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Effectiveness of Modeling Thin Composite Structures Using Hex Shell Elements

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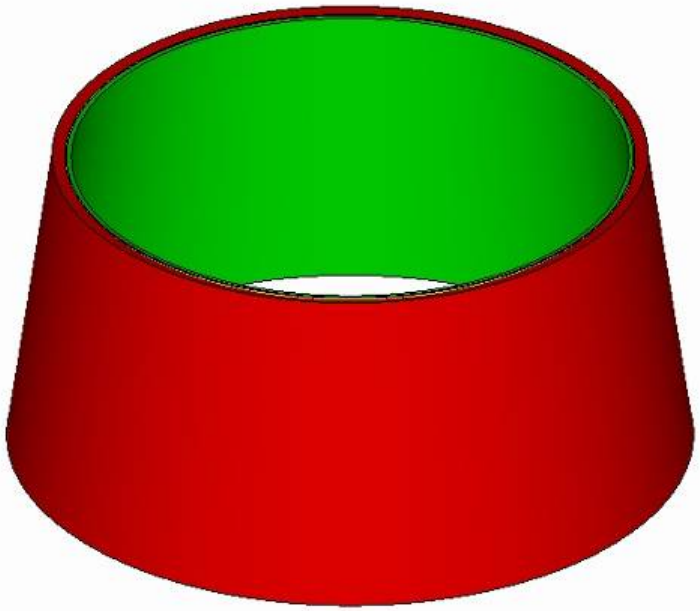
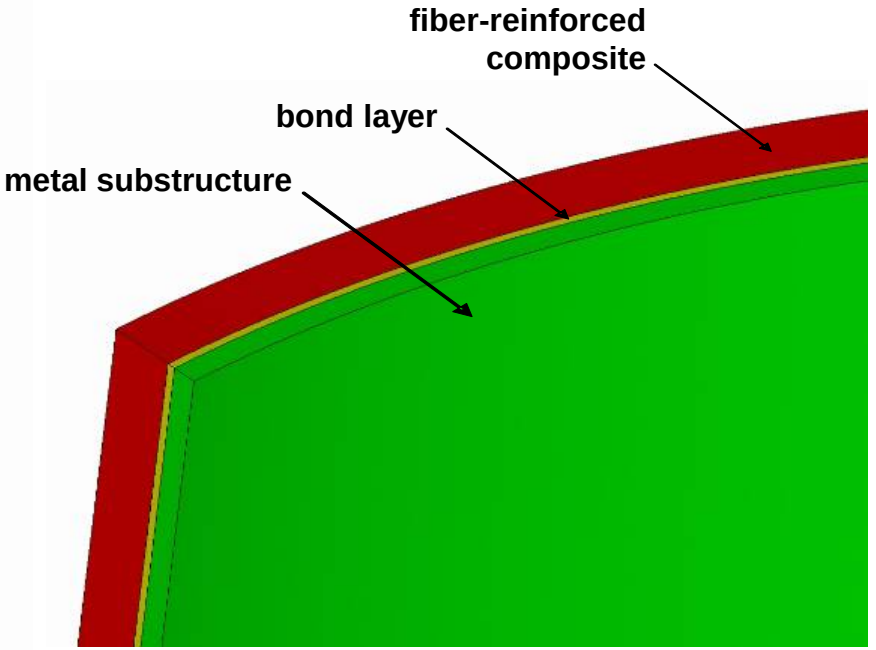
Introduction

Layered Shell Structure Geometry





Introduction

- **Traditional Finite Element Modeling Method**
  - **solid 8-noded hex elements**
  - **expensive**
  - **worth computational effort**
  - **finer mesh**

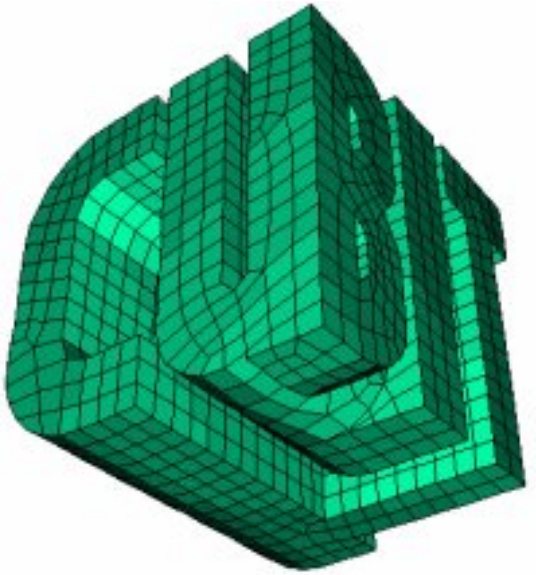
- **Reduced Model**
  - **long simulations or large sets of simulations**
  - **provides tractable run times**

Introduction

- **Mesh Convergence and Element Size Study**
  - **balances accuracy and computing resources**
- **Objective**
  - **investigate effectiveness of modeling thin composite structures with hex shell elements**
- **Approach**
  - **compute natural frequencies and mode shapes for various mesh densities**
  - **generate “truth” results**

Introduction

- **Mesh and Analysis Tools at Sandia National Labs**
  - **CUBIT**
  - **Salinas**



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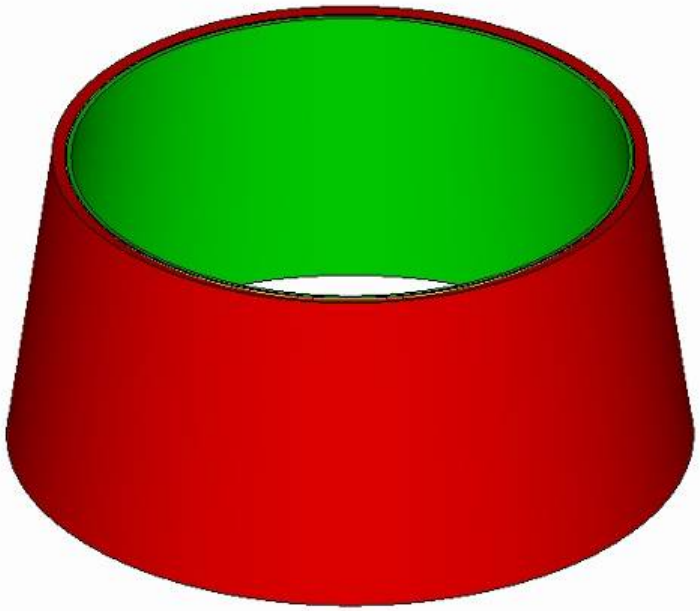
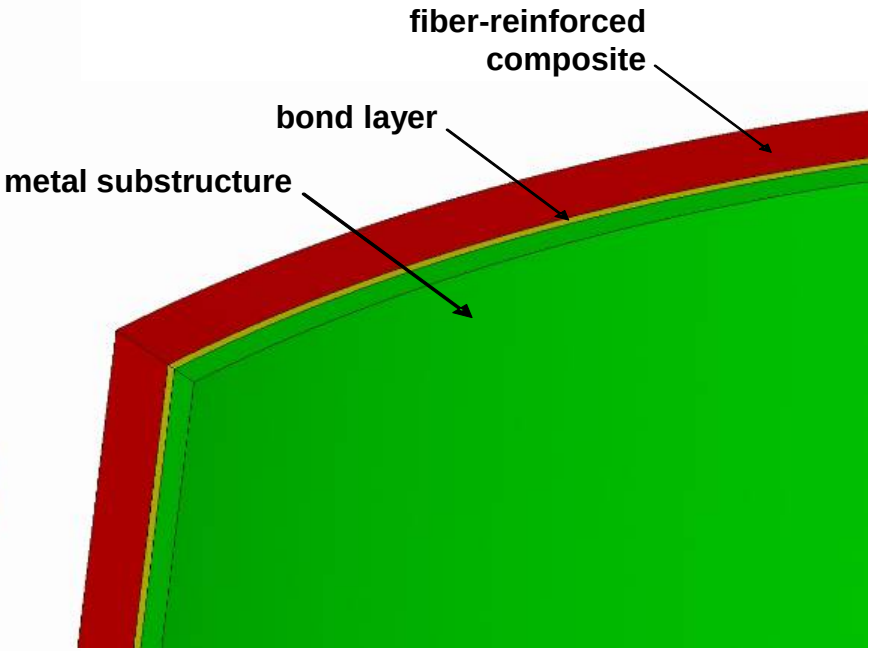
Introduction

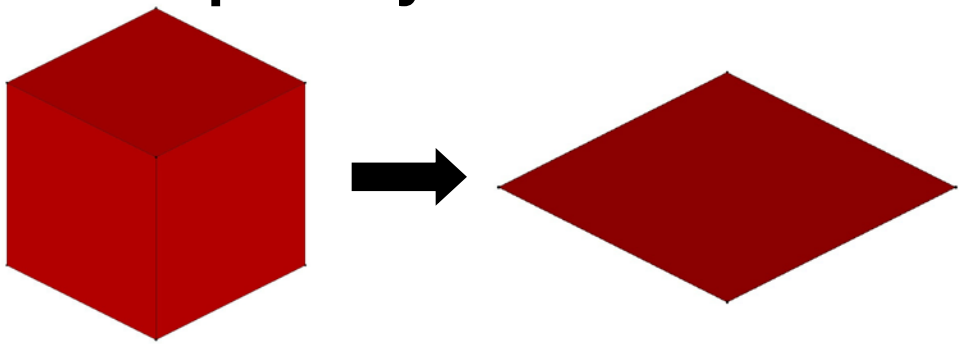
- **Shell Structure Description**
  - **3 material layers**
  - **layered frustum used as validation problem**
  - **quarter model with symmetry boundary conditions**





Hex Shell Elements

- Solid Shell Elements or Thick Shell Elements
- Available in Salinas
- Provide Shell Element Capability with Hex Element Topology



- Provide Intermediate Capability Between Typical Shell Element and Continuum Element

Hex Shell Elements

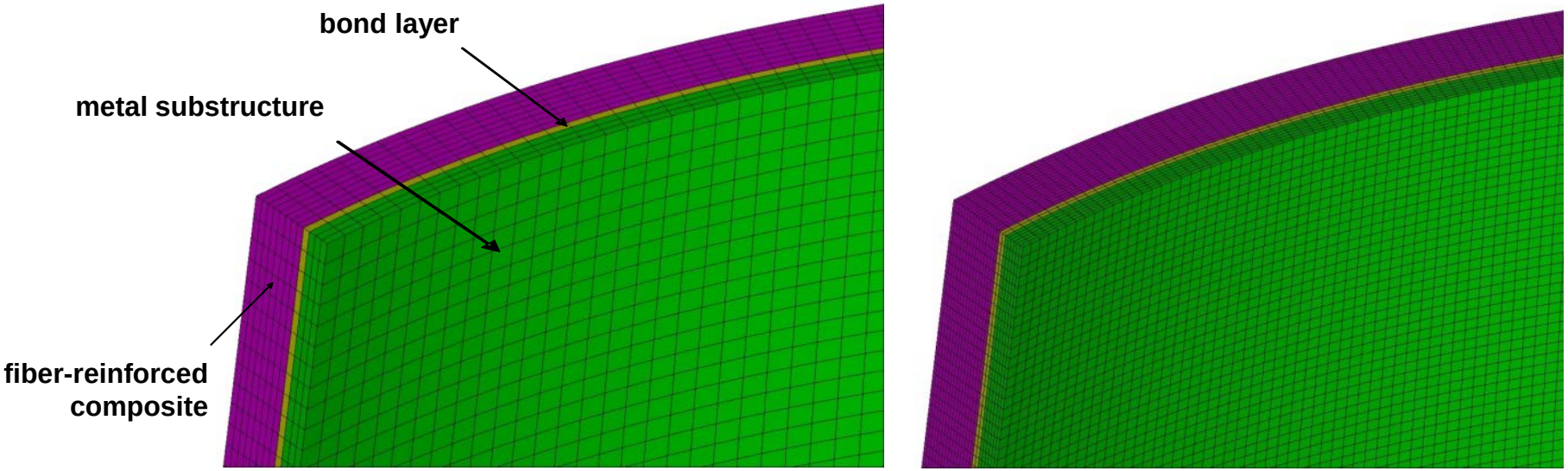
- **Based on Assumed Natural Strain Formulation**
  - **multiple material layers within element allowed**
- **Assume Transverse Isotropy**
- **Modeling of Thin Structures with Hex-Like Elements**
  - **no concern for bad aspect ratio and number of elements through thickness**
- **Mid-Plane Extraction is Irrelevant**
  - **geometry is preserved**

Developing a Truth Model

- **Shell Structure Meshed with 8-noded Hex Elements**
  - **establish “truth” model**
  - **1 element through thin middle layer**
  - **3:1 aspect ratio**
  - **mesh refined twice to establish converged results**

Developing a Truth Model

Baseline and First Level Mesh Refined Models



3:1 aspect ratio (bond layer)

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Developing a Truth Model

- First 20 Modes of Vibration Computed
  - baseline mesh
  - 2x2x2 refinement mesh
  - 4x4x4 refinement mesh
- Richardson Extrapolation
  - estimate converged frequencies
  - sequence acceleration method

Developing a Truth Model

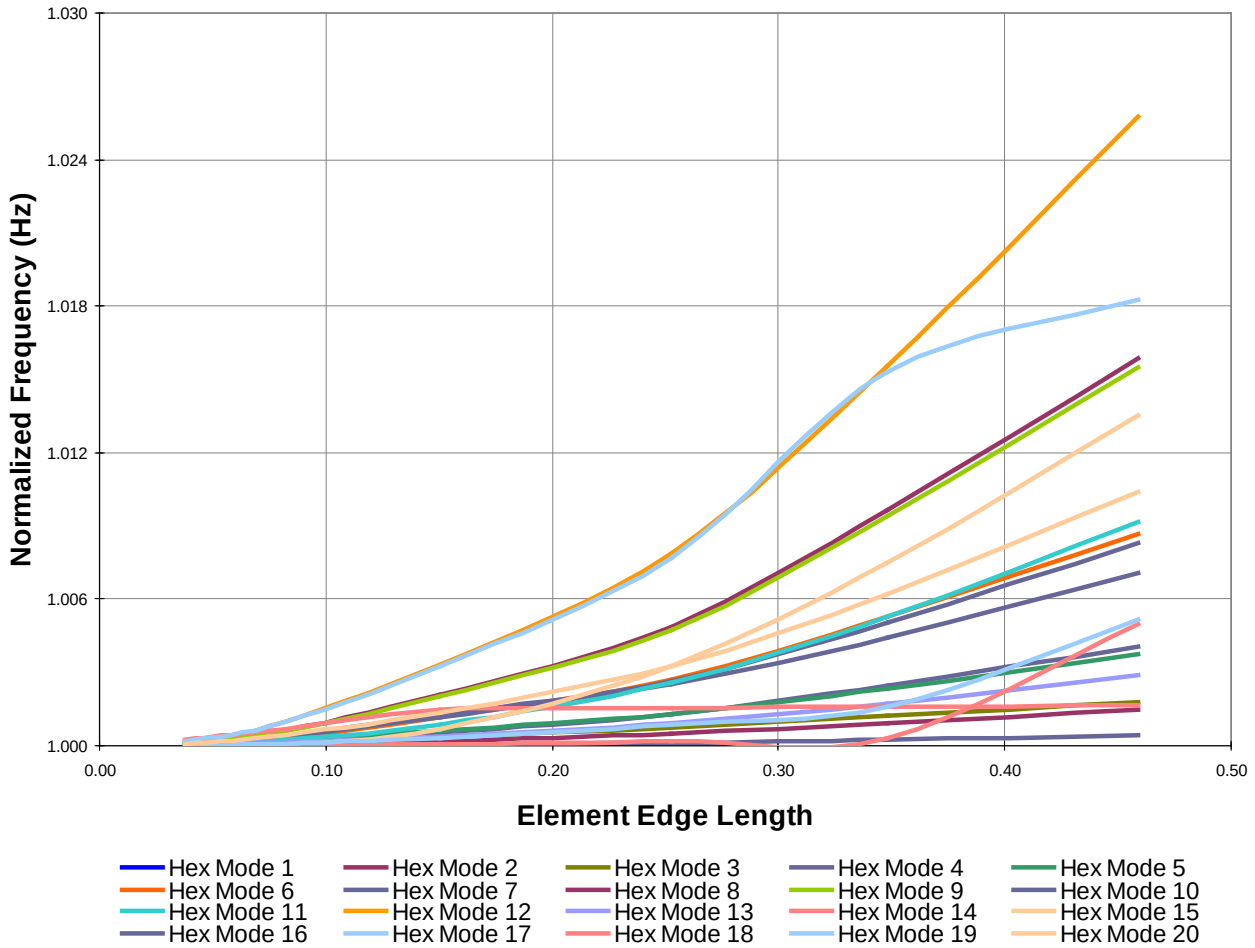
Converged Natural Frequencies

Modes of Vibration	Converged Frequencies (Hertz)
1	0
2	116.662
3	192.982
4	505.836
5	689.991
6	1014.711
7	1250.349
8	1641.02
9	1945.861
10	2028.199

Modes of Vibration	Converged Frequencies (Hertz)
11	2029.044
12	2393.301
13	2473.548
14	2516.158
15	2519.69
16	2688.391
17	2794.034
18	2843.779
19	2850.309
20	2961.505

Developing a Truth Model

- **Coarser Meshes Analyzed For Completeness**



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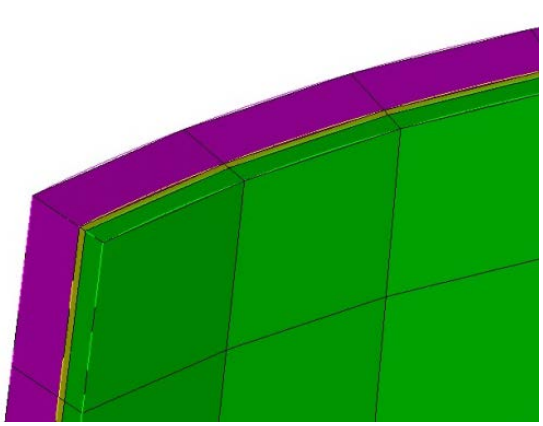
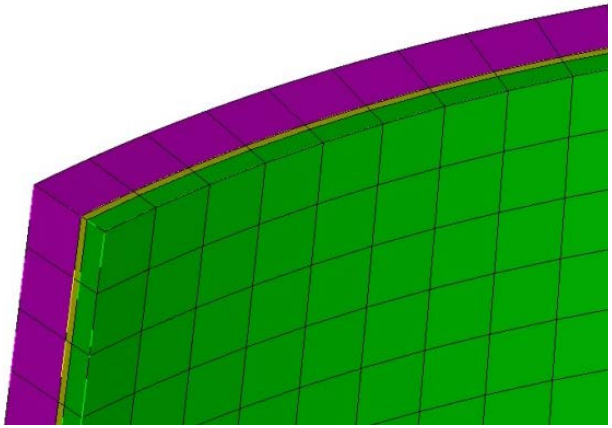
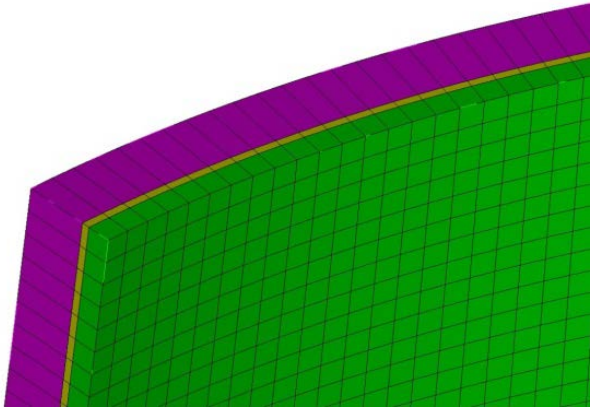
Hex Shell Model Results

- **Hex Shell Mesh Refinement**
  - **meshed with 1 element in each material layer**
  - **aspect ratios for elements in thin middle layer of 24:1 to 1.5:1 analyzed**

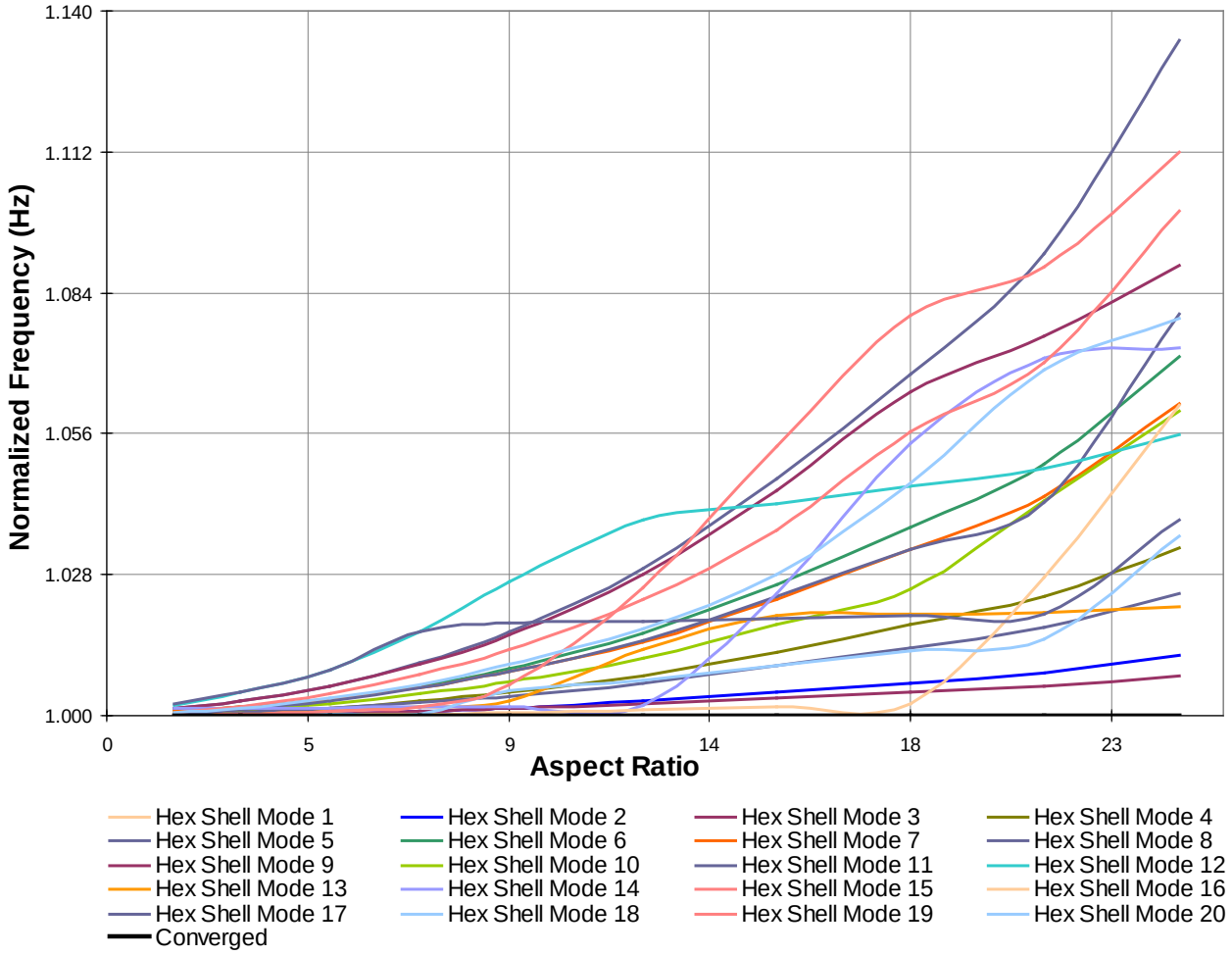






Hex Shell Model Results

- **Hex Shell Mesh Results**



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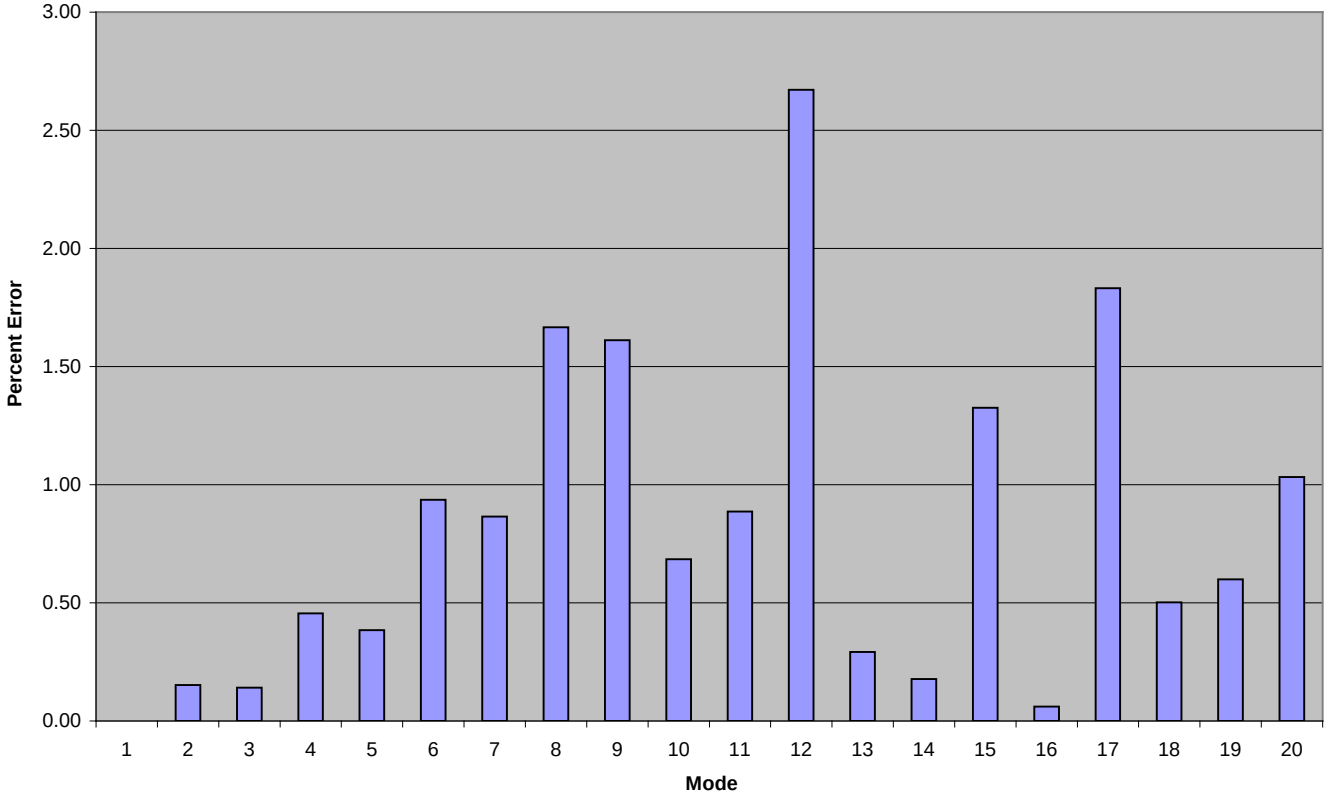
Hex Shell Model Results

- **Percent Error in Frequencies**
  - **coarsest aspect ratio of 24:1**
    - **within 14% of converged results for first 20 modes**
  - **reasonable aspect ratio of 9:1**
    - **within 3% of converged results for first 20 modes**

Mode	Double - 1.5:1	3:1	5:1	7:1	9:1	12:1	15:1	18:1	21:1	24:1
1	0	0	0	0	0	0	0	0	0	0
2	116.649	116.669	116.707	116.765	116.84	116.988	117.193	117.419	117.659	118.045
3	192.92	192.956	193.041	193.137	193.255	193.429	193.667	193.893	194.092	194.507
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
18	2843.84	2843.92	2844.24	2844.63	2858.06	2863.48	2871.74	2880	2887.38	2945.29
19	2850.6	2851.26	2852.76	2854.97	2867.39	2922.79	3002.84	3076.55	3104.41	3169.57
20	2963.04	2965.86	2971.67	2980.11	2992.07	3012.4	3044.42	3098.59	3165.22	3195.44
Maximum % Error	0.24	0.48	0.91	1.68	2.67	3.88	5.35	7.94	9.19	13.40
Element Count	72360	18090	6960	3567	2112	1224	741	528	420	288

Hex Shell Model Results

Percent Error in Frequencies for 9:1 Aspect Ratio Hex Shell Model



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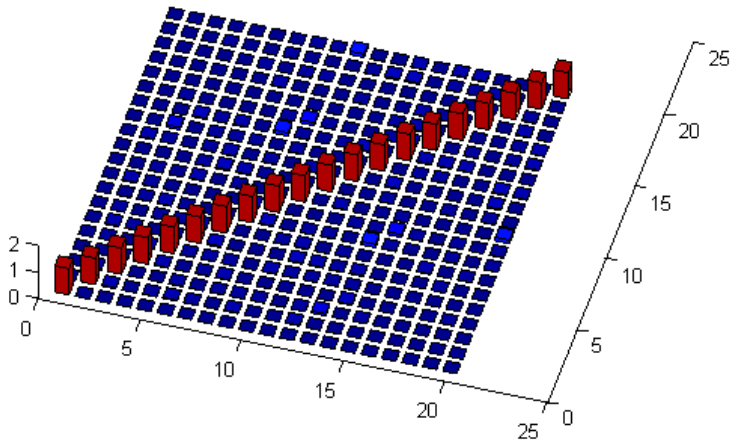
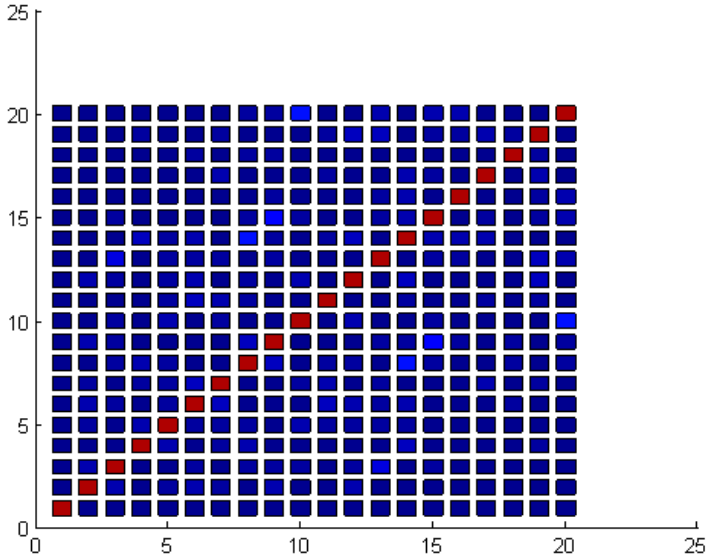
Hex Shell Model Results

- **MAC Calculation**
  - **modes from 9:1 aspect ratio hex shell model compared to finest hex model**
  - **estimate degree of correlation between mode shape vectors**





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Hex Shell Model Results

- **Hex Shell Modeling Technique**
  - **applied to existing aerospace structure**
    - **similar 3-layer construction**
    - **modal test data was available**
  - **9:1 aspect ratio was chosen to model structure**
    - **good balance between element count and solution accuracy**
  - **model results compared to modal test data**
    - **6.69% maximum frequency error from test results**
    - **less than 10% error considered acceptable**

Hex Shell Model Results

Shell Structure Modal Frequency Comparisons

Flexible Body Mode No.	Mode Description	Hex Shell Frequency (Hertz)	Test Frequency (Hertz)	% Error - Hex Shell & Test
7	2,0 ovaling	601.081	581	3.46
8	2,0 ovaling - orthogonal	602.062	588	2.39
9	3,0 ovaling	1393.33	1348	3.36
10	3,0 ovaling - orthogonal	1393.64	1350	3.23
11	2,1 ovaling	1616.68	1653	-2.20
12	2,1 ovaling - orthogonal	1616.74	1670	-3.19
13	1st bending	1619.92	1647	-1.64
14	1st bending - orthogonal	1622.12	1647	-1.51
15	3,1 ovaling	2076.22	2139	-2.94
16	3,1 ovaling - orthogonal	2076.81	2141	-3.00
17	4,0 ovaling	2398.75	2372	1.13
18	4,0 ovaling - orthogonal	2423.07	-	-
19	1st torsional	2424.58	2317	4.64
20	4,1 ovaling	2973.8	3187	-6.69
21	4,1 ovaling - orthogonal	2973.86	-	-
22	2nd bending	3108.19	3136	-0.89
23	2nd bending - orthogonal	3108.44	3142	-1.07
24	1st axial	3112.06	3128	-0.51

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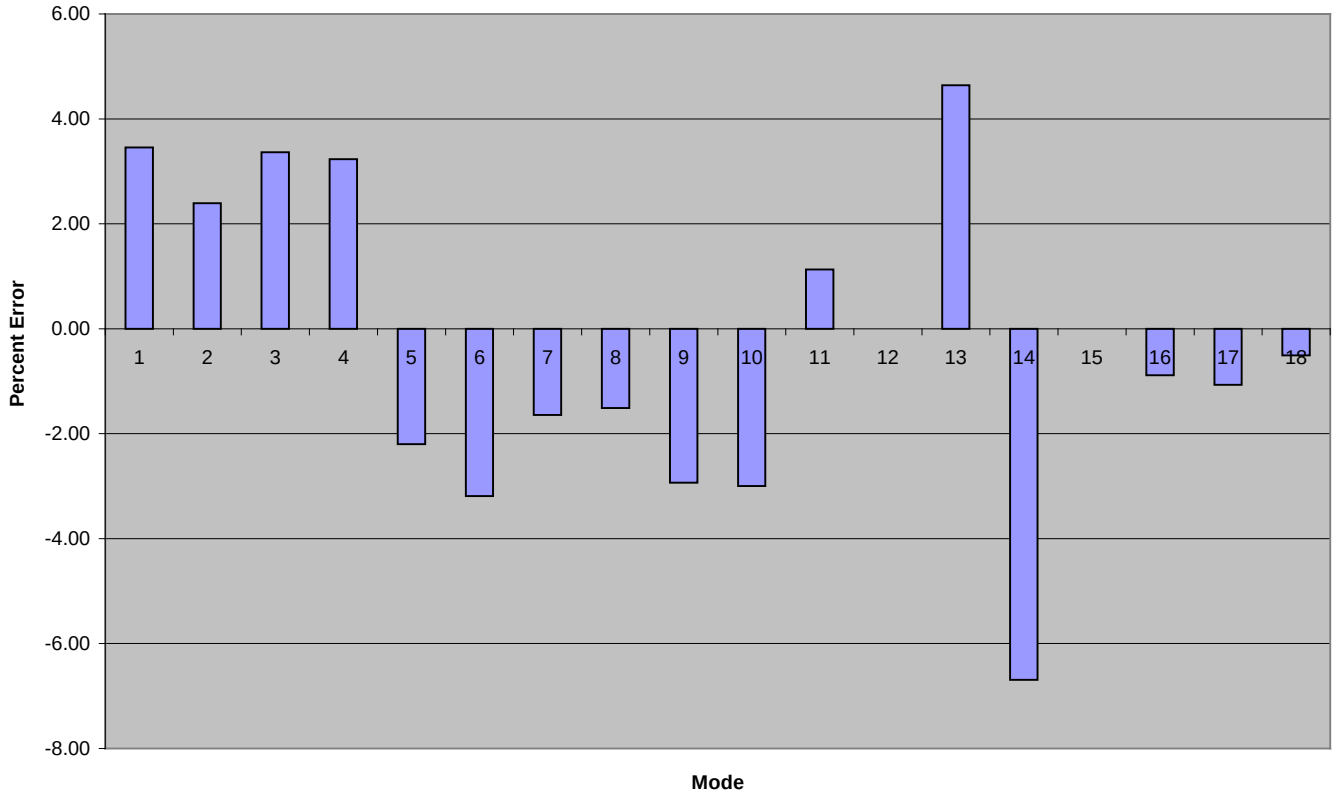
Hex Shell Model Results

Percent Error Between Hex Shell and Test Models



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Conclusions

- **Single layer of hex shell elements are capable of providing solutions that are acceptably accurate to multiple layers of hex elements.**
- **Considerable savings in element count and solution equations result from using hex shell elements.**
- **Fewer elements required through thickness of particular material layer.**
- **Mesh density can be lower without concern for bad aspect ratios.**

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