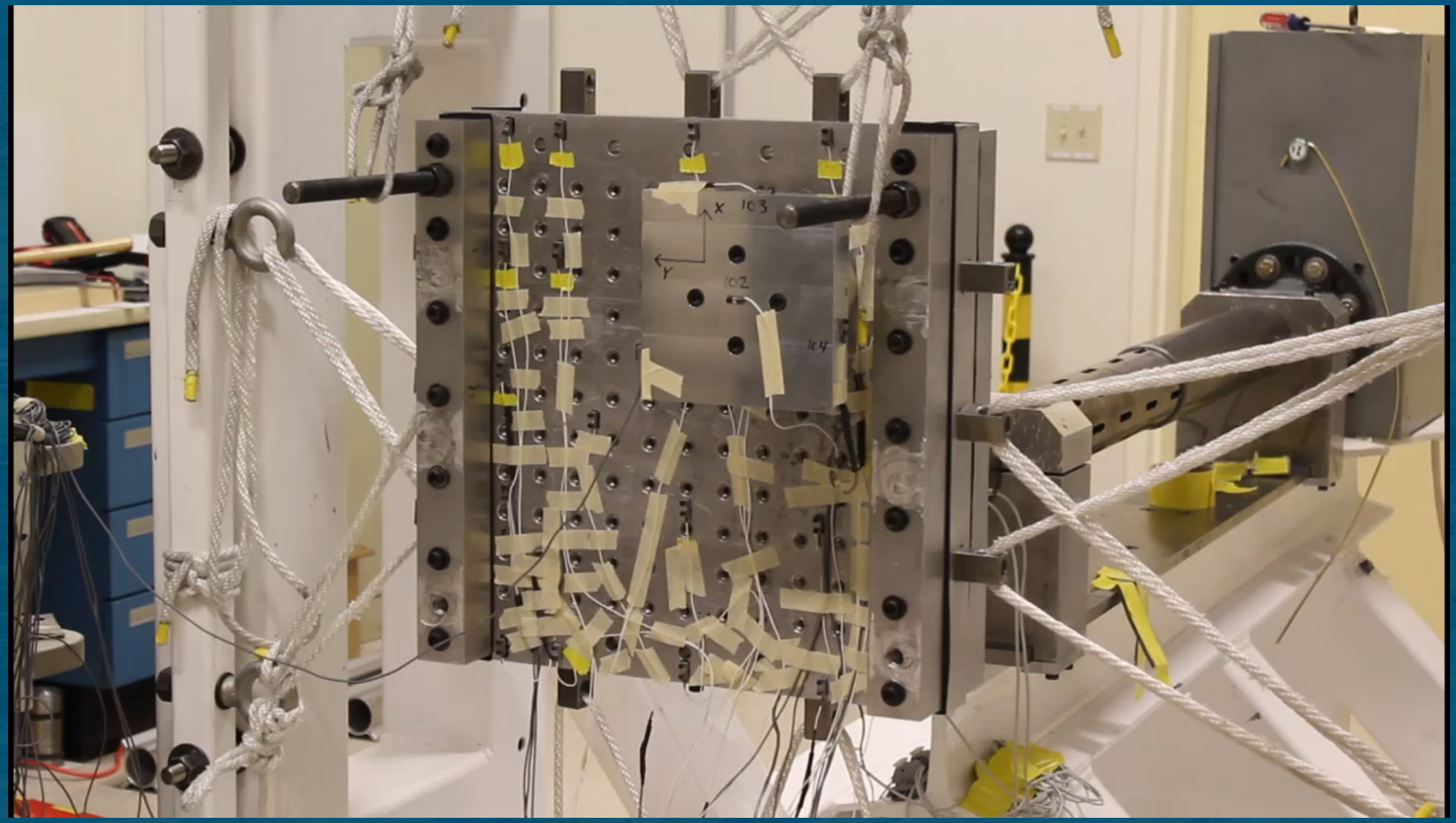
# Goal

Create a **model for design** that is as **simple** as it can be and no more complicated than it must be to provide **reasonably accurate results**.

# Resonant Plate Pyroshock Testing



# How These Presentations are Laid Out

## Talk 1:

- Model Overviews & Modal Verification
  - Problem Description
  - Major Simplifications
  - Model for Bare Plate
  - Model for Plate with Damping Bars

## Talk 2:

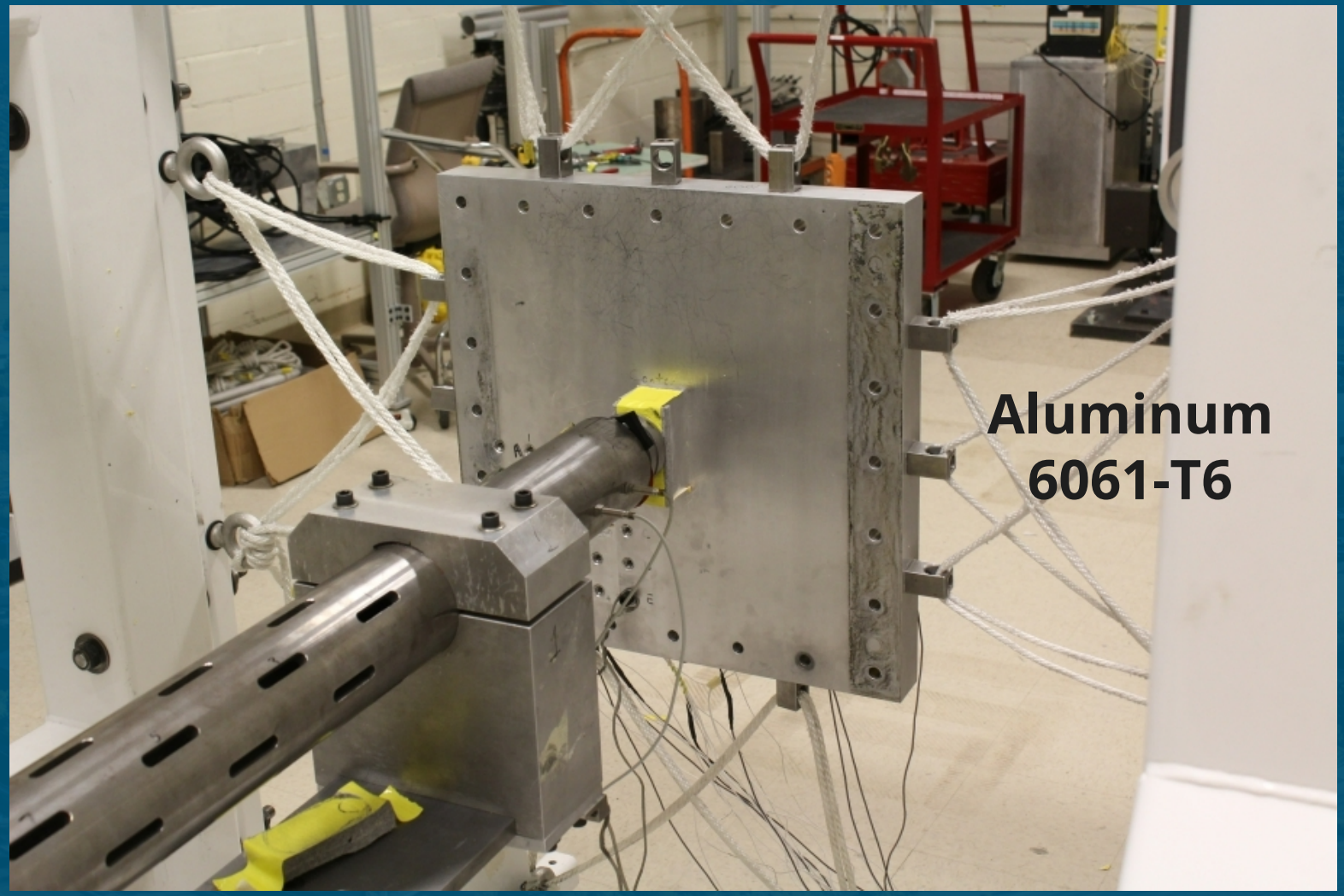
- Lessons Learned during Model Development

## Talk 3:

- Shock Verification & Application to Other Plates

# Problem Description

# 1kHz Resonant Plate



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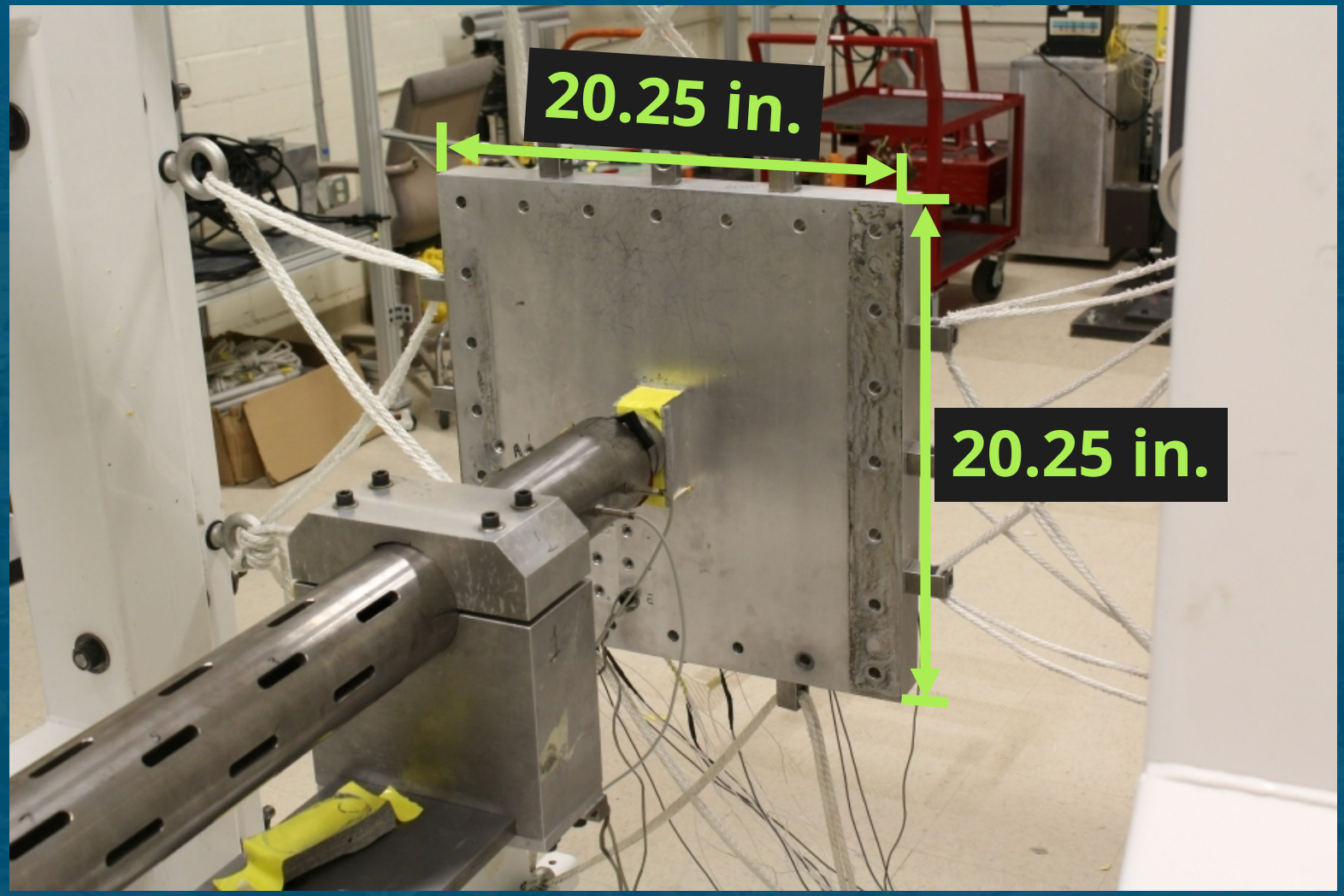

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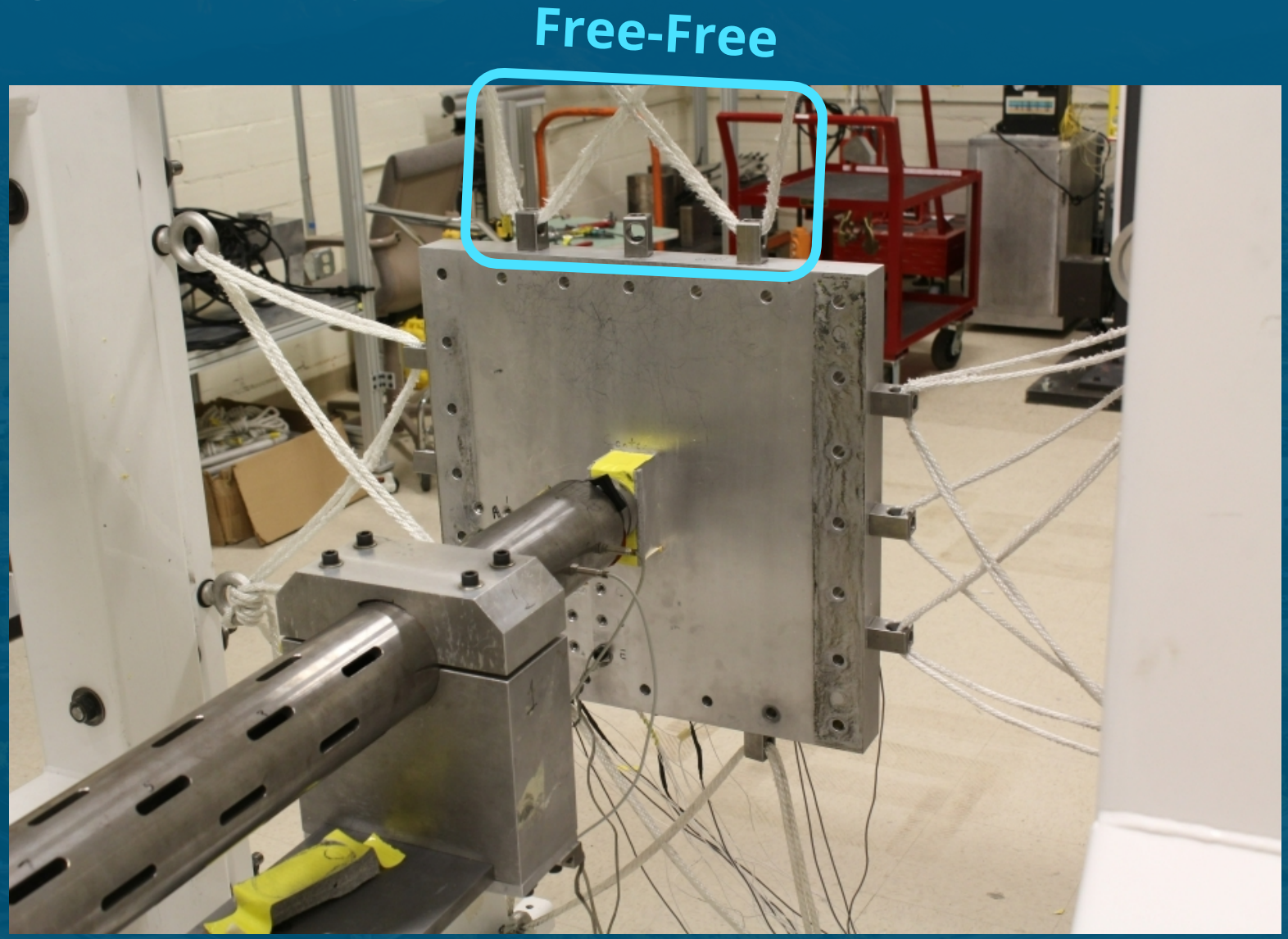

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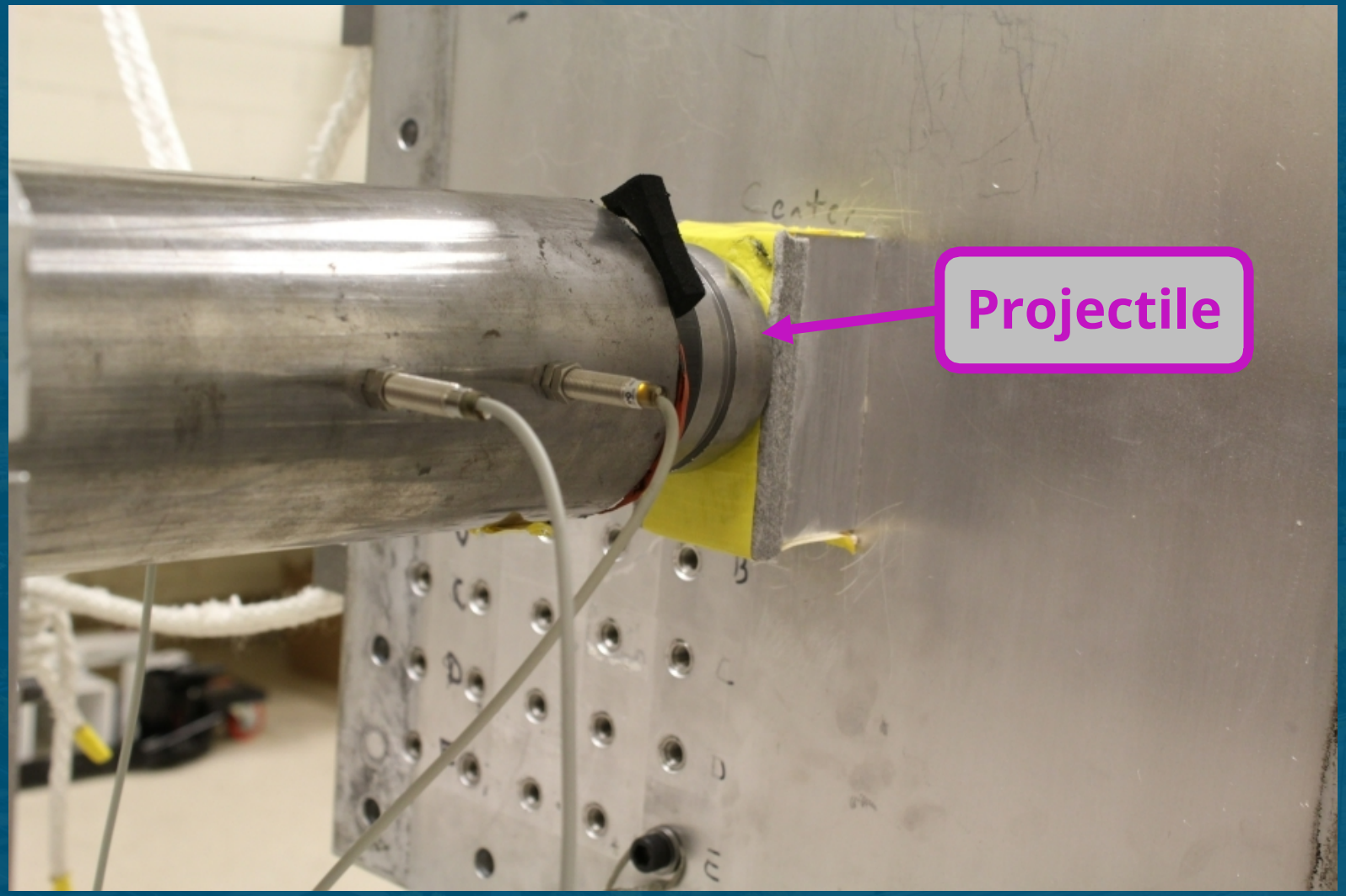

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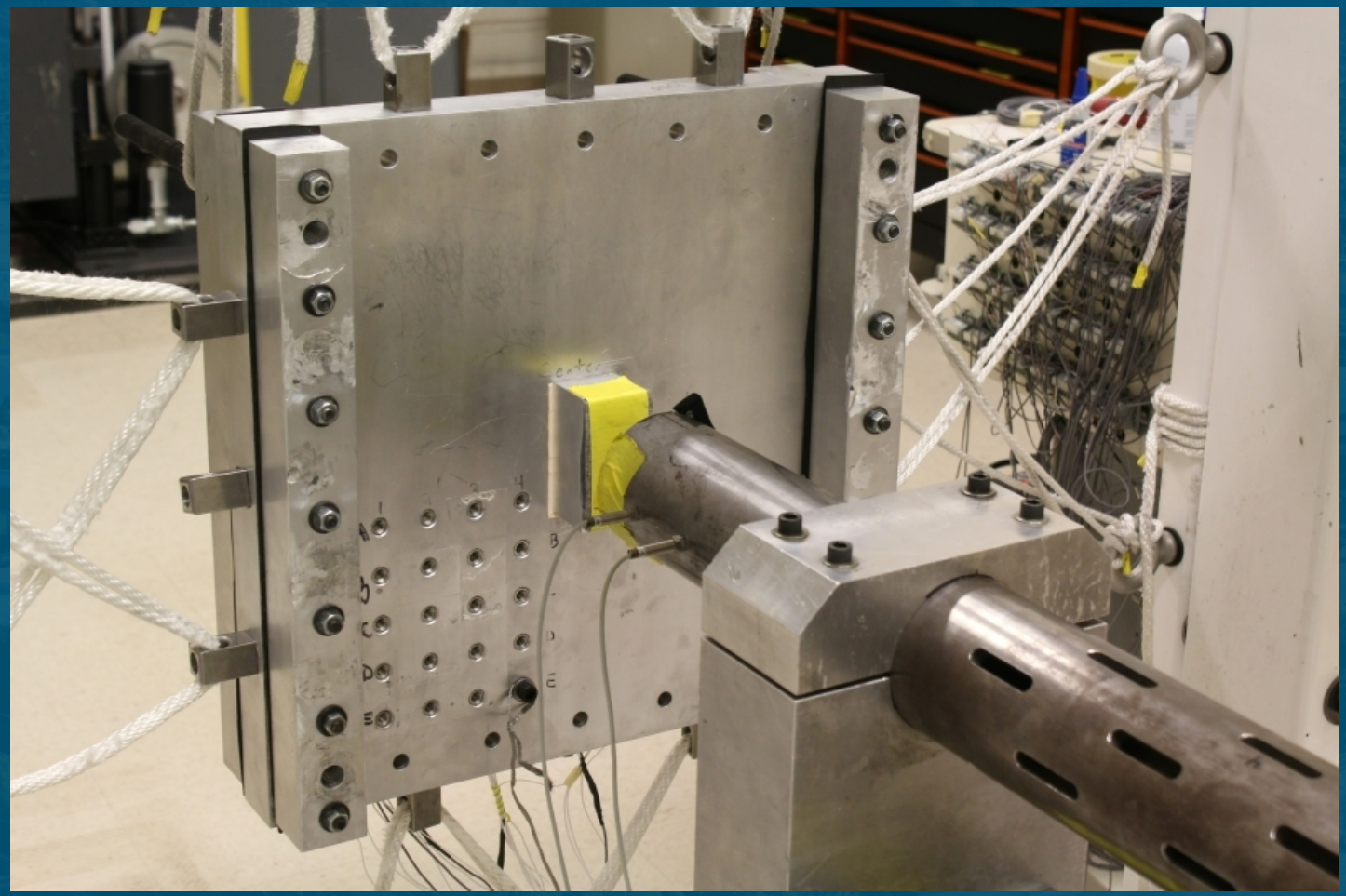

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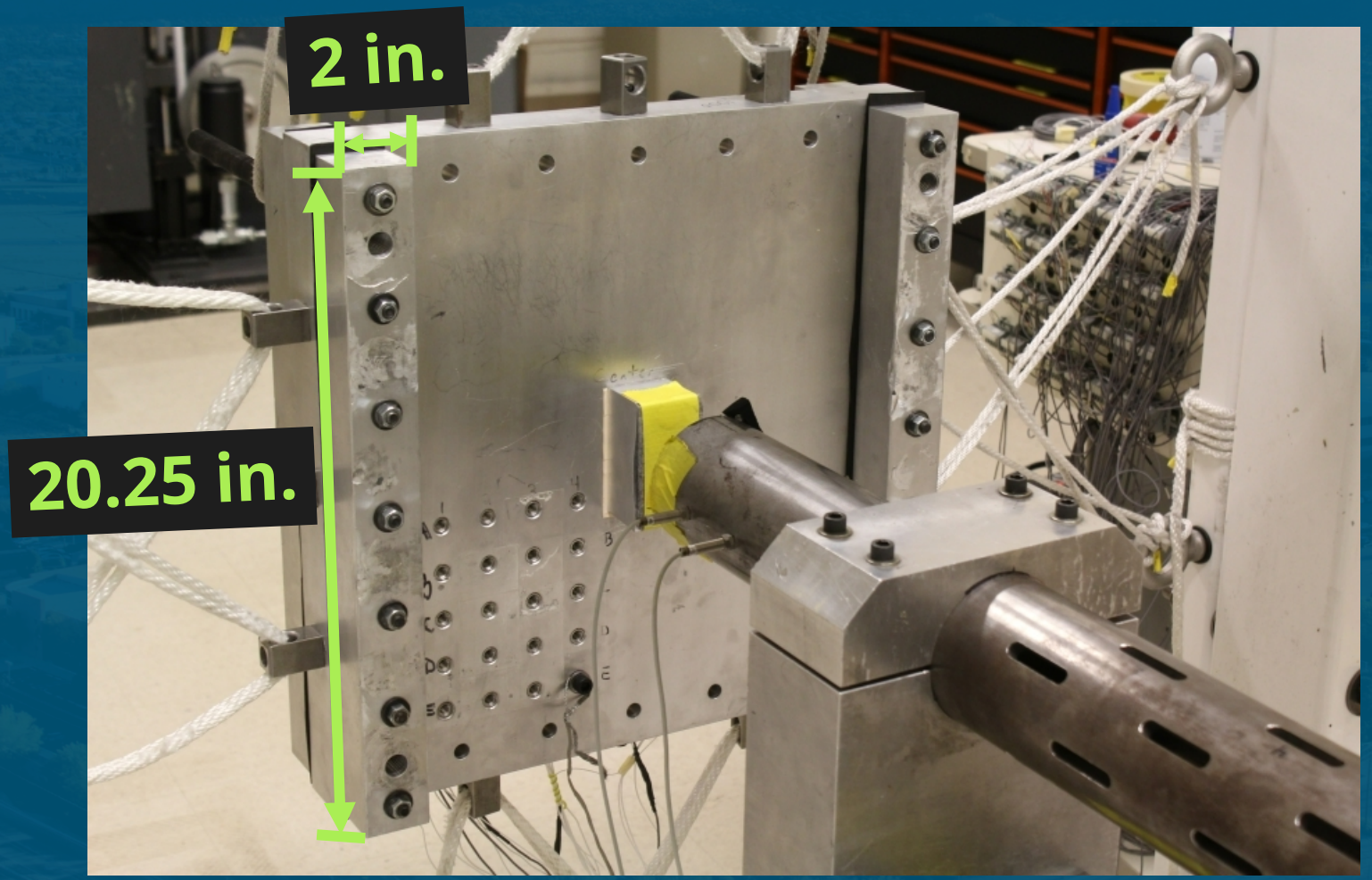
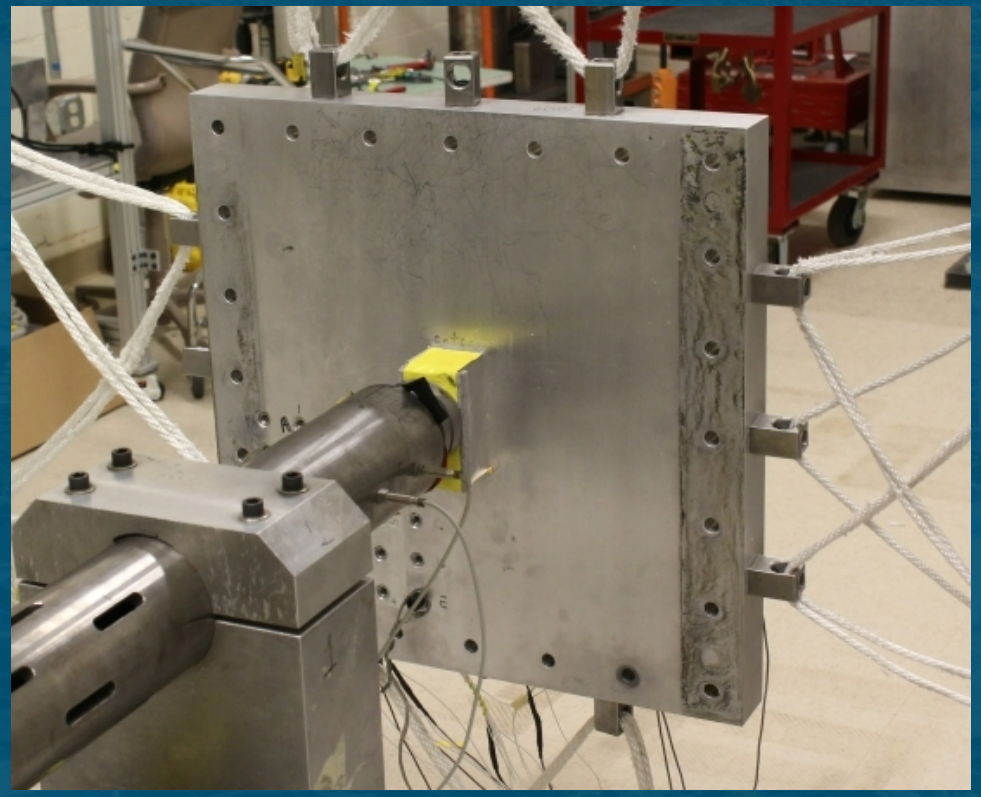


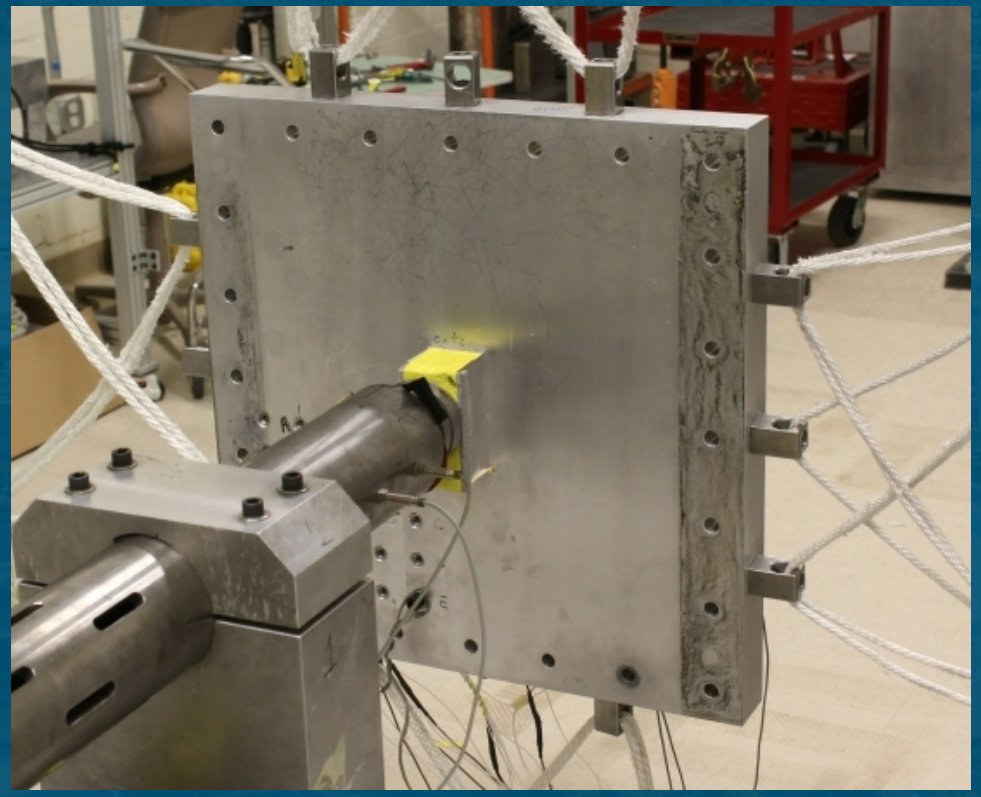
# 1kHz Resonant Plate

Model the Bare Plate

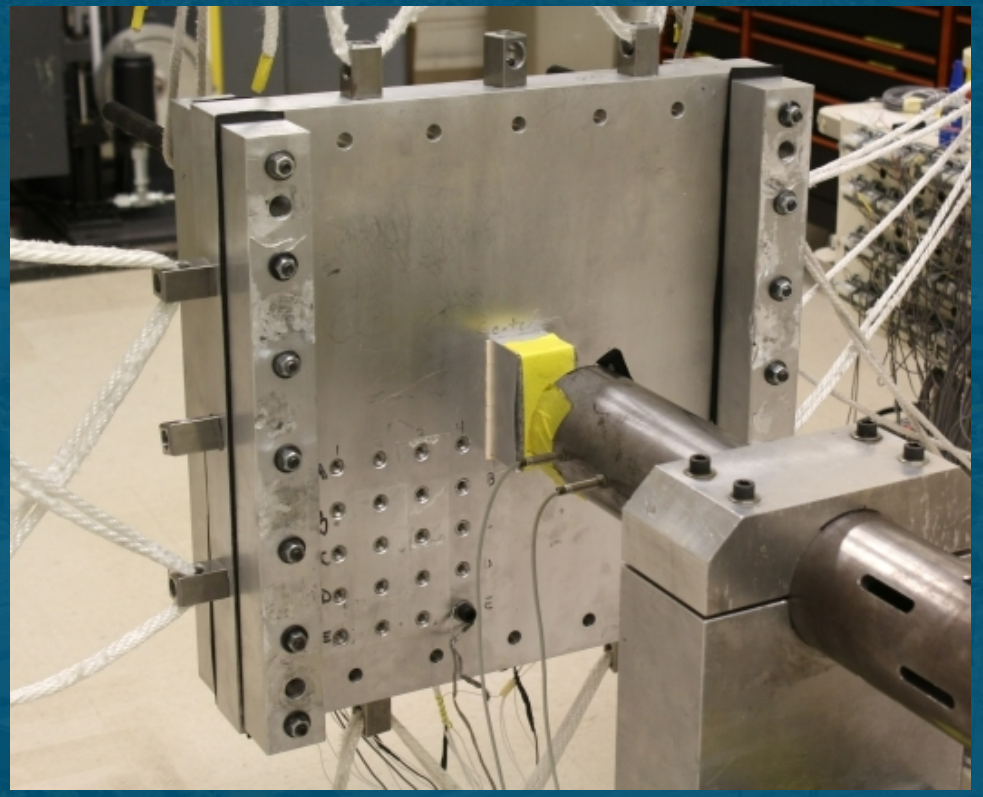


# 1kHz Resonant Plate

Model the Bare Plate



Then Add Damping Bars



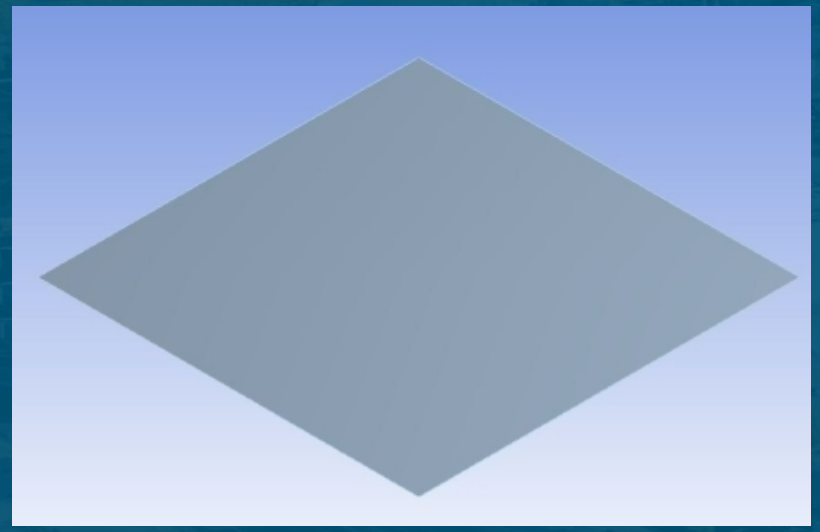
# Major Simplification:

# Shell & Solid Elements

# Shell vs. Solid Elements in Ansys

## Shell (2D) Elements

- 2-Dimensional
- Best for thin structures

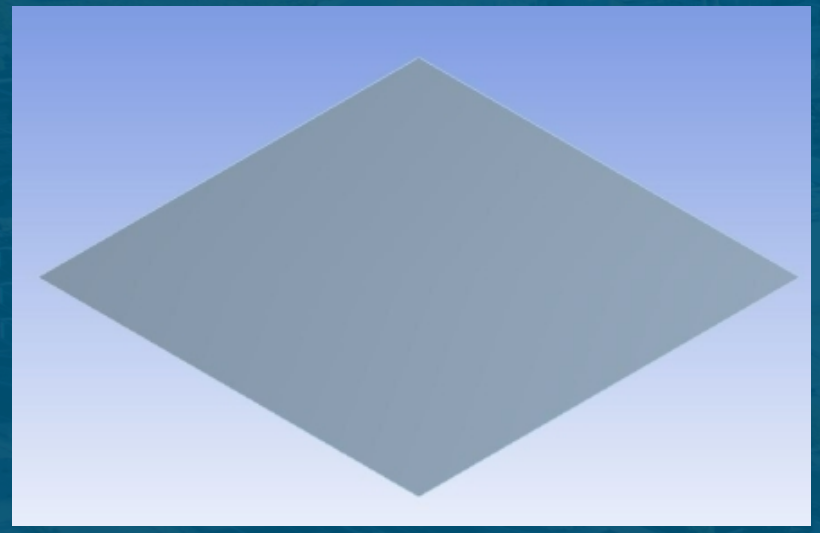


## Solid (3D) Elements

# Shell vs. Solid Elements in Ansys

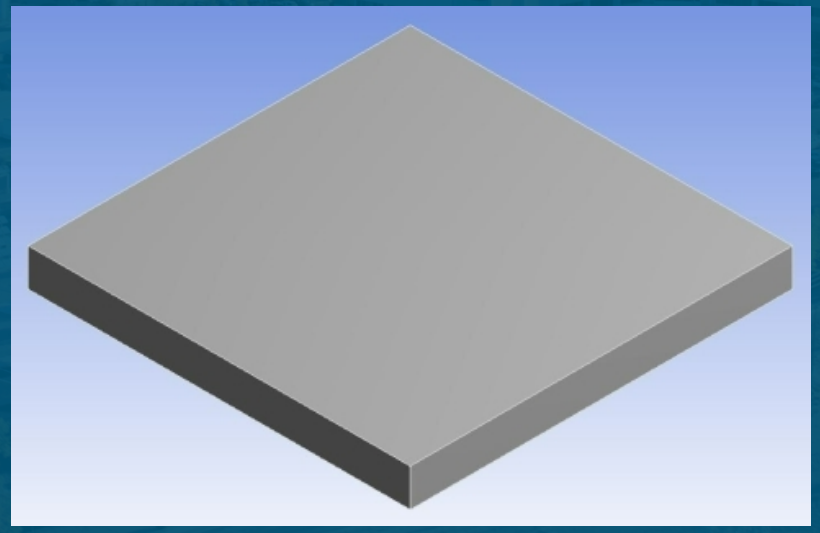
## Shell (2D) Elements

- 2-Dimensional
- Best for thin structures



## Solid (3D) Elements

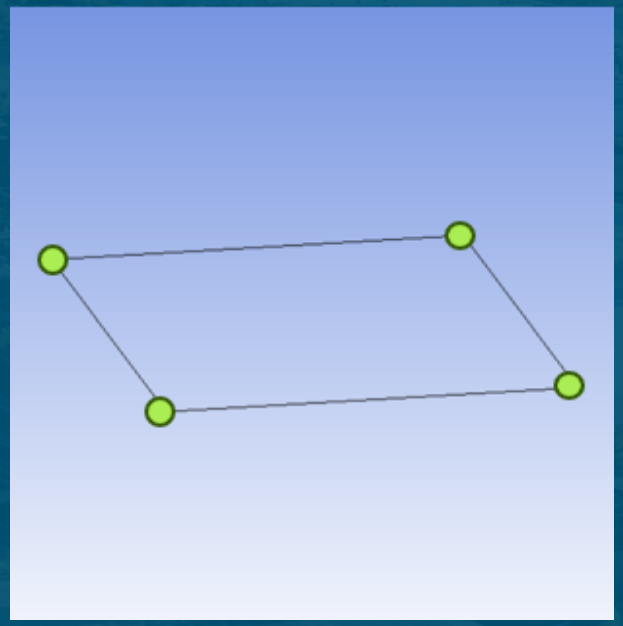
- 3-Dimensional
- Not restricted to thin structures



# Shell vs. Solid Elements in Ansys

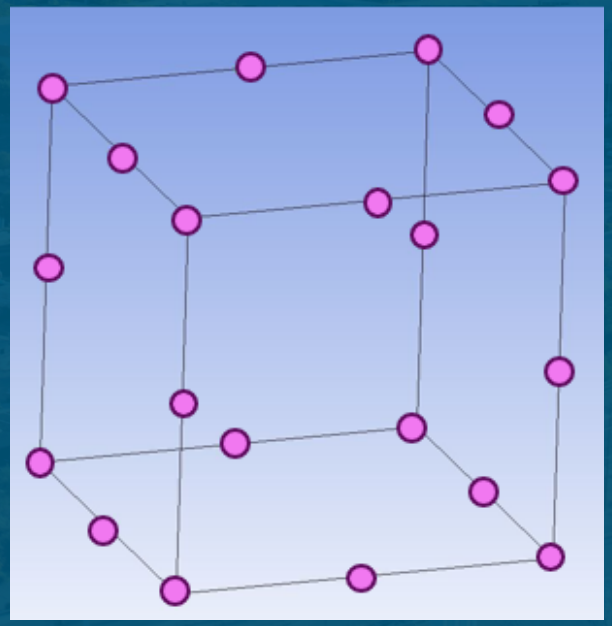
## Shell (2D) Elements

- 4 nodes on a single element
- Nodes have 6 DOF



## Solid (3D) Elements

- 20 nodes on a single element
- Nodes have 3 DOF

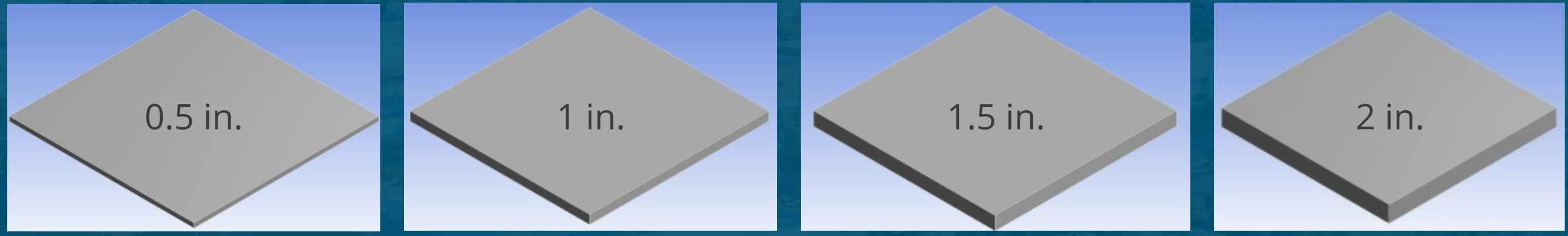


# How Good are Shell Elements in Ansys?

- Model our 1kHz plate with varying thickness

# How Good are Shell Elements in Ansys?

- Model our 1kHz plate with varying thickness
- Start small



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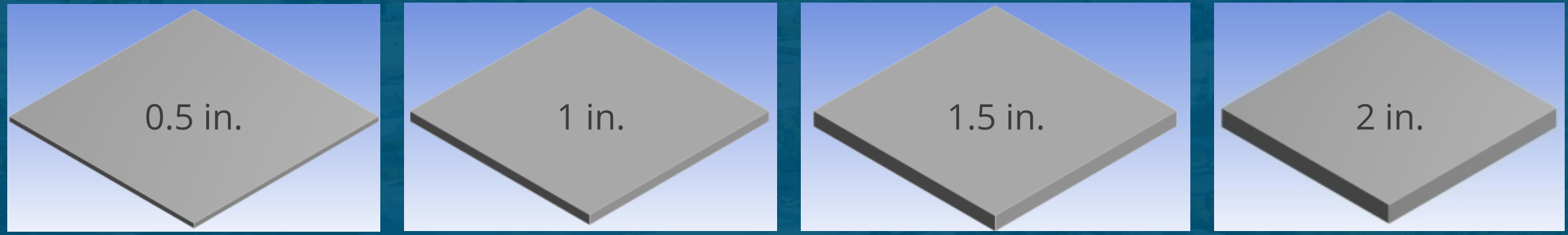
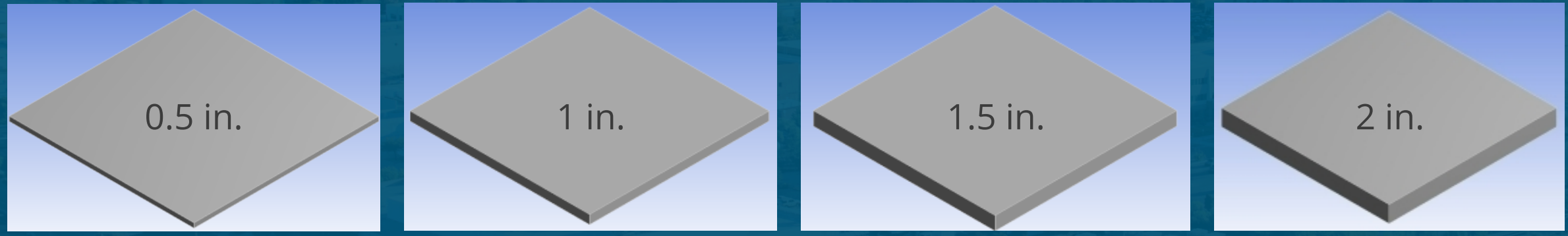



**Rule of Thumb:**
**Thickness ≤ 10% Length**

# How Good are Shell Elements in Ansys?

- Model our 1kHz plate with varying thickness
- Start small




2.5% 5% 7.5% 10%

**Rule of Thumb:**
**Thickness ≤ 10% Length**

# How Good are Shell Elements in Ansys?

- Model our 1kHz plate with varying thickness
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- Push the limits

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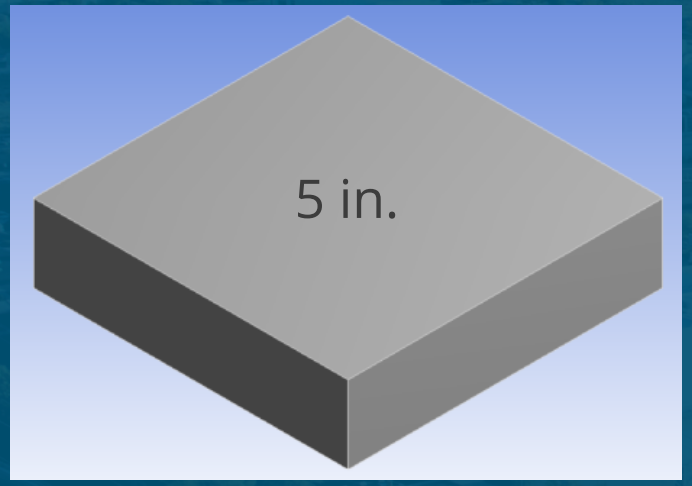
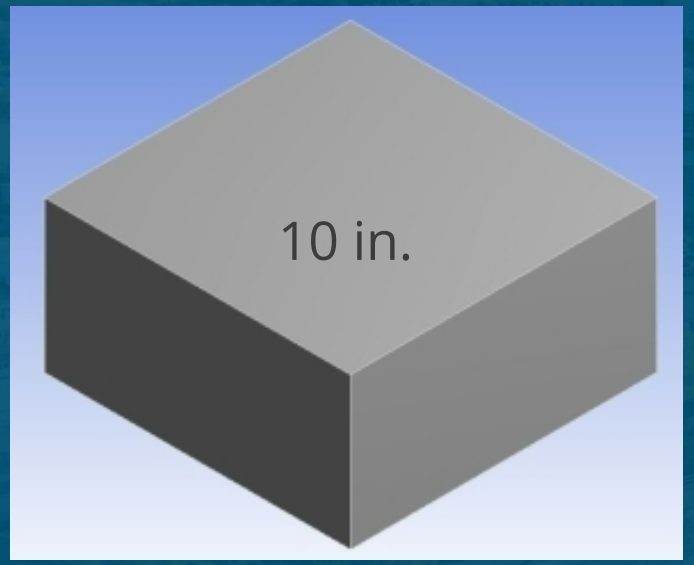



25%




50%

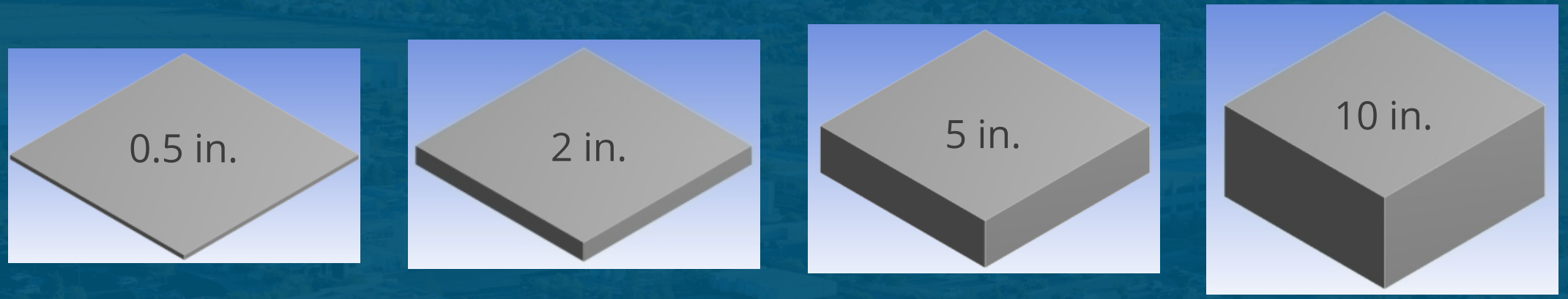
# How Good are Shell Elements in Ansys?

- Model our 1kHz plate with varying thickness
- Start small ( ≤ 10% Length )
- Push the limits ( > 10% Length )

- Compare natural frequencies of the first 10 flexural modes

# Results: Solid vs. Shell Elements in Ansys

- Model our 1kHz plate with varying thickness
- Compare natural frequencies of the first 10 flexural modes




Max.
% Difference
in Frequency

# Results: Solid vs. Shell Elements in Ansys

- Model our 1kHz plate with varying thickness
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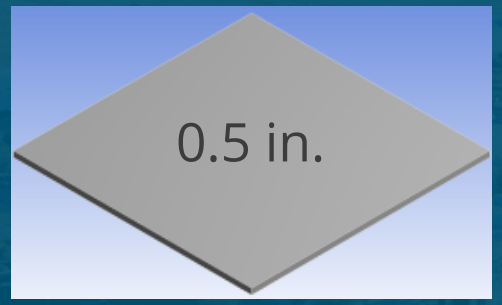
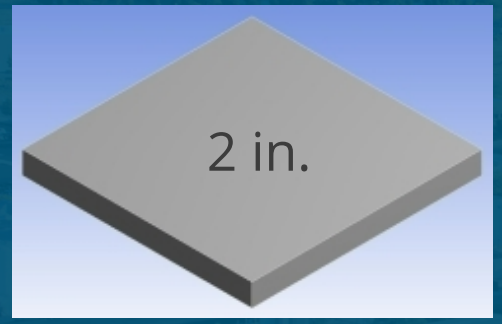
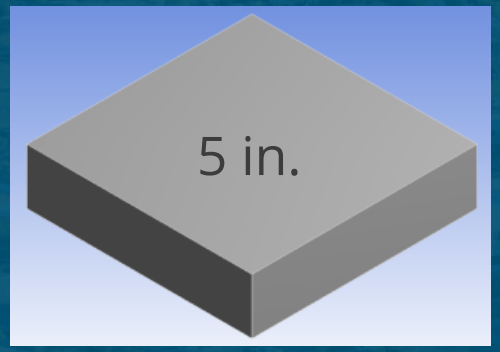
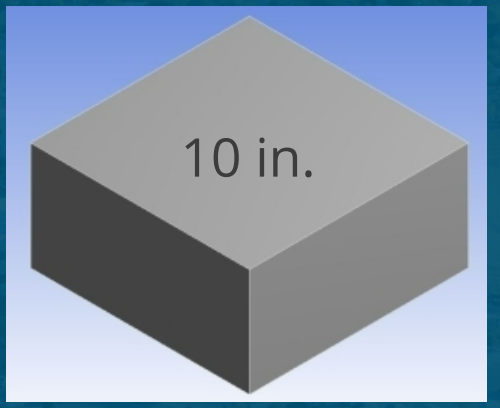


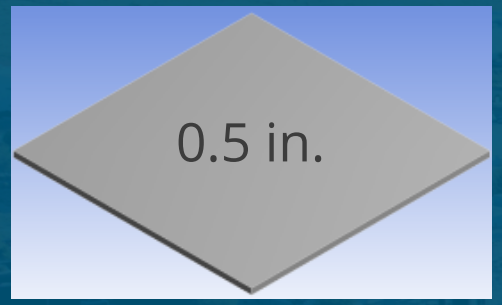



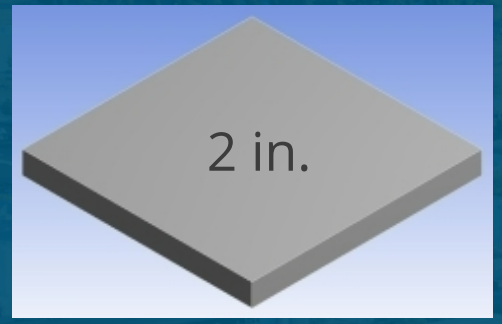



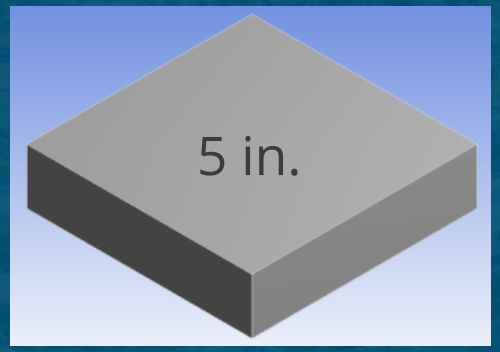

| Max. % Difference in Frequency | 0.36% | 0.10% | 0.44% | 1.49% |
|---|---|---|---|---|

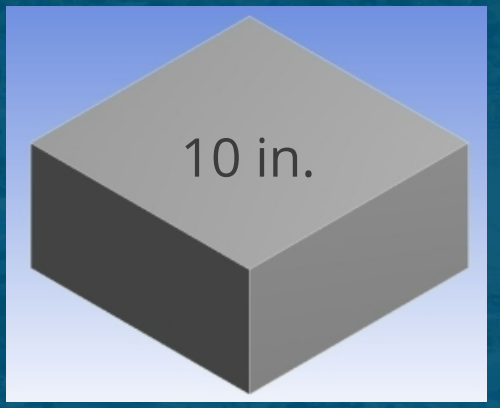
# Results: Solid vs. Shell Elements in Ansys

- Model our 1kHz plate with varying thickness
- Compare natural frequencies of the first 10 flexural modes




| Max. % Difference in Frequency | 0.36% | 0.10% | 0.44% | 1.49% |
|---|---|---|---|---|

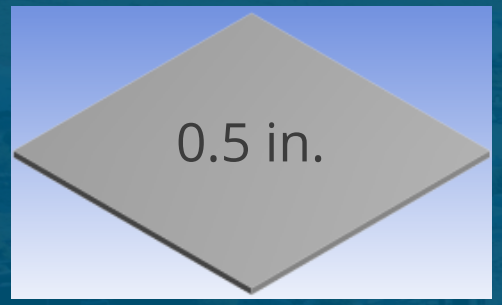
**Key Takeaways**

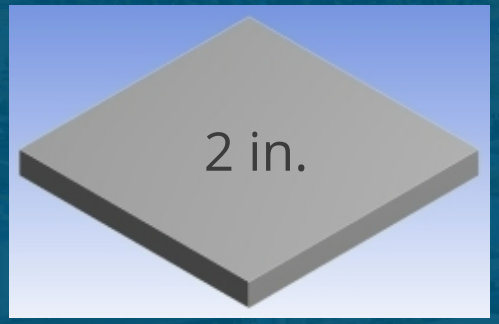
Ansys shell elements performed very well overall

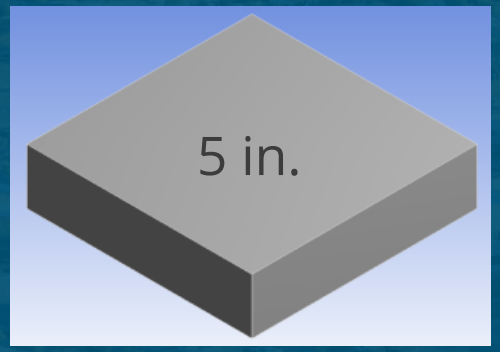
Larger differences occurred in the higher order modes

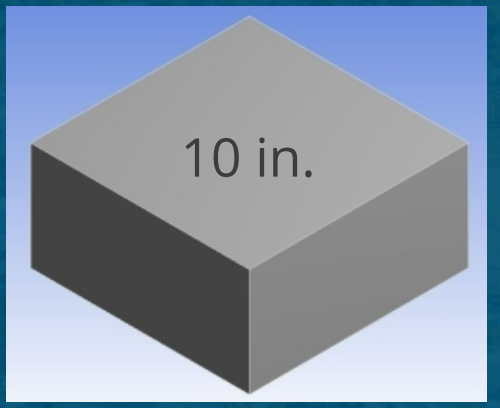
# Results: Solid vs. Shell Elements in Ansys

- Model our 1kHz plate with varying thickness
- Compare natural frequencies of the first 10 flexural modes



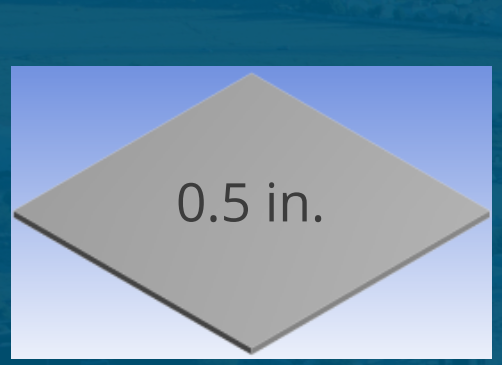



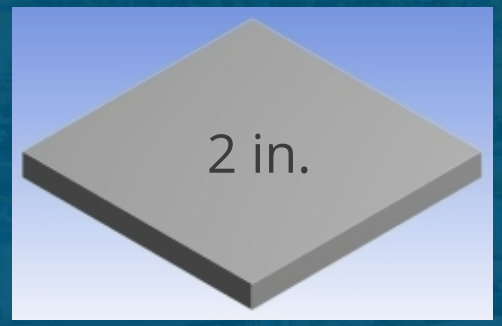



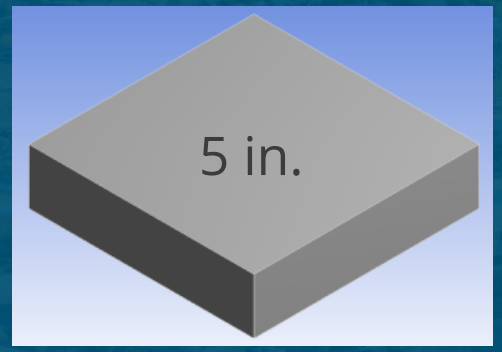

| Computation Time | 0.5 in. | 2 in. | 5 in. | 10 in. |
|---|---|---|---|---|
| Shell (2D) | 6 sec | 8 sec | 8 sec | 7 sec |
| Solid (3D) | 9 sec | 28 sec | 77 sec | 1h 49min |

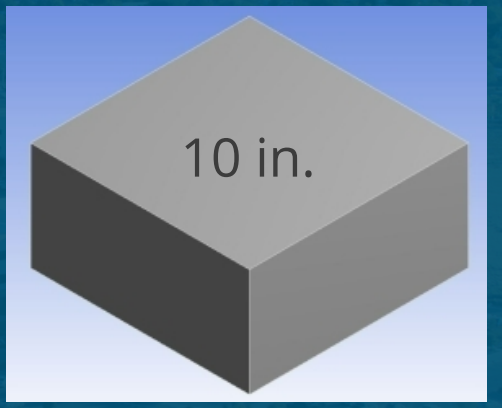
# Results: Solid vs. Shell Elements in Ansys

- Model our 1kHz plate with varying thickness
- Compare natural frequencies of the first 10 flexural modes




| | | | | |
|---|---|---|---|---|
| Computation Time | 6 sec<br>9 sec | 8 sec<br>28 sec | 8 sec<br>77 sec | 7 sec<br>1h 49min |
| Memory | 140 MB<br>363 MB | 140 MB<br>1.43 GB | 140 MB<br>4.74 GB | 140 MB<br>4.71 GB |

# Summary: Solid vs. Shell Elements in Ansys

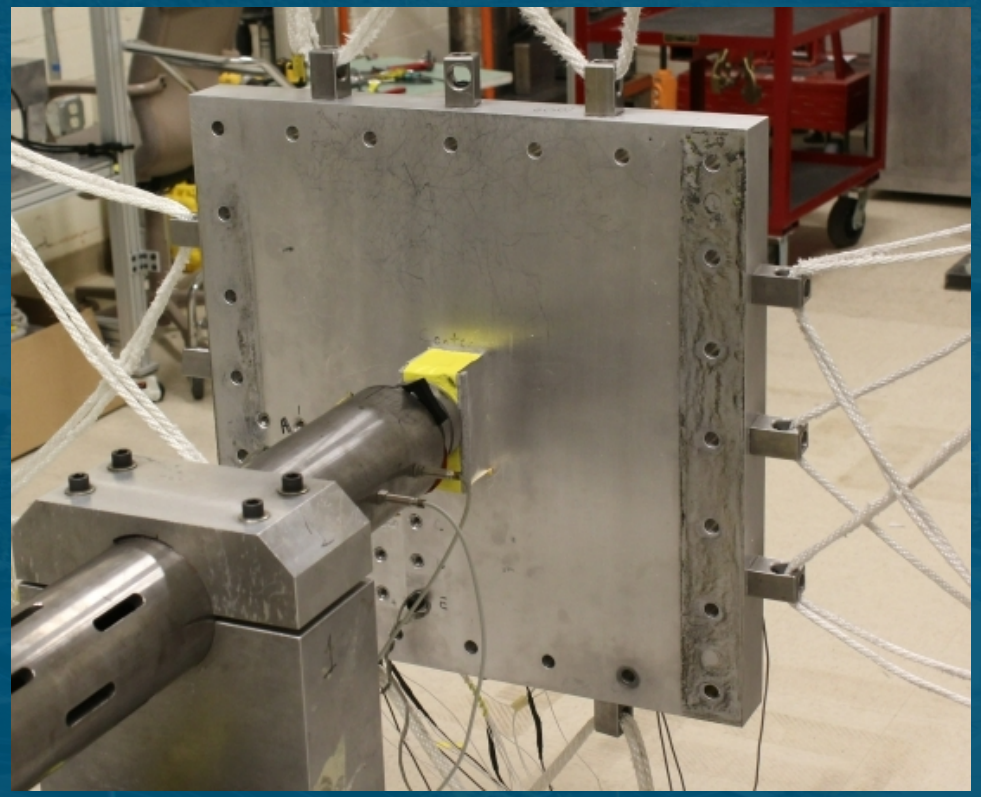
- Modeled our 1kHz plate with varying thickness
- Start small ( ≤ 10% Length )
- Push the limits ( > 10% Length )
- Compared natural frequencies of the first 10 flexural modes

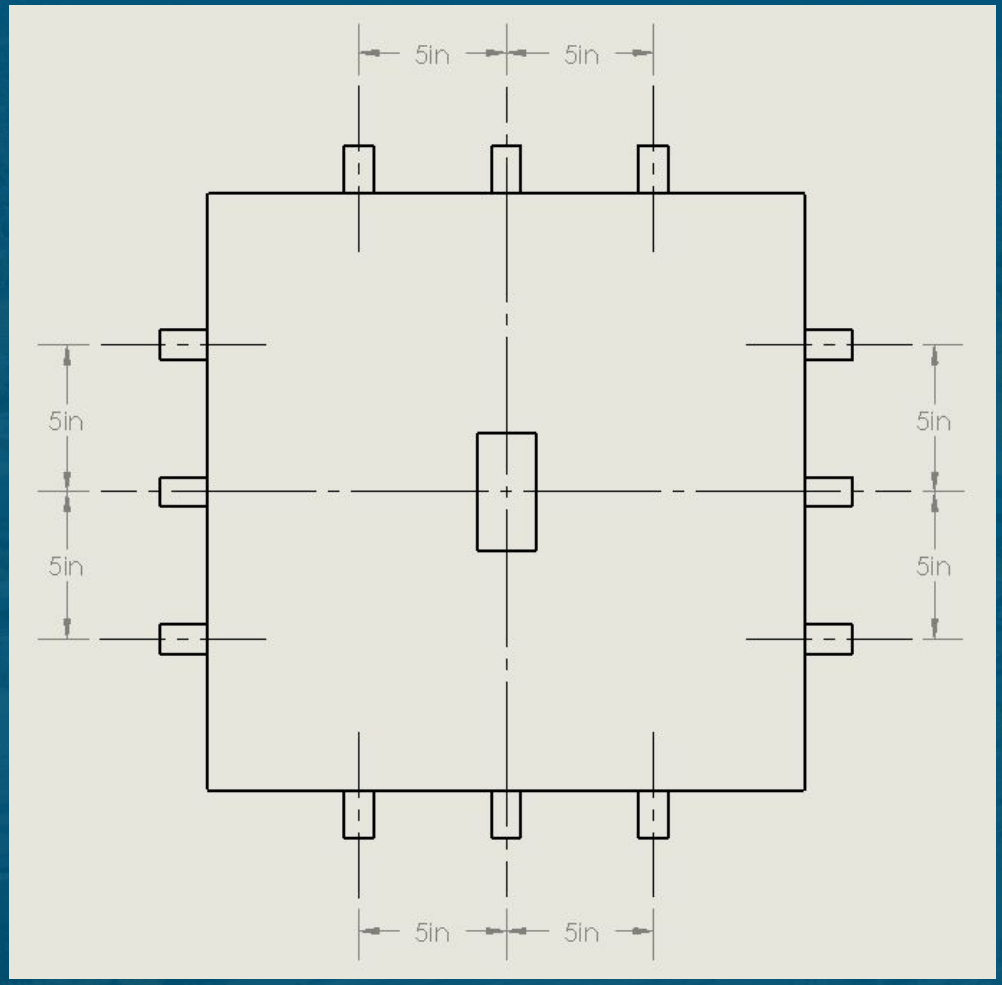
**Results**

- Ansys shell elements performed much better than expected – even for thick plates
- Shell elements much more efficient than solid elements

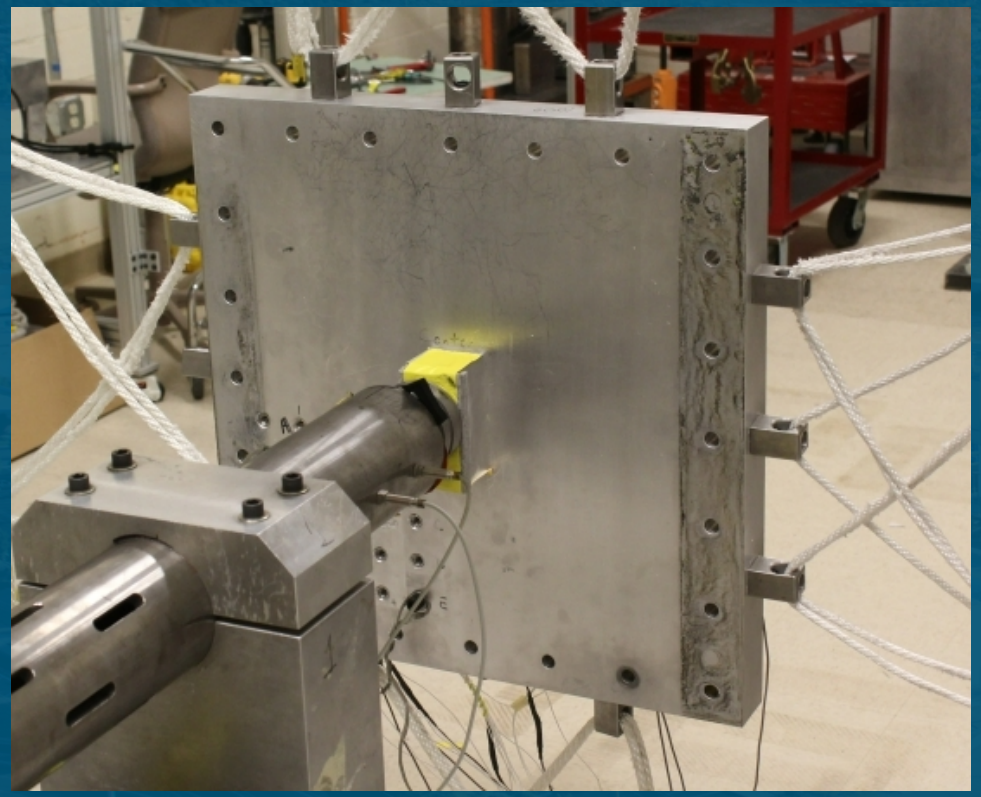
# Model Overview:
# Bare Plate

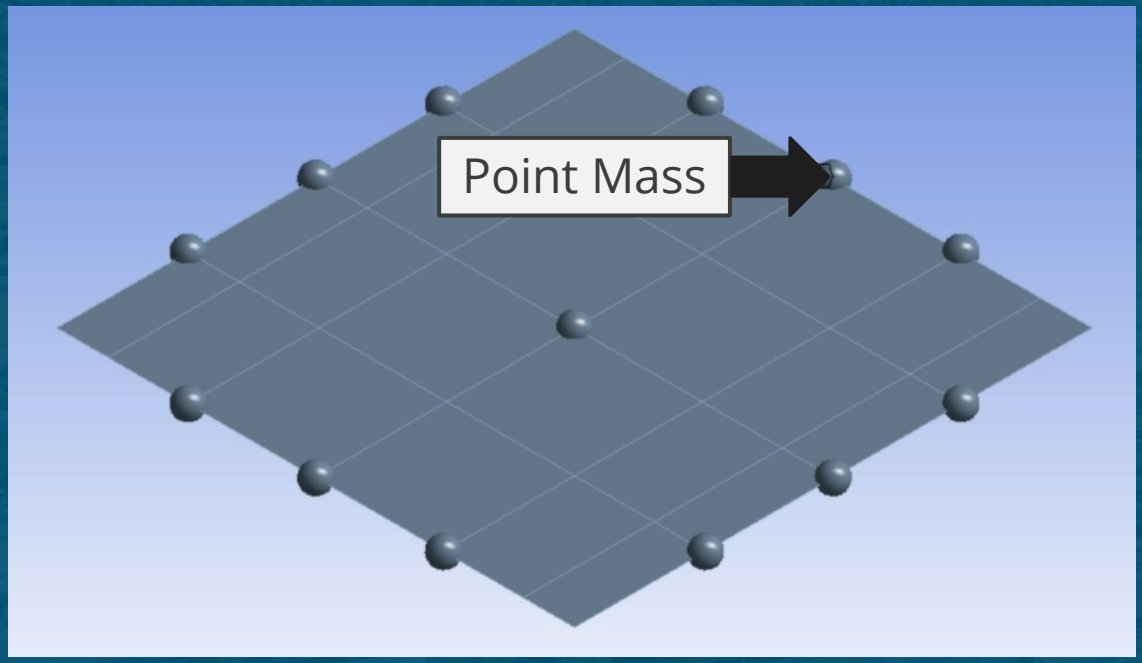
# Model for the Bare Plate





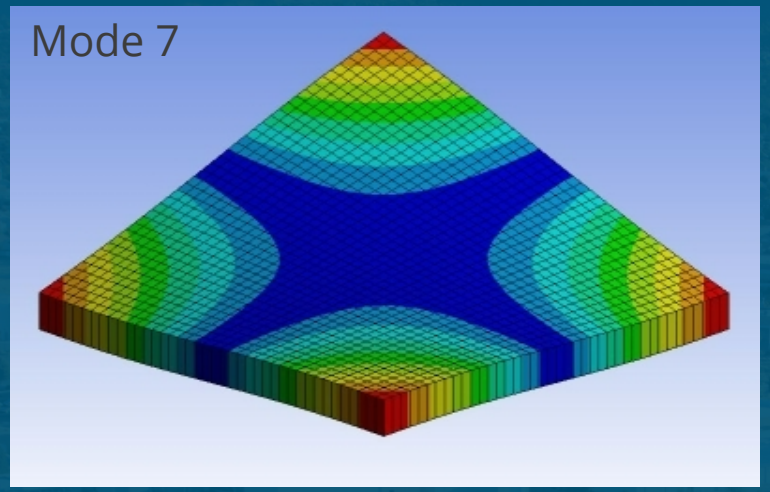
# Model for the Bare Plate

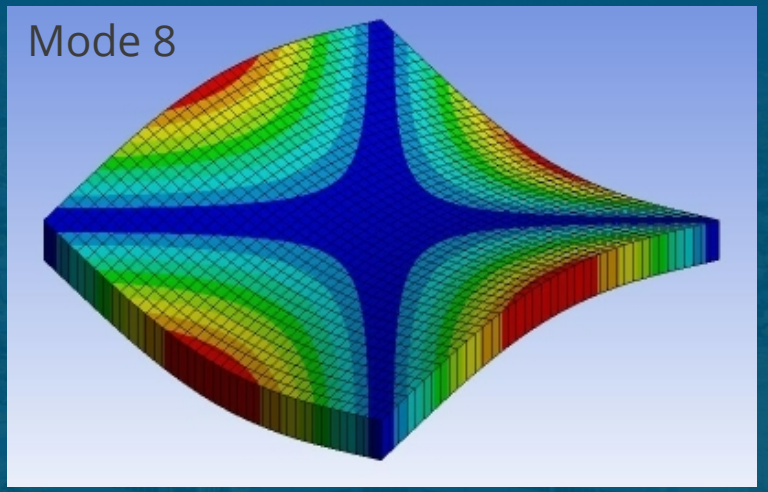


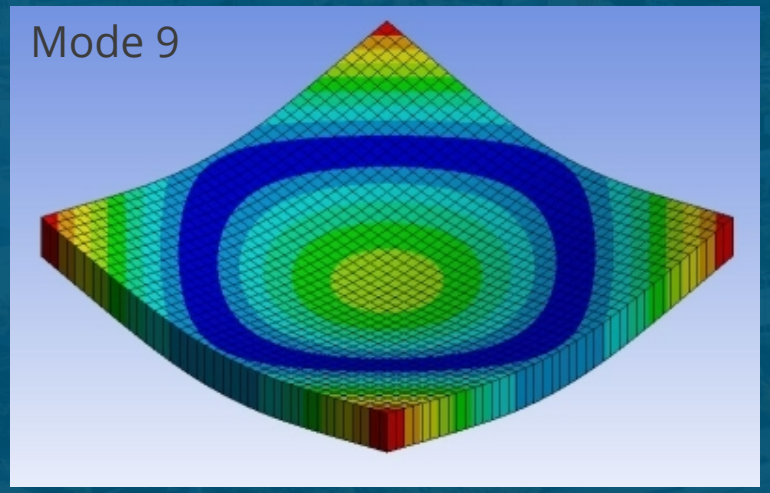


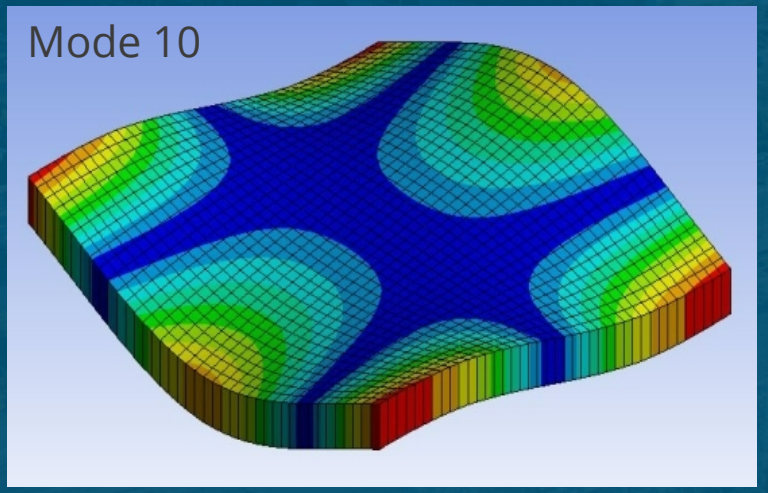
# Mode Shapes for the Bare Plate Model

| Mode | Frequency (Hz) |
|---|---|
| 7 | 559.0 |
| 8 | 798.6 |
| 9 | 1039.2 |
| 10 | 1388 |
| 11 | 1388 |
| 12 | 2381.3 |
| 13 | 2453.9 |
| 14 | 2454 |
| 15 | 2488.5 |
| 16 | 3150 |
| 17 | 3619.1 |
| 18 | 3718.7 |
| 19 | 3718.7 |
| 20 | 3777.7 |
| 21 | 3777.7 |

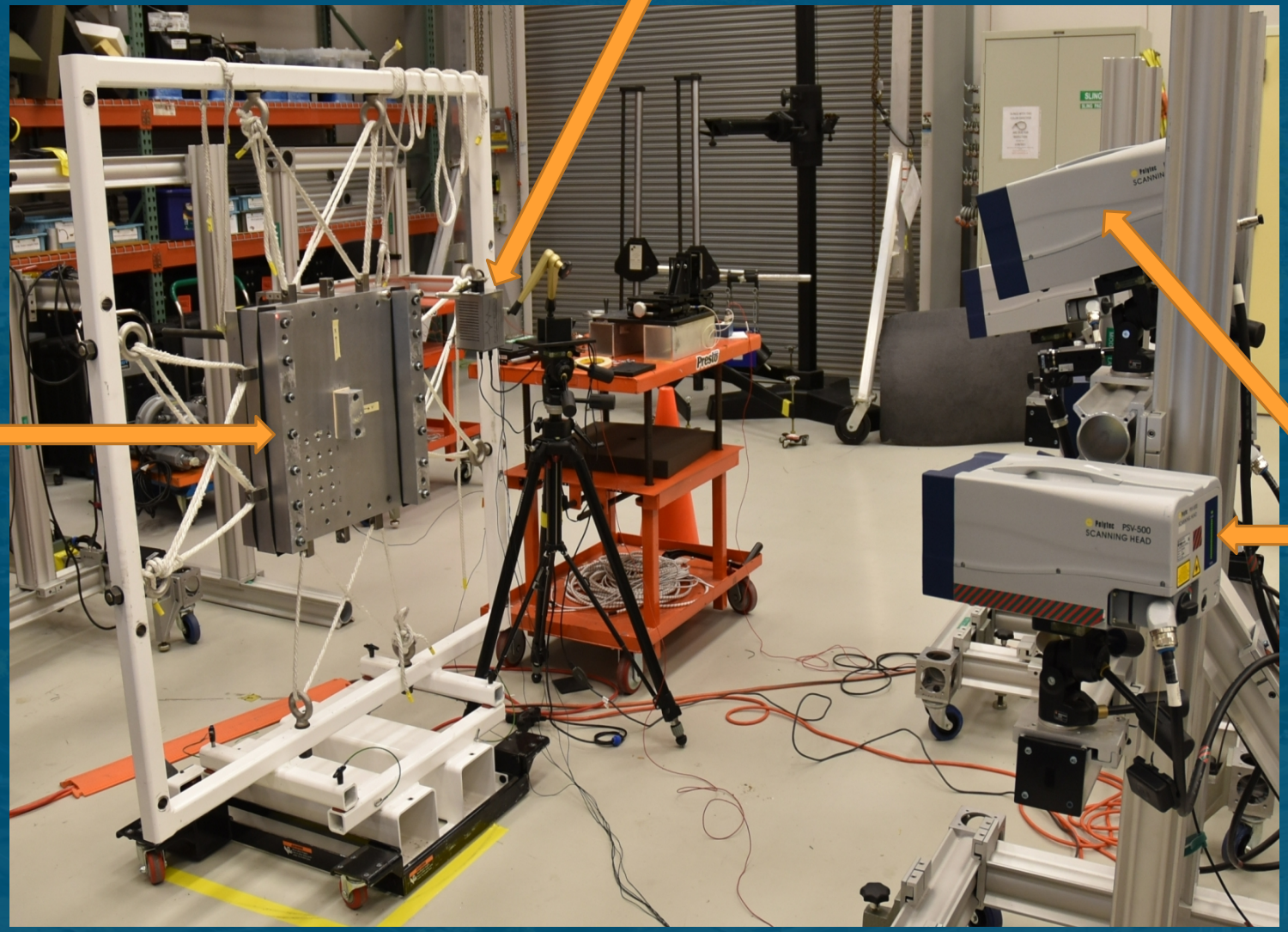


# Validation with Modal Test Data



# Validation with Modal Test Data

- Modal Assurance Criterion (MAC) to match modes between model and test

| MAC Value | Meaning |
|---|---|
| > 0.9 | Matched |
| 0.5 to 0.9 | Investigate Further |
| < 0.5 | Not Correlated |

- Compared natural frequencies of matched modes

# Validation with Modal Test Data – MAC

| Model \ Test | 545.0 | 789.6 | 1020.0 | 1350.0 | 2313.0 | 2347.3 | 2365.0 | 3081.5 | Frequency % Difference |
|---|---|---|---|---|---|---|---|---|---|
| 559.0 | 1.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.007 | 0.126 | 2.57% |
| 798.6 | 0.000 | 1.000 | 0.003 | 0.000 | 0.001 | 0.010 | 0.000 | 0.000 | 1.15% |
| 1039.2 | 0.000 | 0.001 | 0.999 | 0.000 | 0.017 | 0.078 | 0.001 | 0.001 | 1.88% |
| 1388.0 | 0.000 | 0.000 | 0.001 | 0.999 | 0.005 | 0.002 | 0.002 | 0.001 | 2.82% |
| 2381.3 | 0.000 | 0.018 | 0.098 | 0.000 | 0.167 | 0.688 | 0.012 | 0.001 | 1.45% |
| 2453.9 | 0.000 | 0.000 | 0.000 | 0.000 | 0.644 | 0.211 | 0.059 | 0.000 | 6.09% |
| 2488.5 | 0.006 | 0.000 | 0.000 | 0.000 | 0.110 | 0.000 | 0.665 | 0.000 | 5.22% |
| 3150.0 | 0.127 | 0.000 | 0.000 | 0.000 | 0.003 | 0.000 | 0.000 | 0.991 | 2.22% |

# Validation with Modal Test Data - Mode Shapes

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
|---|---|---|---|
| 559.0 | 545.0 | 2.57% | 1.000 |
| 798.6 | 789.6 | 1.15% | 1.000 |
| 1039.2 | 1020.0 | 1.88% | 0.999 |
| 1388.0 | 1350.0 | 2.82% | 0.999 |
| 2381.3 | 2347.3 | 1.45% | 0.688 |
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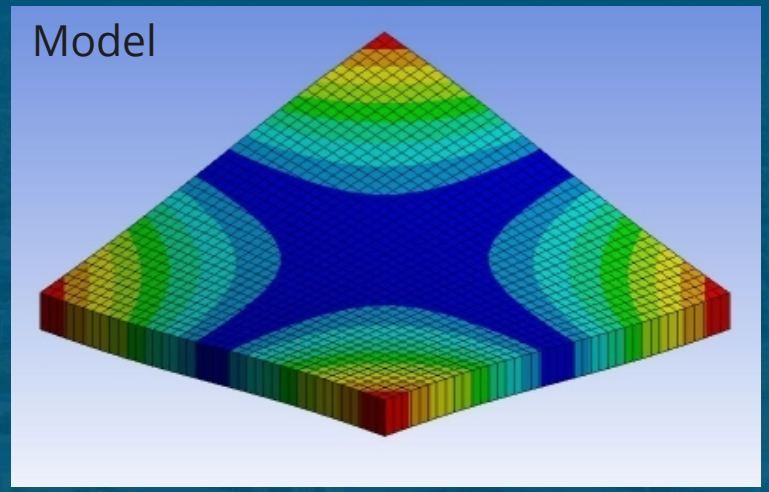


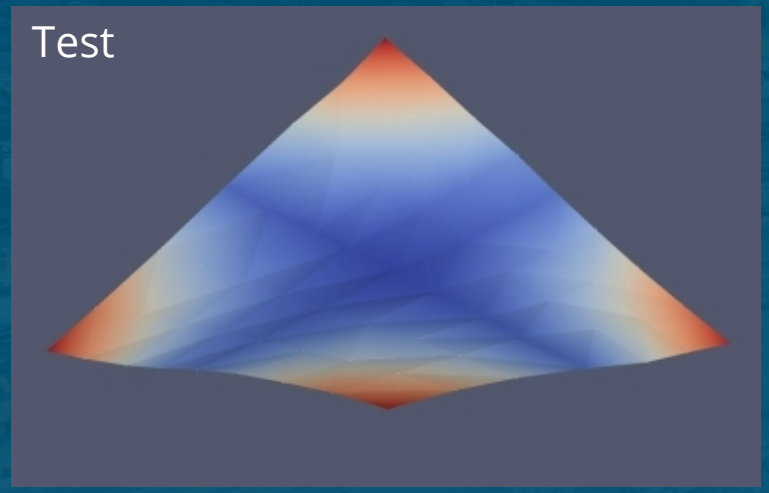

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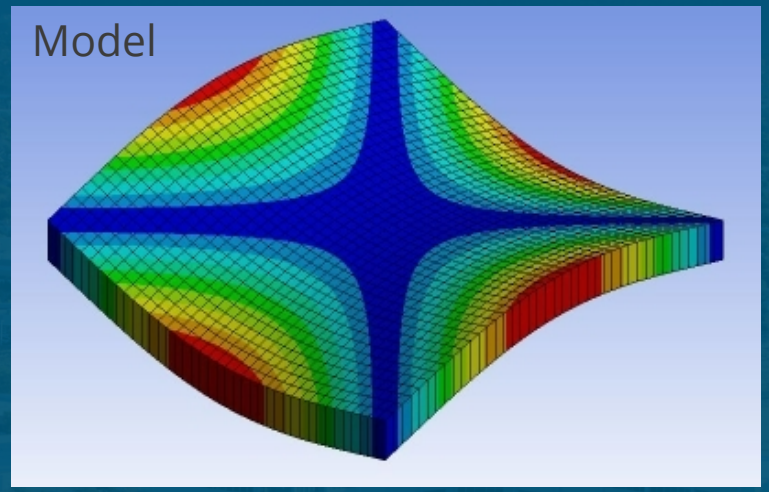


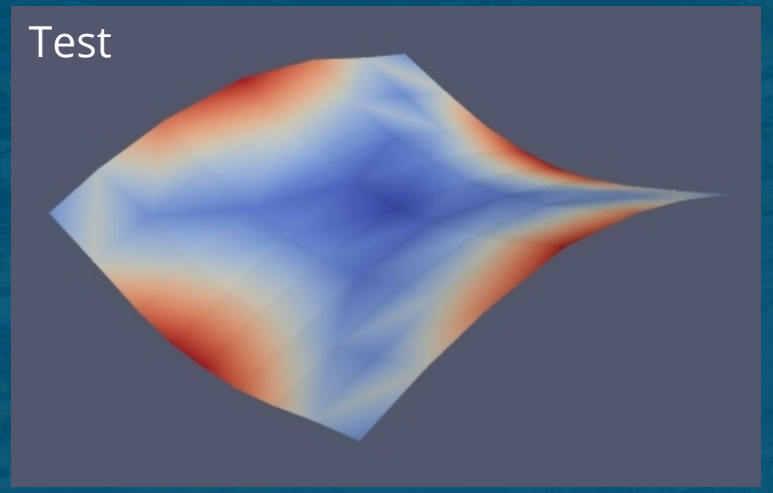

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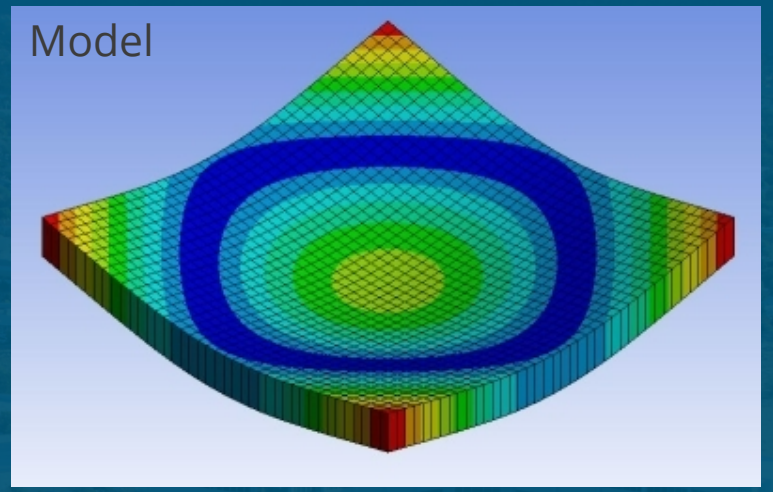


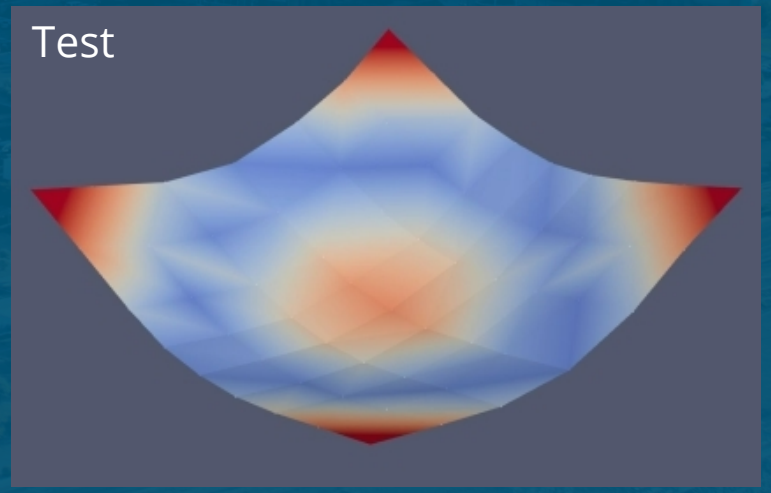

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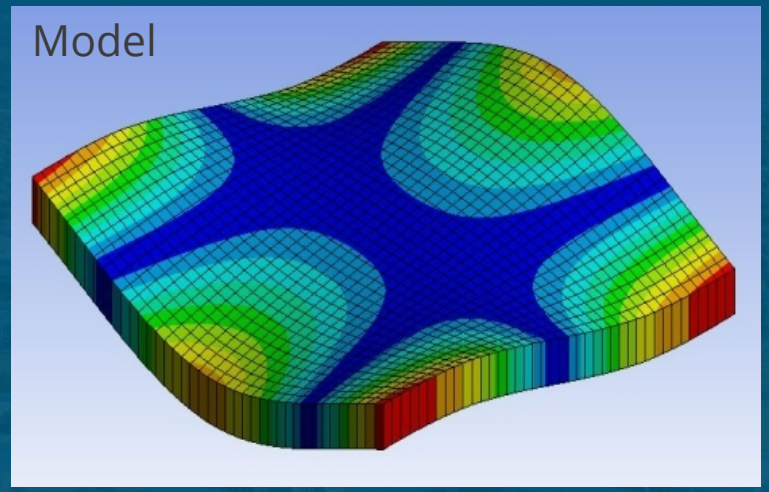


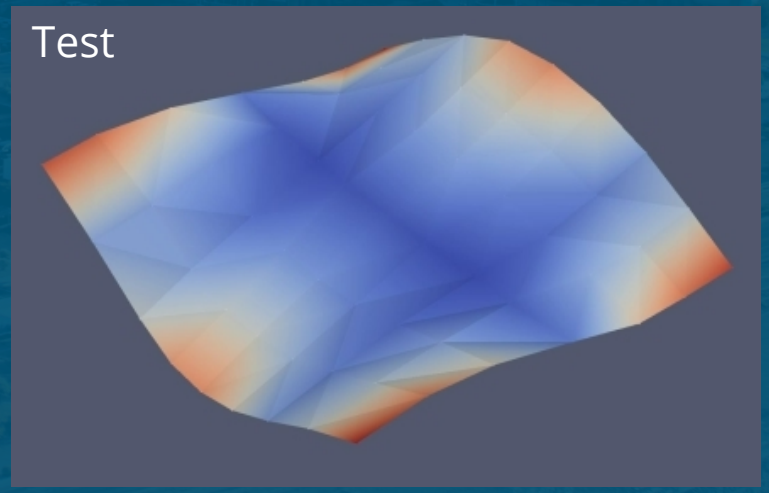

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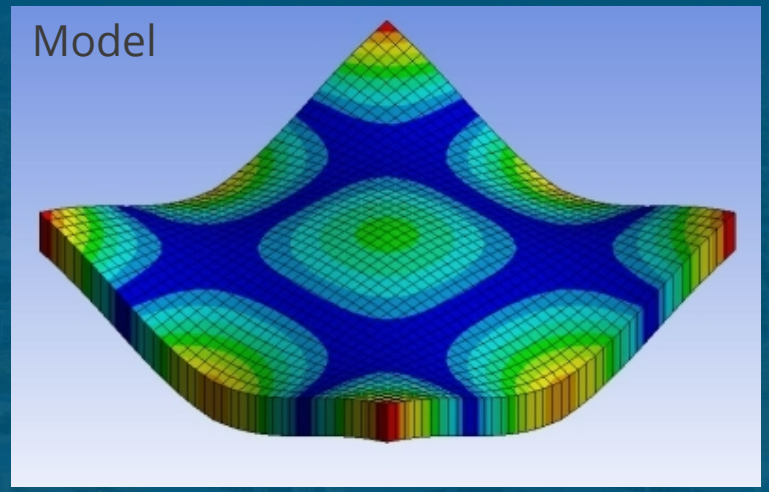


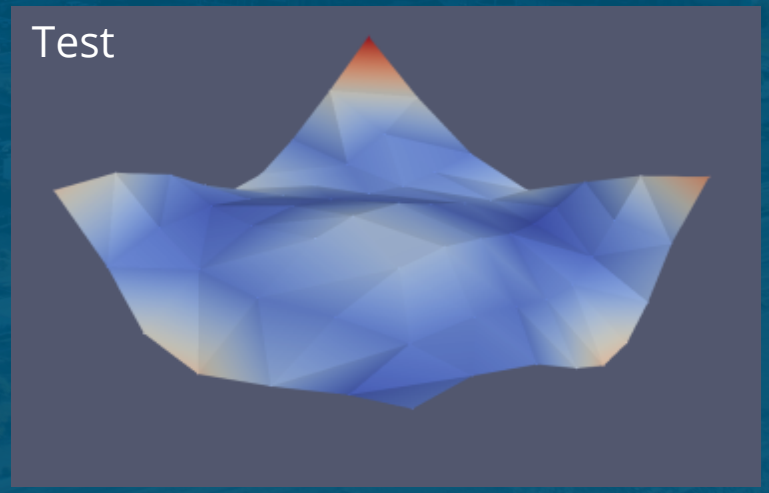

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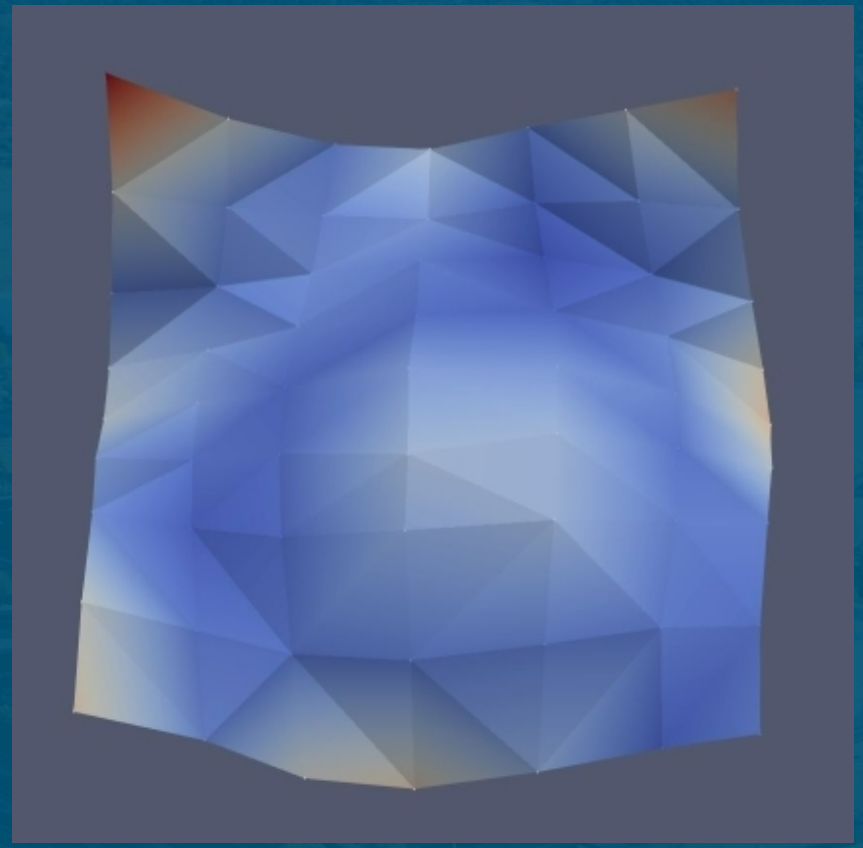

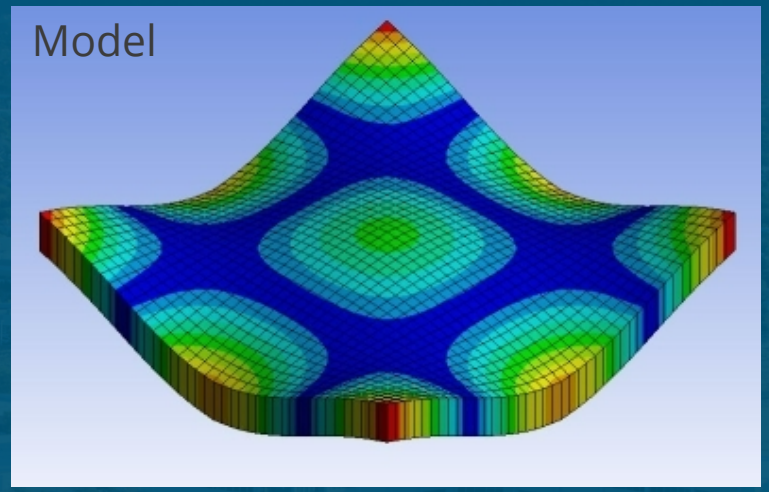


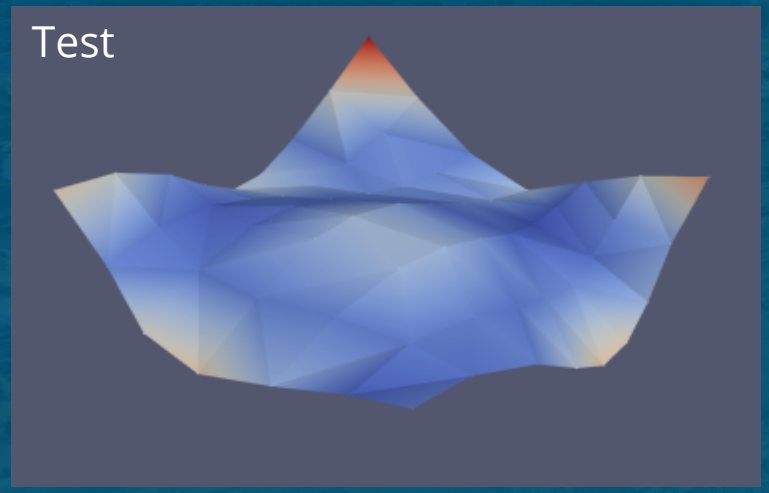

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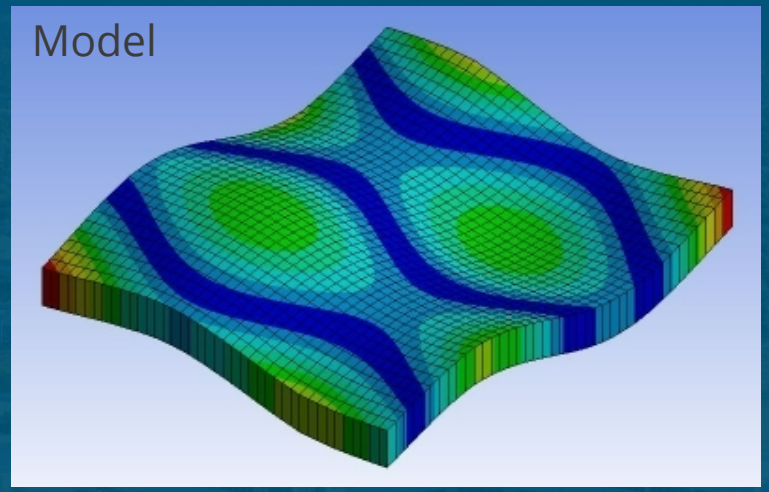


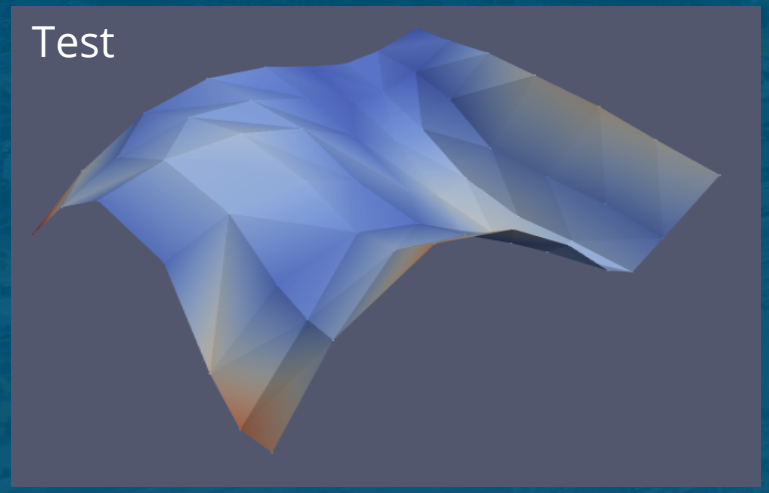

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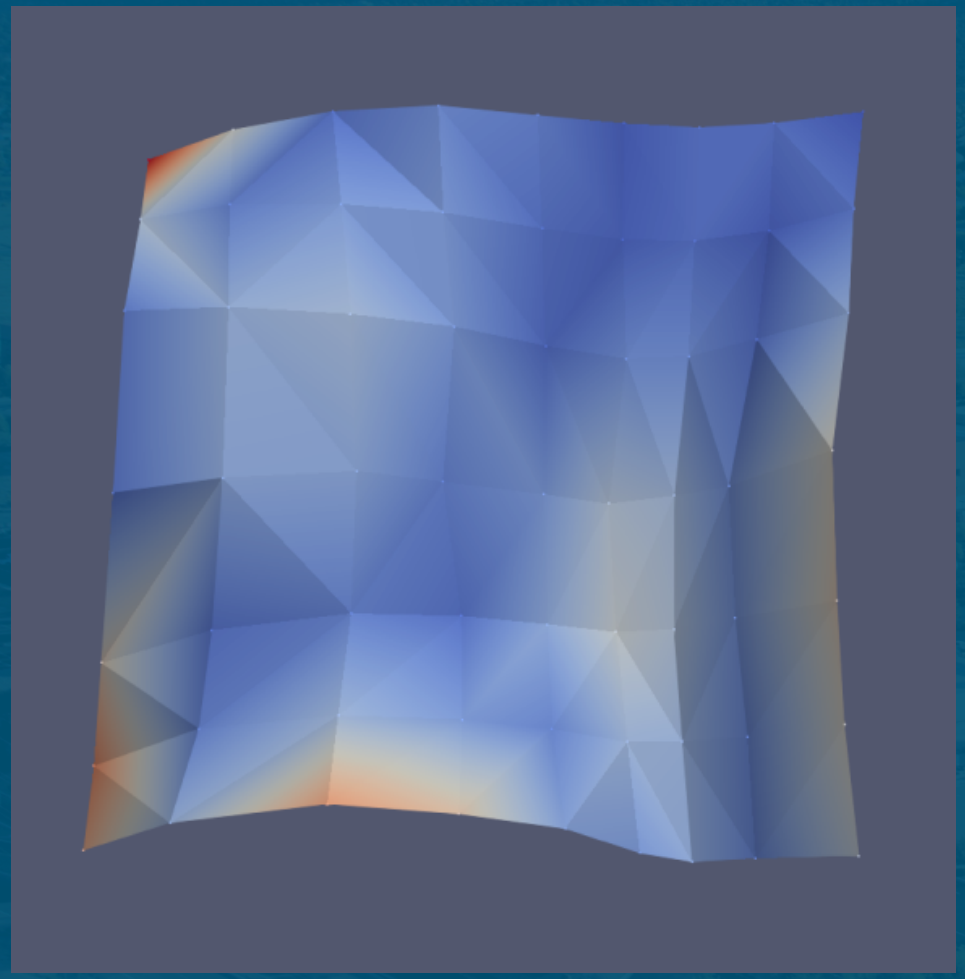

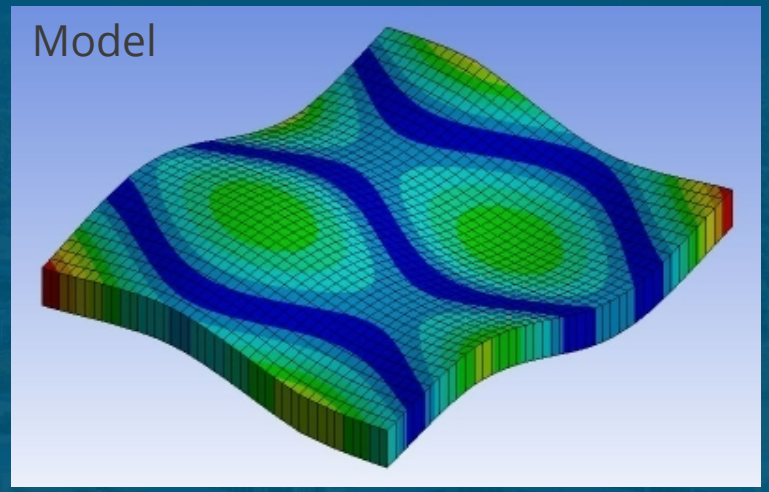


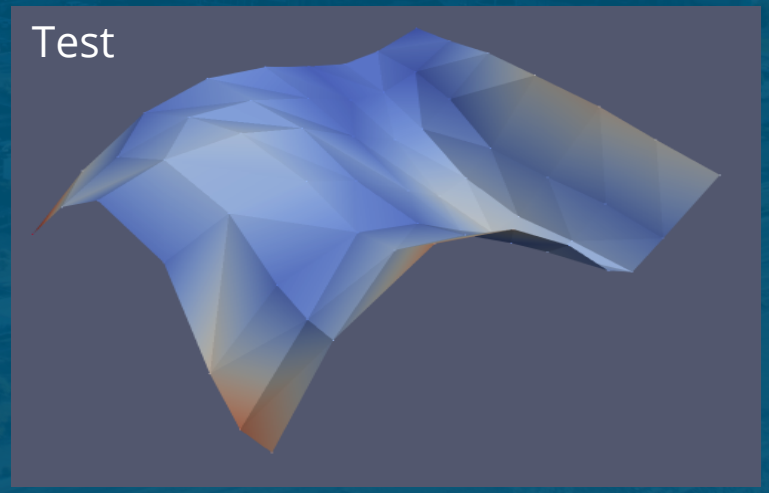

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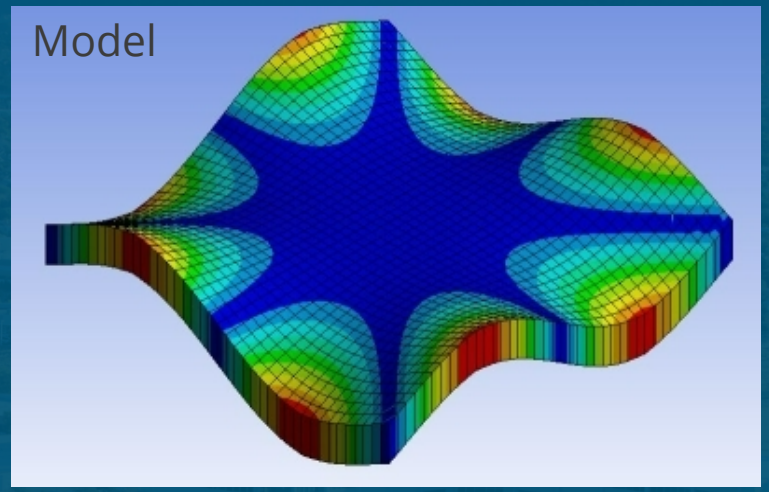


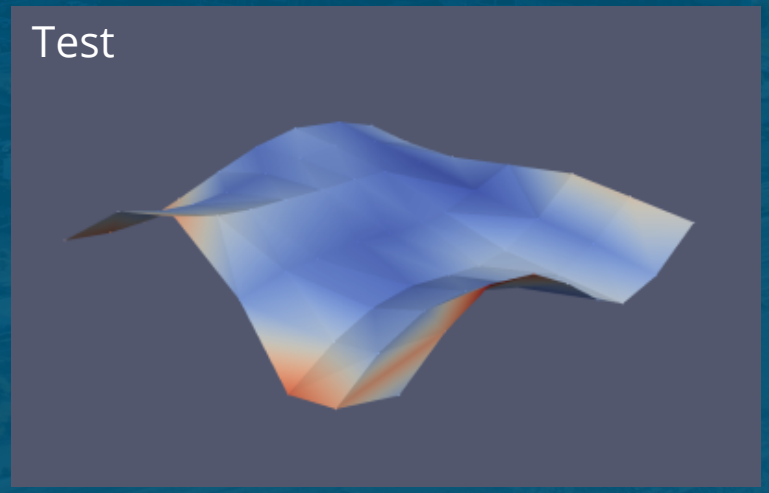

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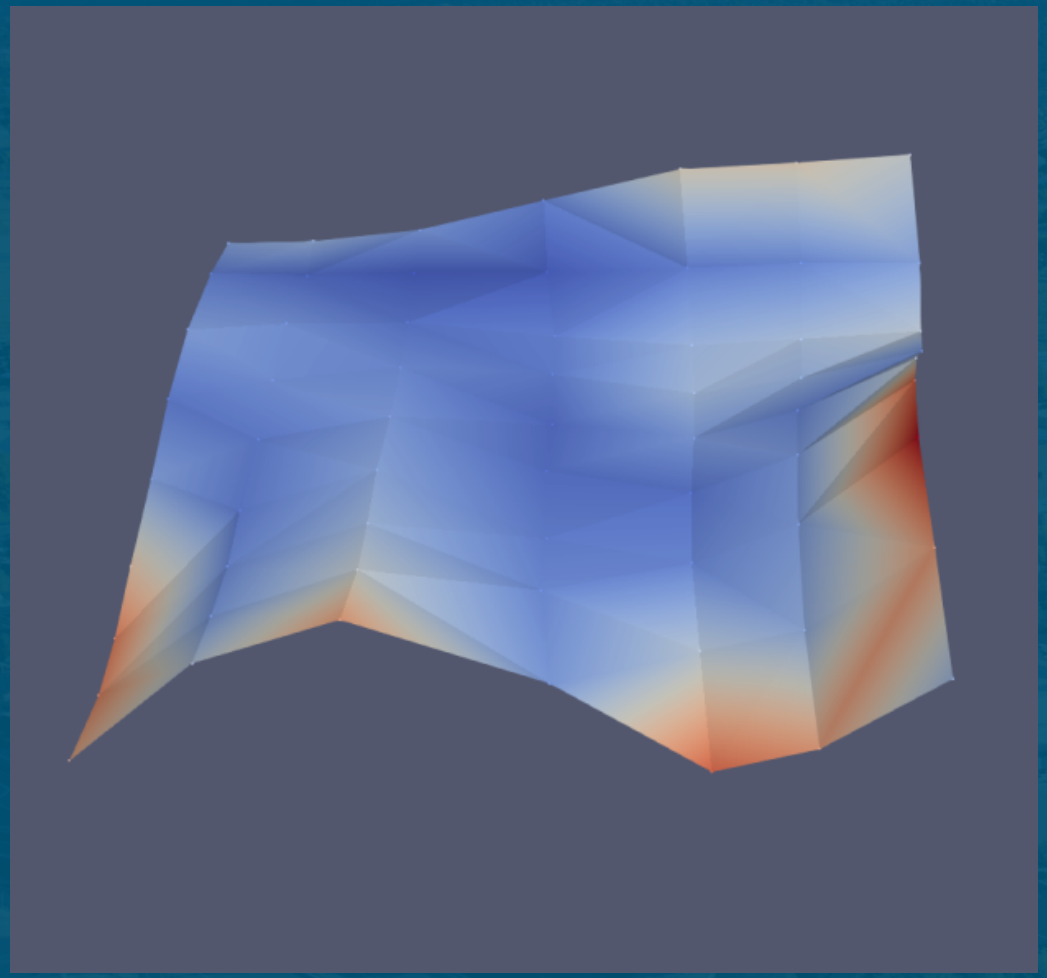

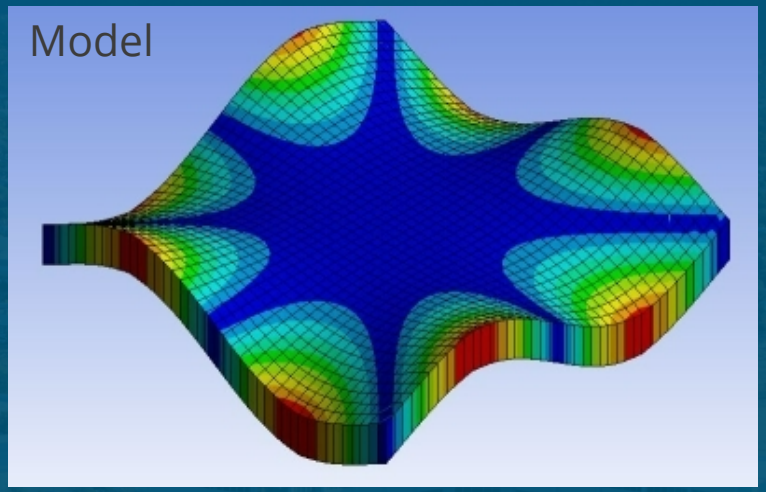


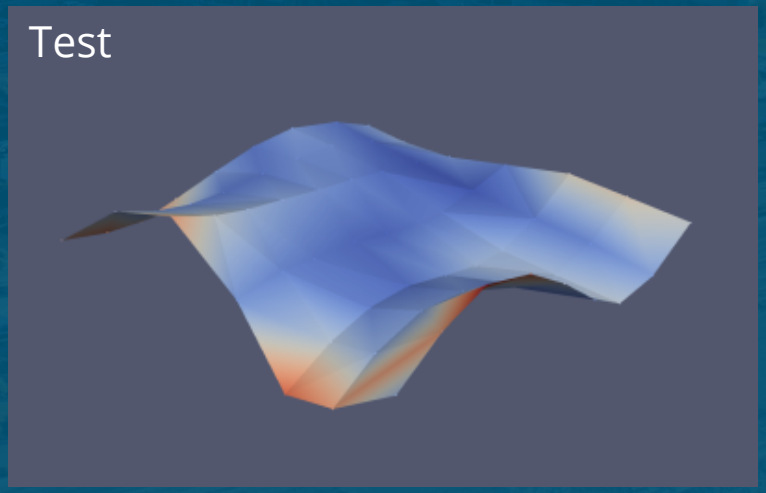

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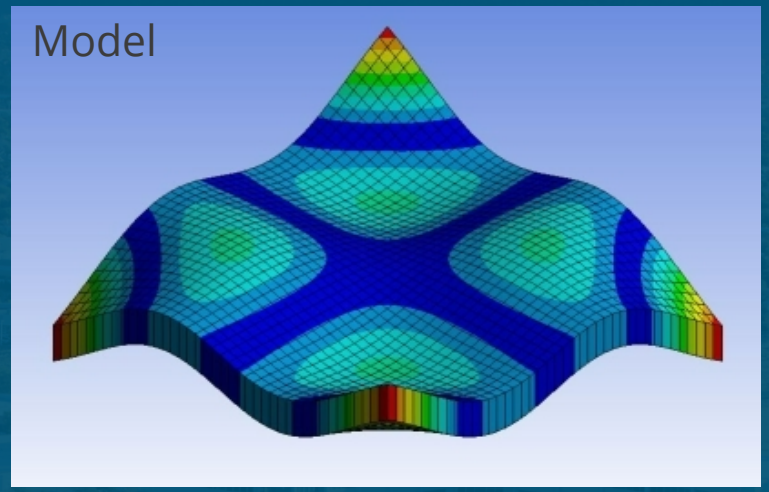
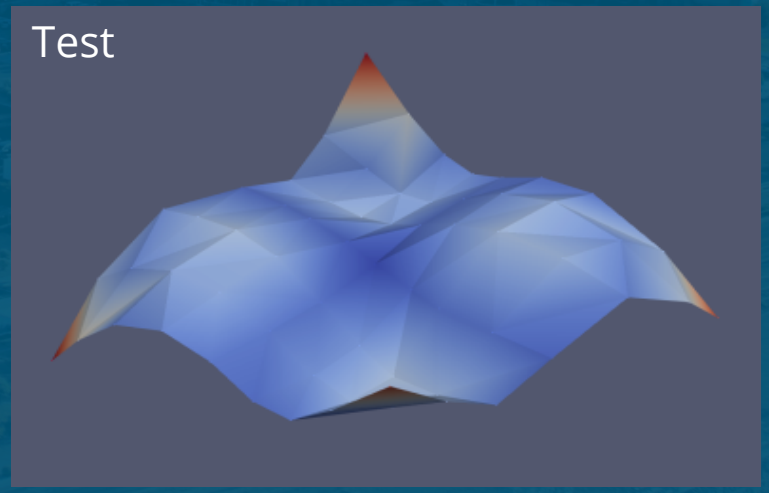


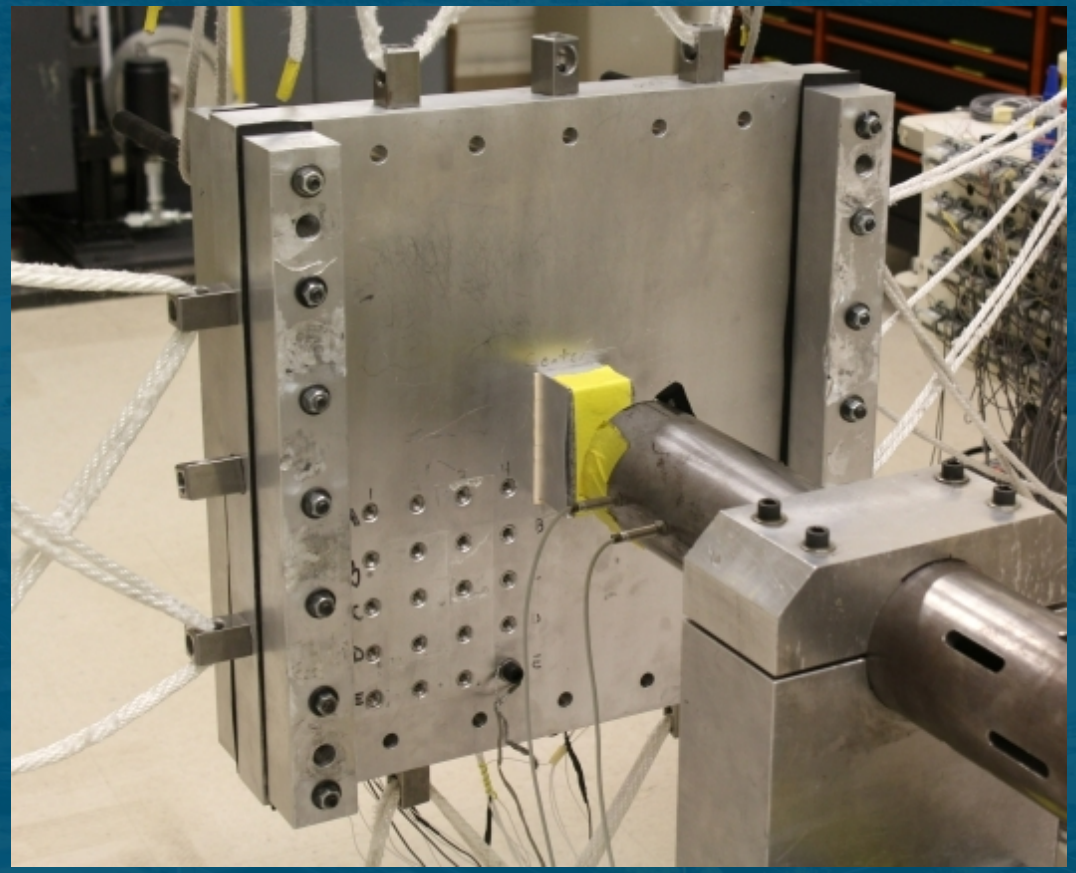
# Key Takeaways

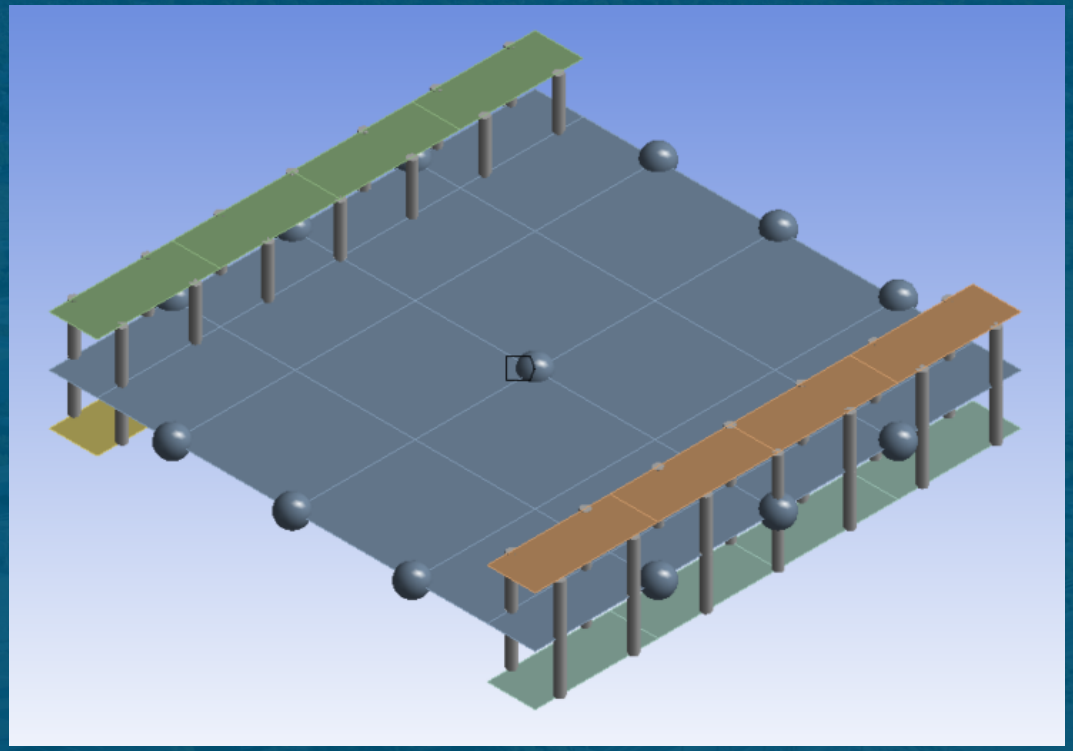
Model Performance in the Modal Domain

- Relatively accurate up to ~3000 Hz
- Accurate mode shape and frequency for the 1kHz mode
- Some modes did not match with the test very well
  - Not trying to match the test exactly
  - Test had asymmetries (loose bolt)
  - Model for design – asymmetry not desirable

# Model for the Plate with Damping Bars

# Model for the Plate with Damping Bars





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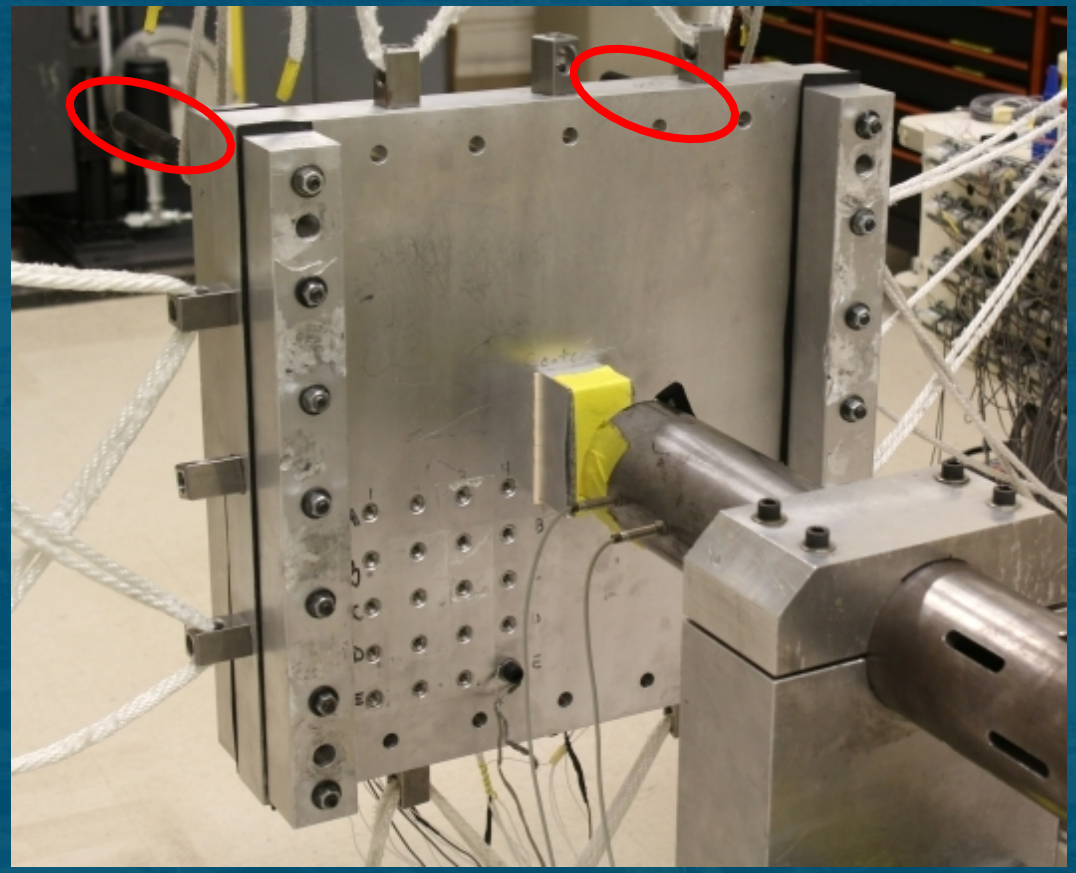

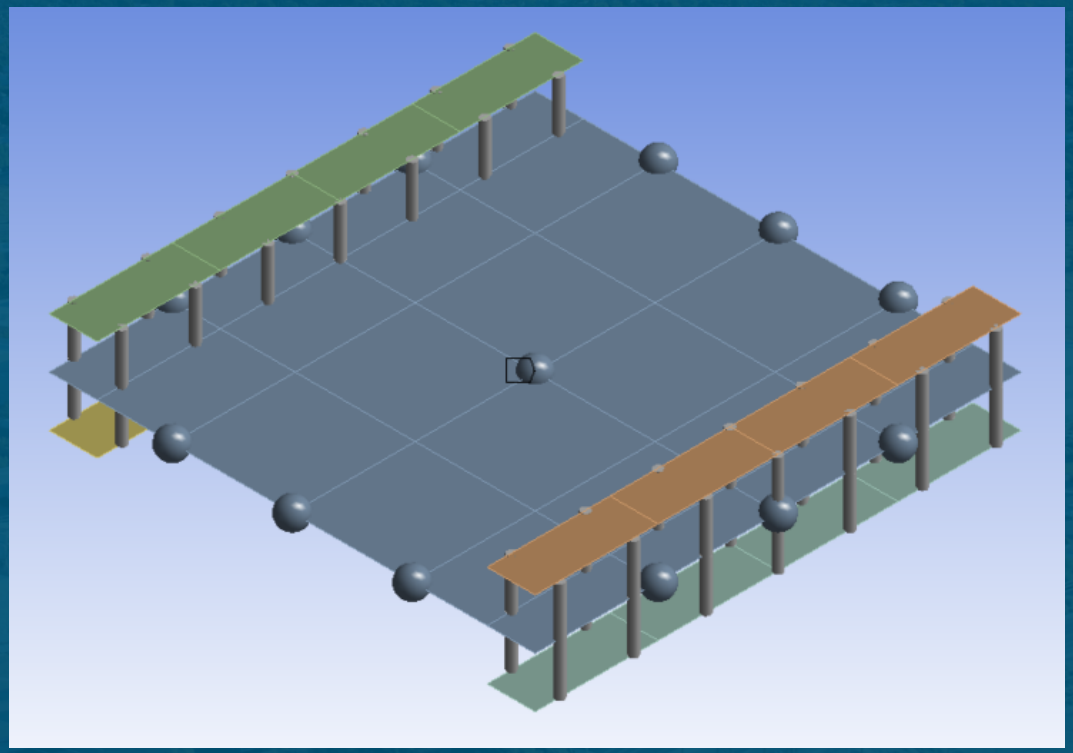

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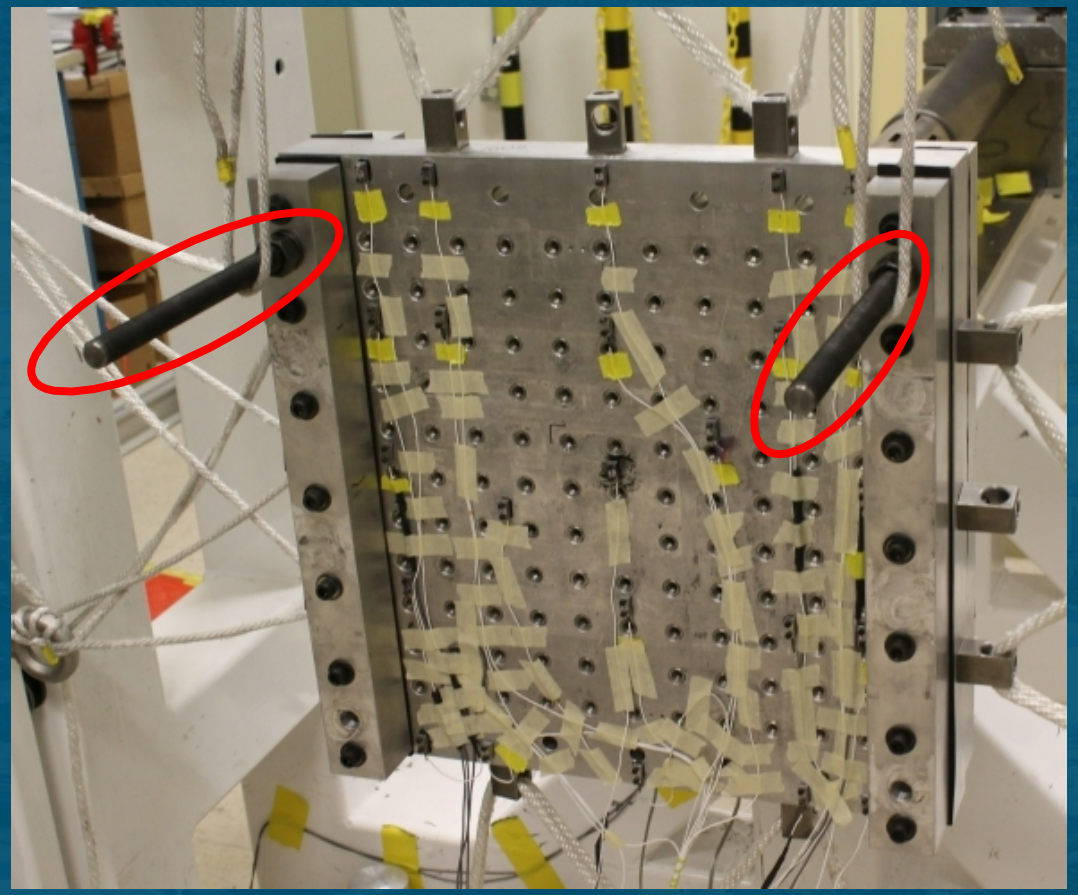

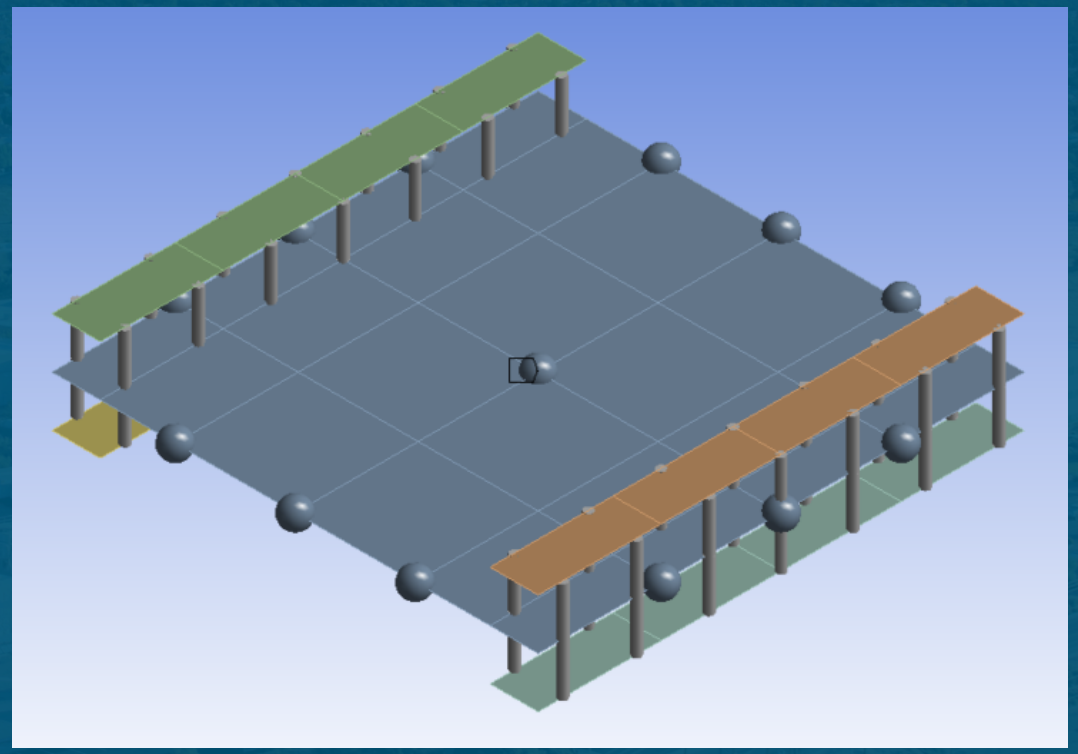

# Validation with Modal Test Data – Test Mode Shapes

- Compared modes for model and test
- Some modes have very little plate movement

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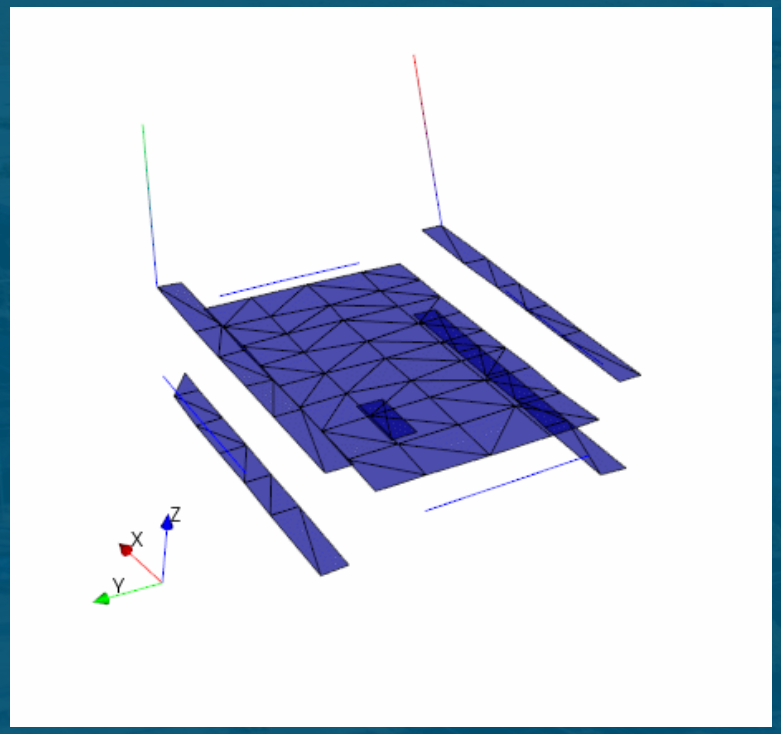
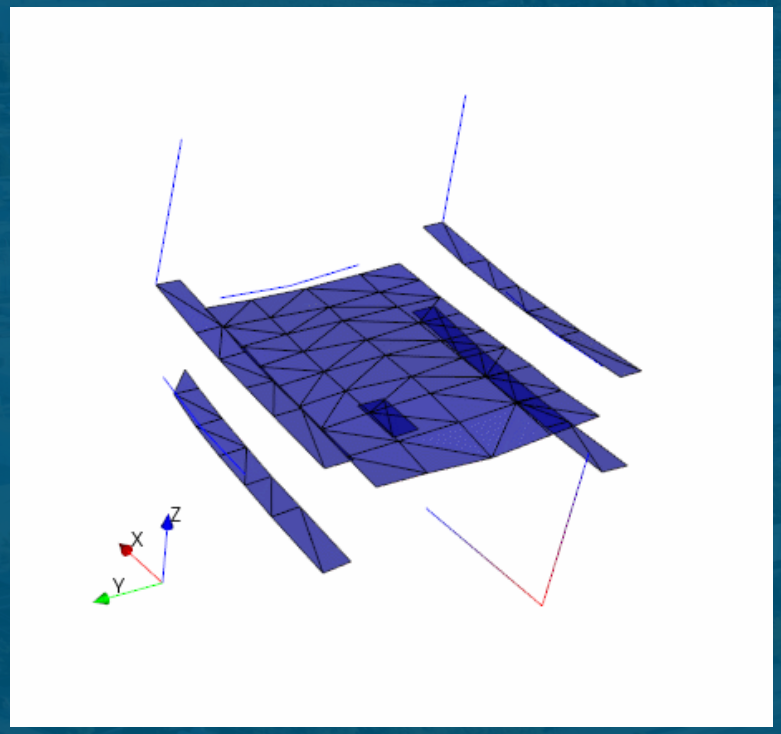
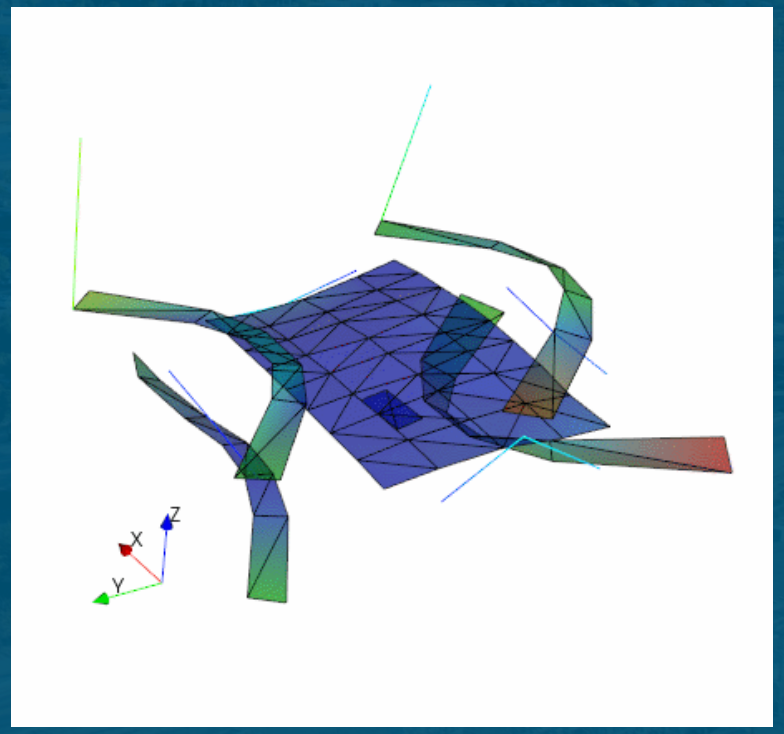


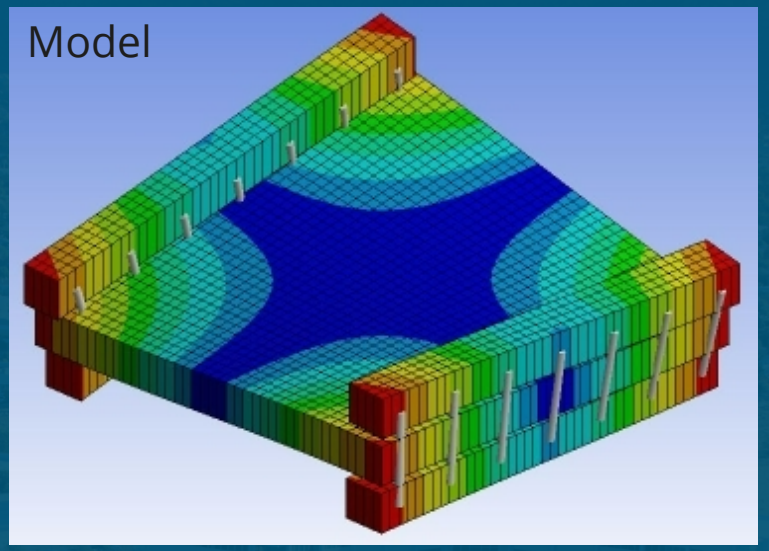



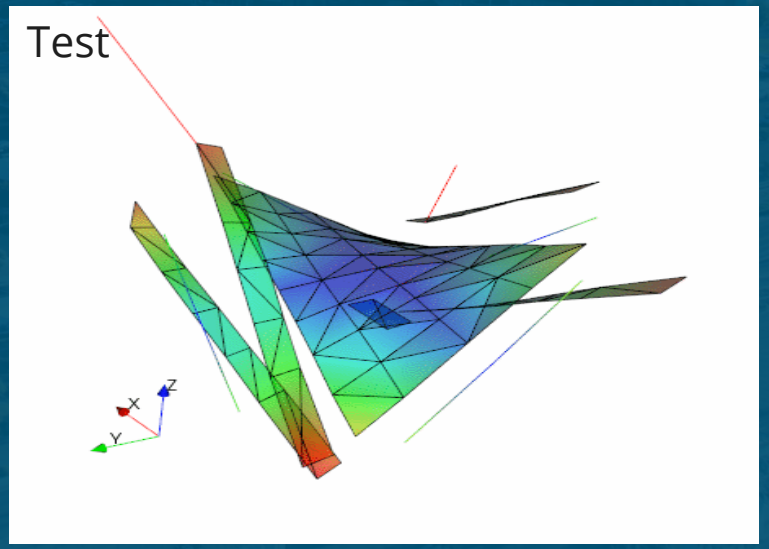



| Model \ Test | 390.8 | 582.0 | 1001 | 1288 | 2087 | 2216 | 2345 | 2397 | 2800 | Frequency % Difference |
|---|---|---|---|---|---|---|---|---|---|---|
| 403.71 | 0.998 | 0.000 | 0.000 | 0.004 | 0.000 | 0.006 | 0.009 | 0.001 | 0.072 | 3.31% |
| 575.3 | 0.000 | 0.991 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.16% |
| 921.0 | 0.000 | 0.661 | 0.425 | 0.002 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | -------- |
| 1008.7 | 0.000 | 0.037 | 0.900 | 0.001 | 0.090 | 0.000 | 0.000 | 0.002 | 0.000 | 0.72% |
| 1224.8 | 0.001 | 0.002 | 0.003 | 0.005 | 0.019 | 0.000 | 0.000 | 0.024 | 0.000 | -------- |
| 1241.9 | 0.000 | 0.000 | 0.000 | 0.991 | 0.000 | 0.008 | 0.008 | 0.001 | 0.004 | 3.58% |
| 2026.6 | 0.000 | 0.001 | 0.097 | 0.001 | 0.901 | 0.005 | 0.000 | 0.002 | 0.000 | 2.90% |
| 2149.9 | 0.001 | 0.000 | 0.002 | 0.019 | 0.005 | 0.910 | 0.009 | 0.001 | 0.013 | 2.96% |
| 2377.6 | 0.013 | 0.000 | 0.000 | 0.000 | 0.002 | 0.050 | 0.951 | 0.006 | 0.029 | 1.39% |
| 2452.5 | 0.001 | 0.000 | 0.001 | 0.000 | 0.009 | 0.000 | 0.005 | 0.983 | 0.000 | 2.30% |
| 2771.3 | 0.095 | 0.000 | 0.000 | 0.002 | 0.000 | 0.001 | 0.027 | 0.002 | 0.873 | 1.01% |

# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
|---|---|---|---|
| 403.7 | 390.8 | 3.31 | 0.998 |
| 575.3 | 582.0 | 1.16 | 0.991 |
| 921.0 | ------- | ------- | ------- |
| 1008.7 | 1001.5 | 0.72 | 0.900 |
| 1224.8 | ------- | ------- | ------- |
| 1241.9 | 1288.0 | 3.58 | 0.991 |
| 2026.6 | 2087.2 | 2.90 | 0.901 |
| 2149.9 | 2215.5 | 2.96 | 0.910 |
| 2377.6 | 2345.0 | 1.39 | 0.951 |
| 2452.5 | 2397.4 | 2.30 | 0.983 |
| 2771.3 | 2799.5 | 1.01 | 0.873 |



# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
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| 403.7 | 390.8 | 3.31 | 0.998 |
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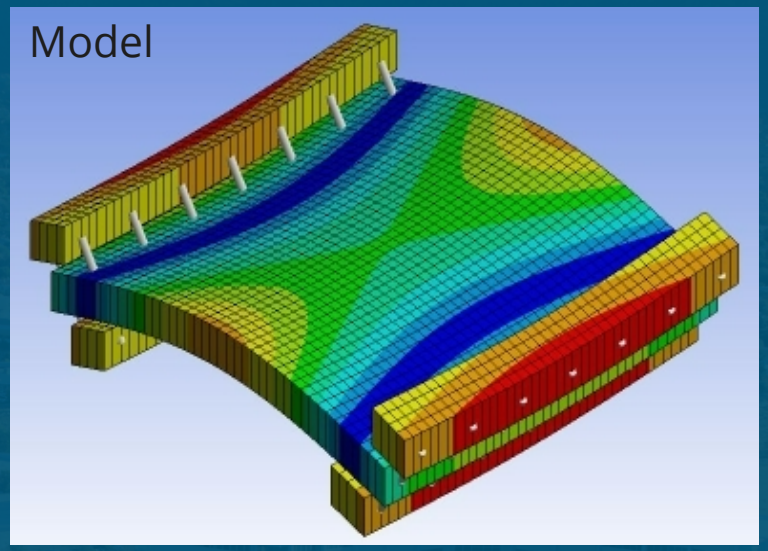
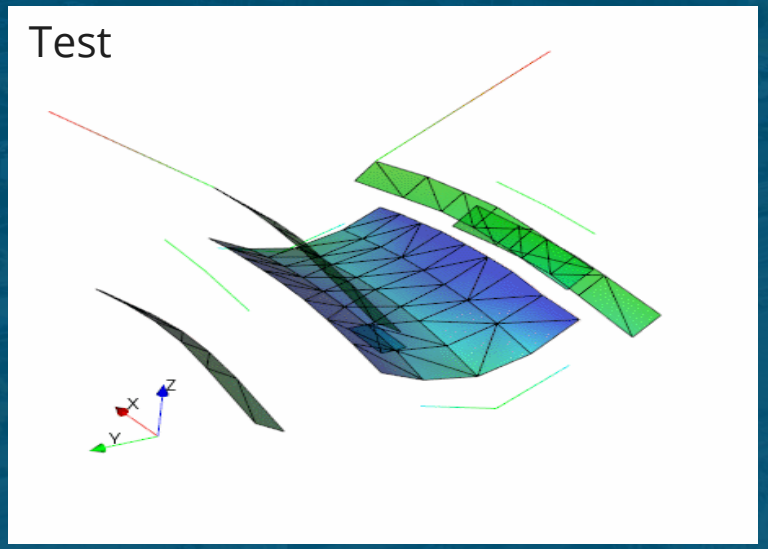
| 2771.3 | 2799.5 | 1.01 | 0.873 |



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| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
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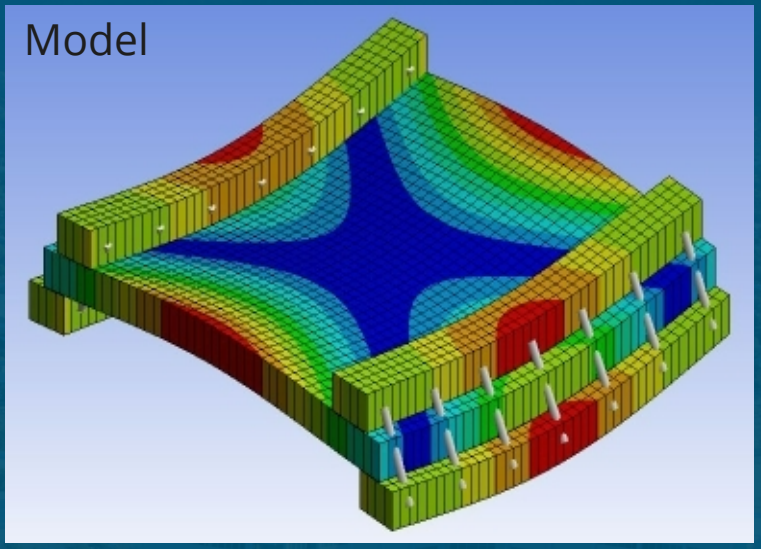
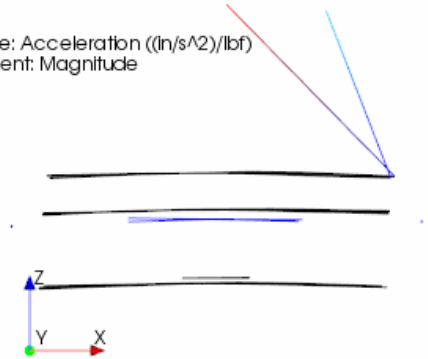
Model

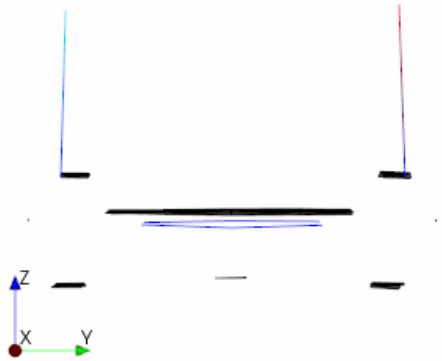


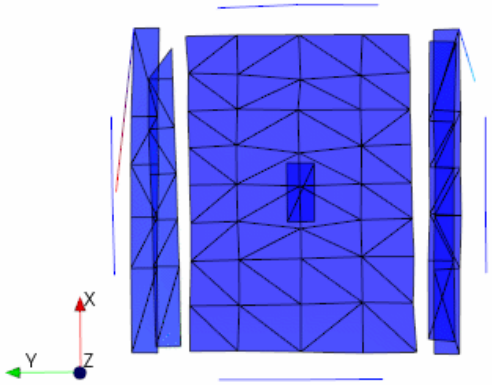
Test

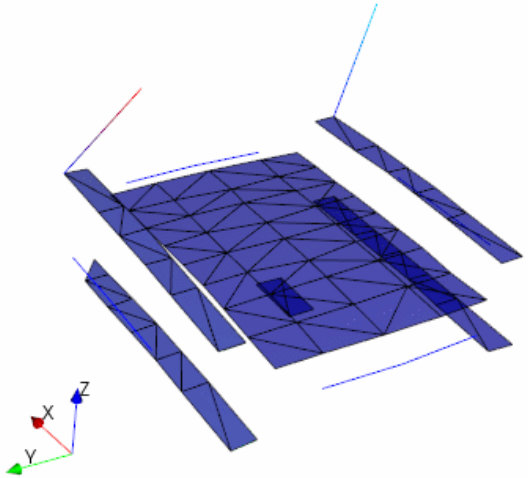
Displacement:
Mode 6
Component: Magnitude
Frequency: 922.763 Hz
Damping: 1.181 %Cr
IDLine1: Generated from reference 1000X-
IDLine4:

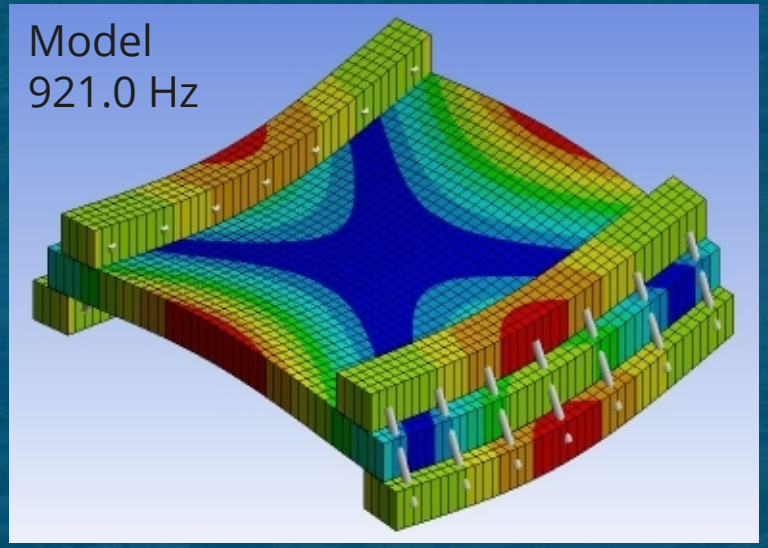
Contour:
Mode 6
Data Type: Acceleration ((in/s^2)/lbf)
Component: Magnitude



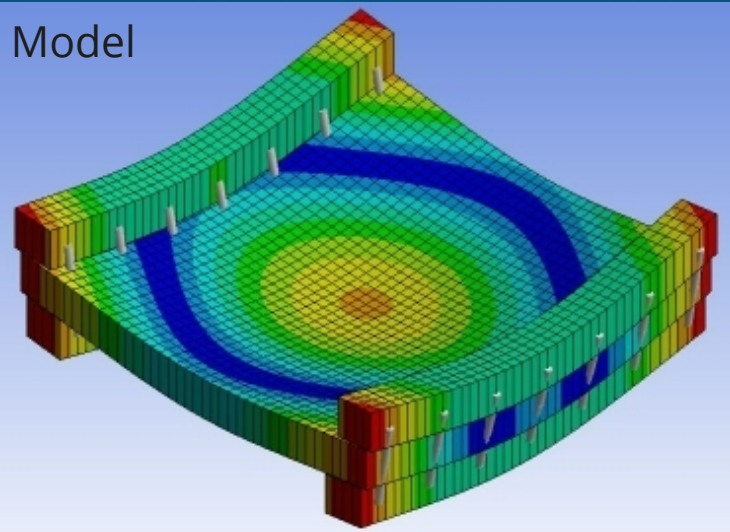



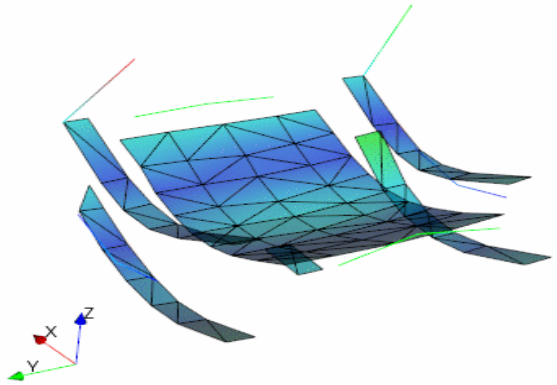
# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
|---|---|---|---|
| 403.7 | 390.8 | 3.31 | 0.998 |
| 575.3 | 582.0 | 1.16 | 0.991 |
| 921.0 | ------- | ------- | ------- |
| 1008.7 | 1001.5 | 0.72 | 0.900 |
| 1224.8 | ------- | ------- | ------- |
| 1241.9 | 1288.0 | 3.58 | 0.991 |
| 2026.6 | 2087.2 | 2.90 | 0.901 |
| 2149.9 | 2215.5 | 2.96 | 0.910 |
| 2377.6 | 2345.0 | 1.39 | 0.951 |
| 2452.5 | 2397.4 | 2.30 | 0.983 |
| 2771.3 | 2799.5 | 1.01 | 0.873 |

Model



Test



# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
|---|---|---|---|
| 403.7 | 390.8 | 3.31 | 0.998 |
| 575.3 | 582.0 | 1.16 | 0.991 |
| 921.0 | ------- | ------- | ------- |
| 1008.7 | 1001.5 | 0.72 | 0.900 |
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| 1241.9 | 1288.0 | 3.58 | 0.991 |
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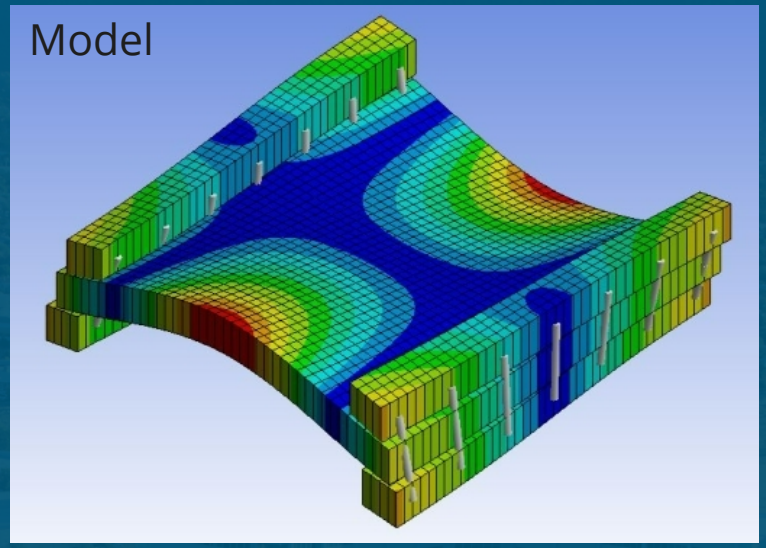
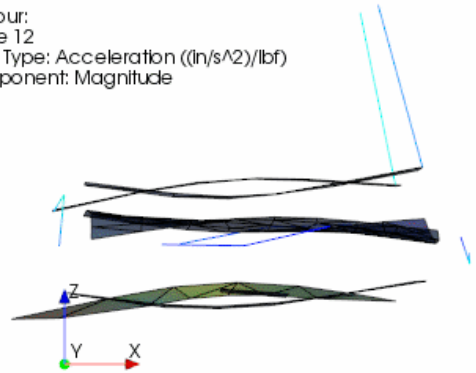
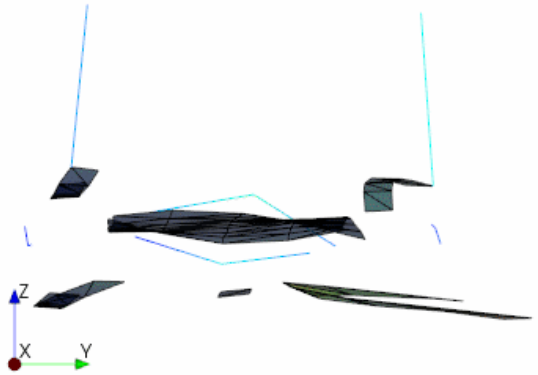
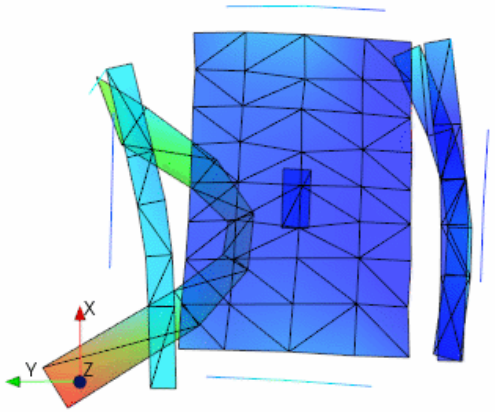


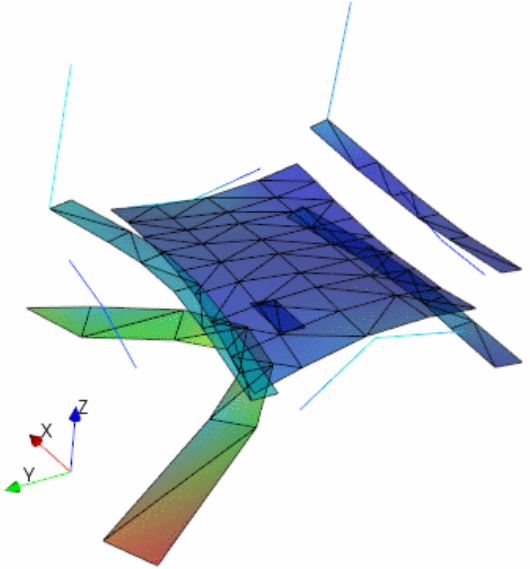
Displacement:
Mode 12
Component: Magnitude
Frequency: 1377.750 Hz
Damping: 1.724 %Cr
IDLine1: Generated from reference 1000X-
IDLine4:

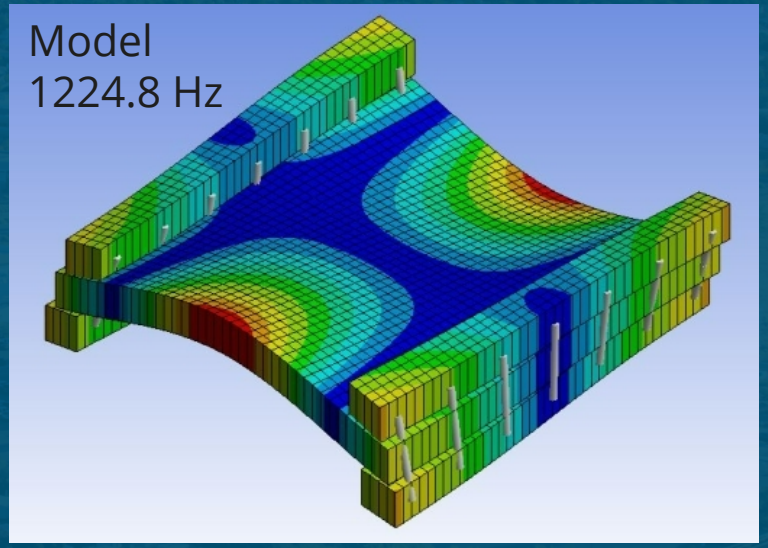
Contour:
Mode 12
Data Type: Acceleration ((in/s^2)/lbf)
Component: Magnitude



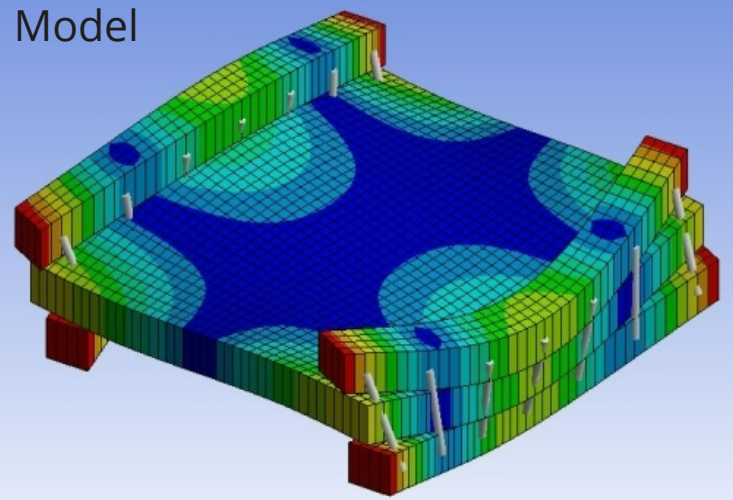



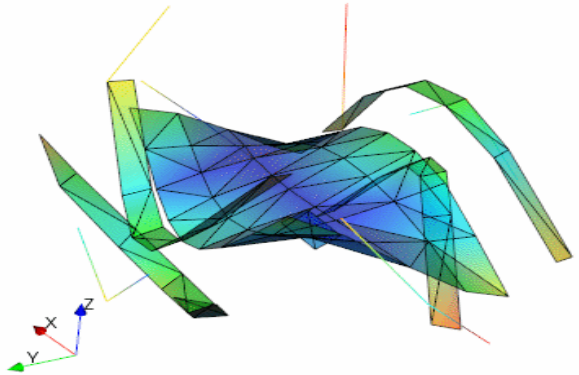
# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
|---|---|---|---|
| 403.7 | 390.8 | 3.31 | 0.998 |
| 575.3 | 582.0 | 1.16 | 0.991 |
| 921.0 | ------- | ------- | ------- |
| 1008.7 | 1001.5 | 0.72 | 0.900 |
| 1224.8 | ------- | ------- | ------- |
| 1241.9 | 1288.0 | 3.58 | 0.991 |
| 2026.6 | 2087.2 | 2.90 | 0.901 |
| 2149.9 | 2215.5 | 2.96 | 0.910 |
| 2377.6 | 2345.0 | 1.39 | 0.951 |
| 2452.5 | 2397.4 | 2.30 | 0.983 |
| 2771.3 | 2799.5 | 1.01 | 0.873 |

Model



Test



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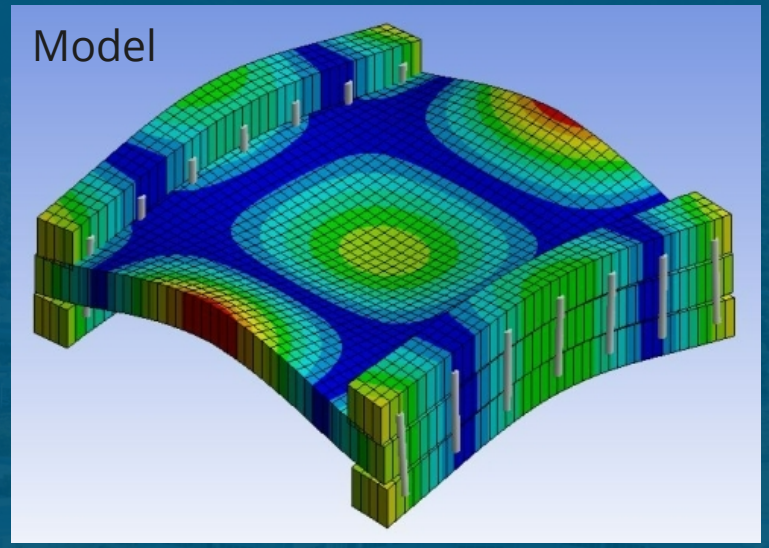


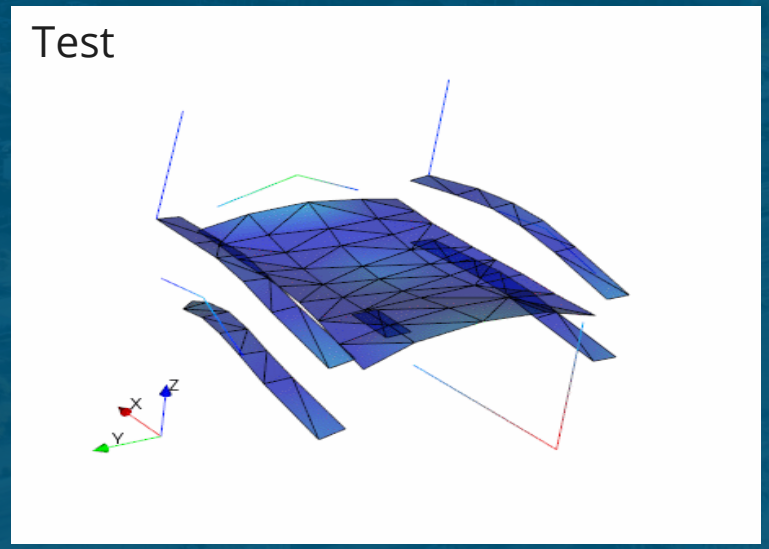

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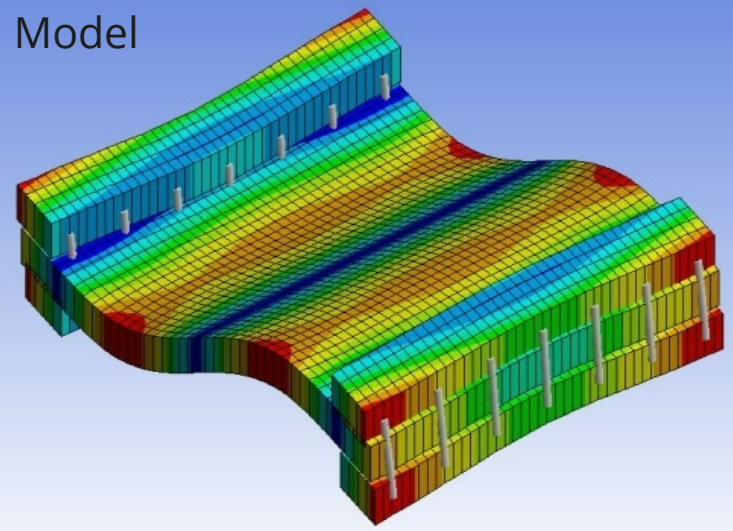
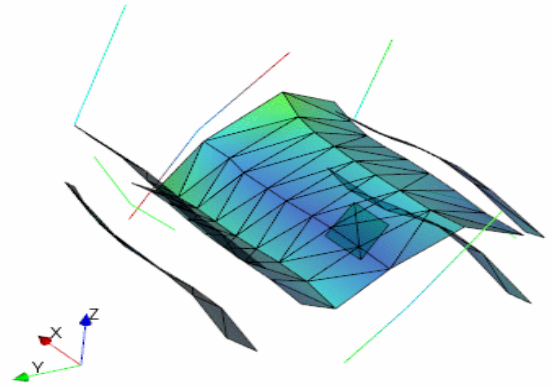
Model



Test



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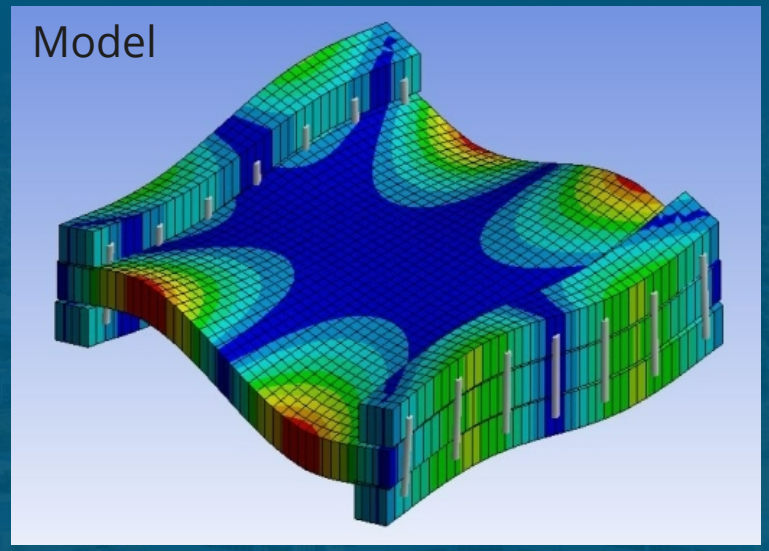


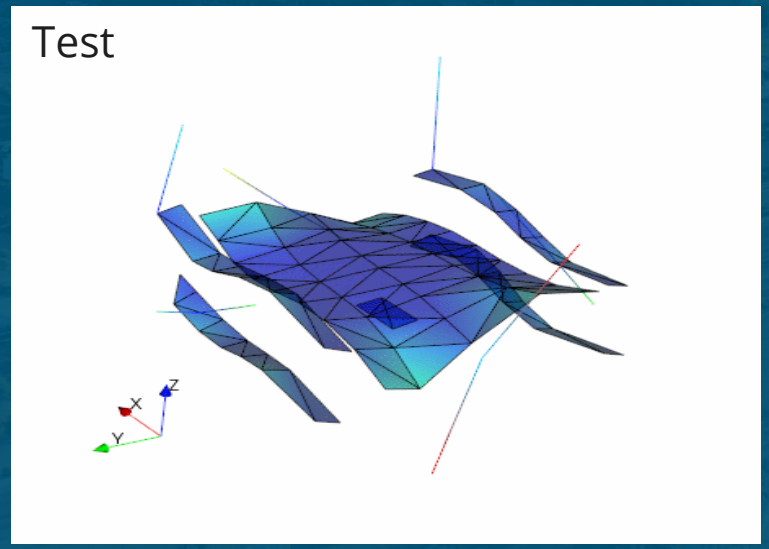

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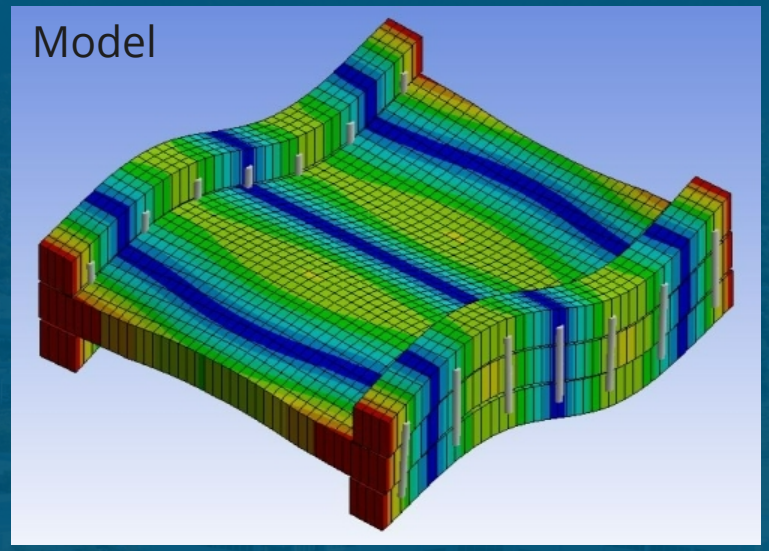


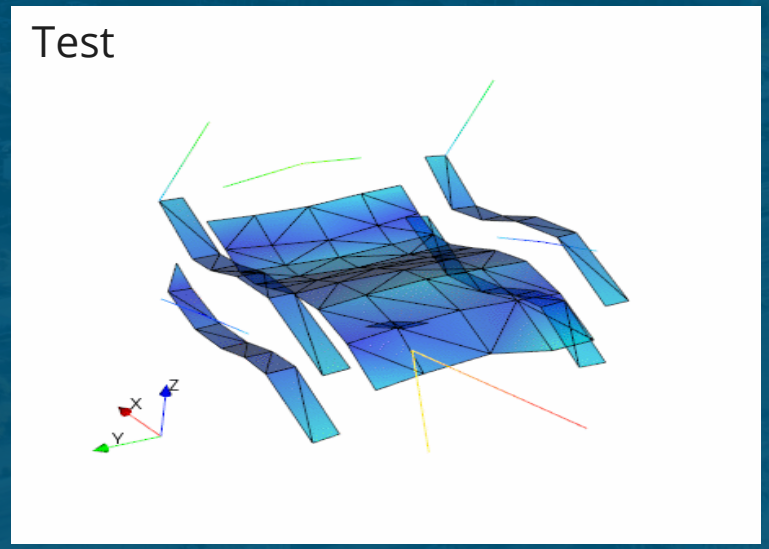

# Validation with Modal Test Data – Mode Shapes & MAC

| Model Frequencies (Hz) | Test Frequencies (Hz) | % Difference | MAC Value |
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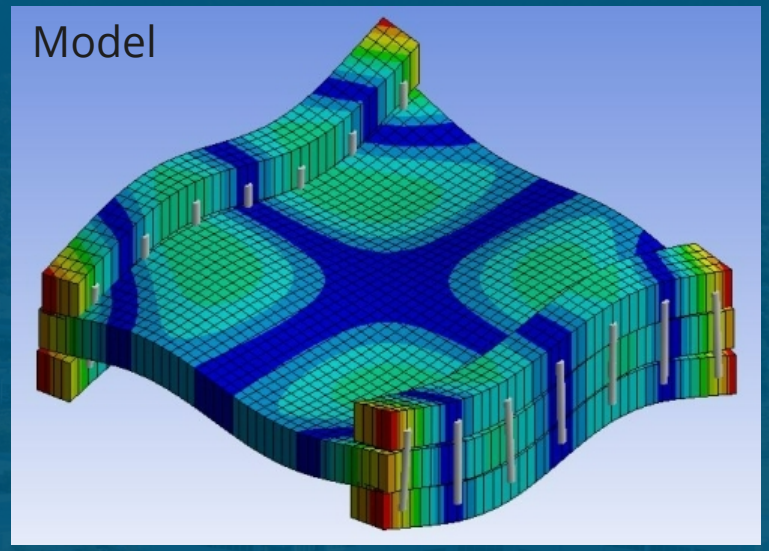


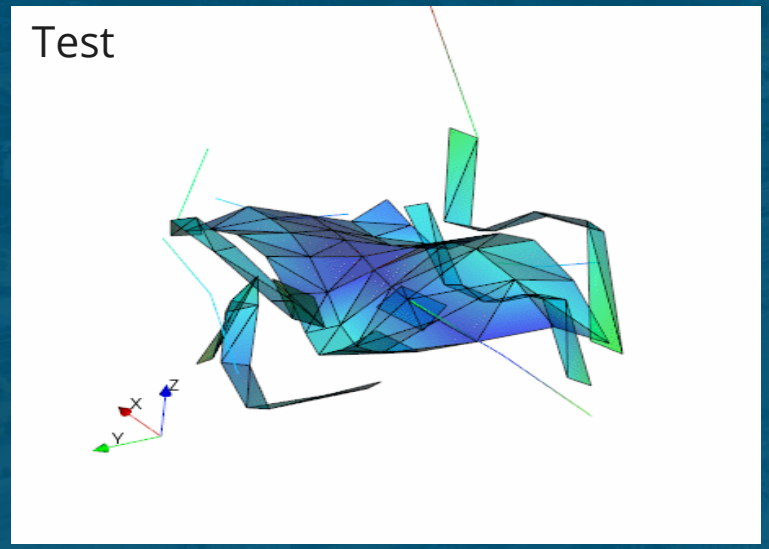

# Key Takeaways

Model Performance in the Modal Domain

- Relatively accurate up to ~3000 Hz
  - Not as good as the bare plate model
- Accurate mode shape and frequency for the 1kHz mode
- Some modes did not match with the test
  - Not trying to match the test exactly
  - Possibly caused by simplifications

# Acknowledgements

Co-authors and Mentors

- Vit Babuska, Dave Soine, and Daniel Lee

Sandia Co-workers

- Tyler Schoenherr, Bryan Witt, Ron Hopkins, Forrest Arnold, Tino Arias, Dylan Landry, and Kevin Brenner