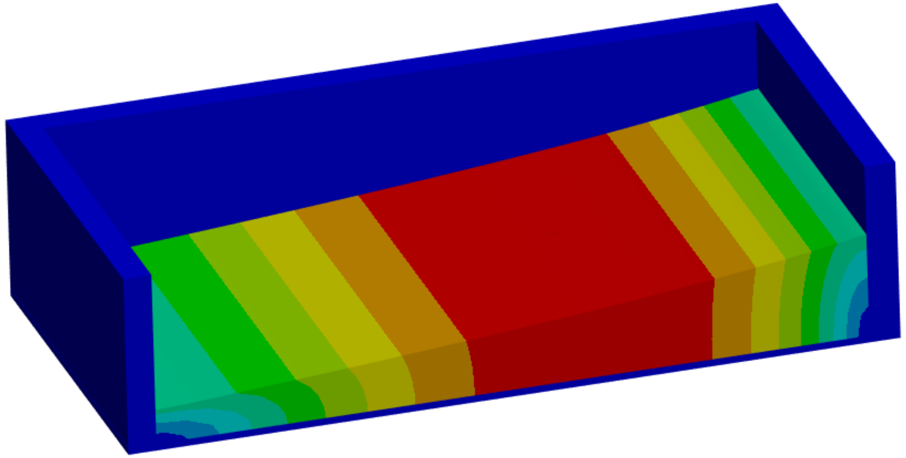
Twin Cities

ANSYS® User Meeting

Liquid Modeling with FLUID80'S

ANSYS Toolset



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About Epsilon

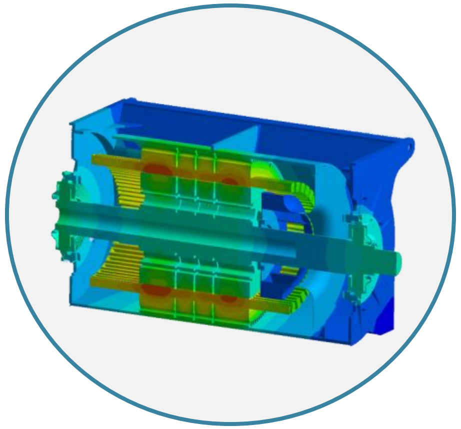
Company Mission

Our Core Values

Epsilon FEA was formed in 2008 in Minneapolis, Minnesota to provide a new class of Engineering Service utilizing the Finite Element method and related CAE tools.

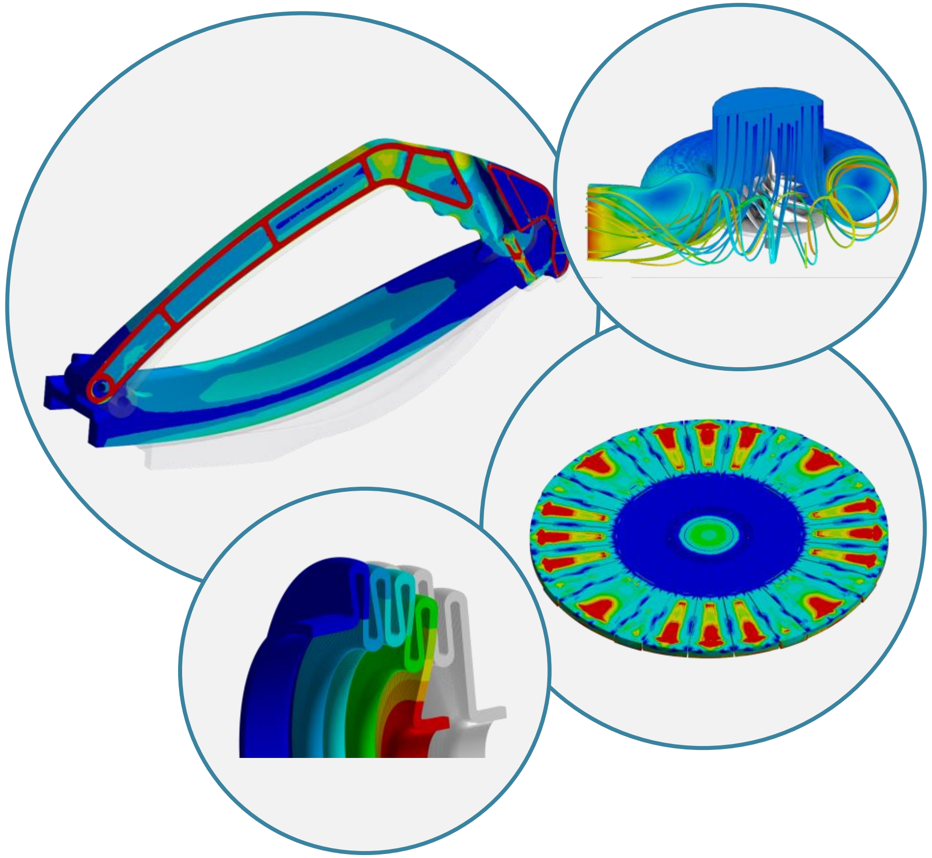
Recognizing this niche CAE tool requires large investment for companies competing in a technically challenging environment, Epsilon focuses on three cumulative characteristics of our services:

- ✓ **Exhibit Excellence with the Simulation Tools**
- ✓ **Infuse Technology into Customer Design System**
- ✓ **Communicate Thoroughly and Clearly**



What We Do

Our Tools



We utilize ANSYS tools both of Workbench as well as classic APDL (ANSYS Parametric Design Language) Fluent, CFX, along with a multitude of supporting engineering and business software.

Using up-to-date licensing and compute solvers we leave your costly internal resources intact, while leveraging our familiarity and expertise with our own in-house toolset that has been customized and augmented for over a decade and a half.

Pairing these long term investments with analysts (consultants) that perform FEA/CFD as their career focus results in a low total project cost thereby making Epsilon FEA a strategic partner for your next engineering challenge.

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Why Epsilon?

Unique Value Proposition to Best Serve Our Customers

Superior Engineering Analysis

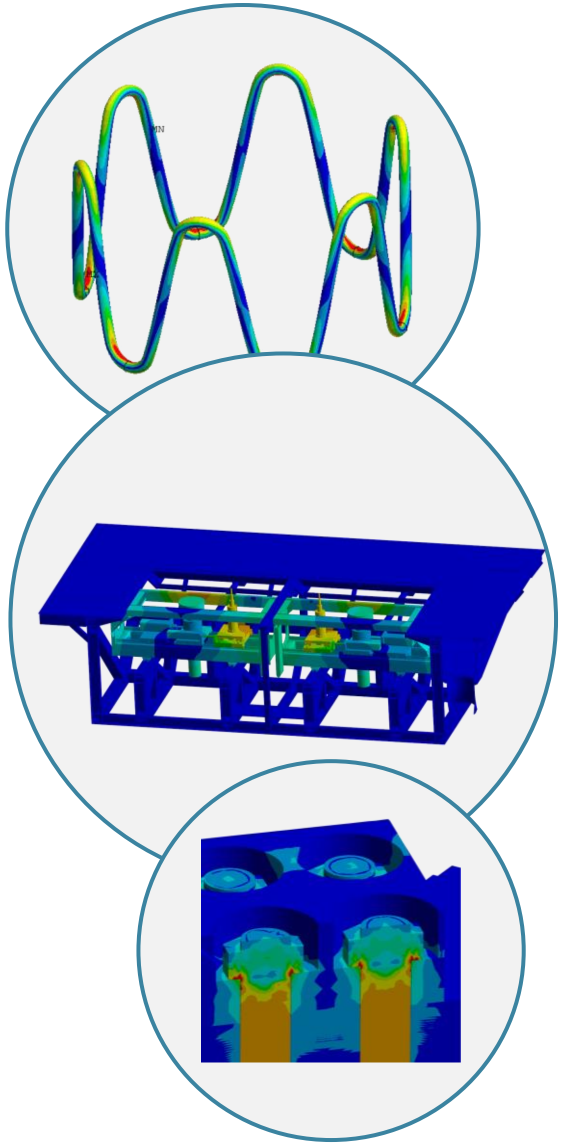
- 3 full-time simulation experts + network of additional experts as needed

Low Overhead

- Support functions outsourced
  - Accounting, IT, Finance, Technical writing, etc.
- Big Business Interface
  - Detailed invoicing/SOWs, updated toolset, insured, quality assurance, etc.

Small Business Service with Single Points of Contact

- Rod’s Cell Phone: 612-819-5288



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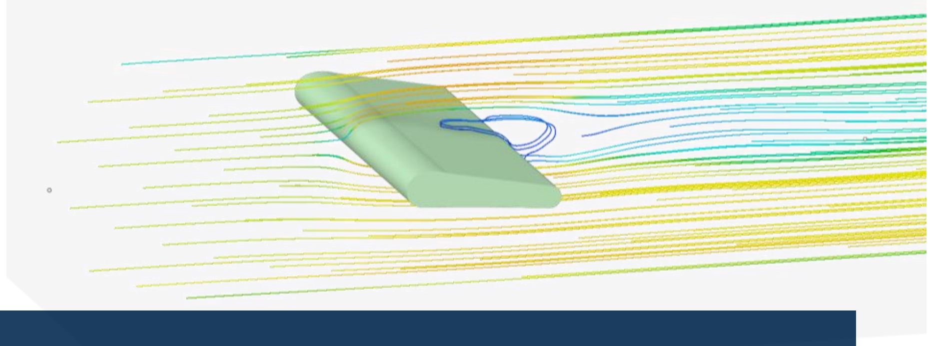
Who Do We Serve?

Our Customers

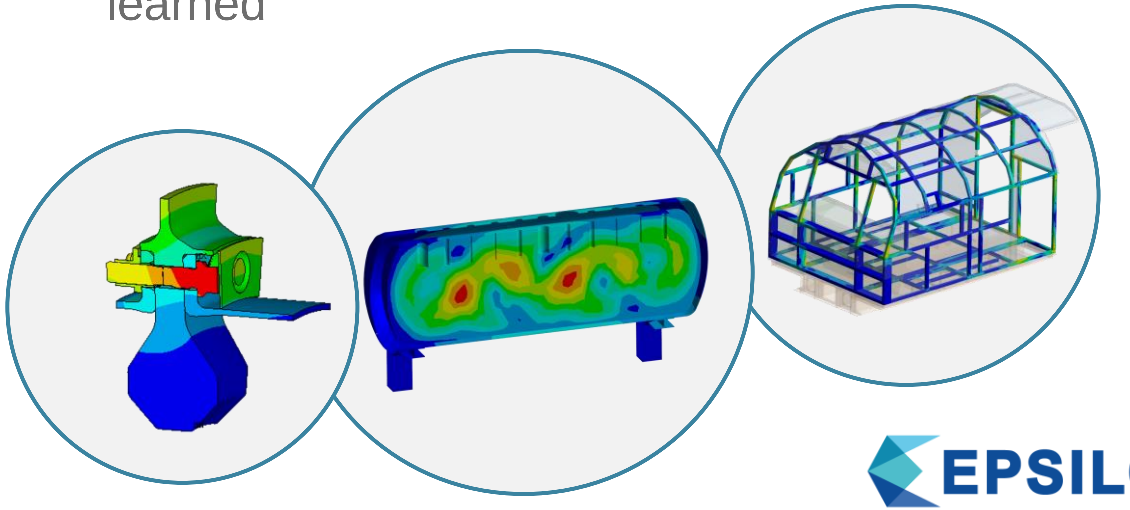


Load-Leveling

- Analyst is a team member, not a black box
  - Interface with same Epsilon analyst to leverage past experience
- Open and frequent communication
- Any new FEA methods/lessons learned are **well communicated**
- Schedule/budget fidelity with frequent status updates
  - Achieved by using the right person, tools, and technical approach

External Expertise

- We infuse up-to-date FEA methods/tools
  - Leverage other industries' FEA innovations
- We are not a software reseller
  - Unbiased tool selection, infrastructure advice
- We share our knowledge, files, and lessons learned



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Epsilon’s Customers

Proudly served dozens of companies across numerous industries

BAE SYSTEMS
cannon EQUIPMENT
MTS
ROSEMOUNT
smiths medical
HORTON
American Superconductor
BARR
Donaldson. FILTRATION SOLUTIONS
Collins Aerospace
Panasonic
FLUIDYNE
LORAM
Park Industries
3M
SEAGATE
ZIMMER BIOMET
AMERIPACK
ergotron
ASE
GE Power
Honeywell
SAATI
E-M WEG Group
Calspan FluiDyne
Maxol Studios
United Technologies
VES-Artex a TURNTIDE company
First Solar
SAFETY POLE
Tolomatic EXCELLENCE IN MOTION
RME
PIPELINE DESIGN & ENGINEERING
PRIDE SOLUTIONS
CREATIVE MACHINES
ORTHOSCAN
PHOENIX Solutions Co
QUALITY TOOL
HYDRA-FLEX FLUID INNOVATION
DANOTEK motion technologies
PADT
tes
CRAFT Tech
EASI
ScooterBug
NARVO ENGINEERING
Advatech Pacific
MODERN MOLDING, INC.

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Epsilon’s Unique Capabilities

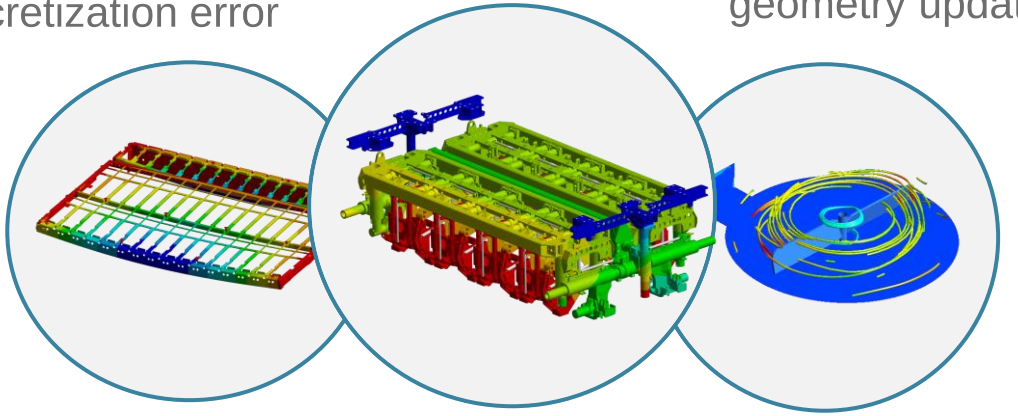
Expertise and Technology to Ensure Accuracy and Affordability

Accurate Simulation

- In-depth knowledge of tools
  - ANSYS® Suite of Multi-Physics software
- Experience with industry successes/failures
  - Aerospace, Rotating Machinery, Electronics, Manufacturing, Packaging, etc.
- Validation with calibration runs and hand-calcs
  - Experience assessing discretization error

Affordable Simulation

- Low hourly rates and/or fixed-price estimates
- Specialized, experienced engineers
- Detailed statements of work, scope, and budget tracking
- Automation (APDL, CAD-associativity)
  - Accommodates shifting inputs, materials, minor geometry updates, etc.



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Agenda

1. FLUID80 Element Overview
   A. Description / Assumptions
   B. Inputs / Outputs
   C. Comparison to Other Fluid Elements
   D. Use Case Restrictions
2. Implementing FLUID80 Elements in Mechanical
   A. Command Snippets
   B. Mesh Requirements & Pitfalls
3. Comparison to Hand Calculations
4. Case Studies
5. Q&A

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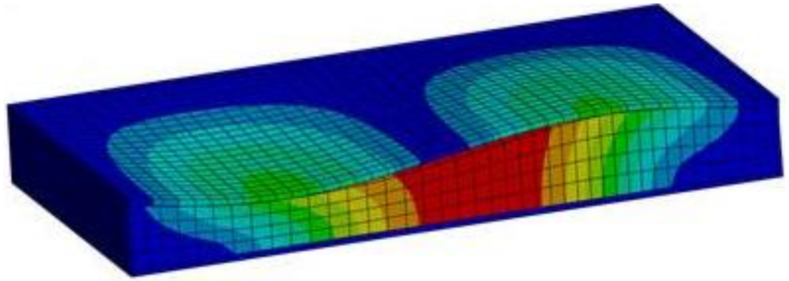
FLUID80 Element Description

Legacy Element

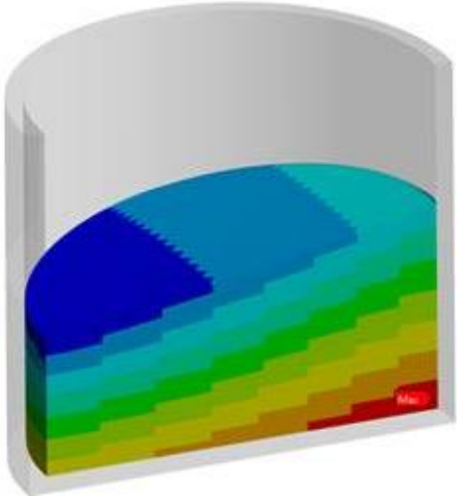
- ANSYS recommends using current-technology elements that all come with their own pros/cons

Model fluids contained within vessels having no net flow rate

Useful for Calculating:



- Hydrostatic pressures
- Fluid/Solid interactions (FSI)
- Sloshing problems: can have a free surface and pressure gradient



FLUID80 Element Definition

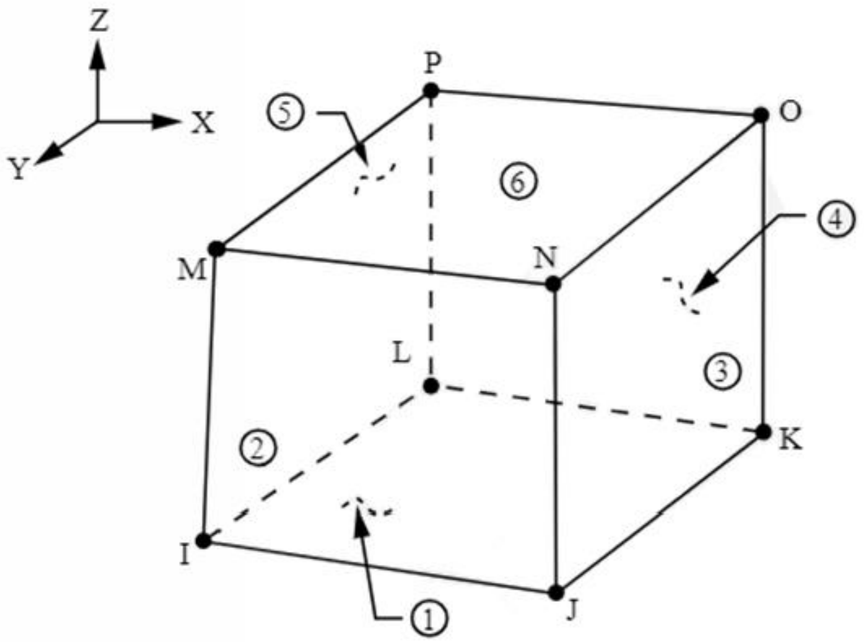
8 node, first-order element

3 degrees of freedom at each node

- Translation in nodal X, Y, Z

Utilizes lumped mass matrix where rotational DOF's are excluded

- Cannot use consistent mass matrix



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FLUID80 Element Definition

Free surface is controlled by using springs connected to ground attached to element faces

- Imagine tube filled with fluid with one side pushed down; displaced fluid mass is

$$M_D = \Delta h\, A\, \rho$$

- Force required to hold the fluid is

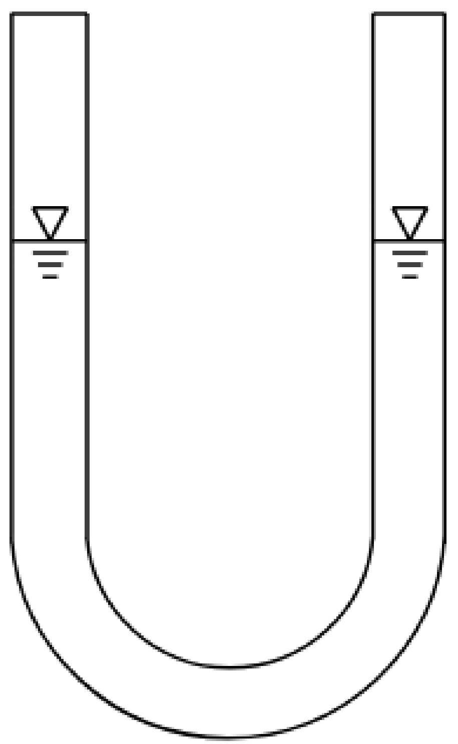
$$F_D = M_D\, g$$

- Stiffness at the surface is force divided by distance

$$K_s = \frac{F_D}{\Delta h} = \rho A g$$

- Generalized expression

$$K_s = \rho A_F (g_x C_x + g_y C_y + g_z C_z)$$



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FLUID80 Possible Inputs

Isotropic material properties available

- EX: Bulk modulus of the fluid
- VISC: Fluid viscosity – used to compute damping matrix for dynamic analysis
- DENS: Fluid density
- SONC: Fluid sonic velocity
- ALPX: Secant coefficients of thermal expansion
- ALPD: Mass matrix multiplier for damping
- BETD: Stiffness matrix multiplier for damping
- DMPR: Constant structural damping coefficient in harmonic analysis

Pressures as surface loads

Temperatures as element body loads

- Average of the 8 nodal temperatures is used throughout the element

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FLUID80 Outputs

Standard outputs

- Element number, nodes, material number, volume, element location of reported results

Temperature & pressure values

- Temperatures available as nodal values or as average evaluated at the element centroid
- Pressure values coincide with element facets ([J, I, L, K], [I, J, N, M], etc.) or as average evaluated at the element centroid

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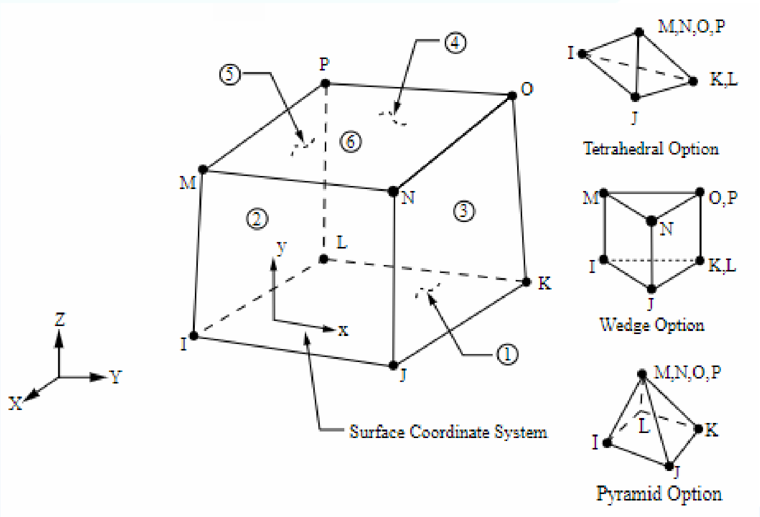
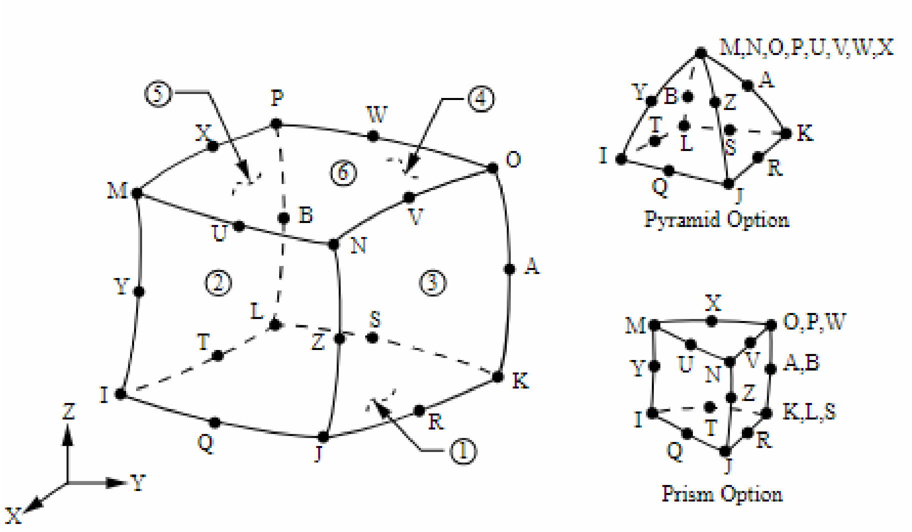
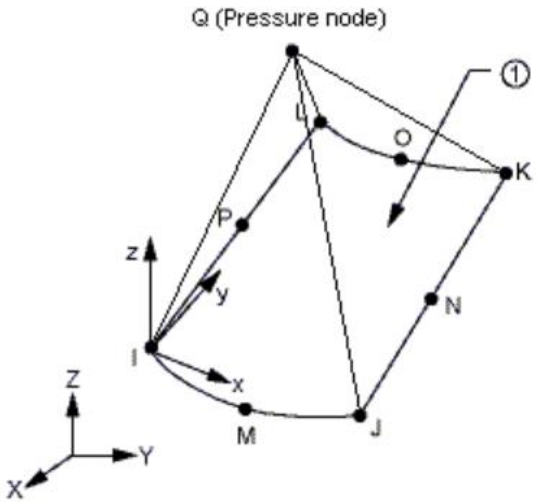
Comparison to Other Element Types

FLUID30, FLUID220, 221: Acoustic fluid elements

- Used for modeling acoustic phenomena in the fluid medium and at the interface in FSI problems
- Cannot be used for structural applications
- These are the current-technology elements that ANSYS recommends using in place of FLUID80







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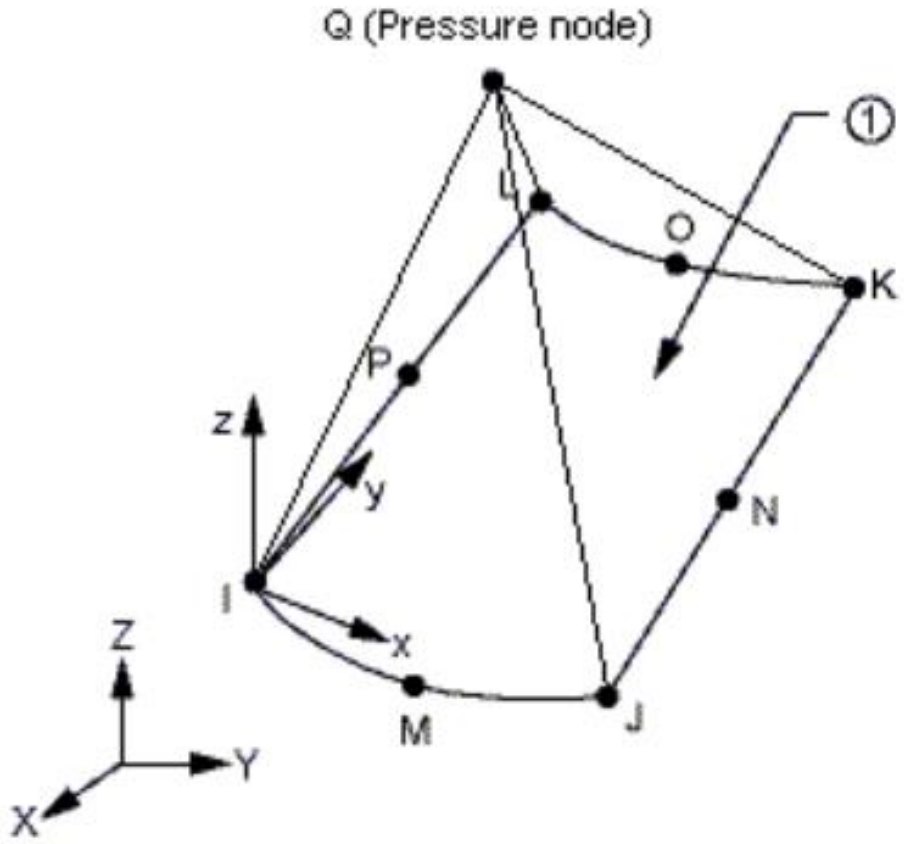
Comparison to Other Element Types

HSFLD242: Hydrostatic Fluid Element

- Also good for specific types of FSI
- Only useable for fully enclosed vessels
- Pressure is assumed to be uniform
- No pressure gradients or free surfaces
- No sloshing effects



FLUID80 Use Case Restrictions & Assumptions

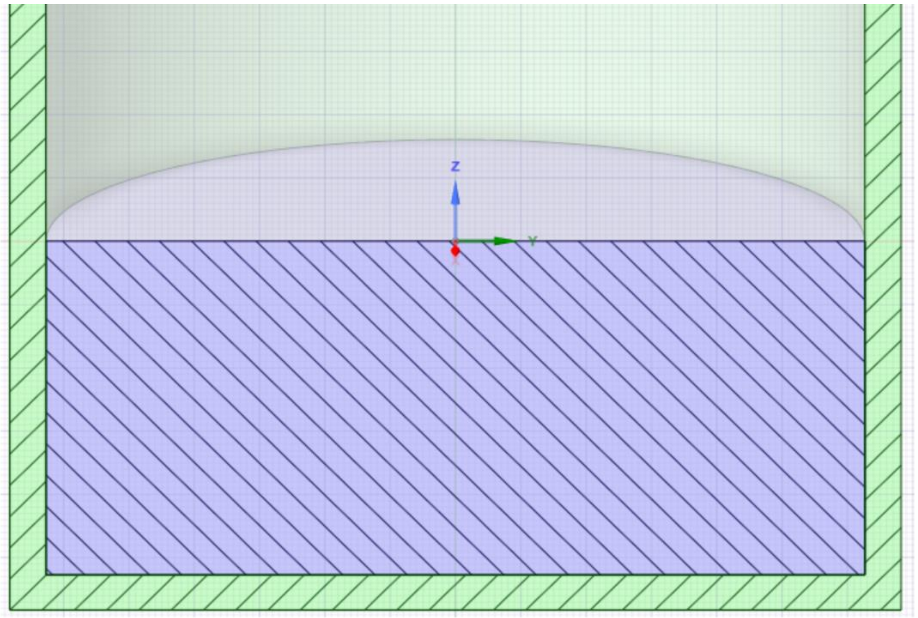
Cannot be used for modal analysis

If KEYOPT(2) = 1, free surface must coincide with Z = 0.0 plane

- FLUID80 elements must not have positive Z coordinates

For static application

- Free surface must be flat
- Gravity must be included if there is a free surface



Large Deflection should not be used for analysis

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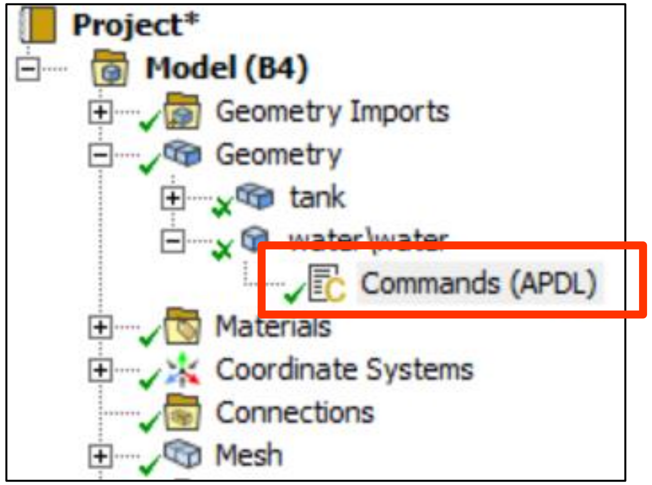
Using FLUID80 Elements in Mechanical:

APDL Scripting

Cannot be defined using built-in material parameters for liquid water contained within ANSYS library; defaults to SOLID185 element for structural analysis

Element defined using a command snippet under individual bodies in Geometry section of the Project Outline

- Parameters used for static structural:
  - Fluid Bulk Modulus
  - Fluid Density
  - Fluid Sonic Velocity




```
ET,MATID,80

MP,EX,MATID,2.2E9     !Fluid Bulk modulus
MP,DENS,MATID,1000    !Fluid Density [kg/m^3]
MP,SONC,MATID,1483    !Fluid Sonic Velocity [m/s]
```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Using FLUID80 Elements in Mechanical:

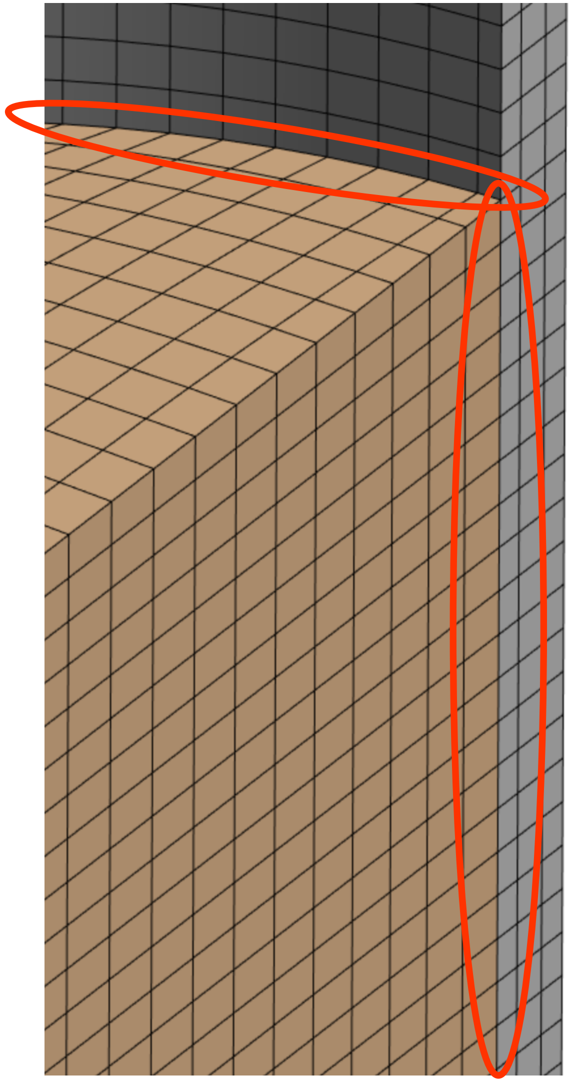
Meshing

Mesh should be hexahedral bricks whenever possible for “best practice”

Fluid elements at boundaries should have separate, coincident nodes

Adjacent bodies should also be meshed using lower order, linear elements

Nodes that are coupled should be in a direction normal to the interface



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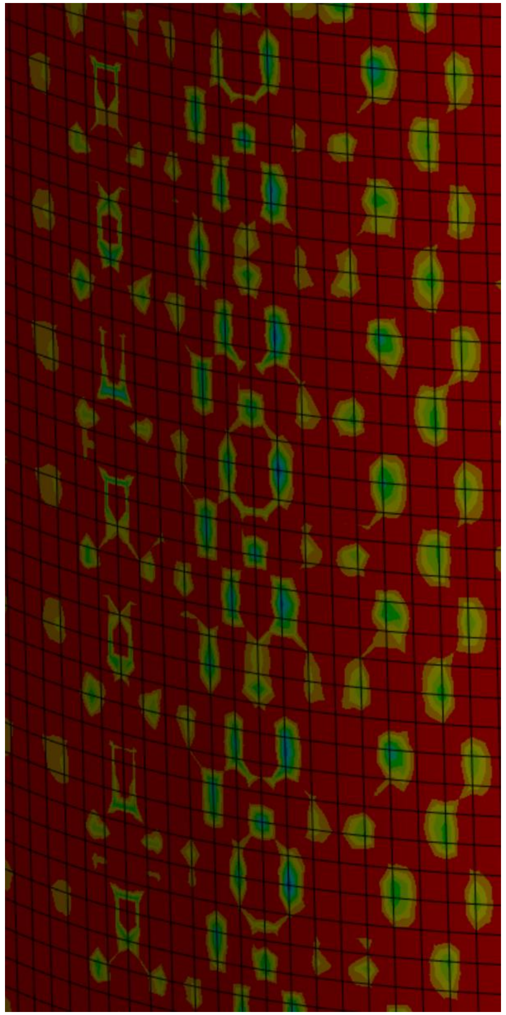
Using FLUID80 Elements in Mechanical:

Meshing

Non-coincident nodal interfaces can lead to inaccurate results

- Good practice is to use sweepable bodies to control node locations
- Centrifuge example with minorly different element sizes results in stress results as shown



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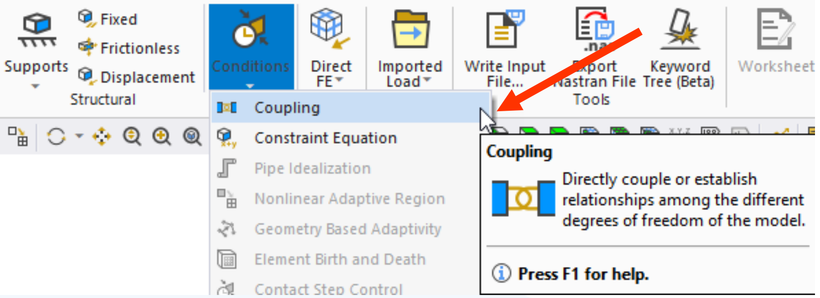
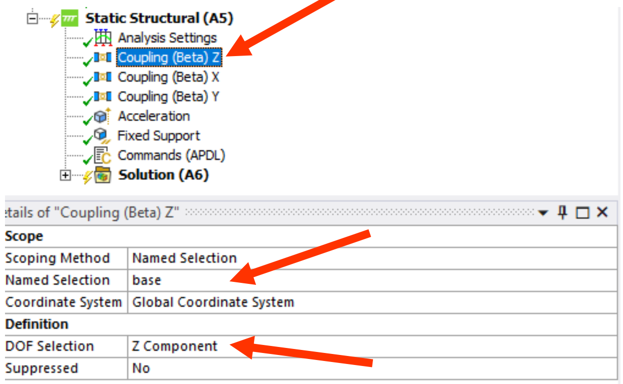
Using FLUID80 Elements in Mechanical:

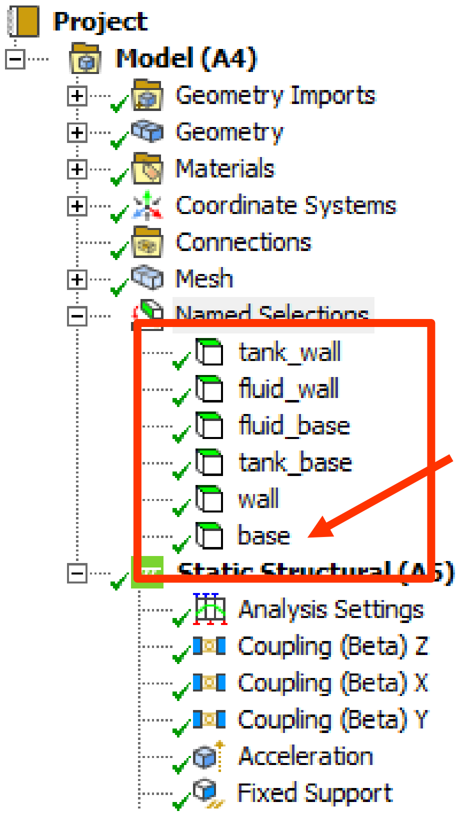
Setup

Setup Using Coupling

- ANSYS beta options must be turned on from Workbench project page
- Generate named selections for each group of interfacing surfaces in X, Y, Z
- Look at environment ribbon under conditions dropdown and choose coupling (if beta options are on)
- Scope the coupling item to defined interfaces and select the appropriate DOF







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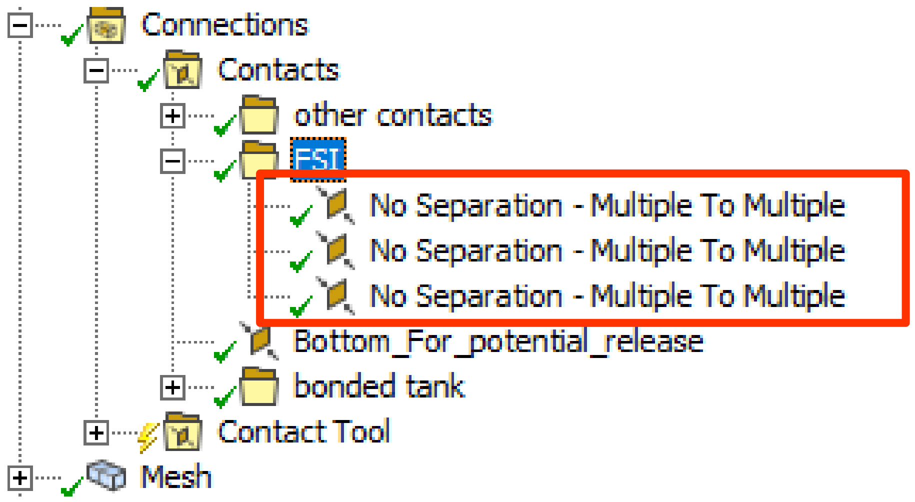
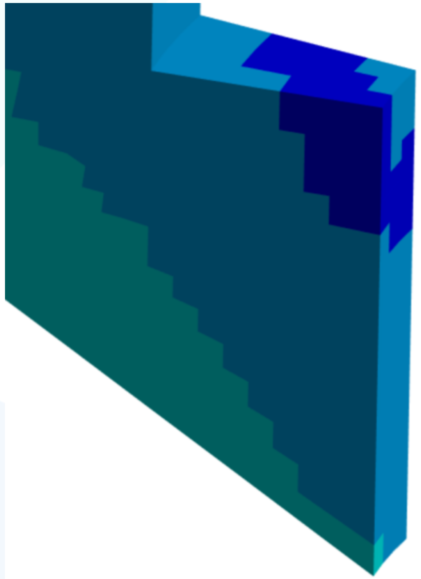
Using FLUID80 Elements in Mechanical:

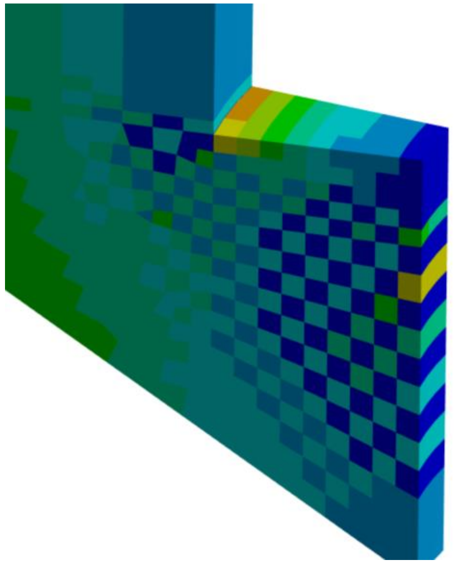
Setup

Setup using contacts

- Use no separation contacts at FSI locations
- Only regions that remain in compression should be have contacts defined
- Contacts in tension lead to erroneous results







Pressure results for inner surface region of spinning centrifuge with no contact defined vs no separation contact in tension

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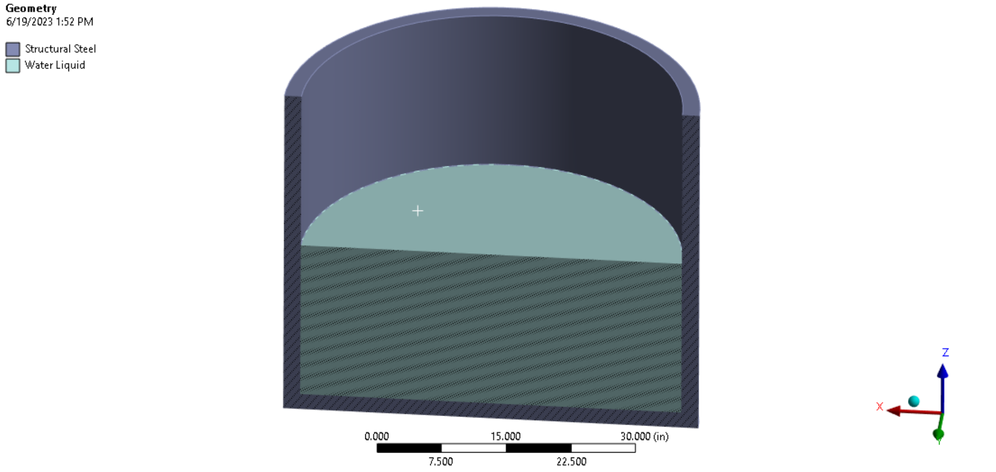
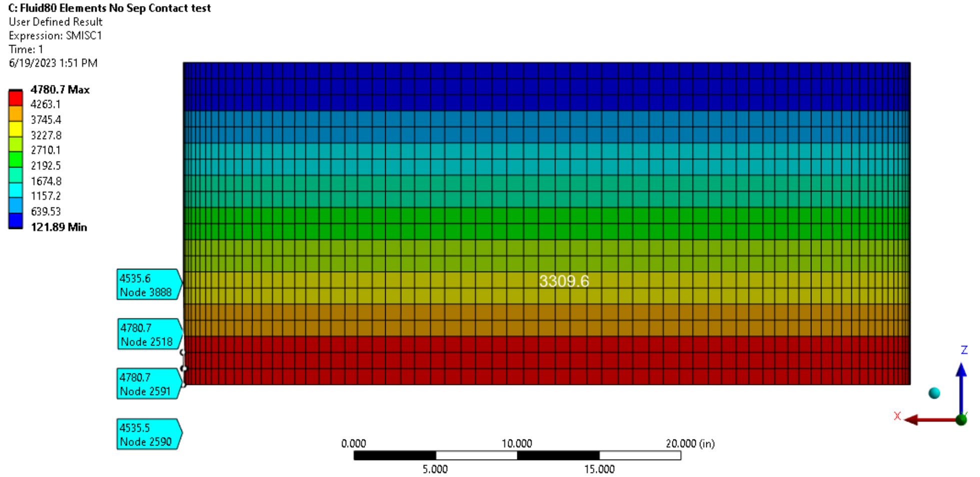
Comparing FLUID80 Results to Hand Calculations

Cylindrical tank with a free surface setup with a known quantity of water subjected to 1g vertical acceleration to verify simulation results to hand calcs.

Hydrostatic hand calcs extrapolates linearly the last half of element, 0.04% difference

Mass	kg	499.1
Force	N	4894.47406
Area	m2	0.99886
Pressure	Pa	4900.060129
ANSYS pressure	Pa	4902
% difference		0.04%





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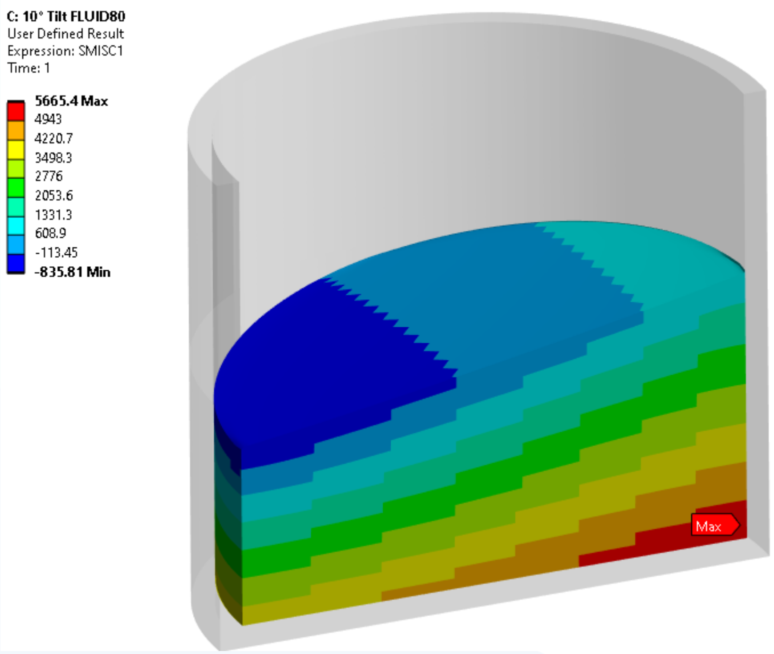
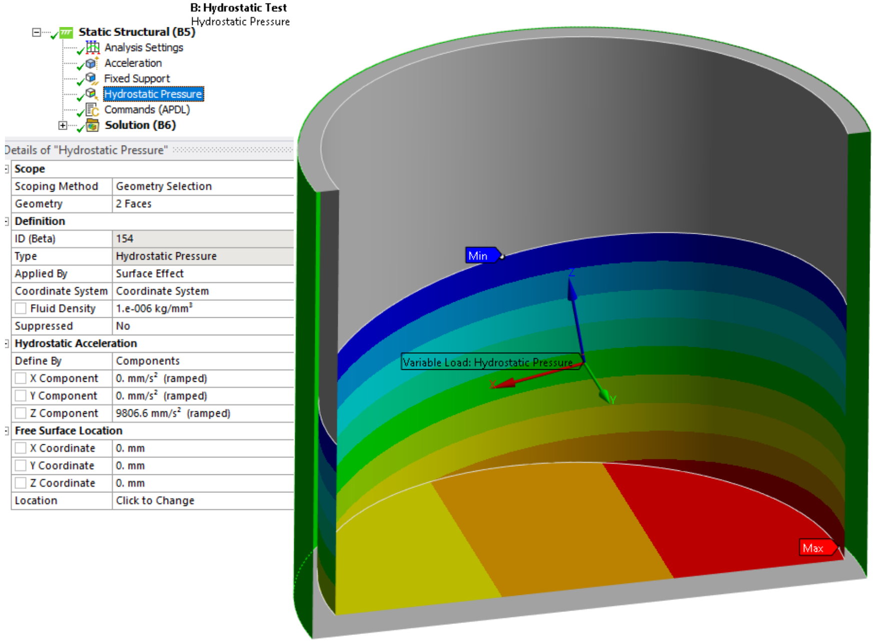
Comparing FLUID80 Results to Hand Calculations

Similar open tank model setup with gravity applied at 10° angle

- No-Separation contact at fluid/structure boundary allows free surface movement
- Coupling condition allows for same result
- Matches hand calcs for pressure as well as ANSYS model defined using Hydrostatic Pressure load

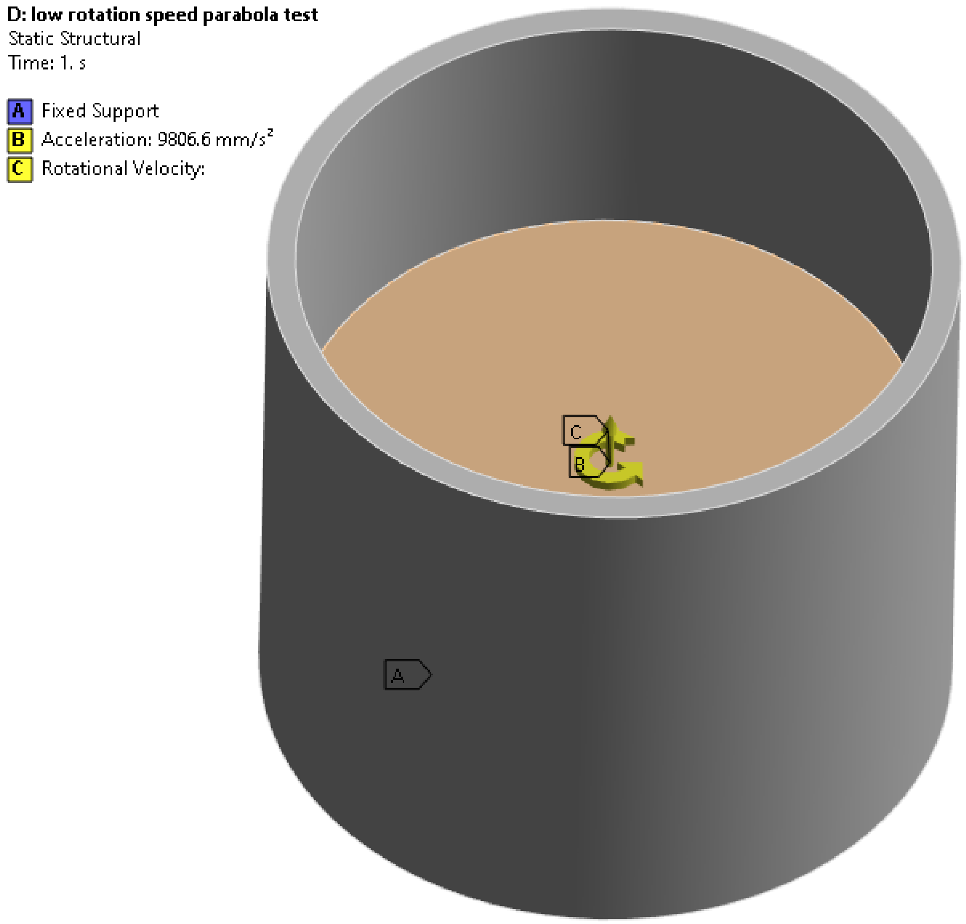




Comparing FLUID80 Results to Hand Calculations

Parabola check

- Multiple test cases setup where different rotational velocities are applied to fluid volume
- Use known equation to determine fluid height distance X away from rotational axis.
  - Balance equations for pressure acting on a fluid element caused by being distance, X, from rotational axis with decrease in pressure caused by height of element



$$P = \frac{\rho\omega^2 x^2}{2}$$

$$P = y\rho g$$

$$y = \frac{\omega^2 x^2}{2g}$$

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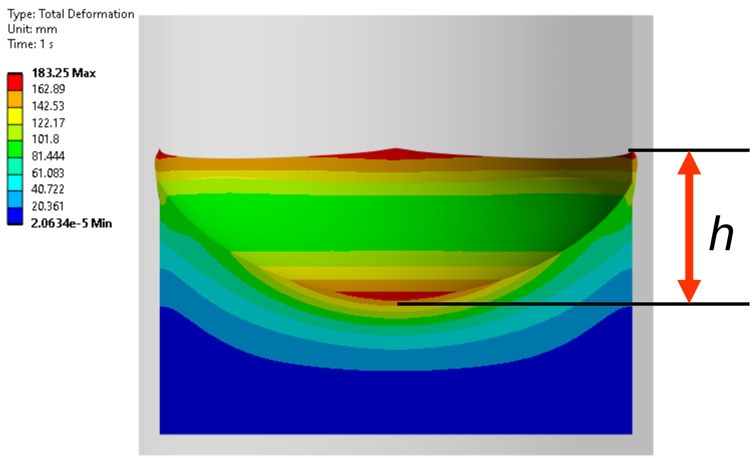
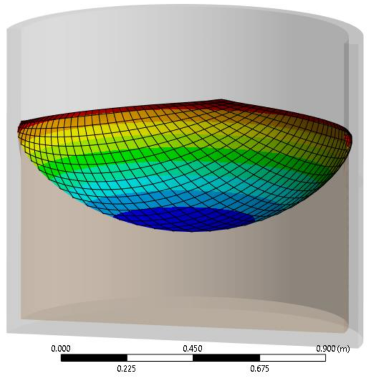
Comparing FLUID80 Results to Hand Calculations

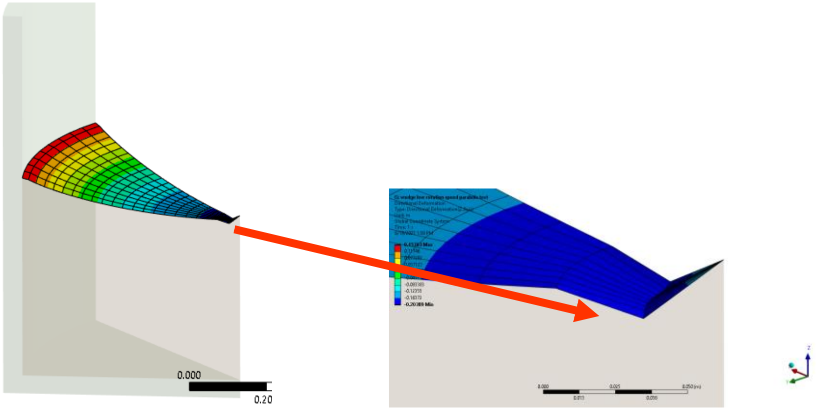
Parabola check

- Target height picked and angular velocity determined that would cause parabola height to be matched at outer radius of tank
- Hand calcs compared to ANSYS results using no separation contact
- Predictions within 2%



eqn	y=omega^2*x^2/2g)	test 1	test 2	test 3
target height	m	0.25	0.3	0.35
x	m	0.56419	0.56419	0.56419
g	m/s2	9.8066	9.8066	9.8066
w	rad/s	3.924815	4.299419	4.643903
Ansys H1	z1	0.13089	0.15707	0.18325
Ansys H2	z2	-0.12378	-0.14854	-0.17329
Ansys delta z		0.25467	0.30561	0.35654
% dif		1.9%	1.9%	1.9%





- Inaccuracy at center node
- Perimeter values match full 360° model

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FLUID80 Case Study

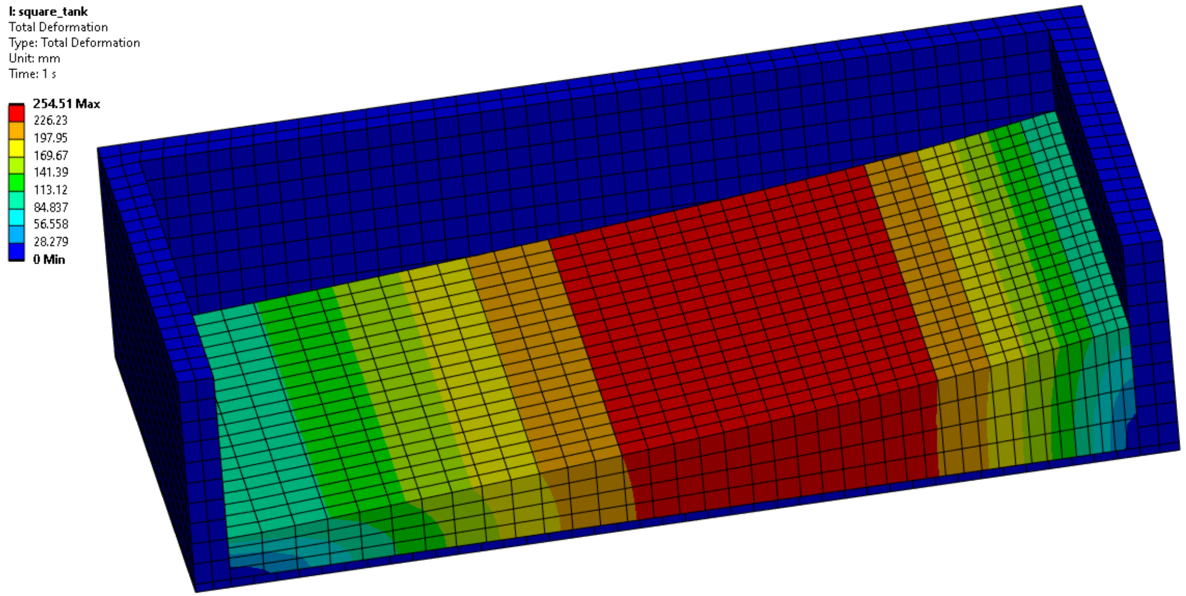
Acceleration & Bulkhead

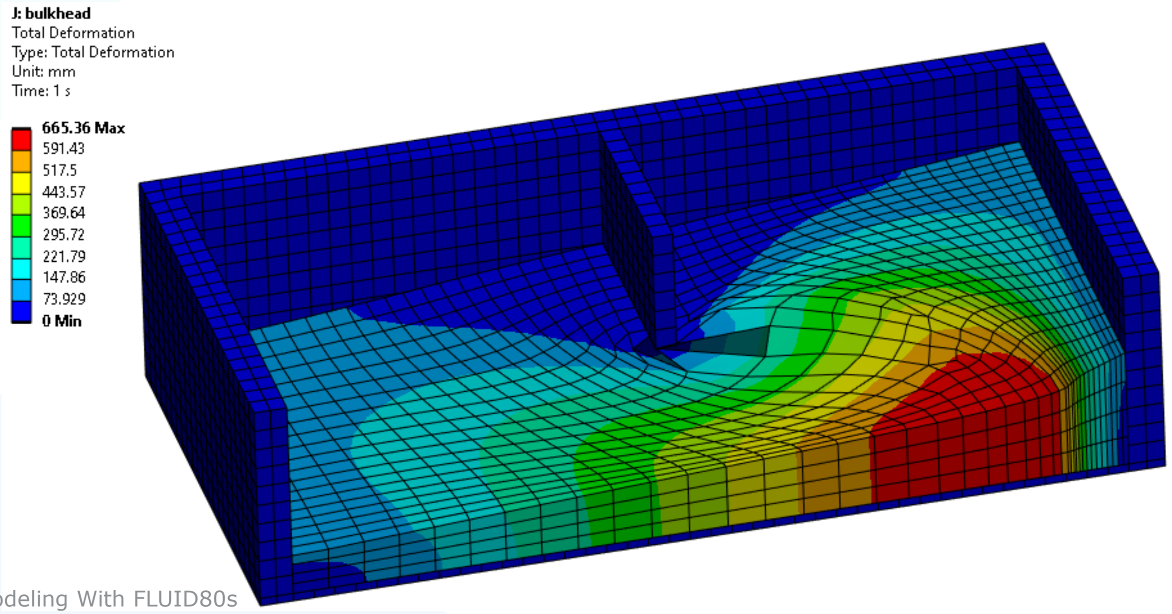
Square tank with symmetry

- Normal behavior

Square tank with bulkhead

- Contact allowed to go in tension on left wall; causes error





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FLUID80 Case Study

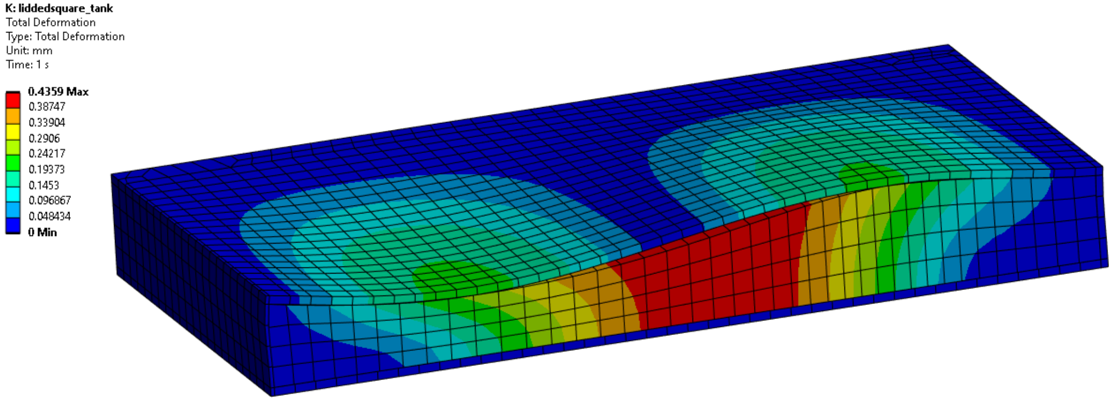
Tank with Lid

Sealed square tank with lid

- Performs as expected
- Matches hand calcs with minor deviation because walls are flexible

Cohesive Zone Material (CZM) based contact failure

- Input parameters for max contact normal stress, contact gap after debonding, max tangential contact stress, etc.

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tb,czm,cid,,,expo,,
tbdata,,10,.001,.001
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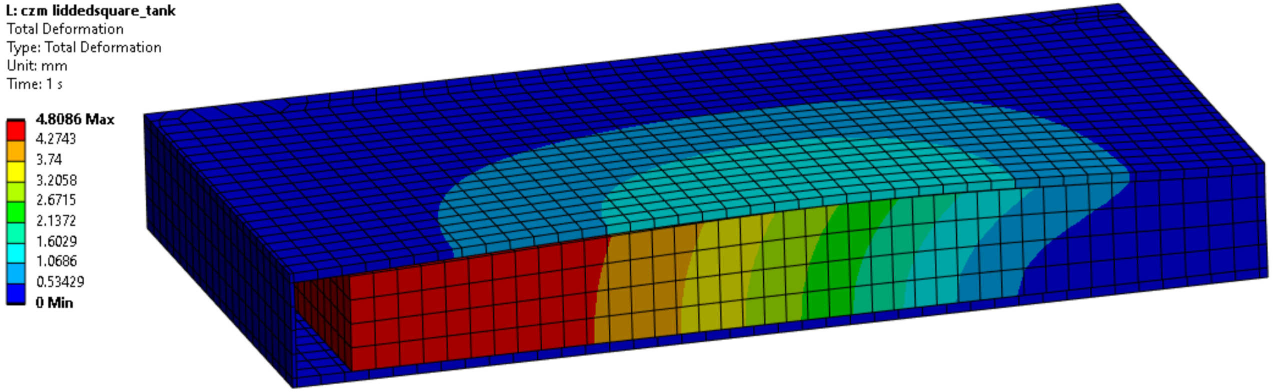

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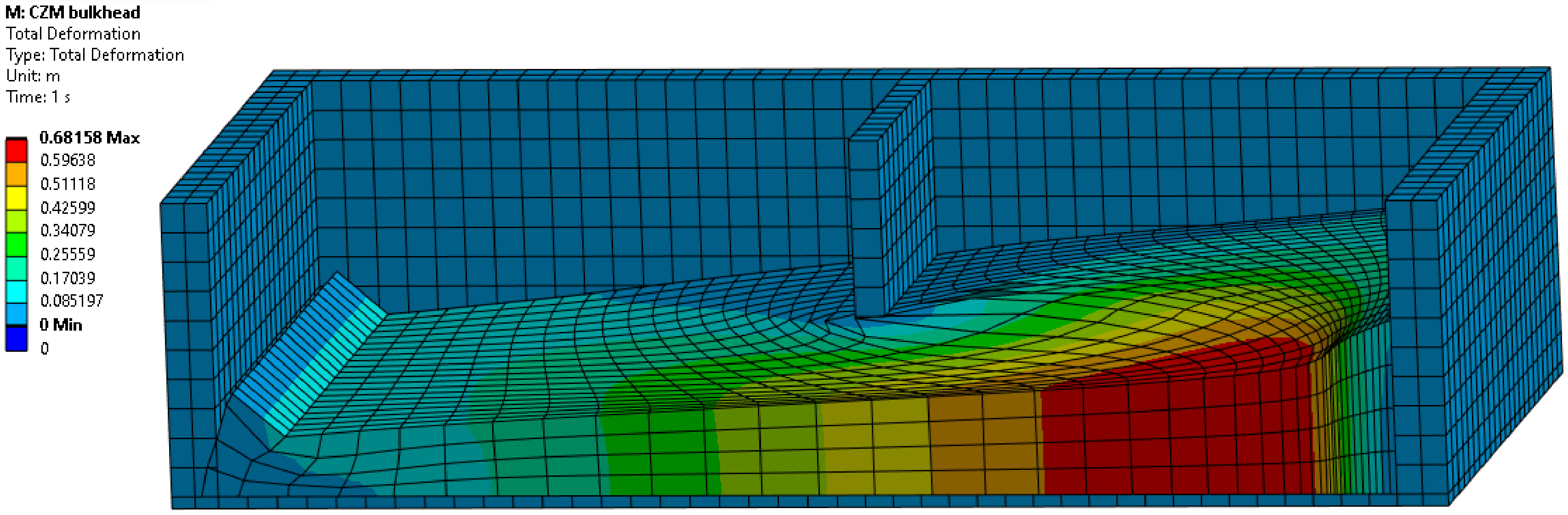
FLUID80 Case Study

Bulkhead Including Separation Using Contact Failure

Potential to automate fluid release at negative pressure locations

Demo shows sensitivity to CZM parameters

- Pass though can occur during compression
- Error introduced if CZM parameters not well-tuned
- Will more fully implement on our next commercial project



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FLUID80 Summary

Legacy element that allows for simulating fluid inertia and FSI without the need for CFD

- Best suited for non-standard shape tank models where hand calcs are not useable
- Some current technology elements can do parts of what FLUID80 can do, but better, and other parts not at all

Somewhat limited use cases due to restrictions on free surfaces and need for zero net flow rate

Drawbacks include constructing a mesh with coincident nodes at all FSI boundaries as well as realistic modeling of contact separation (CMZ)

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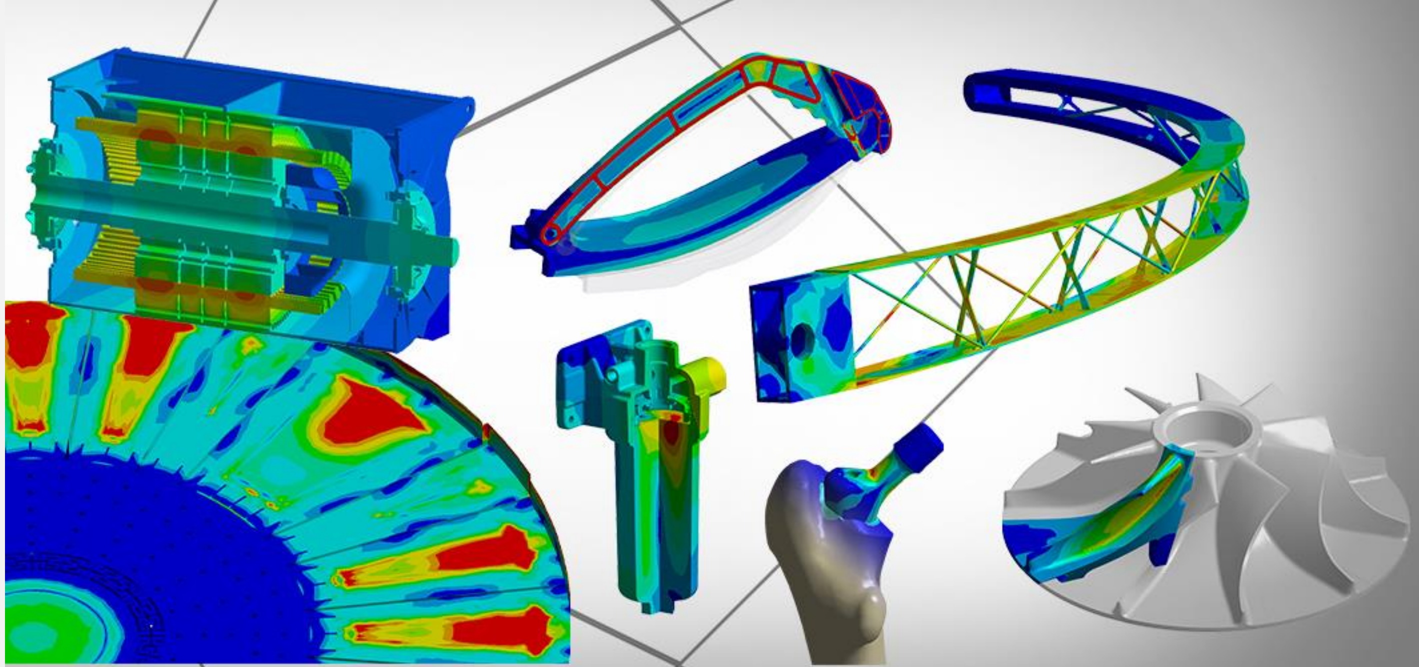
Input / Questions



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