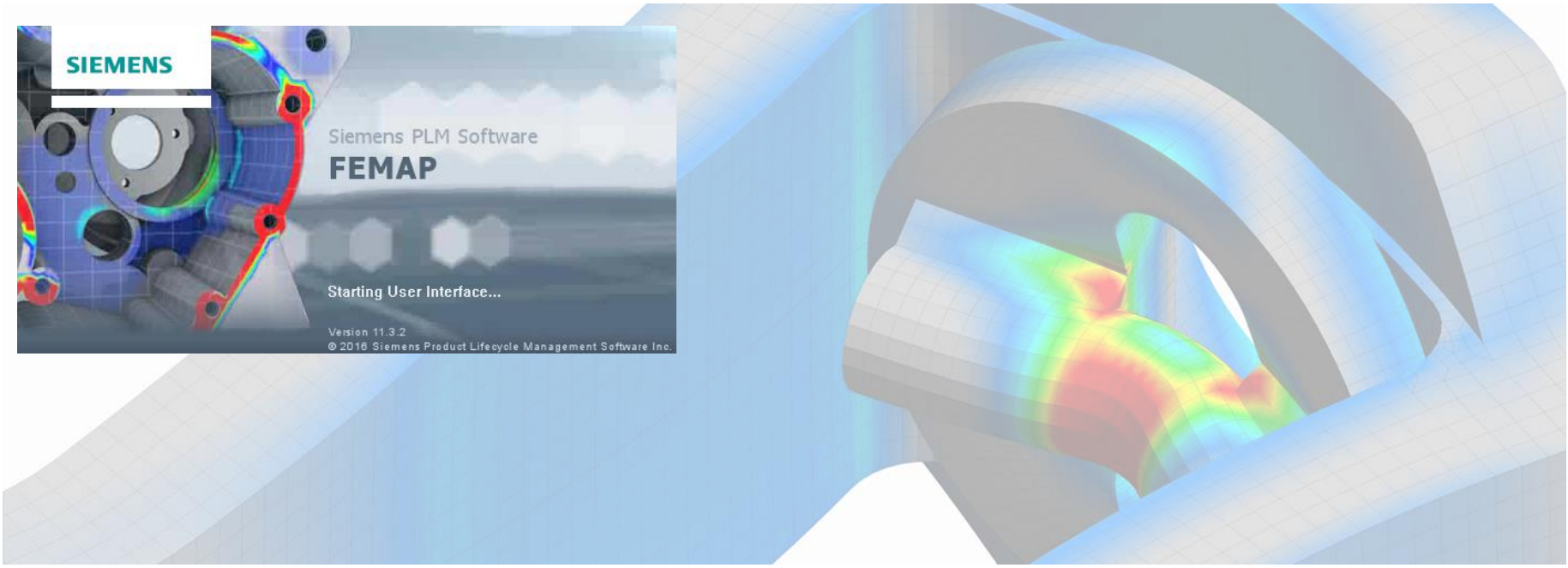

Solid Geometry Meshing from Tet to Hex

A Seminar for FEMAP, NX Nastran and LS-DYNA Users

George Laird, PhD, PE | Principal Mechanical Engineer

Our Focus:

- Ensuring our clients are utilizing FEA tools in the most effective fashion

How We Can Help:

- Superior technical support and ongoing training
- Switching maintenance to us costs you nothing
- Software licenses - FEMAP, NX CAD-CAM, Fibersim, LS-DYNA, Teamcenter

Upcoming Training:

- New live online course for the FEMAP API begins Tuesday, Feb. 21st
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- Next hands-on FEMAP training class will be April 24-28

Support Review:

"After having worked with a couple of FEMAP suppliers in the past I can say that Adrian at Applied CAx has far exceeded my expectations... We use FEA for vessel design and having the support from Applied that helps break down the core problem to simple examples helps in multiple ways."

— Nathan
Mechanical Engineer
Bristol Harbor Group, Inc.

Interested in becoming a client, or in training?

Please contact Erik Barber
(503) 962-0287
Erik.Barber@AppliedCAx.com

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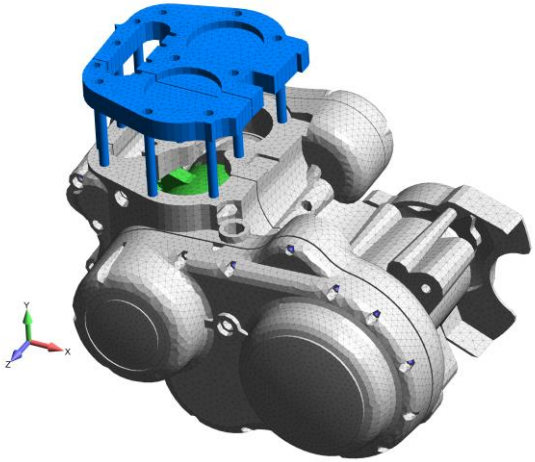
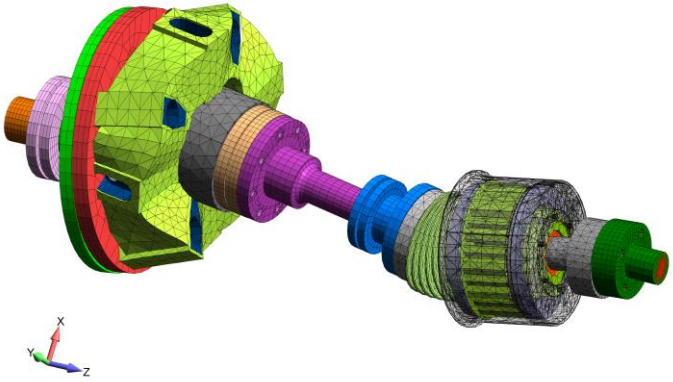
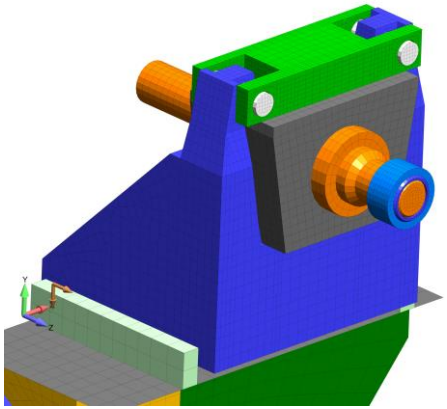
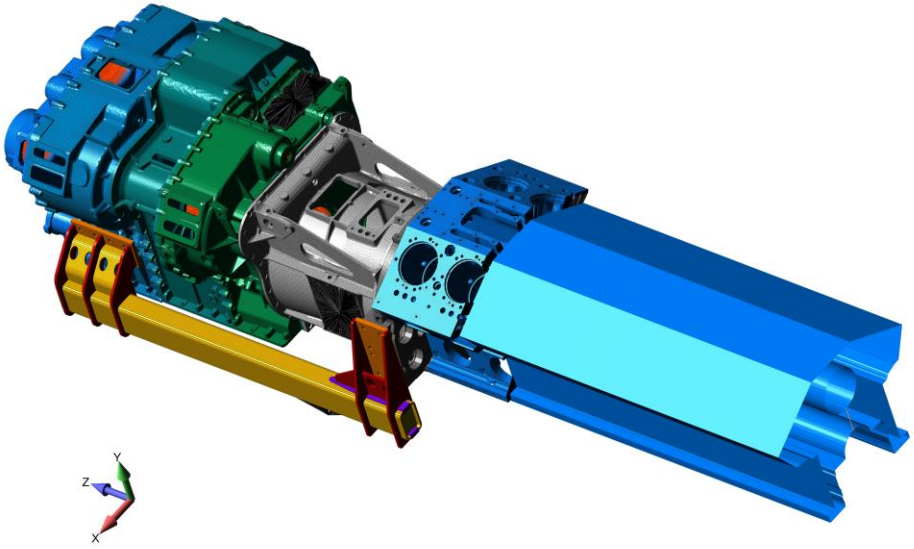
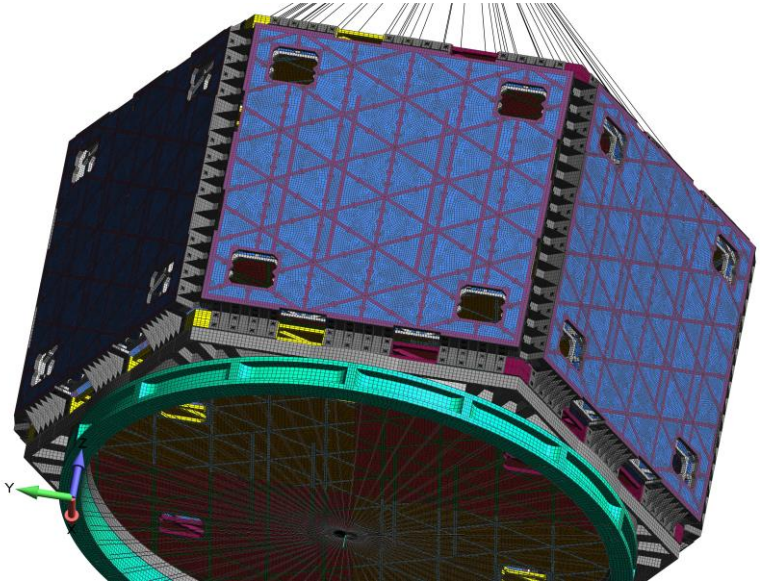










Let's Sharpen Up Our Skill Set

THE OUTLINE

I. Why Do We Care About Tet or Hex?

II. Tet Meshing Fundamentals
   a. How tetrahedral meshing of a solid works (surface inward)
   b. Surface quality controls the tetrahedral quality
   c. Simple checks

III. Hex Meshing Fundamentals
   a. How hexahedral meshing of a solid works (everything is a six-sided block)
   b. Sub-dividing complex solids (importance of surface pairing)
   c. When to stop
   d. Troubleshooting

IV. Hex What is Hex 'able and Tet the Rest

V. Seminar Q & A

1. WHY DO WE CARE ABOUT TET OR HEX?

I'll skip the lecture about good mesh / bad mesh and just get to the point about why hexing is has some advantages:

Simply Supported Bending = 12,000

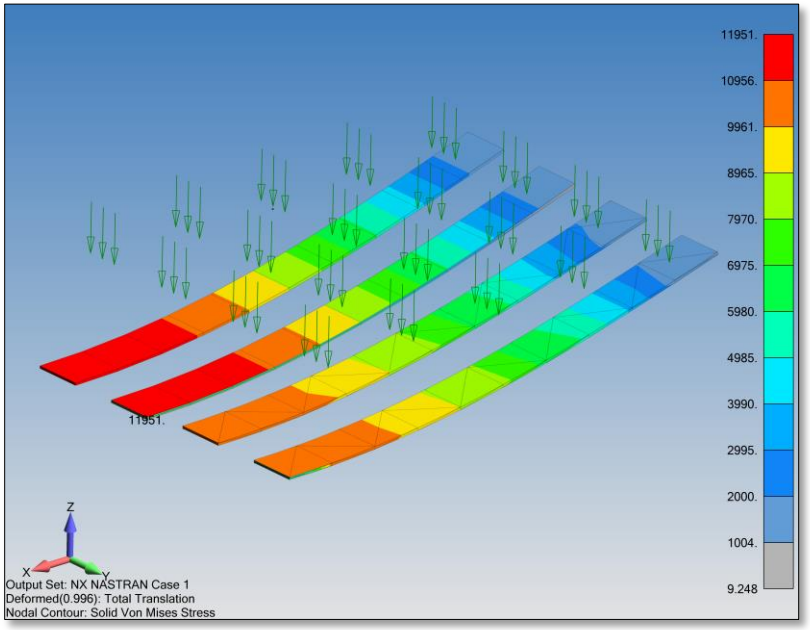
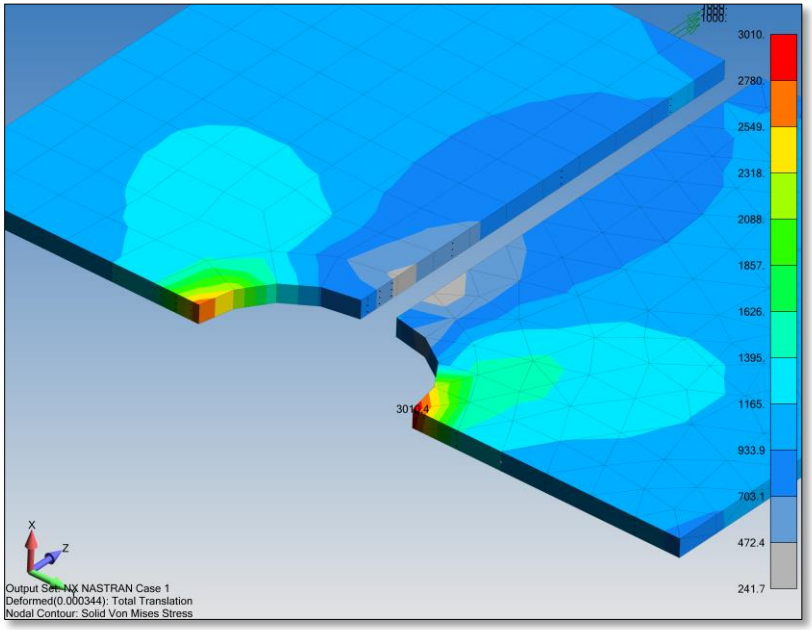


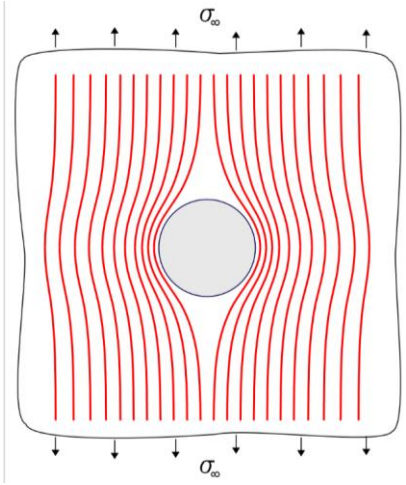
Plate with Hole under Uniform Tension K_t = 3.0



Pros	Cons
Tet is "easy" and for linear analysis hard to justify hex	Tet is heavy (to fill a cube: 26 v 8 nodes)
Tet provides acceptable linear elastic stress results	Often unsuitable for material nonlinear analysis
Good Tets = Good Stress (watch Jacobian – no free lunch)	Can be unwieldy in large models that require normal modes solution (e.g., PSD)

1.1 Just a Quick Note About Stresses

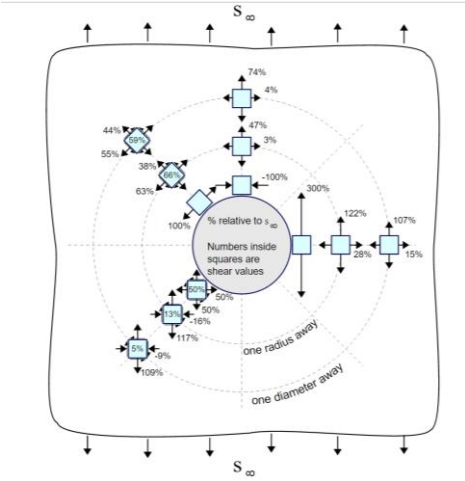
www.FractureMechanics.org



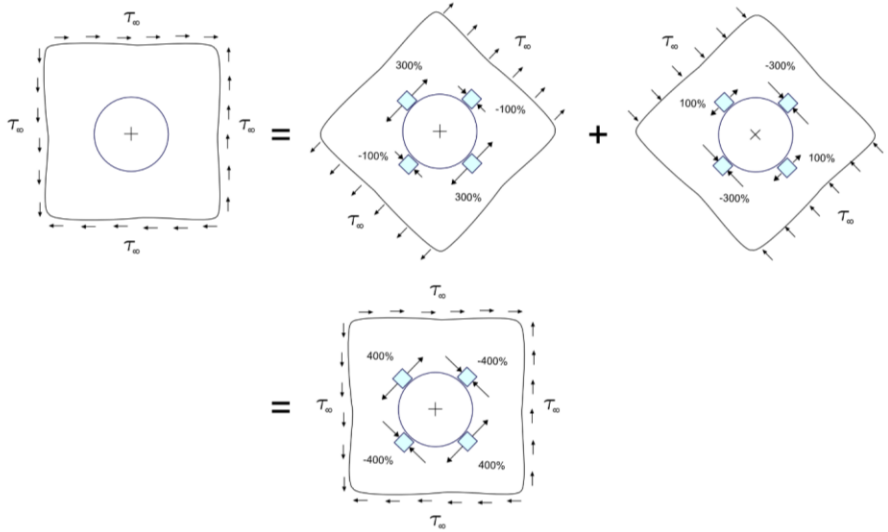
Stress Flows

Stress (2D) in an isotropic solid can be described using the Airy Function that satisfies the *Biharmonic Equation:*

$$\frac{\partial^4\phi}{\partial x^4} + 2\frac{\partial^4\phi}{\partial x^2 \partial y^2} + \frac{\partial^4\phi}{\partial y^4} = 0$$



Stresses around holes have stress concentrations of -1 and +3 under pure tension and +4 under pure shear



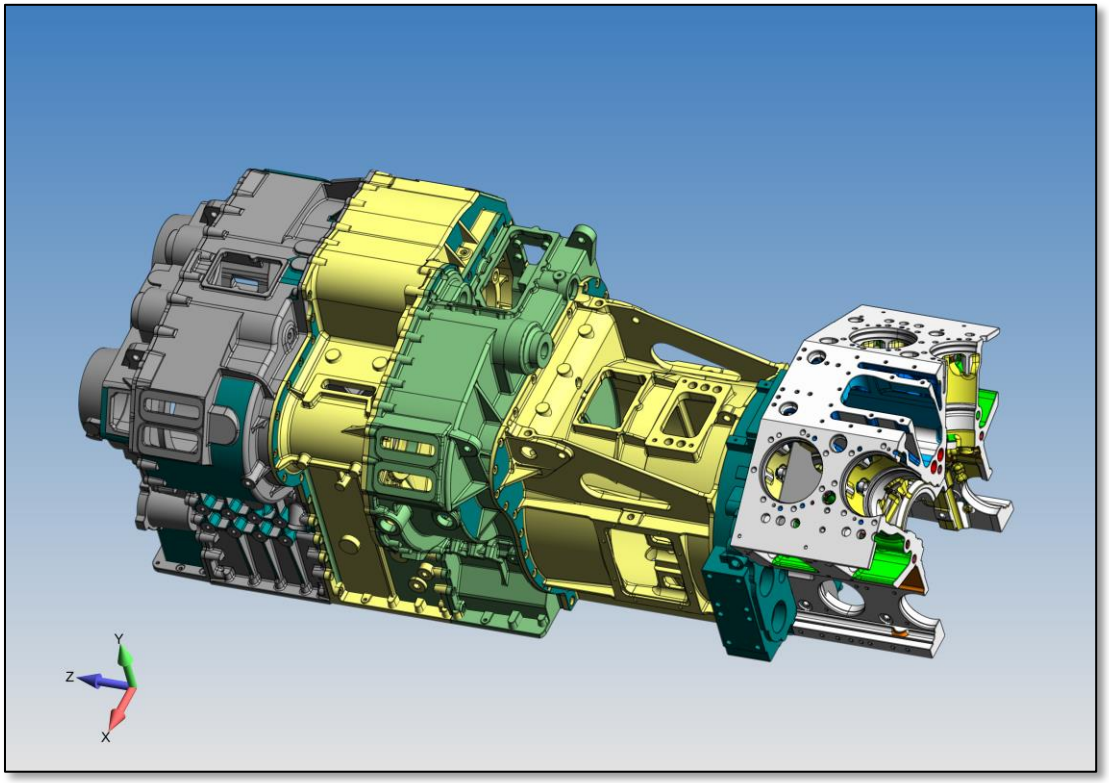
2. TETRAHEDRAL MESHING FUNDAMENTALS

2.1 How it Tet meshing works

Everybody does it the same: (i) surfaces are meshed with three-node triangular elements (FEMAP plot-only), (ii) the surface mesh is "sealed" (nodes are merged and elements are checked) and (iii) the surface mesh is submitted to the a solid tet mesher.

2.2 The Real World

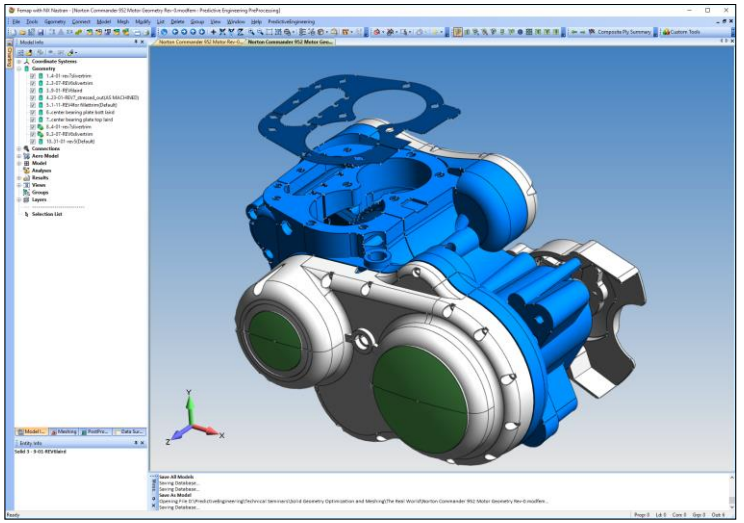
In this example, we will go through the operations to clean up bad geometry, use Mesh Preparation and then how to debug a troublesome surface mesh

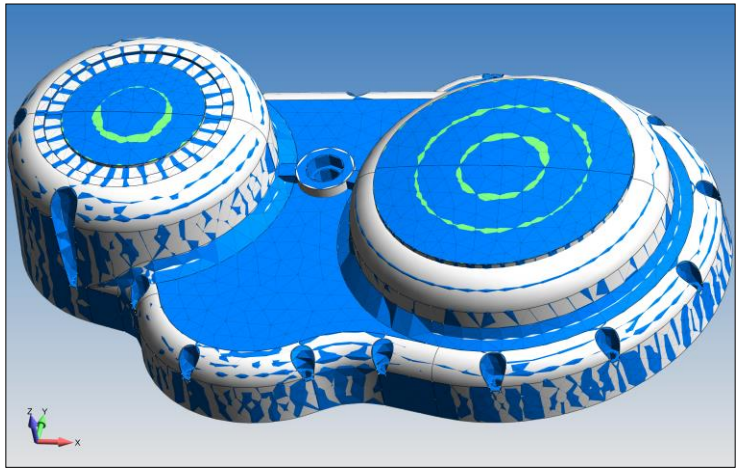


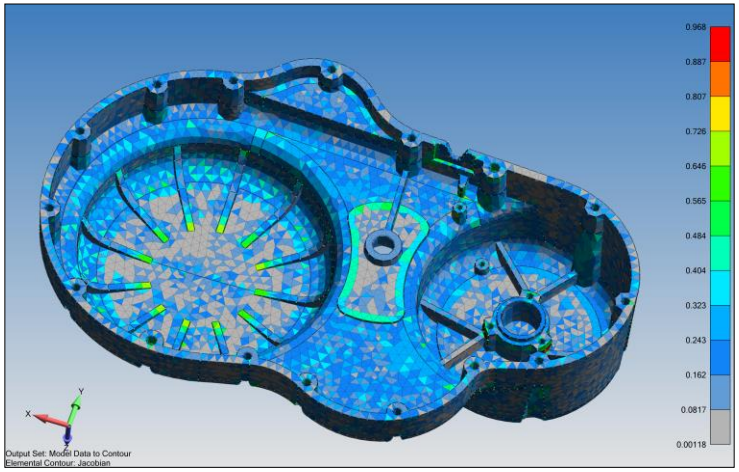
2.3 One-Two-Three – When one understands the process almost anything can be meshed

2.3.1 Mesh Fundamentals and How to Improve the Quality of Your Tet Mesh

- Pick a part and then start with a reasonable mesh size
- Read the messages and think a bit
- Investigate to see if it seems reasonable
- Try Mesh / Geometry Preparation / Mesh Size = ?
- What is it doing in the background?
- Check Mesh Quality?

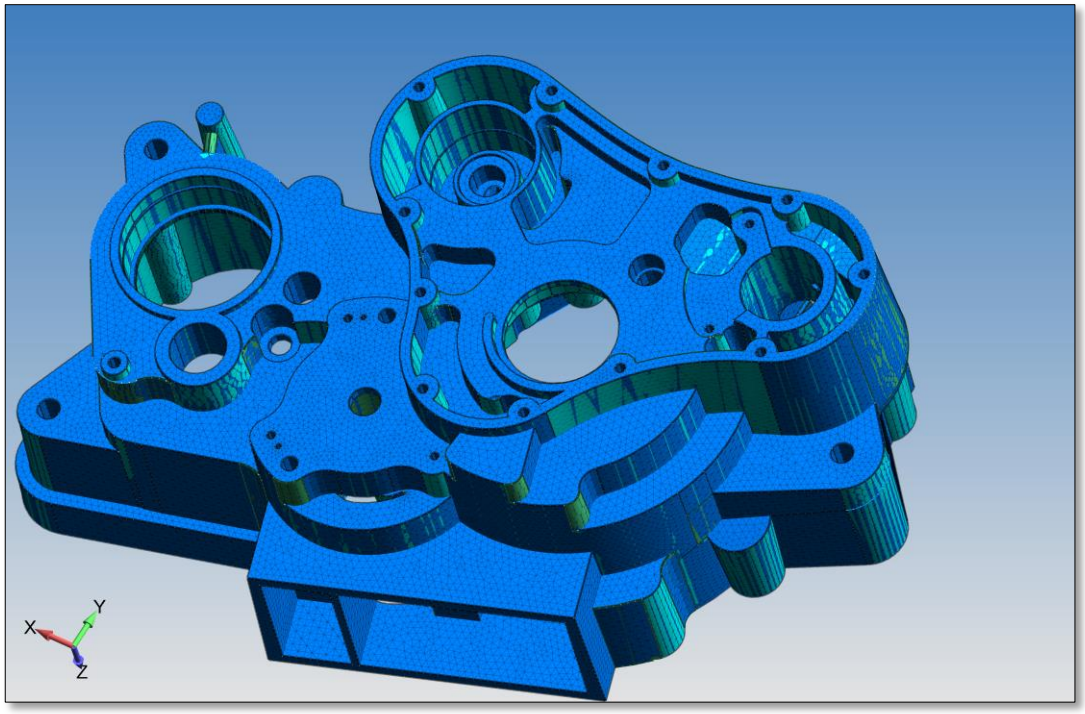






2.3.2 Troubleshooting Bad Geometry: Brute Force Tet Meshing

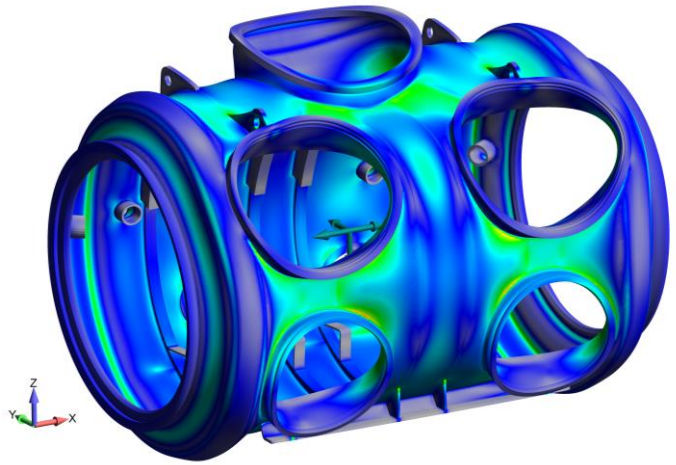
- Try to be systematic
- Look at mesh
- Try Mesh Preparation
- Start ripping apart geometry
- Try Geometry / Solid / Cleanup
- Sometimes it is good'nough

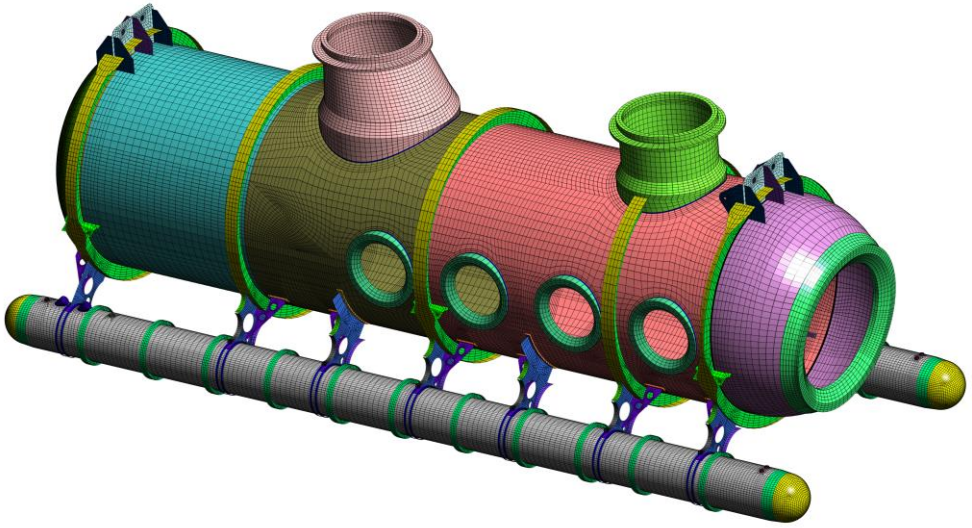


No magic bullet - No perfect system – Still jobs for simulation engineers

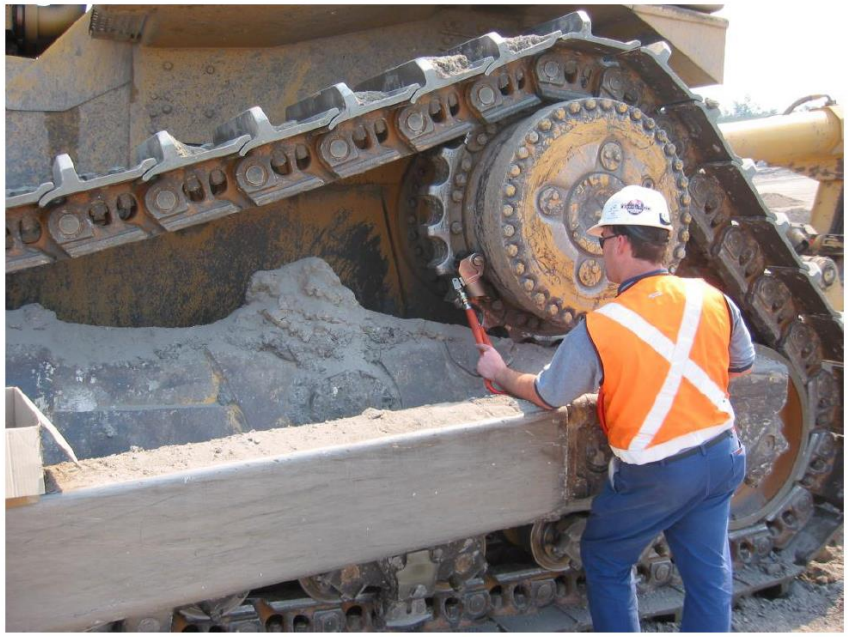
3. WHY WE HEX (PREDICTIVE ENGINEERING FEA CONSULTING SERVICES)

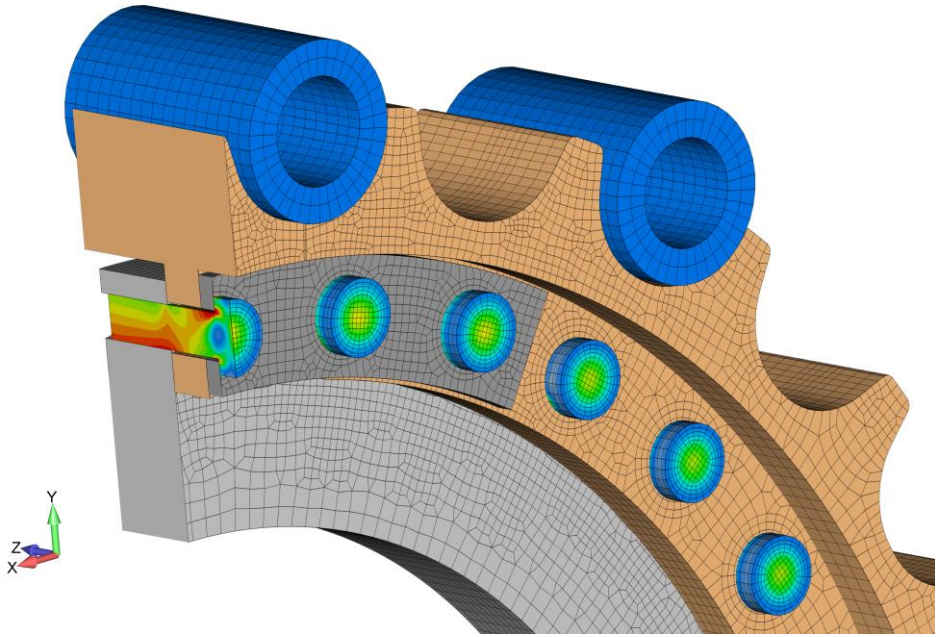
Buckling Analyses

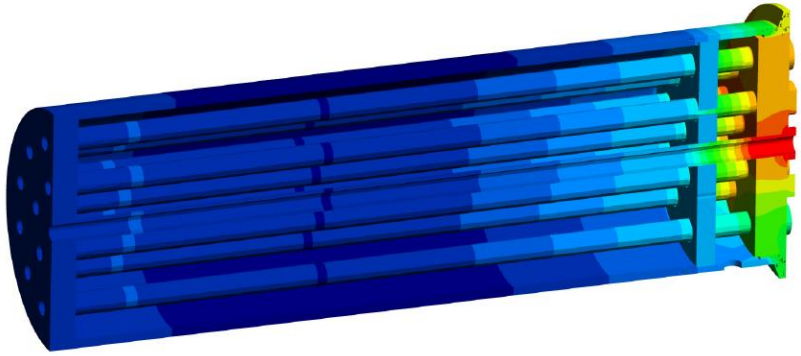


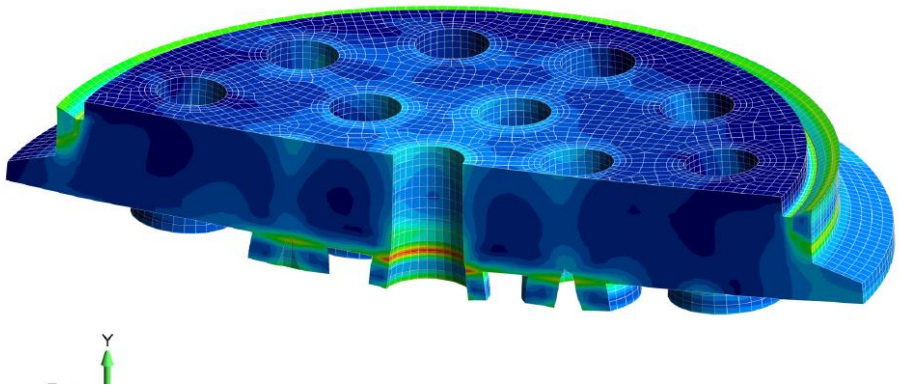


Bolt Preload Analyses (Contact Analysis) and Transient Thermal Analysis

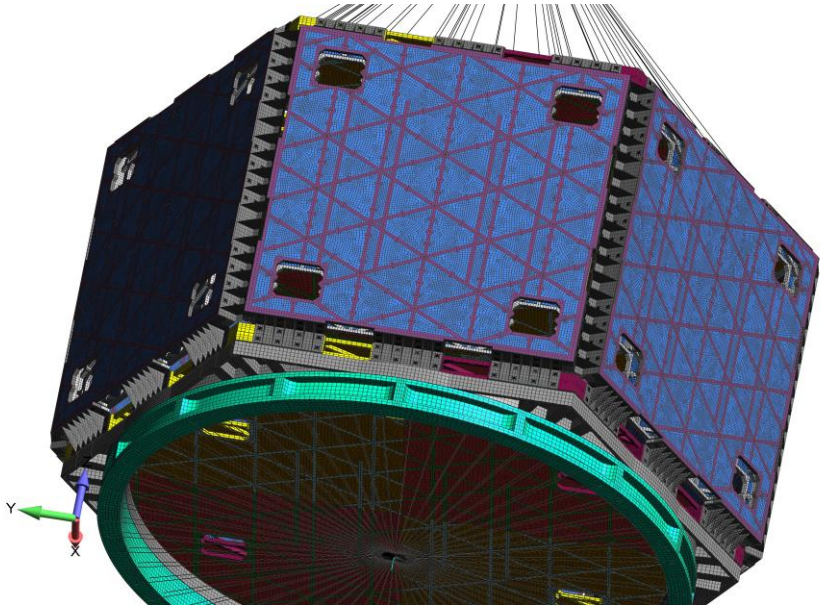


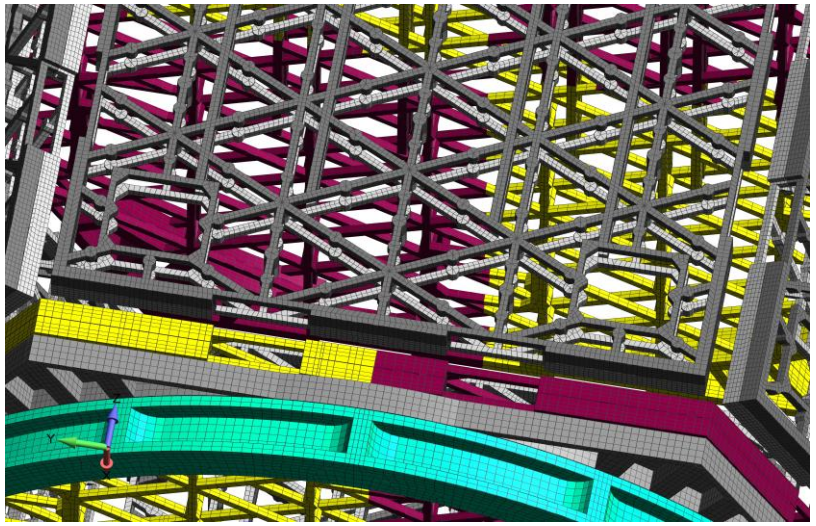


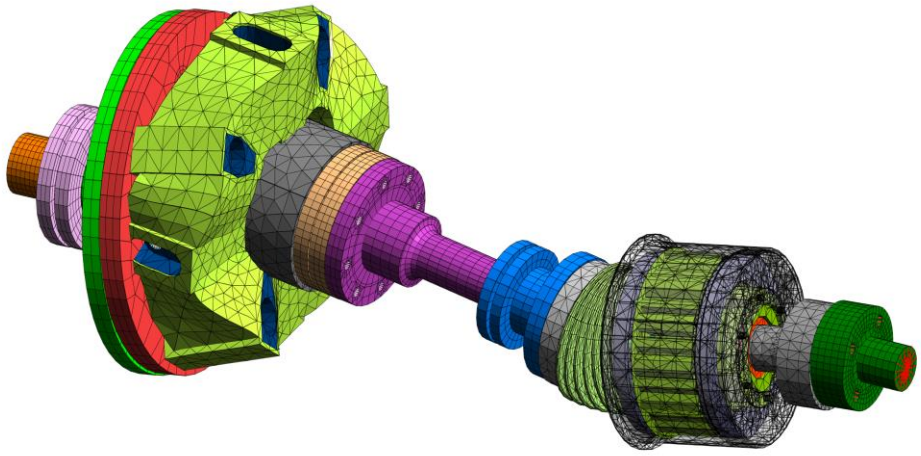




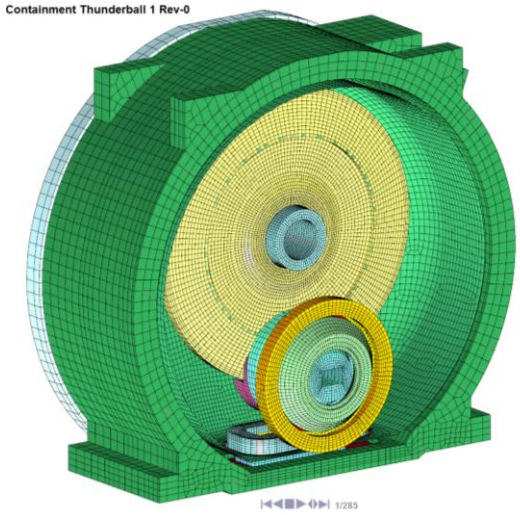
Linear Dynamics (PSD, Sine Sweep, Shock Response) Analyses

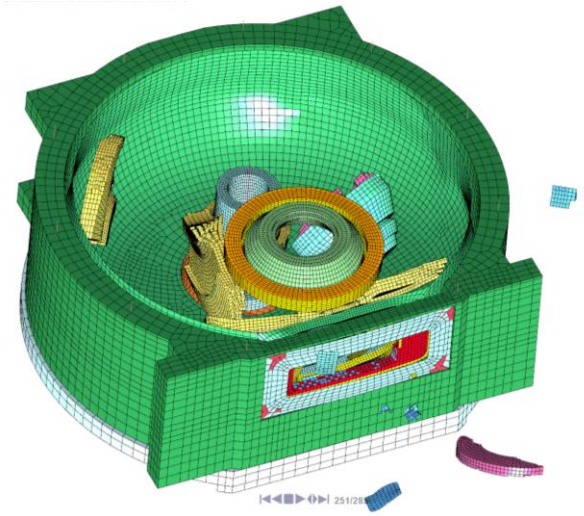


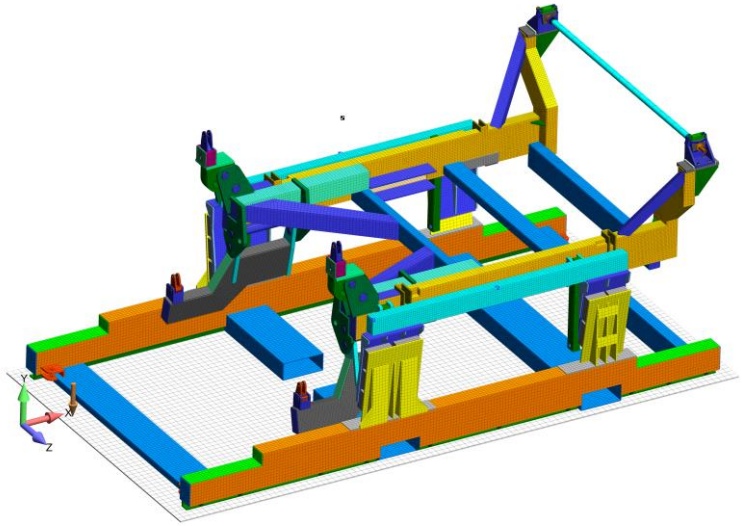


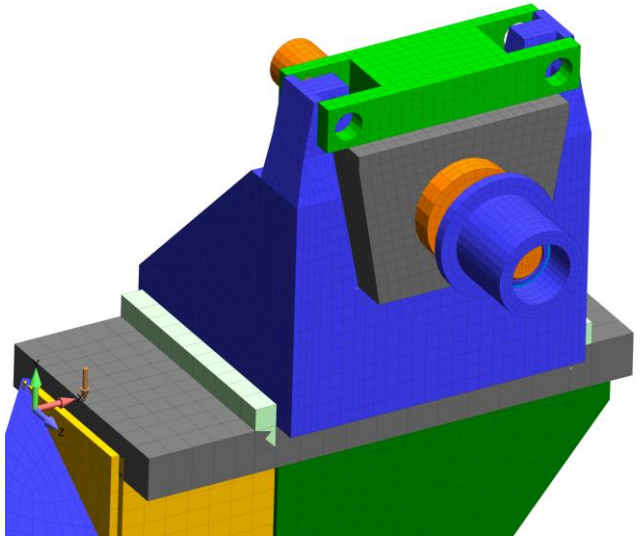


Nonlinear Analyses (LS-DYNA)

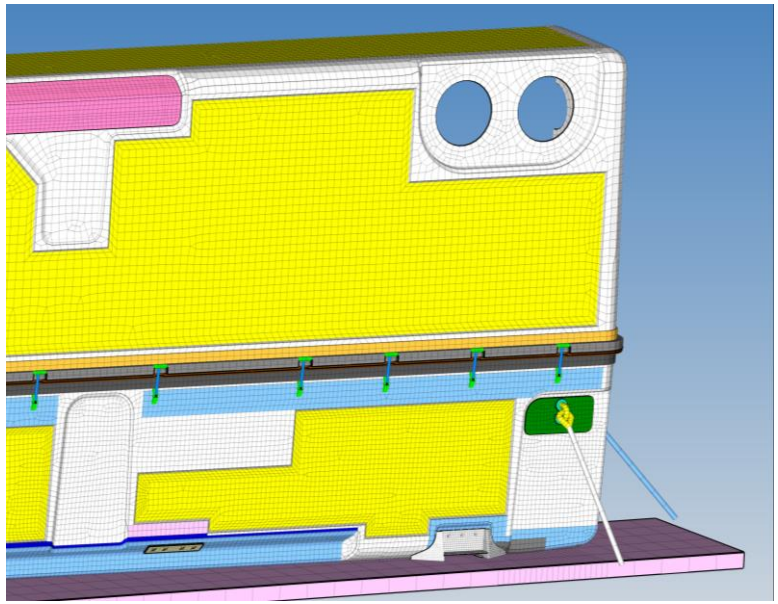


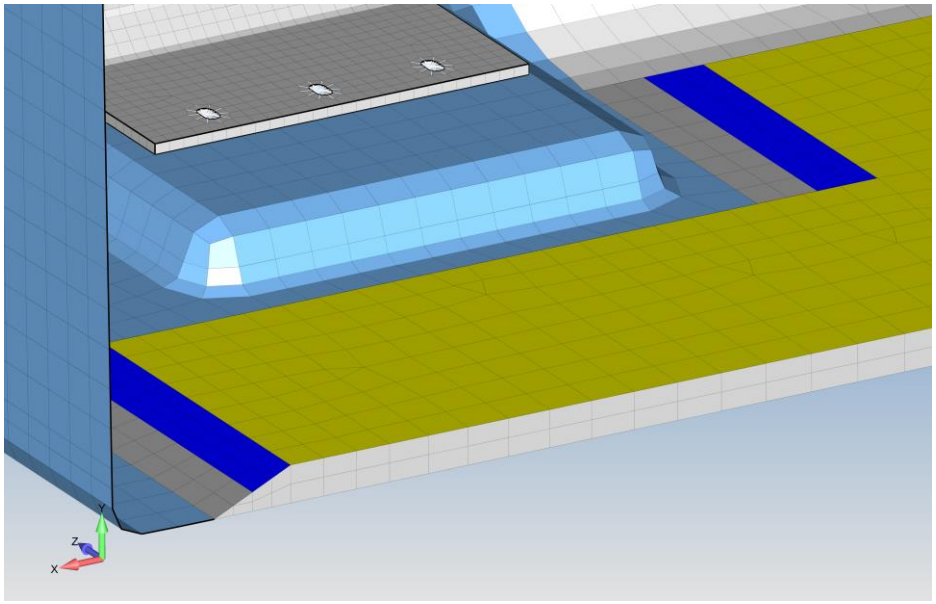


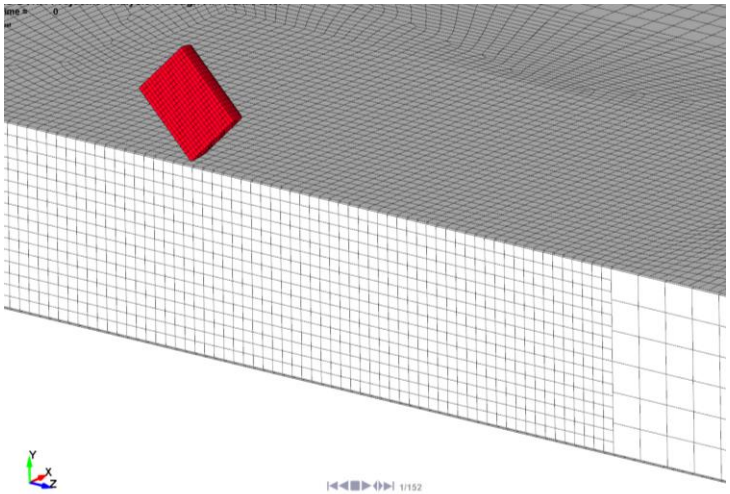


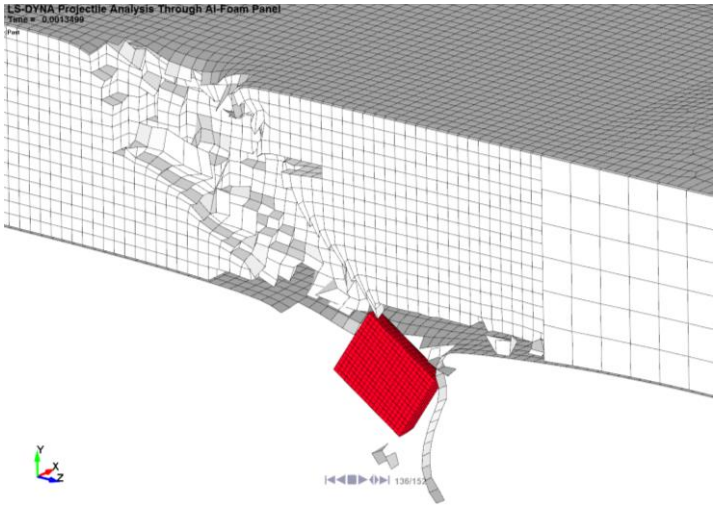


Composite Analysis (LS-DYNA)

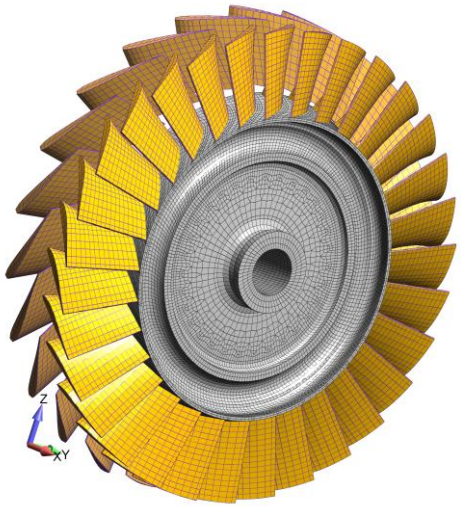


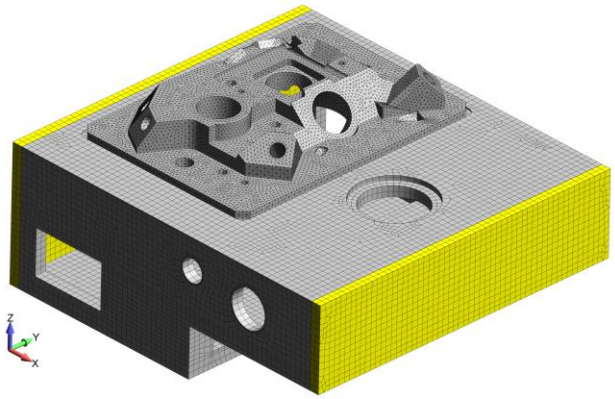


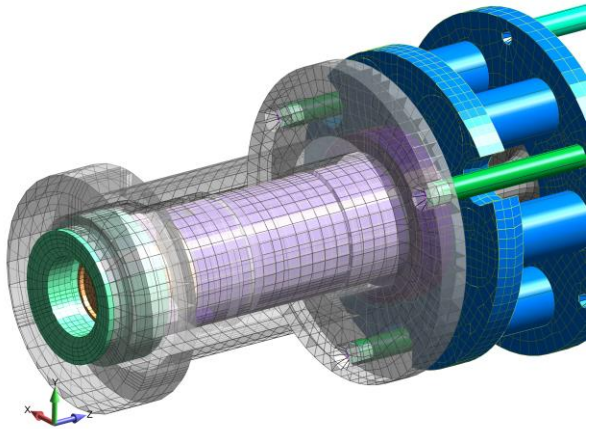


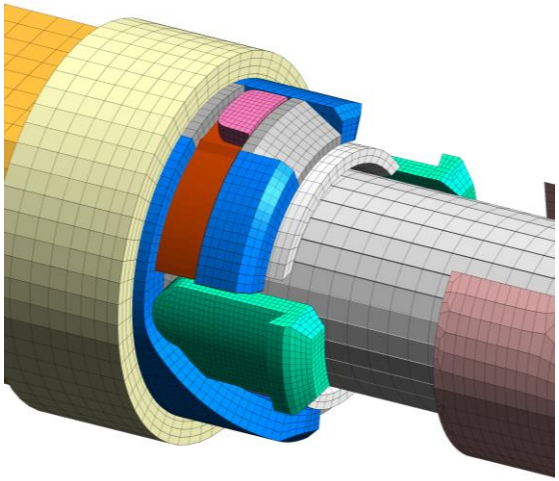


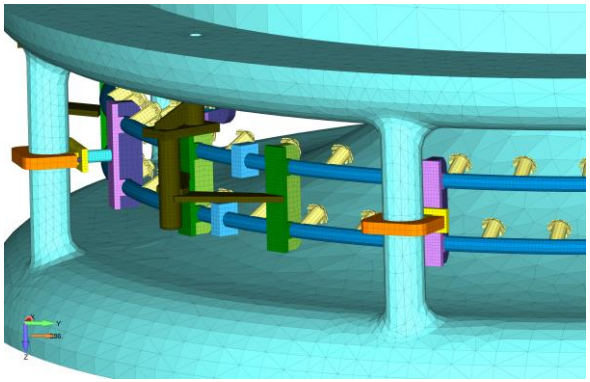
Because Hex is Efficient (Nastran, LS-DYNA and STAR CCM+)

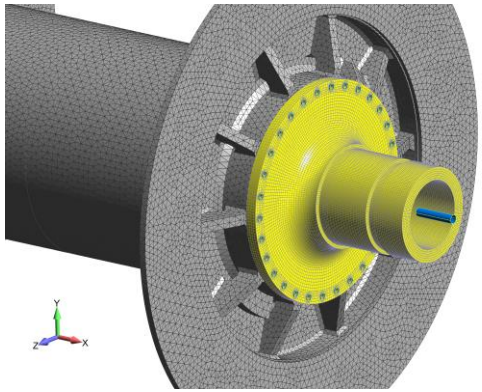








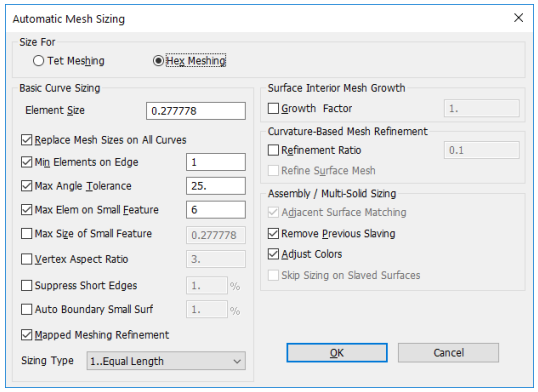


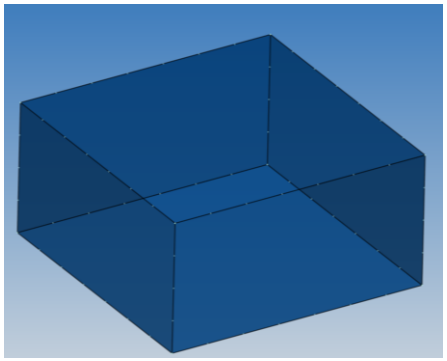


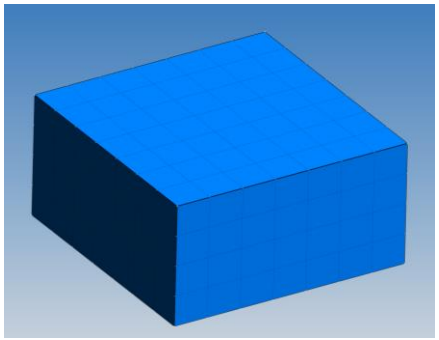
4. HEX MESHING FUNDAMENTALS

Very old school – all geometry is six sided. Let's go slow and do a block and see what we can learn

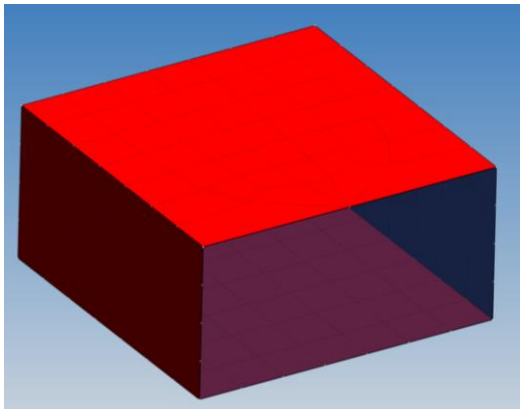
Let's Start Basic







Now Let's Break It



Solid 1 can not be hex meshed. Either Meshes on lateral surfaces are not fully mapped or base and top surface meshes do not match.

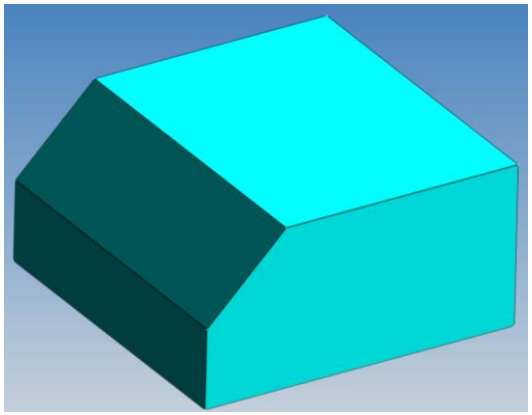
6 Surface(s) Selected...

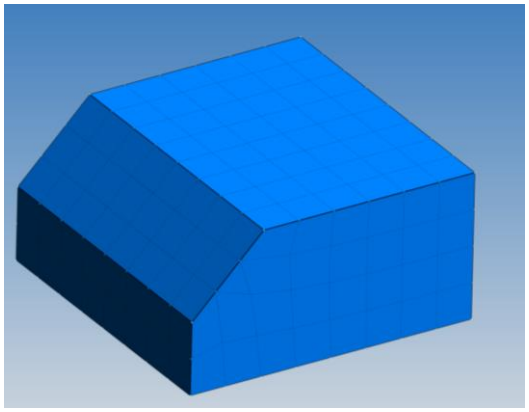
```
    ID      Type Color Divisions <--- Curves ( R = Reversed Directic
-------------------------------------------------------------------
     5      Face  3127   3 x 4
                Segments:    2  Address: 1355

     8      Face  3127   3 x 4
                Segments:    2  Address: 1335

     9      Face  3127   3 x 4
                Segments:    2  Address: 1338

    10      Face  3127   3 x 4
                Segments:    2  Address: 1341
                Mesh Approach: Matched - Linked to Surface  12

    11      Face  3127   3 x 4
                Segments:    2  Address: 1344

    12      Face  3127   3 x 4
                Segments:    2  Address: 1347
```

Concepts: Matched Surfaces, FEMAP is extruding between matched surfaces, mesh sizing can be edited (carefully)

4.1 Let's Take It To The Next Level

It Works

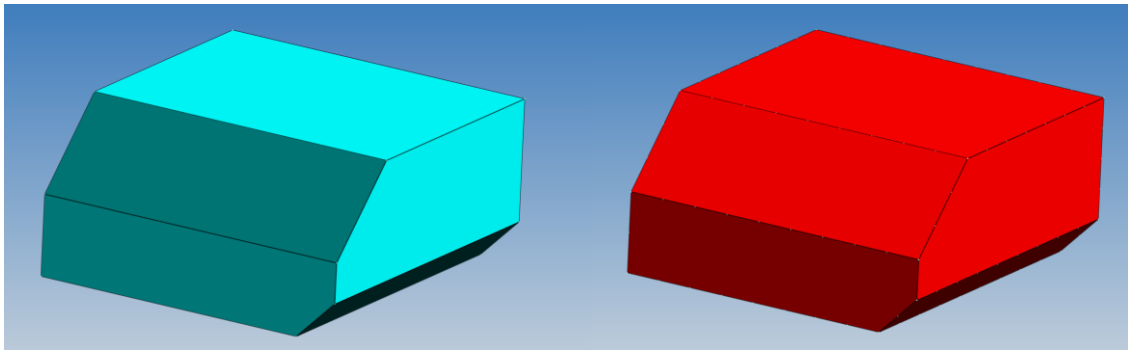




```
7 Surface(s) Selected...

    ID      Type Color Divisions <--- Curves ( R = Reversed Directio
-------------------------------------------------------------------

     5      Face  3127   3 x 4
               Segments:    2  Address: 4713

     8      Face  3127   3 x 4
               Segments:    2  Address: 4693

     9      Face  3127   3 x 4
               Segments:    2  Address: 4696

    10      Face  3127   3 x 4
               Segments:    3  Address: 4699

    11      Face  3127   3 x 4
               Segments:    2  Address: 4702

    12      Face  3127   3 x 4
               Segments:    3  Address: 4705
            Mesh Approach: Matched - Linked to Surface  10

    19      Face  3127   3 x 4
               Segments:    2  Address: 5416
```

Why?

Nope

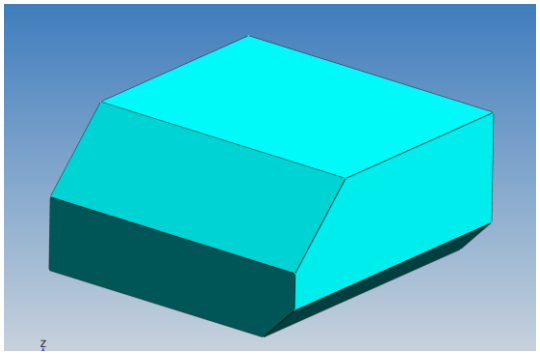
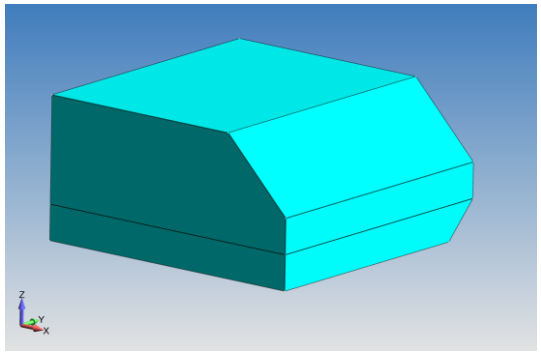
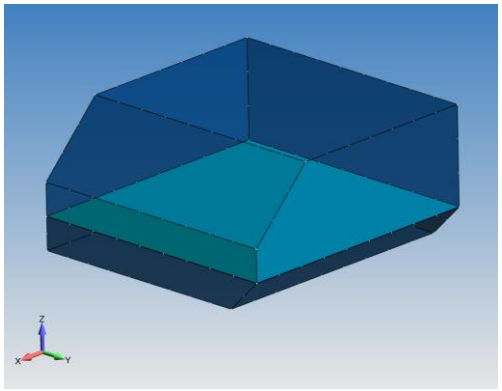
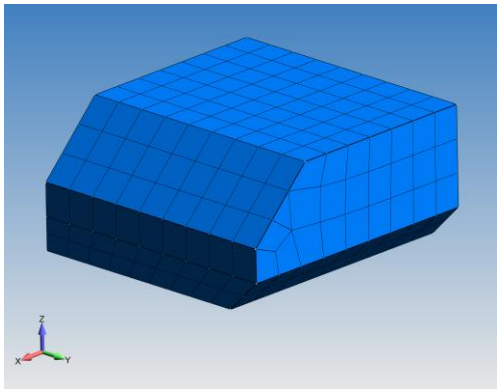


```
8 Surface(s) Selected...

    ID      Type Color Divisions <--- Curves ( R =
-------------------------------------------------------------------

     5      Face      4   3 x 4
               Segments:    3  Address: 4713

     8      Face      4   3 x 4
               Segments:    3  Address: 4693

     9      Face      4   3 x 4
               Segments:    2  Address: 4696

    10      Face      4   3 x 4
               Segments:    3  Address: 4699

    11      Face      4   3 x 4
               Segments:    2  Address: 4702

    12      Face      4   3 x 4
               Segments:    3  Address: 4705

    19      Face      4   3 x 4
               Segments:    2  Address: 5416

    22      Face      4   3 x 4
               Segments:    2  Address: 5776
```

Solid 1 can not be hex meshed. Either subdivide further, or specify a mapped mesh approach on one or more surfaces.
Solid 1 can not be hex meshed. Unable to identify the surfaces for the base and top of the mesh.

4.2 Basic Hexing: Subdividing

The first step is recognizing a sub-dividable solid. When doing a “hex project”, I’ll make a custom toolbar with the commands that I’ll be using frequently.

1	2
	
3	**4**
	

How It Works

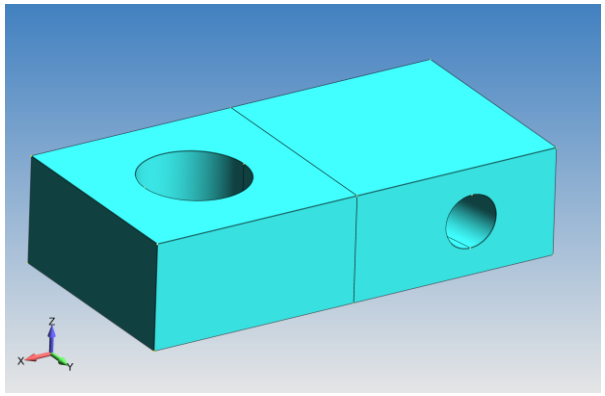
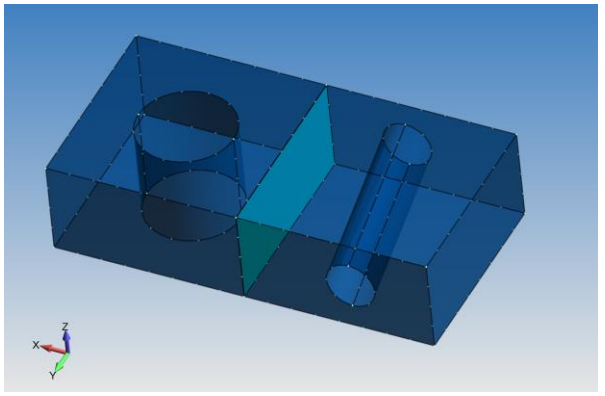
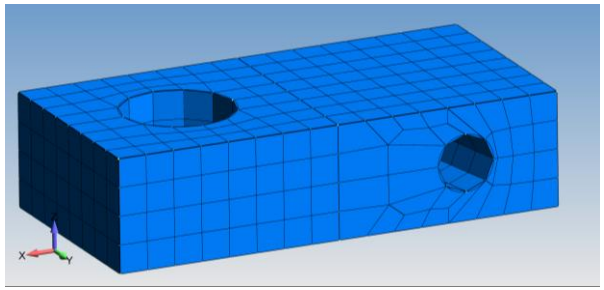
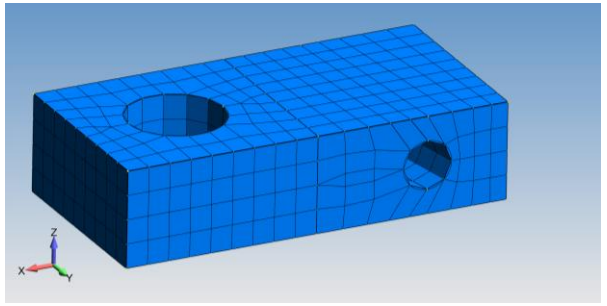
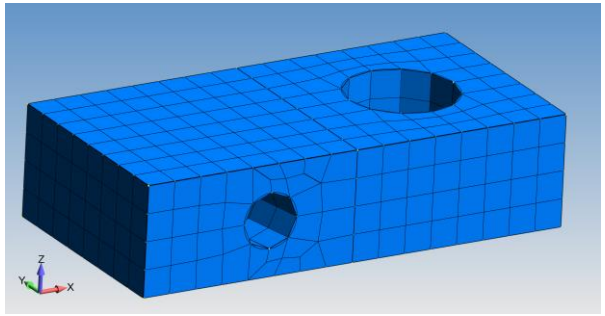
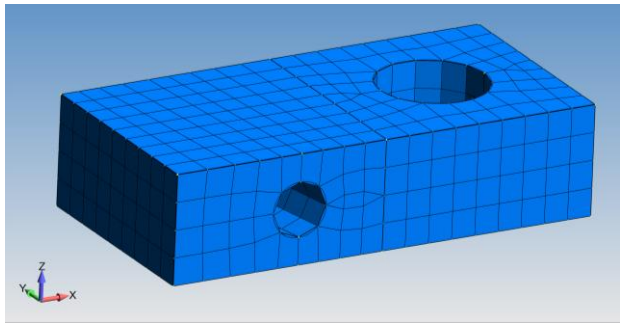
```
List Solids
List Surfaces
7 Surface(s) Selected...

     ID      Type Color Divisions <--- Curves ( R = Reversed Direction ) --->
-------------------------------------------------------------------------------
      5     Face  3127   3 x 4
                Segments:    2  Address: 4713

      8     Face  3127   3 x 4
                Segments:    2  Address: 4693

      9     Face  3127   3 x 4
                Segments:    2  Address: 4696

     10     Face  3127   3 x 4
                Segments:    3  Address: 4699

     12     Face  3127   3 x 4
                Segments:    3  Address: 4705
                Mesh Approach: Matched - Linked to Surface  10

     19     Face  3127   3 x 4
                Segments:    2  Address: 5416

     46     Face   120   3 x 4
                Segments:    2  Address: 1648495
                Mesh Approach: Matched - Linked to Surface  52
```

```
List Surfaces
6 Surface(s) Selected...

     ID      Type Color Divisions <--- Curves ( R = Reversed Direction
-------------------------------------------------------------------------------
     11     Face  3127   3 x 4
                Segments:    2  Address: 4702

     22     Face  3127   3 x 4
                Segments:    2  Address: 5776

     49     Face  3127   3 x 4
                Segments:    2  Address: 1648454

     50     Face  3127   3 x 4
                Segments:    2  Address: 1648446
                Mesh Approach: Matched - Linked to Surface  51

     51     Face  3127   3 x 4
                Segments:    2  Address: 1648432

     52     Face   120   3 x 4
                Segments:    2  Address: 1648381
```

The linking or pairing makes sense after you play with it for awhile….

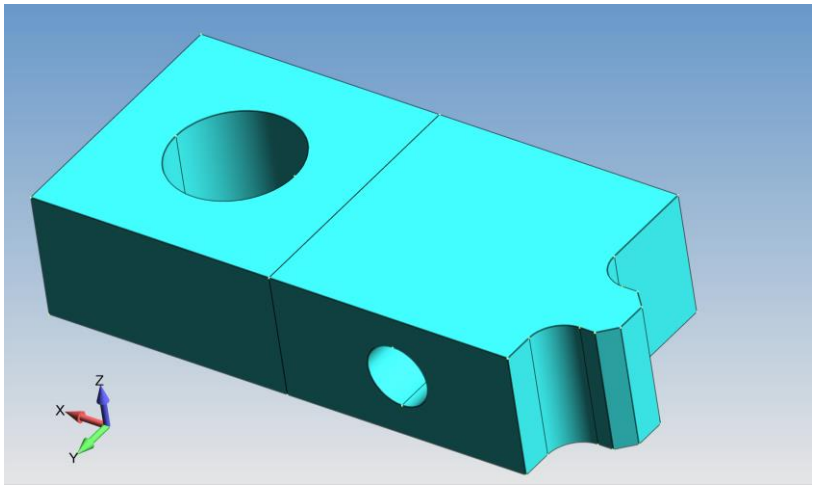
4.3 Leveraging Basic Knowledge

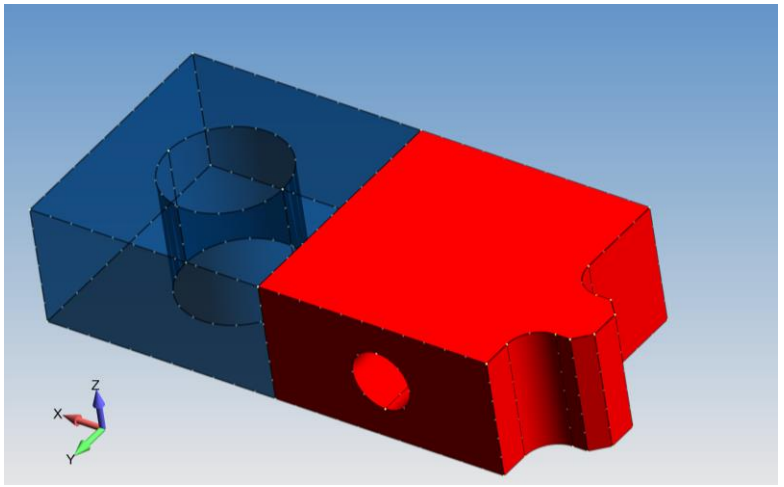
Let's do the first baby step – now it seems too simple

4.3.1 What About Strange Geometry?

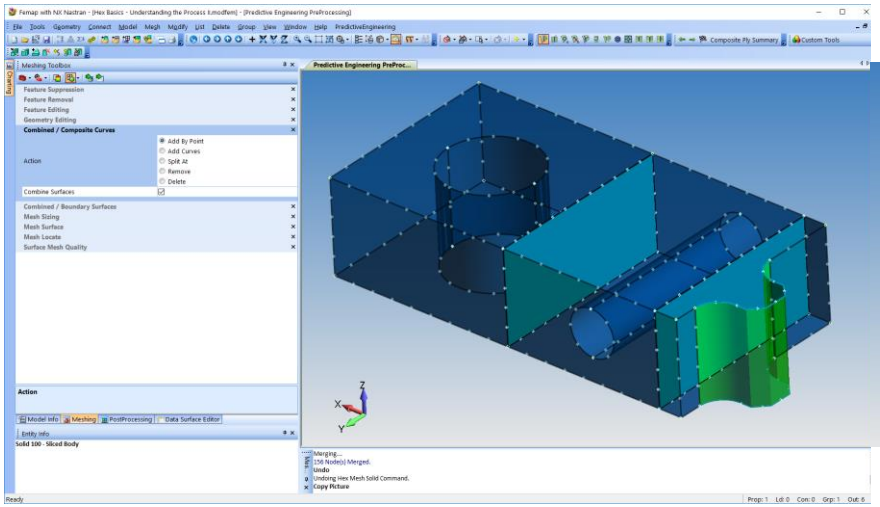
What I want to show is that, if one understands the theory behind the hex process, one can leverage the Meshing Toolbox to encourage challenging geometry to hex along preferred paths. It can be tricky to debug and it took me a few tries but if you truly understand the process, it will work as advertised.

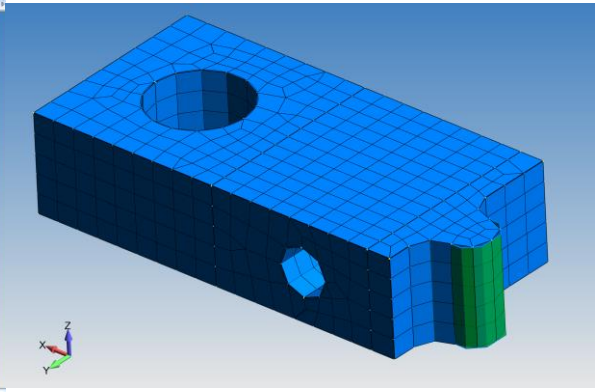




It is two-step process:

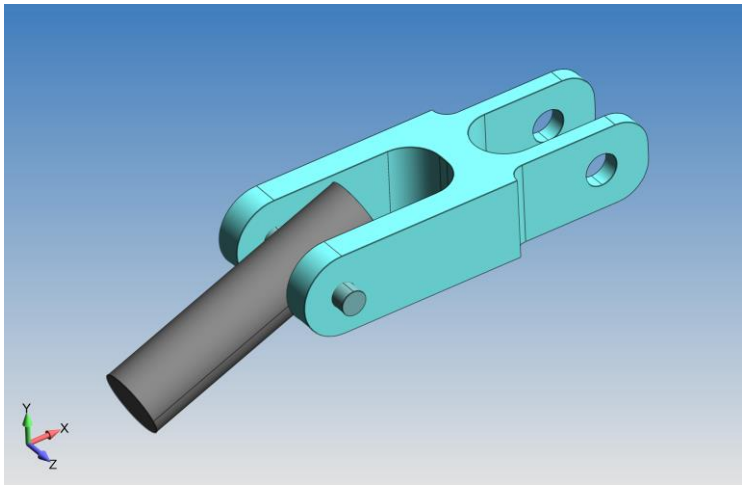
- Look for opportunities (sub-divide)
- It works but a bit "mesh ugly"
- Meshing Toolbox to create clean combined surface

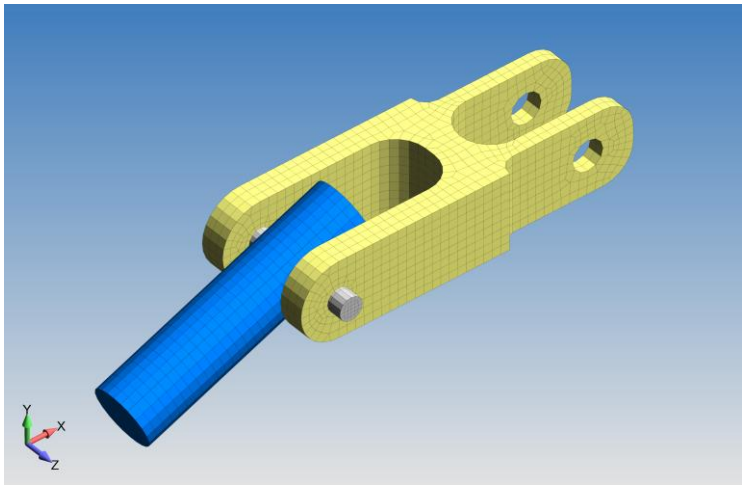


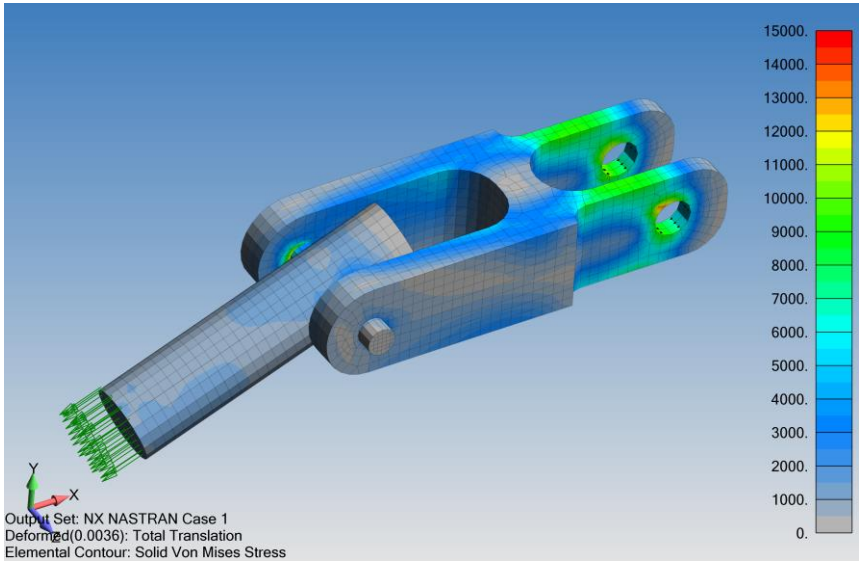


4.4 The Test Piece (Could You Hex Mesh This Chunk After the Seminar?)

One can find this geometry in your FEMAPv1132 / Examples / Assembly.x_t





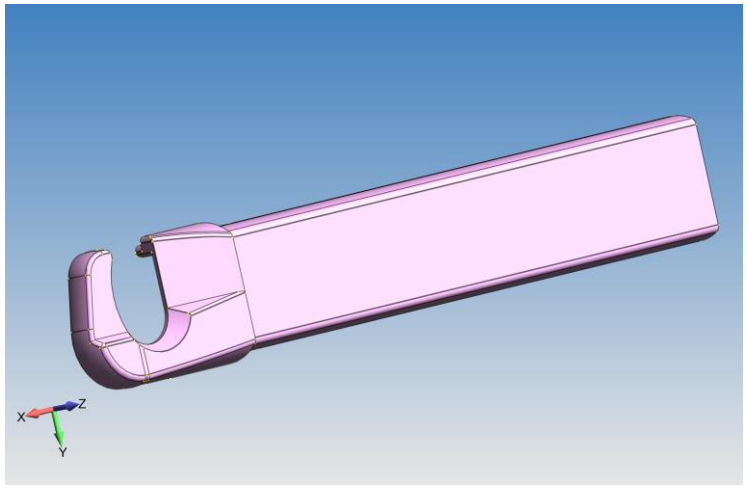


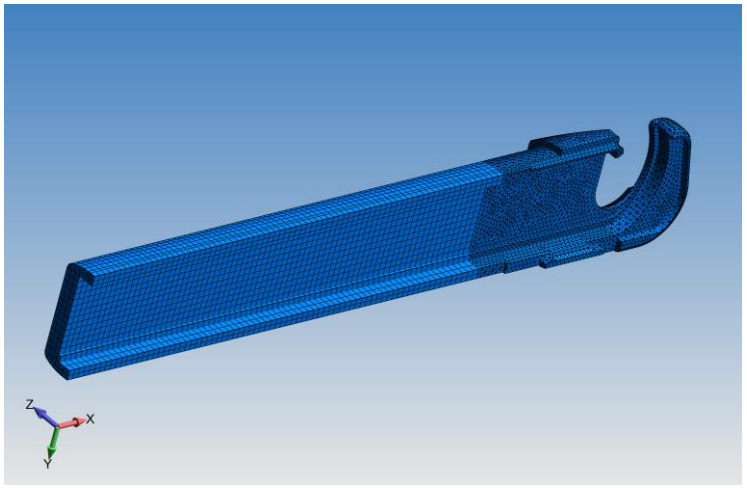
4.5 TROUBLESHOOTING

Symptom	Solution
It won't hex but it has "six sides"?	Most likely you have a small edge(s) or a silver surface. Use Entity Locate in the Meshing Toolbox to find'em
It looks hexable but it won't hex and I have checked for small edges and slivers?	Sometimes the underlying geometry is corrupt. Try Geometry / Solid / Cleanup and then try meshing the opposing sides and Hex Mesh it using Mesh / Geometry / HexMesh from Elements
My subdivided assembly of blocks Hex Meshes and then I change the mesh size and some turn red?	The hex meshing process is dependent upon element quality. If a particular mesh size creates a "un-meshable surface" due to poor element quality, things will turn red.
I have large assembly and individual pieces hex but when I try to hex the complete assembly I get red blocks?	FEMAP tries to match up curves between solids to the best of its parametric ability. In rare occasions the parametric sizing between two solids will be different. In this case, one needs to set the curves manually (Mesh / Mesh Control / Size Along Curve and specify Node Spacing as "Length".
Analysis Errors	
It looks great but generates negative pivot ratios	Most likely something didn't merge. Turn on transparency and look for un-merged surfaces or Free Edges

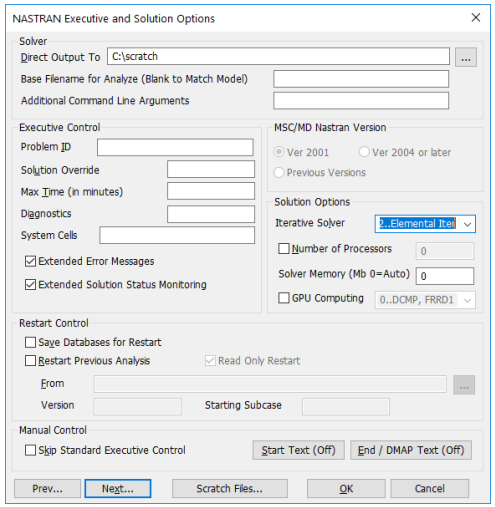
5. HEX WHAT IS HEXABLE AND TET THE REST

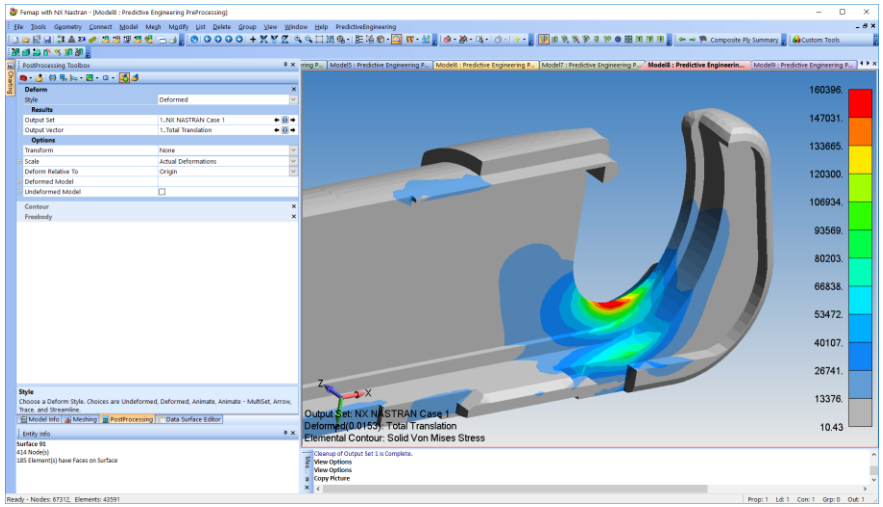
When you have the option, it can be effective to use a glued connection to join an easily hexed part of the model to something that might take days to hex.





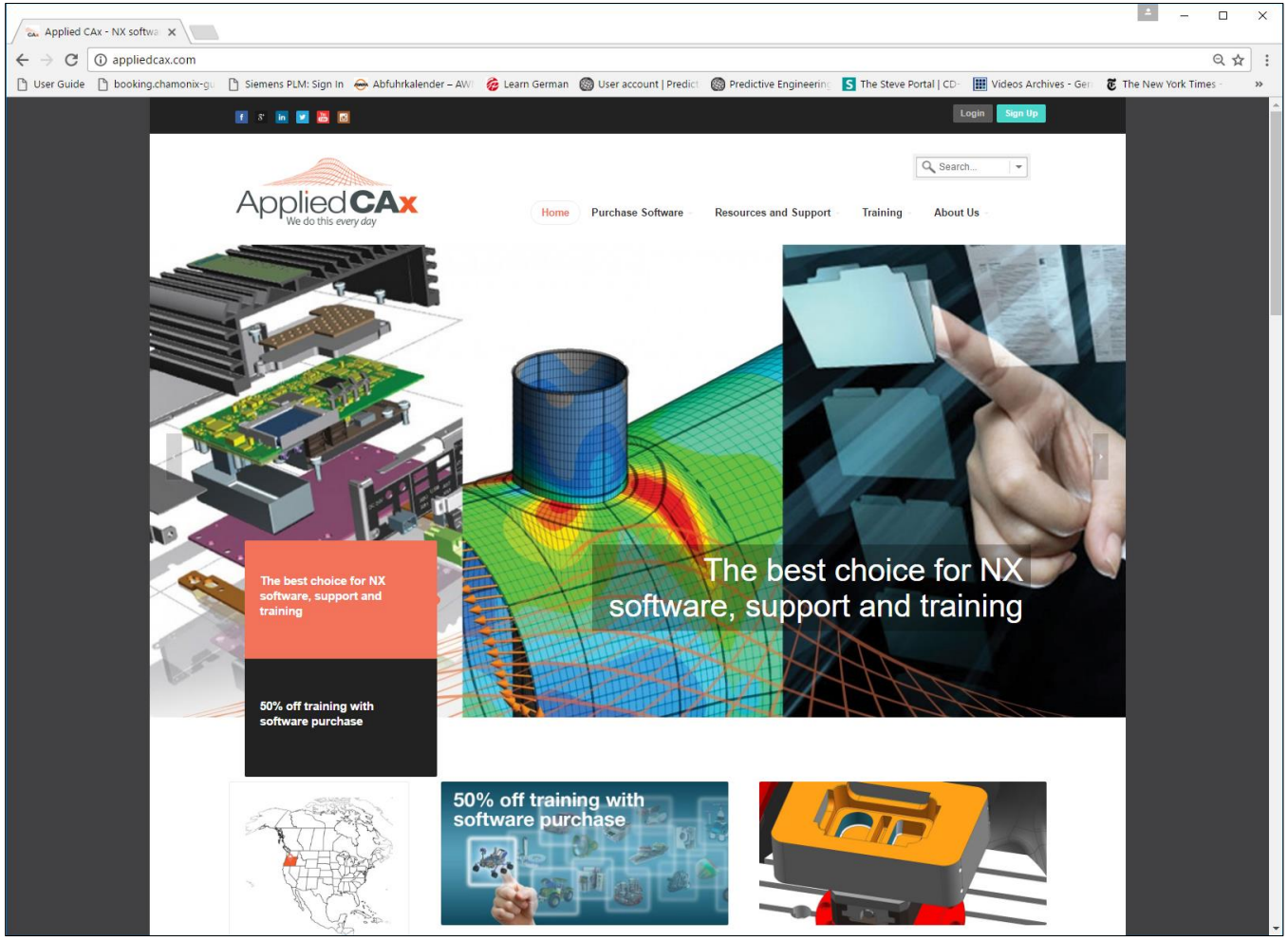
- Automatic Glued Connection (?)
- Iterative Solver – 2
- Fast
- Stress Results show max stress at 160ksi, material yield is 100ksi.





6. SEMINAR Q & A

More seminars at AppliedCAx.com



Thank you!