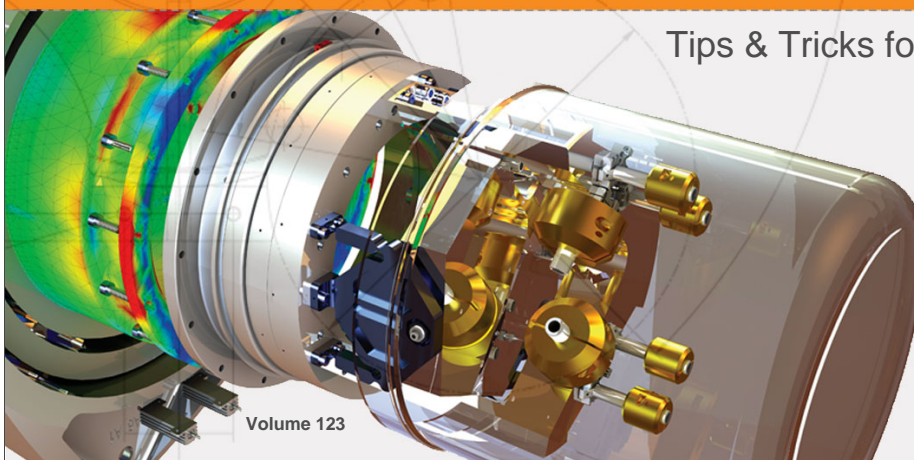




The COSMOS Companion

Tips & Tricks for Loads & Restraints Part 2



Volume 123

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What is the COSMOS Companion?



- The COSMOS Companion is a series of short subjects to help design engineers build better products with SolidWorks Analysis
- Video presentations and accompanying exercises
- A tool for Continuous Learning on your schedule
- Pre-recorded videos are accompanied by a more detailed webcast with Q & A
 - Download videos and review webcast schedule at:
 - <http://www.solidworks.com/Companion>
- It is not an alternative to instructor-led introductory training
 - We highly recommend you take a course with your local reseller to build a solid knowledge base

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If you are new to the COSMOS Companion, a few comments on the program are warranted. The COSMOS Companion series was developed in response to the request from many of our users for more detailed information on specific and/or new functionality within the COSMOS products. Additionally, many users have been asking for clarification of common design analysis questions to enable them to make more representative analysis models and make better decisions with the data. What's more, users have asked for this material to be made available in a variety of formats so they can review it how and when they wish. To address this, each COSMOS Companion topic has been pre-recorded and made available thru the COSMOS Companion homepage as a downloadable or streaming video with audio, as static PDF slides for printing, or as a live webcast enabling attendees to ask questions and engage in additional discussion. We are trying to provide continuous learning on your schedule so you can be as effective and efficient as possible when using COSMOS for design analysis and validation.

It is important to note that this material is not developed as an alternative to instructor led training. We still believe that the best introduction to any of the COSMOS products is in a class led by your reseller's certified instructor. In this program, we are hoping to build on the lessons learned in your initial training. In fact, we will make the assumption that you have basic knowledge of the interface and workflow from intro training or equivalent experience. We will try not to repeat what was taught in those classes or can be found in the on-line help but to augment that information.

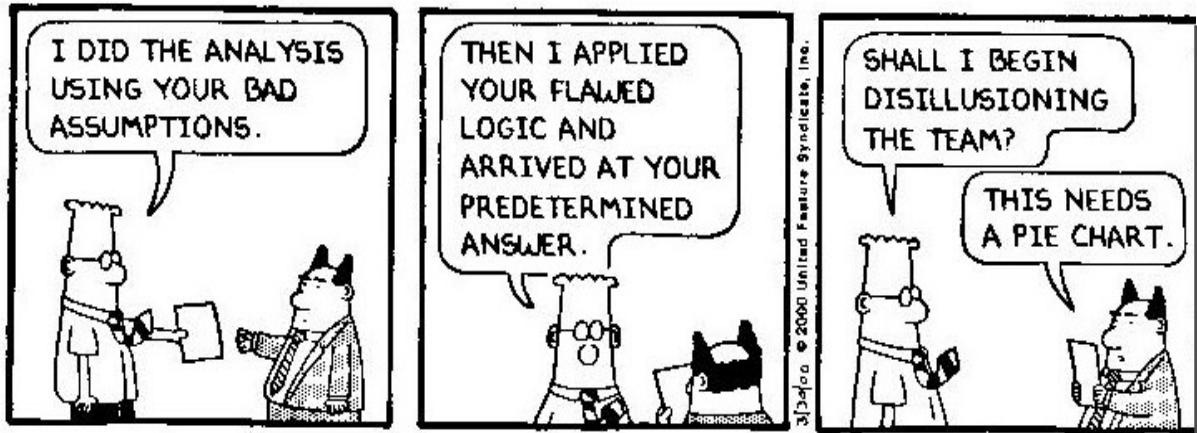
Agenda



- Important reminders for Loads & Restraints
- Remote Load
- Non-Uniform Loading
- Rotational Loading (Velocity & Acceleration)

In this edition of the COSMOS Companion, we'll review some important guidelines for choosing appropriate loads and restraints and then focus on three less well-known techniques in COSMOSWorks that can provide great benefit when the situation calls for them.

A Common Problem with Loads/Restraints

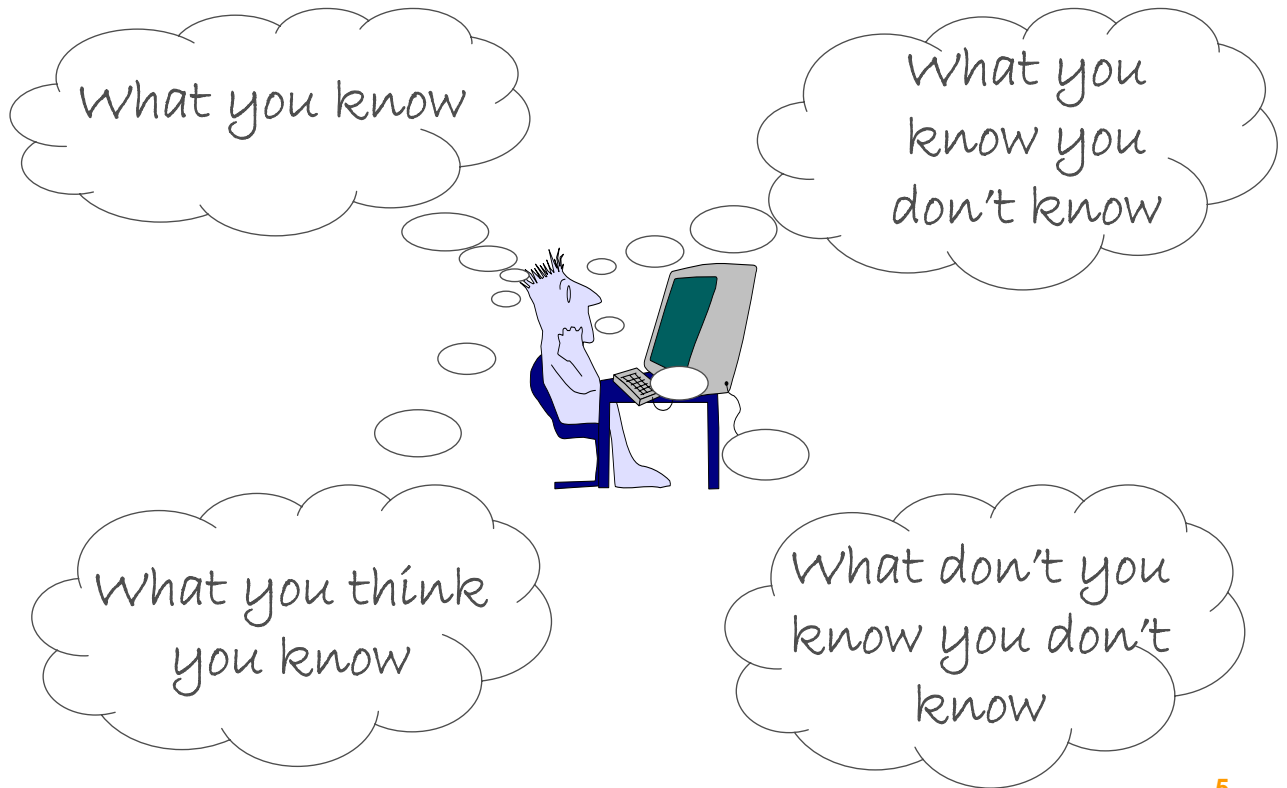


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It is common practice with many users to choose loads and restraints that produce a desired, "predetermined" response versus choosing the L/Rs that best represent the physics of the problem. One equipment manufacturer I've worked with developed loads for their system to produce a static solution that gave them high stress where welds in a dynamic test were cracking. When I helped them take a step backwards at the end of this process, it was clear they were applying external forces in places and directions that could never have occurred in real life. How reliable do you think geometric corrections to their system were based on these loads?

The Underlying Cause...



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As I've observed, one of the biggest hindrances to more appropriate load/restraint choices is confusion by the modeler between what they know vs. what they think they know. At a workshop I chaired on analysis education, one attendee offered up an even more complete classification of knowledge that I've found helpful to consider. All of our knowledge, at least our engineering and design knowledge can be categorized as "What we know", "What we think we know", "What we know we don't know" and "What we don't know we don't know". Differentiating between these bits of knowledge (or lack of knowledge) is important for determining what decisions can be counted on as fact, which should be preceded by more investigation and which should be looked at with a grain of salt.

Solving the problem...



- What you know vs. What you think you know
 - Biggest cause of load and restraint mistakes
 - Assume you don't know and check with research & test models
- What you know you don't know
 - Ask! Don't we tell our kids to "look it up!"
- What you don't know you don't know
 - Keep learning
 - Attend all the seminars and workshops you can
 - Even free "salesy" seminars can teach you something
 - Read about related physics, manufacturing techniques, and material info... not just FEA related stuff
 - Schedule some "Surfing Time"

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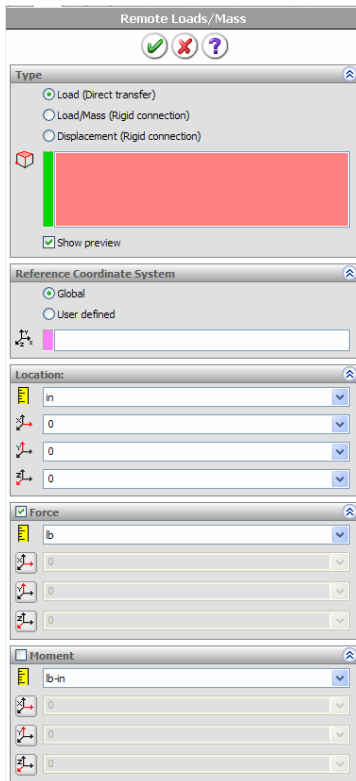
Some thoughts on managing these "knowledge categories"...

The biggest problems I've seen in Load/Restraint choices stem from designers who can't, don't, or choose not to differentiate what they know from what they think they know. The safest approach is to default to the assumption that you don't really know how two parts might interact or how your system might deform under load and try some test models of the various options available to you. Set up lab tests if possible and just watch the parts slide, bend, or move. I've found that while many erroneous L/R choices seem to respond correctly, it is only because we established preconceived conclusions about the response & forced the model to respond like that. When you get a chance to compare a mistakenly contrived response to the actual response, the difference is usually very clear.

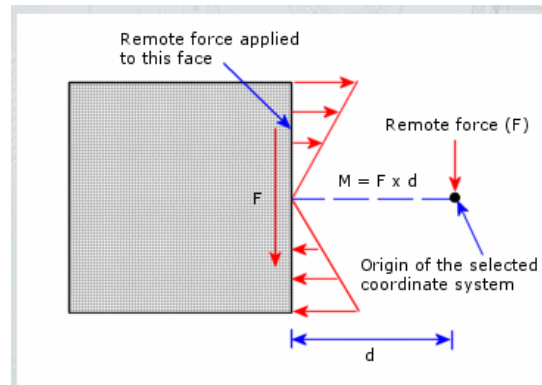
Things that we know we don't know... look it up! Don't guess as to how a part might deform or how a material might respond. When you know you've exceeded your personal knowledge base, be diligent about filling in the gaps before proceeding.

Resolving holes in your knowledge base that you don't know exist is tough. The best you can do is to keep learning. Keep exposing yourself to seminars, webcasts, books, publications, and classes. I've learned things that never occurred to me to look up at even the most salesy of seminars. I also recommend finding time to surf the Internet with no particular agenda or deadline. In compiling data on weld fatigue, I spent a few hours surfing the web a few months ago. Just recently, I repeated the search and found documents that provided better and more concise explanations of things I hadn't found previously. You'll be surprised what is out there if you take the time to look.

Remote Load – Direct Transfer



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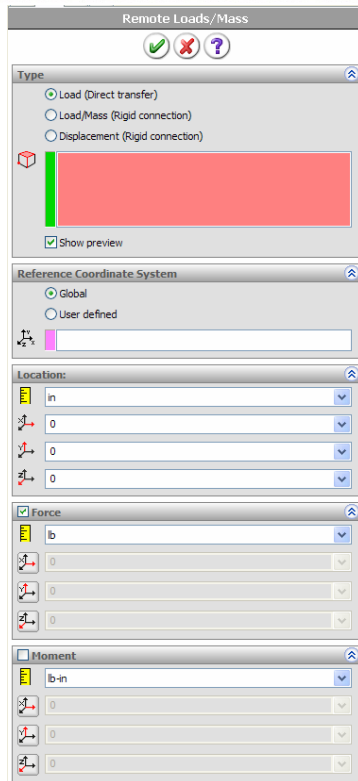


- A non-uniform force distribution
- Load applied thru or by something much less stiff than the part of interest

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The first option on the Remote Load Property Manager is Load (Direct Transfer). This is a load application, much like a force or a pressure. It doesn't add stiffness to the model and acts as if the load is applied thru a soft (relatively speaking) bonded member. This load can push and pull a surface so moments equivalent to force times moment arm will be generated, even if only a force quantity was applied.

Remote Load – Direct Transfer



Loading on a motorcycle wheel...

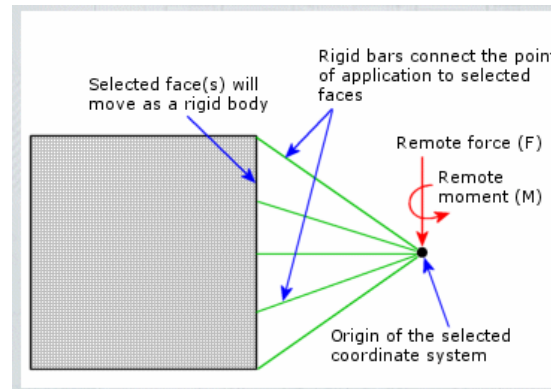
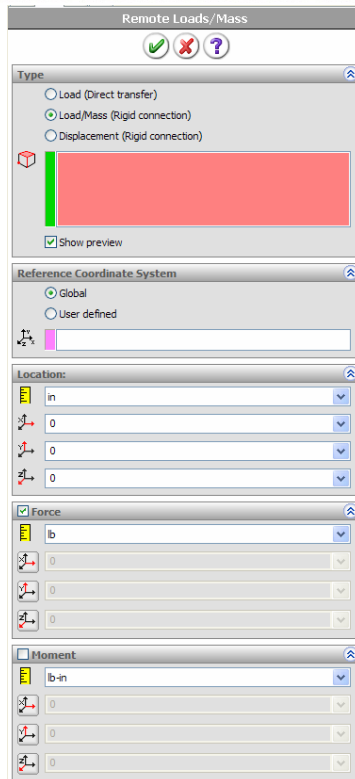


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A good example of the use of this load is in the loading on an automobile, motorcycle, or even bicycle wheel transferred from the road thru the tire and onto the wheel itself. Due to the intimate contact between the tire and the rim, side (turning), vertical (bump), or radial (accel/decel/braking) loads get distributed on a larger portion of the rim than just the contact patch between the tire and the ground. Moments from this load, due to tire thickness, must be applied and it is reasonable to assume the tire adds no stiffness to the steel or aluminum wheel. Remote loads serve the wheel designer well in this case.

Remote Load – Rigid Connection



- Load transferred through a MUCH more rigid component
- Potential for over-stiffening the selected face exists

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Remote Load/Mass (Rigid Connection) is much like the previous option, Direct Transfer, except for the fact that it does add stiffness to the model. Whereas Direct Transfer behaved as if the load was transferred through a part with no stiffness, this option assumes the load is transferred through a perfectly rigid part. The same force/moment transfer can be expected but the entities selected will remain rigidly oriented, with respect to each other, in their initial orientation and will deform spatially, with the load application point as a rigid body while the rest of the unrestrained system deforms in response. As with Rigid Connectors and any other FEA input termed “rigid”, there is always the danger of over-stiffening the system. No parts are truly “perfectly rigid” so if the differential isn’t significant, you may want to re-think this option or explore test models.

Remote Load – Direct vs. Rigid



Remote Loads/Mass

Type

- Load (Direct transfer)
- Load/Mass (Rigid connection)
- Displacement (Rigid connection)

Face<1>

Show preview

Reference Coordinate System

- Global
- User defined

Coordinate System1

Location:

in

0

10

0

Force

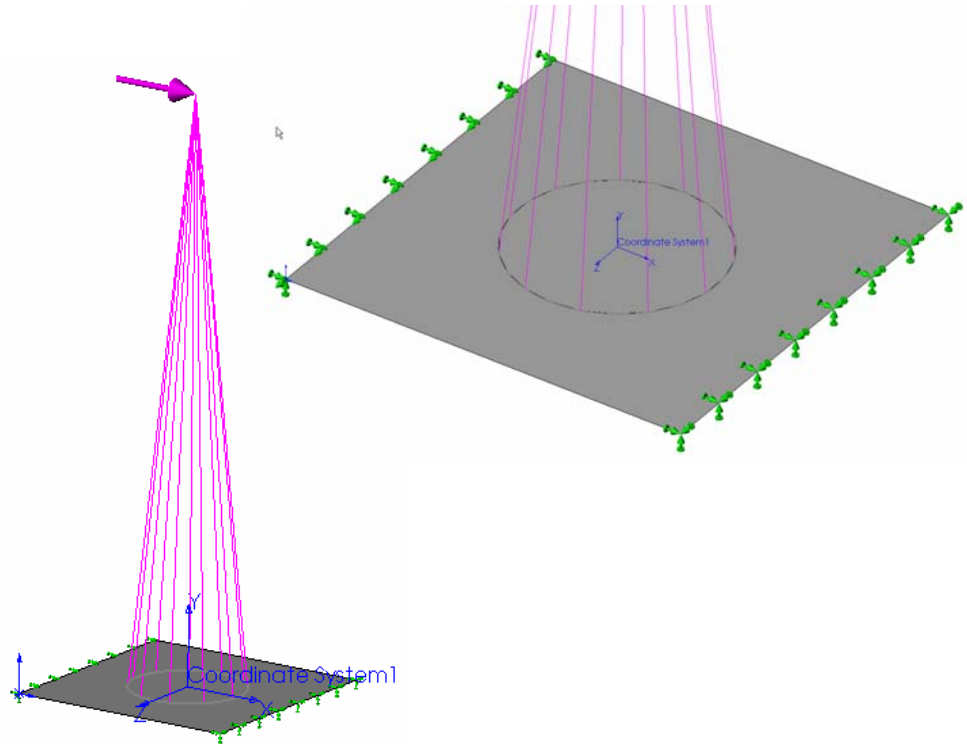
lb

100

Reverse direction

0

0

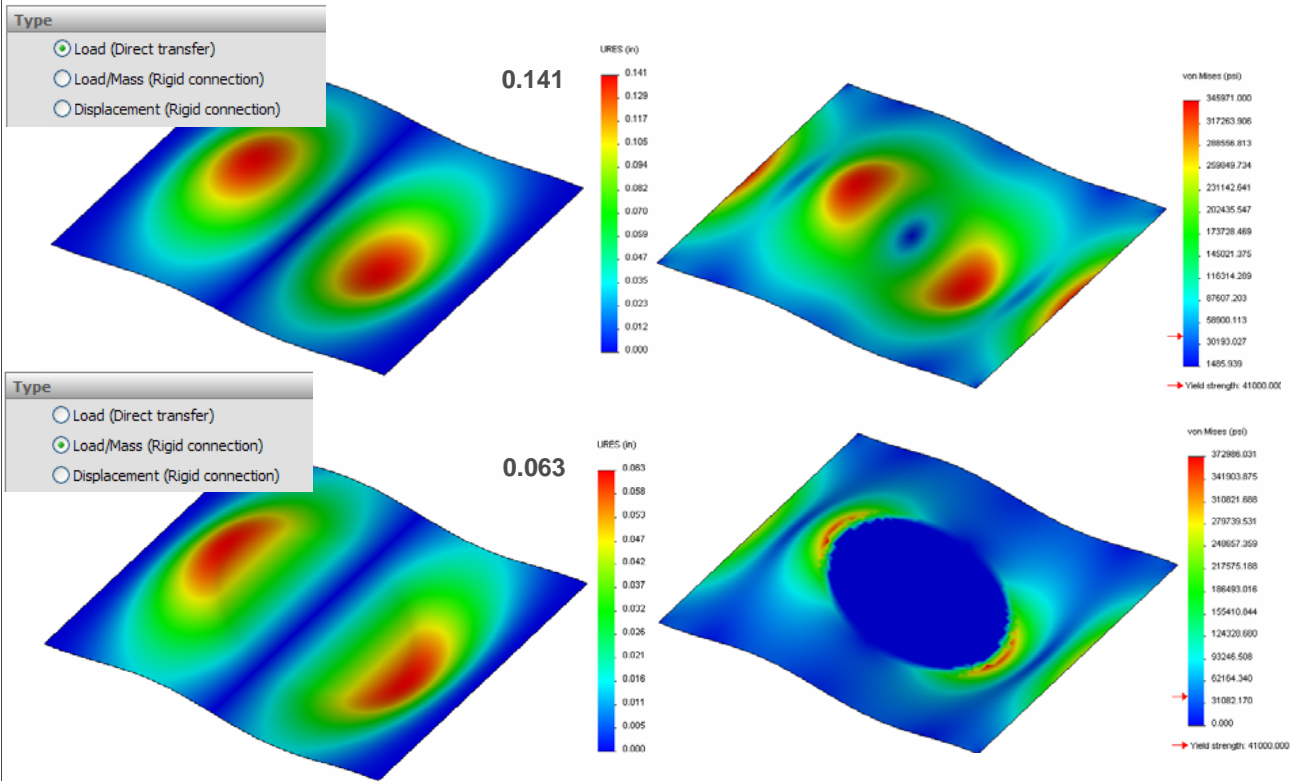


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One such test model that highlights the difference between Direct and Rigid is a plate with a circular patch in the middle. A physical analogy might be a plate with a tall rod welded or bolted to it. If that rod was extremely stiff compared to the plate, the Rigid option might make sense. If the rod was soft (think rubber or foam), the Direct option might be a better bet. Reality is usually somewhere in between so a comparison is warranted.

Remote Load – Direct vs. Rigid

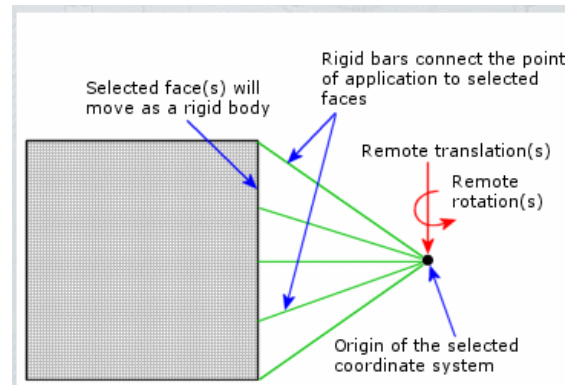
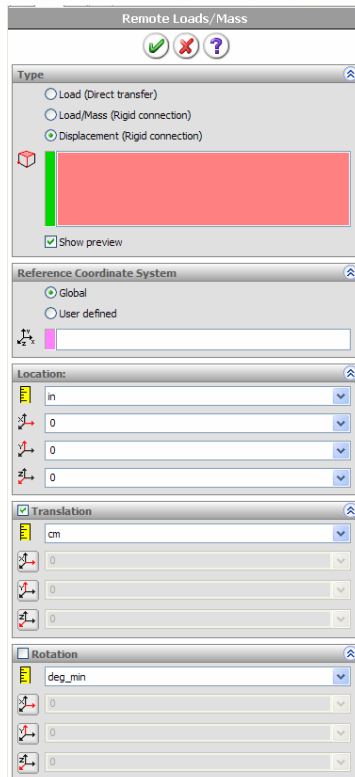


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The top two images show the displacement & stress response of the plate with the Direct option (that adds no stiffness to the model). The bottom two images show the Rigid response. You can see that the displacement solutions appear similar until you examine the magnitudes. There is more than a 2:1 difference between the results. The stress solutions are very different in every way. The rigid nature of the selection set in the Rigid results is apparent. If an examination of these two results doesn't make the choice on how to proceed clear, you should either base your decision on the worst case scenario or consider modeling the part you were trying to represent with virtual structure as the Remote Load.

Remote Load - Displacement



- Restraint on entities controlled by a point
- Rigidly restrains selected entities
- Potential for over-stiffening exists
- Can replace stiff part in load path to ground
- One of those “Don’t Know you Don’t Know’s” that you need to know!

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The third option, Remote Load – Displacement might be better termed Remote Restraint. Again, a rigid body is defined between your selection set and the remote application point. Restraints you specify in the Translation or Rotation panels are actually the restraints applied to the Remote Location. A good way to understand this is to consider the case where all translations are indicated as zero translation. This essentially ties the selected edges or faces to this point as a ball joint. Indicating two rotations as zero ties the selected entities to a single Degree of Freedom (DOF) hinge. Indicating all translations and rotations as zero essentially fixes the selection set, providing the same behavior as if those entities were simply fixed with a restraint.

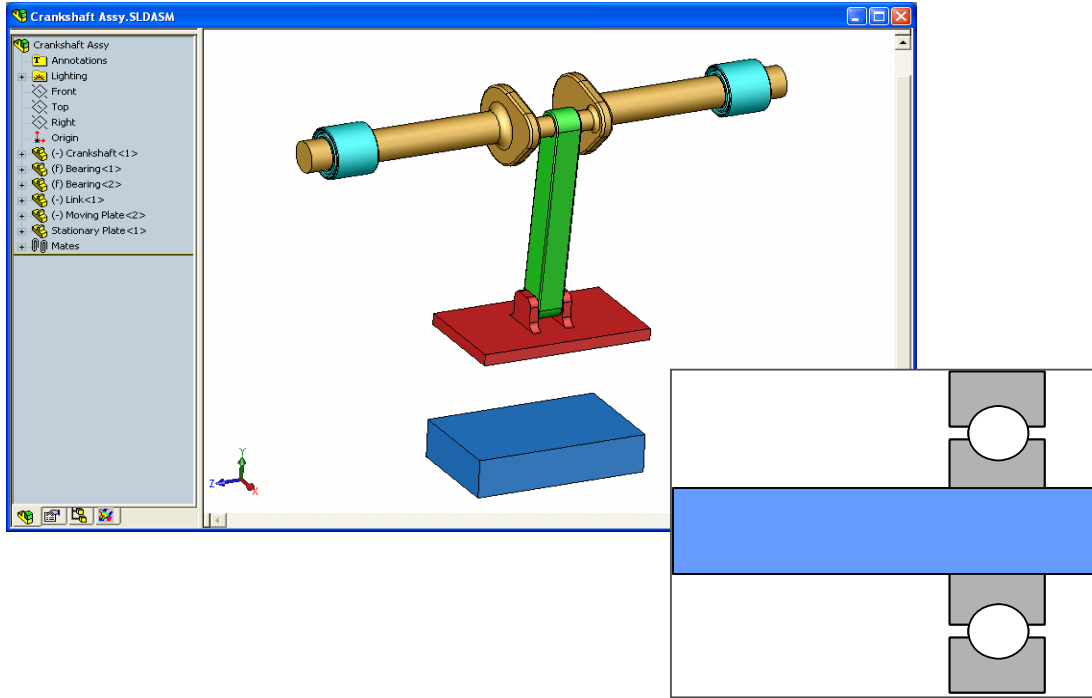
This does behave as a rigid body was inserted between the selection set and the reference location so the danger of over-stiffening still exists. However, it can often provide a more natural restraint in a solid model when entities pivot or rotate about a fixed reference point.

This restraint type has been referenced many times in other sessions of the Companion program and if you aren’t yet familiar with it, you are highly encouraged to experiment with it so you are ready when the need arises. Here are a couple of examples where the correct model response required the use of this technique, in lieu of modeling more complex contact interactions.

Remote Load - Displacement



Ball Bearing Connection with Off-Axis Rotation



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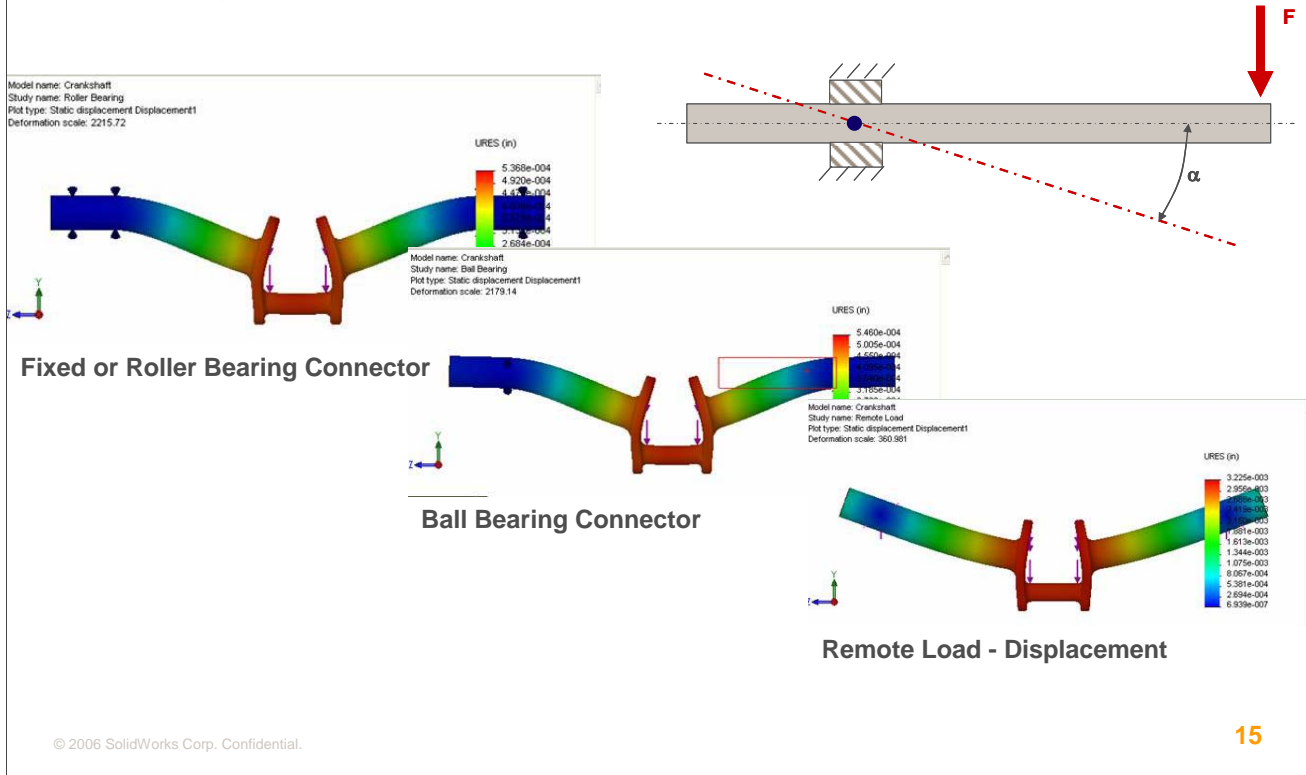
14

In this simple example, a shaft is supported in two locations by ball bearings. Unless you plan to model the bearings, you are most likely going to try to model a restraint interaction on the portion of the shaft that contacts the inner race. This could be modeled as a fixed restraint, assuming the bearing is solid and tightly attached to the shaft. Other options might be to use the Roller or Ball Bearing Connectors. These Connectors were reviewed in detail in a previous Companion unit. Here are the results from that study...

Remote Load - Displacement



Ball Bearing Connection with Off-Axis Rotation



The cases with the Roller Bearing connector and the fixed restraint gave essentially the same response. The shaft is held pretty rigidly within this connector.

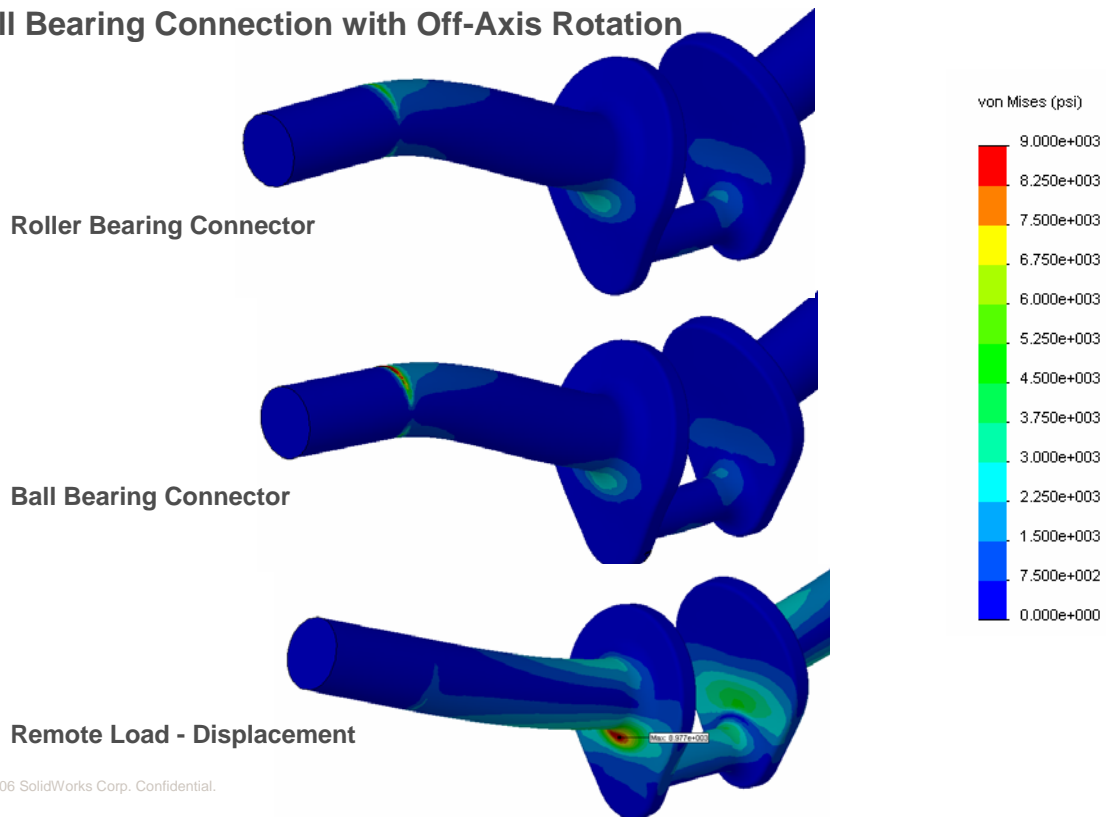
The Ball bearing connector applied on a split line edge isn't afforded any off-axis rotational flexibility but, as you can see from the image, a little deformation behind the connector is generated due to the volumetric load path thru the shaft.

The third case, the Remote Load Displacement applied at the geometric center of the bearing surface, allows the shaft to rotate freely. The displacement is significantly higher than with the other two options.

Remote Load - Displacement



Ball Bearing Connection with Off-Axis Rotation



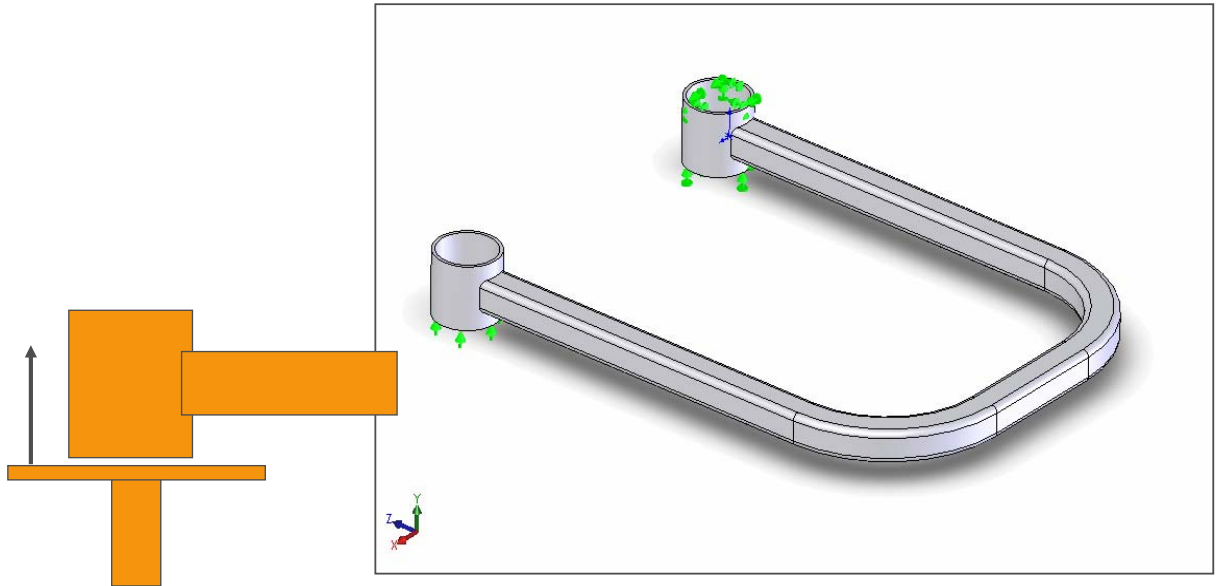
As can be seen from this image, the stress levels are much higher as well, showing the conservative nature of the Remote Load option.

A simple test with a bearing and shaft will show you that most ball bearings allow some off-axis rotation and, in the realm of linear, small displacement analysis, this degree of rotation should probably be accounted for in your model. Short of building additional geometry, the Remote Load Displacement is the most effective way to achieve the correct response.

Remote Load - Displacement



Torqued Frame



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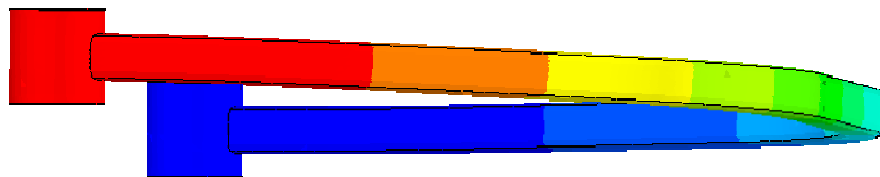
17

In this example, the pinned properties of the Remote Load Displacement will again come into play. A disconnect happened in this problem when the engineer assumed that a translational input on the bottom of the left-most cylinder, produced by a jack stand in the testing lab, equated to an enforced displacement on the entire lower perimeter. Forcing the entire perimeter to lift simultaneously actually imparts a significant moment on the part that the jack stand didn't produce. The cylinder could simply tip on the flat face.

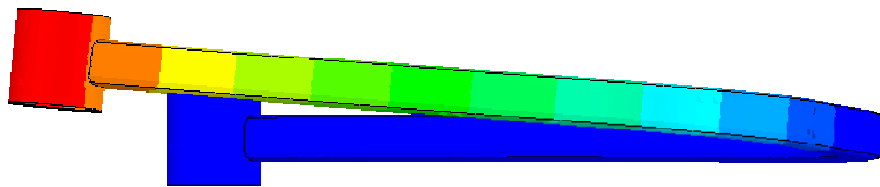
Remote Load - Displacement



Torqued Frame



Enforced Displacement - Surface



Remote Load Displacement - Pinned Tube

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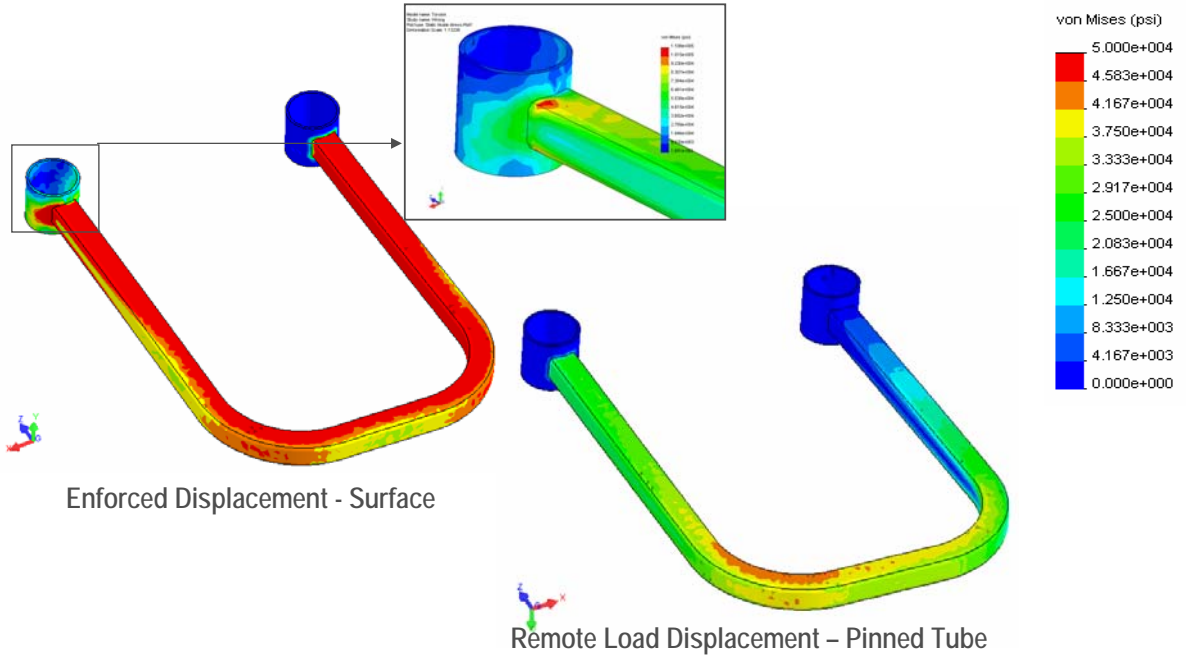
18

The top image shows the displacement of the cylinder with an enforced translational restraint on the entire bottom edge while the bottom image shows a more natural deformation indicative of the true response at the jack stand. Since this engineer started with a preconceived notion of how this system should respond, he wasn't surprised when the restraint he chose to provide the preconceived response behaved just as expected. However, when encouraged to actually review the part in test at this interaction, the error in his assumption was clear.

Remote Load - Displacement



Torqued Frame



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At the time we pointed out this mistake, the engineer had spent several days trying to design out the high stresses caused by this fictitious moment. When the correct behavior was modeled using the Remote Load Displacement, the stress in the part dropped off to nearly nothing and the engineer could begin to undo all the stiffening he'd designed in for previous few days.

Non-Uniform Load Distribution

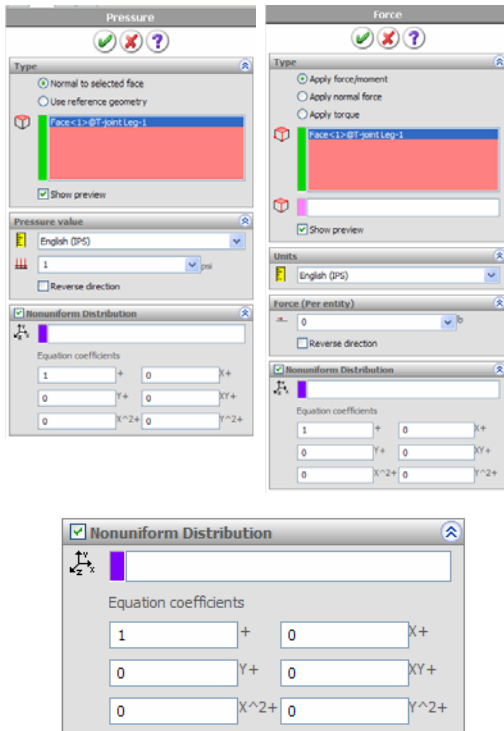


- Surprisingly few loads on an area are uniform
- The larger the area is, the less uniform the loads tends to be
- Do you KNOW the load is uniform?
- Does it matter to the response of interest?
- Multiple ways to apply non-uniform loads in COSMOSWorks:
 - Force/Pressure with Non-Uniform Load
 - Bearing Loads

The next technique to be familiar with is the application of Non-Uniform Loading on a face in COSMOSWorks. When you stop to think about it, a uniform pressure or force distribution on an entire face is a pretty gross assumption. The larger the area of the face is, the less likely the load is to be uniform. Again, going back to the discussion at the beginning of this segment, when you apply a uniform load (which is the default method), are you doing it because you know the load is uniform or because it was convenient and/or the default? As you are thinking about this, also ask yourself if the uniformity of the load will impact the results of interest. In some cases it may and if you haven't considered the option, you may make erroneous decisions based on this assumption.

There are multiple ways to apply non-uniform loads in COSMOSWorks and these will be discussed further...

Non-Uniform Load Distribution – Force/Pressure



- Same UI for Force & Pressure
- Equation is distribution of Force or Pressure Magnitude defined in the previous field
- Must select a User Defined CS
- Only Cartesian CS is available
 - Do you need Cylindrical or Spherical?
- What distribution/equation is appropriate?

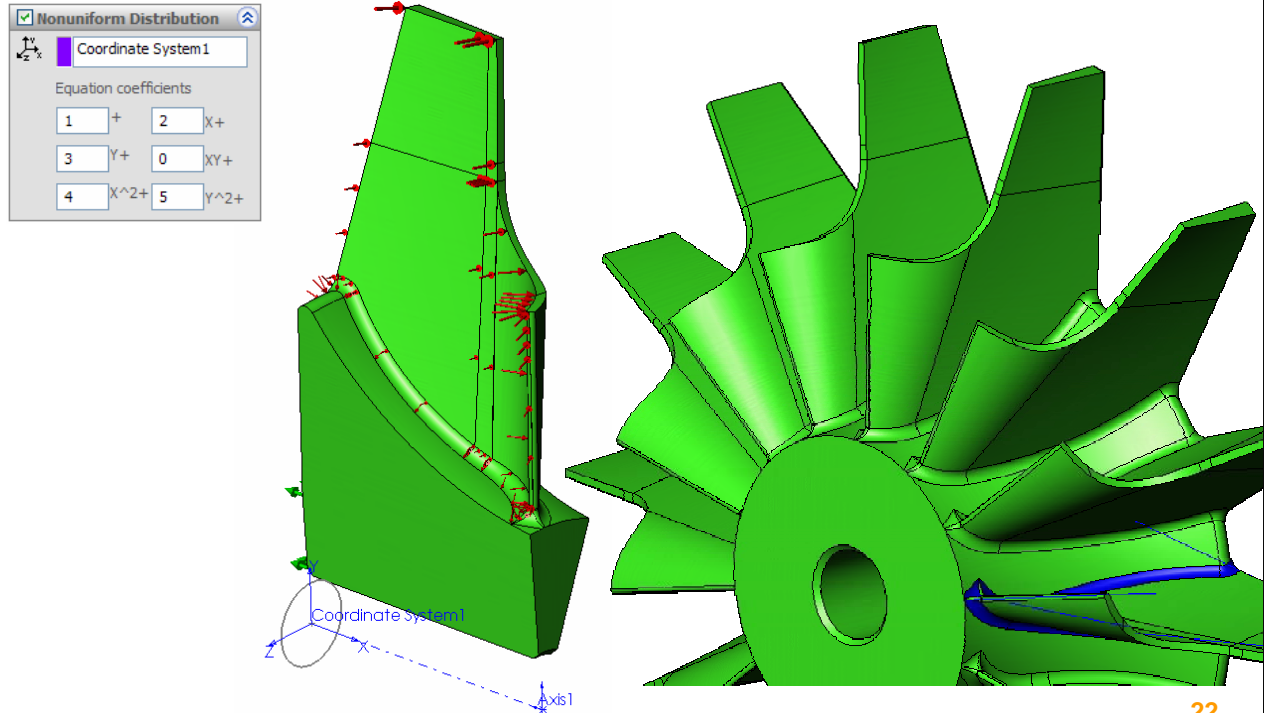
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In the Force and Pressure Property Managers, the Non-uniform Distribution UI is the same. A User Defined Coordinate System must exist prior to the definition of the non-uniform load and will be used as the basis for the XY distribution function defined in the dialog. Only a Cartesian (XYZ) CS is allowed currently but if you think a spherical or cylindrical CS would be helpful, please fill out an enhancement request on the SolidWorks website.

Knowing the interface is one thing... knowing what distribution to use is another. In many simple cases, such as a tank full of water, the distribution is clear. In others, some testing or exploration with test models might be warranted. I've come across many cases in my career where a good guess at a non-uniform distribution was still significantly better than assuming uniform.

Prop or Turbine Blade Pressure

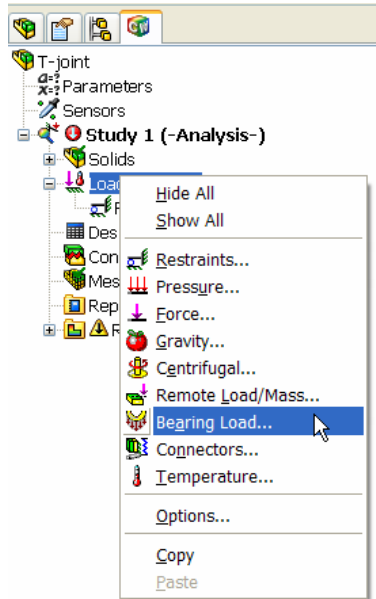


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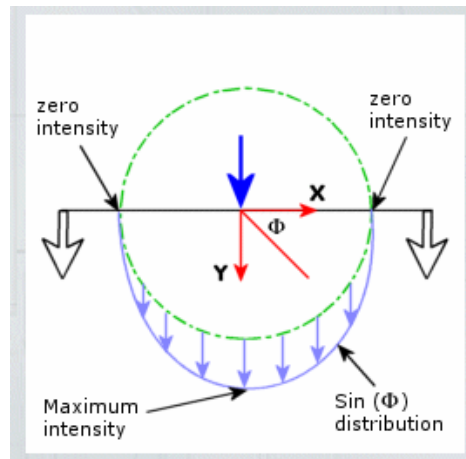
22

In the case of a Propeller or Turbine blade, the ideal situation is to perform a Computational Fluid Dynamics (CFD) study in COSMOSFloWorks to determine the true fluid pressures on each blade and then transfer those loads directly into COSMOSWorks. However, a review of these results may suggest a simplified distribution that can be constructed with the Non-uniform load UI. Another approach is to try 2-3 extreme options and see if they impact the results of interest or the decision you might make from those results. If the distribution doesn't seem to matter, then the added cost/trouble of running the CFD first may not matter.

Non-Uniform Load Distribution – Bearing Load



- Most appropriate when holes are near the edge of a feature
 - Otherwise, St. Venant's rules...

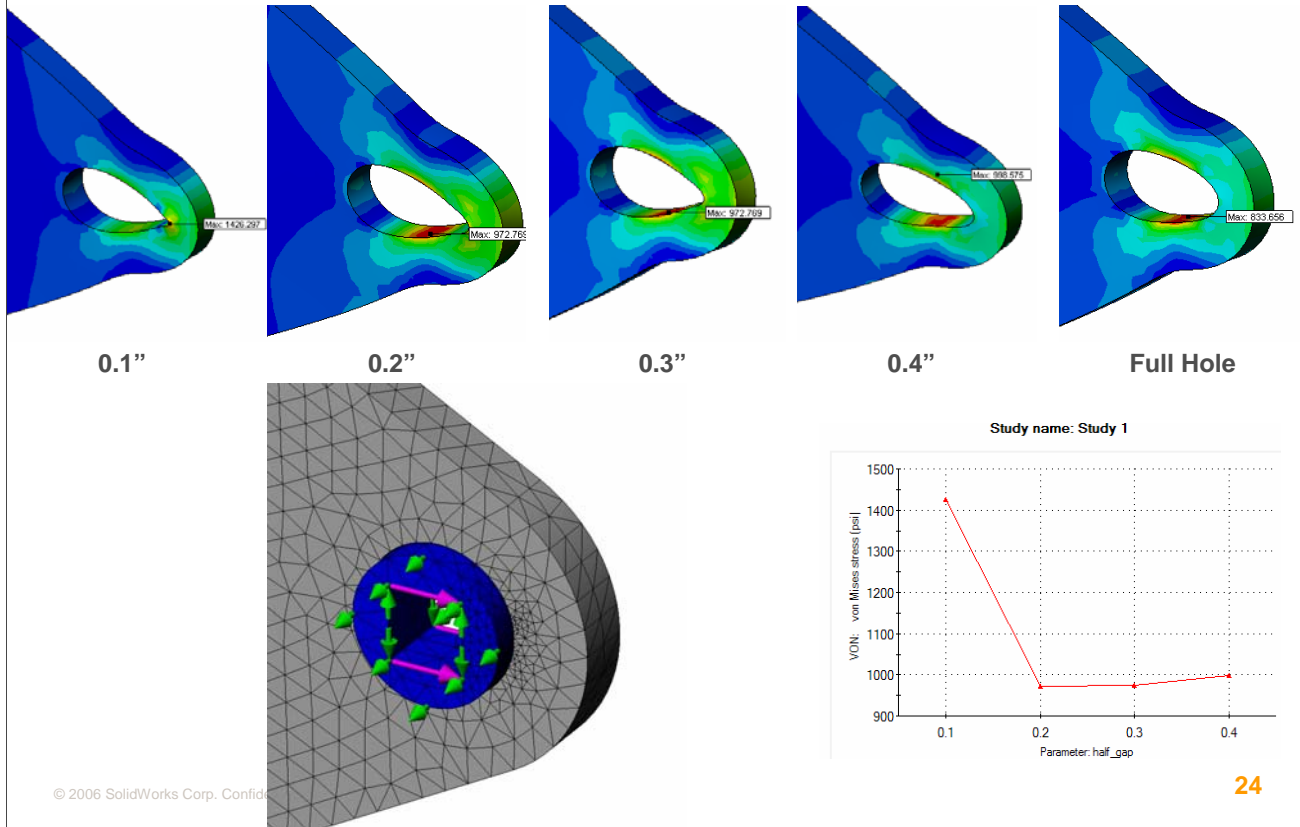


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One specialized non-uniform load distribution is the radial load imparted on a bore by a pin or shaft. This is often called a Bearing Load and COSMOSWorks provides a direct selection for the application of Bearing Loads. This load is most valuable when the wall thickness around the hole is small, as in a shock eye, or near the edge of a plate. In the middle of a larger component, you'll find that the distribution of the load on the hole doesn't matter so much as long as the magnitude and orientation are correct.

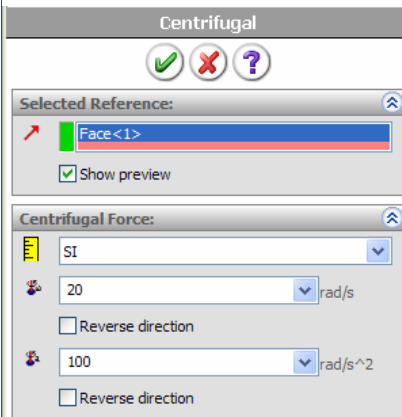
Non-Uniform Load Distribution – Bearing Load



By default, a bearing load applied to a hole will act on 180 degrees of that hole, essentially assuming a tight fit between pin and bore. However, it is reasonable to assume that once the hole starts to deform, that load may not remain distributed on half the hole. If there is any radial clearance, the load will never act on more than a few degrees. So, how can this be dealt with in COSMOSWorks?

In this simple test model, the response of an eye hole to a pin load, using contact, was compared to a Bearing Load applied over greater and greater portions of the hole. As can be seen from the plot, there was a point where changing the distribution ceased to matter. Test models like this may only need to be run once or twice for a given feature in your product but if they suggest an alternate approach that gives you better results, those one or two times is important.

Centrifugal = Spinning



- Both angular velocity and acceleration can be defined with Centrifugal load
- Direction is not important for Velocity
- Direction IS important for Acceleration
- Units in rad/sec or rad/sec²
- Velocities & Accelerations may be obtained from testing or a COSMOSMotion Analysis and applied to perform a pseudo-static analysis

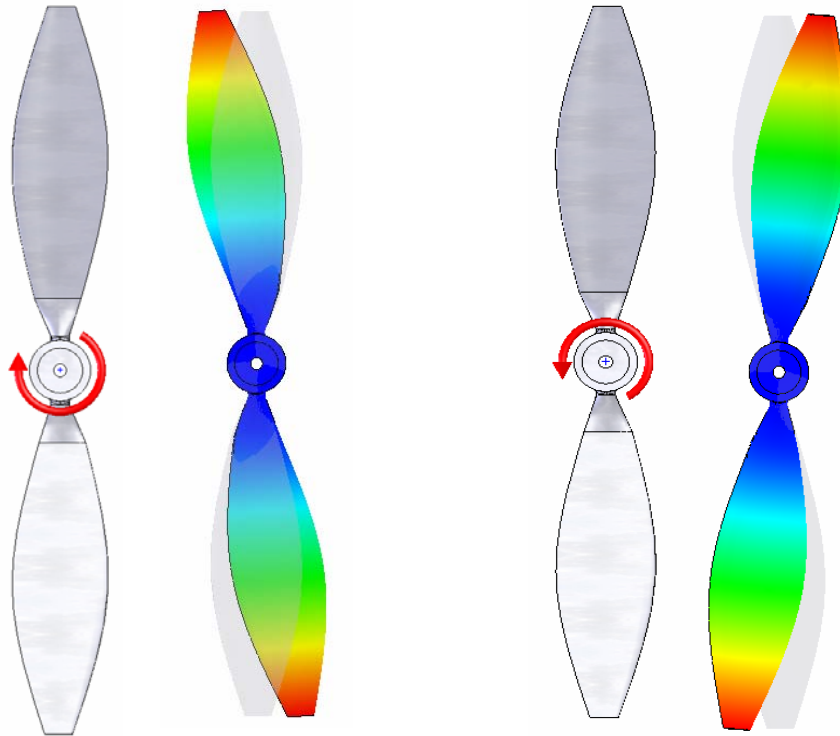
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The last technique to discuss involves spinning. If the axis of rotation is fixed and the rotational velocity or acceleration is constant, a system can be assumed static with these centrifugal loads. In many cases, a static snap shot of a dynamics system with rotational accelerations and velocities is important to understand the performance of a machine at increased operating speeds. You should carefully examine the acceleration vs. time curve for your system, ideally from a tool like COSMOSMotion. If the duration of a peak acceleration is small, the system may never reach displacements and stresses suggested by a statically applied rotational acceleration. Keep this in mind when evaluating the results.

Spin direction isn't important for rotational velocity. Consider a ball spinning on the end of a string. The tension in the string will be the same, regardless of which direction it is spun. This is not the case for accelerations. Consider linear accelerations in an automobile. If you hit the gas, you are thrown backwards in your seat. Slam on the brakes, you are pitched forward. Even if the magnitudes of the accel & decel were the same, you'd still flop in different directions. Rotational accelerations are subject to the same directional effects.

Centrifugal = Spinning



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In the case of this propeller blade, if it is accelerated in the directions of the arrows, you can expect an inertial lag in the displacements as shown. If the accel/decel is the only load in the model, the results will be equal and opposite and won't really make a difference in your design decisions. However, if other loads are applied that might add to the response of one direction but subtract from the response of the other, getting it right is important.

Guidelines for Improved BCs...



1. **Anticipate Behavior – Use Common Sense**
2. **Build Free Body Diagrams**
3. **Identify Stiffness Differentials**
4. **Determine Model Sensitivity**
5. **Utilize Hand Calculations**
6. **Beware of Over-Constraining**
7. **Watch out for Rigid Body Motion**
8. **Utilize Force Summations**
9. **Review Historical Data**
10. **Utilize Outside/Inside Support for Sanity Check**
11. **Build Test Models**
12. **Correlate to Appropriate Constructed Tests**
13. **Generate Reports / Document Sources**
14. **Build up Assy Models Slowly – Use Simplified Techniques First**

Finally, here is a general guideline list for applying Loads and Restraints in your model. They aren't necessarily related to the topics we discussed in this unit but the list is still important and might be worth printing or keeping handy to review in your day-to-day modeling work.

Presentation Summary



In this COSMOS Companion unit, we reviewed:

- The right “frame of mind” for developing Load & Restraint strategies
- Various applications for Remote Loads (especially RL-Disp)
- The difference between Direct and Rigid Remote Loads
- Various applications for non-uniform pressure distribution
- Important considerations for rotating parts

Conclusion



For more information...

- Contact your local reseller for more in-depth training or support on any of the Load or Restraint options in COSMOSWorks to make your design process more efficient.
- Review the on-line help for a more detailed description of the features discussed
- Attend, or better yet, present at a local COSMOS or SolidWorks user group.
 - See <http://www.swugn.org/> for a user group near you