Experimental Solvers: New Capabilities in Generative Design.

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Description

Autodesk is famed for having robust and reliable simulation tools. On the other hand, we have Generative Design in Fusion 360 software—the technology that revolutionizes the engineering world and the ways we design things. Autodesk development teams have been working on capitalizing on these proven simulation solvers as well as the latest technologies in generative design. As a result a new tech preview feature named Experimental Solver is enabled in Fusion 360. This means every user of the generative design feature will also see new outcomes with new sophisticated shapes, in addition to the existing traditional solutions. This technology brings new functionalities and delivers forms optimized in a new way, opening doors that have been closed previously. In addition to showing how to use the new technology of Generative Design in Fusion 360, above all, we will present how the new functionalities empower the new applications using real-world examples.
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Speakers

Krystian Motawa graduated with an M.Sc. degree in Structural Engineering. He also completed post-graduate studies in software development methodologies. Prior to Autodesk, he worked as a Structural Engineer. Joined Autodesk in 2016, currently working as a Senior Software Engineer in Test. Involved in Generative Design from the beginning of this project. Based in Krakow, Poland.

Grzegorz Borowski an Autodesk employee with 4 years of service. Currently a Product Owner working mainly on Generative Design. Graduated with a M.Sc. degree in Mechanical Engineering, specializing in Finite Element Method (FEM) simulations. Prior to joining Autodesk, he worked as a CAE Engineer for several companies in Automotive Industry.

Karolina Czechowicz is a Software Engineer with research background in materials engineering and simulation. Graduated Applied Computer Science with specialization in Modelling and Information Technologies. An Autodesk employee for 3 years, currently working on Generative Design solver.
What are Experimental Solvers in Generative Design?

Experimental Generative Solvers and Features is a preview feature available in Fusion 360. This is a technology which combines all abilities of Generative Design (advanced optimization algorithms, manufacturing constraints, design permutations) supported by new features (enforcing symmetry in outcomes, voids insertion in shapes) with the mature, reliable simulation tools (advanced physics, buckling analysis, displacements limitation, frequency constraints, removing rigid modes). Additionally, Experimental Solvers and Features improves the robustness and performance of Generative Design solutions.

How to use new Experimental Solvers in Fusion 360

Experimental Solvers feature is a part of Generative Design which is available to every Fusion 360 user. To open Generative Design Workspace inside Fusion 360 you need to navigate to the "Generative Design" option (2) inside the workspace picker (1) in the upper left corner of the Fusion 360 window.

As the Experimental Solvers feature is still being developed and improved, it is available as preview feature. This means that to use it, you will need to enable it in the Preferences dialog of Fusion 360. To do this first open the Preferences window by choosing the “Preferences” option (4) inside the menu (3) in the upper right corner of the Fusion 360 window.
Inside the Preferences window find the “Preview Features” option (5) and then make sure that under the Generative Design tab you have selected “Experimental Generative Solvers and Features” (6).
The above steps will enable Experimental Solvers Tech Preview for your account. Now to explore alternative outcomes for a specific study one more step is needed. After creating a new study open its “Study Settings” (7,8) and select the “Alternative Outcomes” option (9).

When you run the study with the “Alternative Outcomes” option selected, you will be able to use new features that are described in more detail in the next chapters of this document, as well as you may get some additional outcomes on top of the default ones.

If you are a new user of Generative Design and have no knowledge of how to create or run a Generative Design study, we strongly encourage you to try out some of the tutorials that are available on this webpage.
**Alternative Outcomes**

Thanks to the continuous work on design divergence, new Experimental Solvers offer up to 4 additional outcomes on top of the default ones for every study setup. The final number of outcomes may vary depending on the chosen study configuration, that is manufacturing constraints, additional constraints like symmetry, etc.

Please note that Experimental Solvers is still a preview feature, which means that some of the new features may not be working with all manufacturing constraints and final outcomes count might be smaller. Some of the configurations are not possible to run at all. The full list of supported manufacturing methods is presented later in this document, next to the description of every new constraint.
After opening the results in the Explore tab you can identify the outcomes that were generated by Experimental Solvers by a flask icon visible in the upper right corner of the outcome thumbnail.
Capabilities - New design variants

One of the characteristics of new Experimental Solvers is already mentioned increased variety of shapes. Thanks to new ways of optimization the results you get for the same study setup can differ significantly in terms of the form while continuing to meet the optimization objectives. This gives you the freedom to choose the design based on its aesthetic values and not only mechanical properties. Below are presented some examples that show this behavior. Both design variants have remarkably similar parameters like a minimum factor of safety or mass but are completely different visually.
Capabilities - Shapes with voids

Another interesting feature of Experimental Solvers is its ability to create void shapes. In the standard approach of Generative Design solver, the material can only be removed from the outer surface of the model. In most cases this method provides satisfactory results, however, there are some situations where it is insufficient, and the outcomes that it produces are not the optimal ones.

The improved algorithms of Experimental Solvers provide the possibility to remove the material also from the inside if it makes sense for a given model. This allows for faster optimization in some of the cases and produces the shapes that are more optimal from an engineering point of view.
Let's look at the example. The picture below shows the beam being subjected to a torque load. The green parts are preserve geometries while the yellow part is a starting shape. If you are unfamiliar with these terms, please refer to Generative Design tutorials. You can access them by following the instruction from “How to use new Experimental Solver in Fusion 360” section.

When you run the static stress analysis on this model (e.g. in Simulation workspace inside Fusion 360) you will see that maximum stresses are located on the outer surface of the model, while the inside of the model is subjected to much lower stress values.

The most logical and most optimal solution here would be the shape that has its outer edges preserved and is empty inside. However, up until now, Generative Design solver was unable to produce such a shape. Experimental Solver brings new possibilities, and you can see the results in the below picture. At the top of the picture is the design produced by standard Generative Design solver, at the bottom, there is an outcome created by a new optimization method used in Experimental Solver. The second design is much closer to the one that is
indicated by stresses distribution inside of the model. It is also much lighter and has a much lower displacement value than the traditional design.

### Capabilities - Displacements limitation

**Displacements**

Displacements are directional motions of the structure under applied loads. Apart from the load-bearing capacity requirements, many design standards also limit the maximum allowable displacements. In the Traditional Generative Design approach, we can see the maximum displacement of the generated outcome, but we are unable to directly impact it before the post-processing stage.
Parameters of the generated outcome.

Simulation results on the outcome - displacements.

With Experimental Solvers and Features, we can get more control over it by constraining allowable displacements. As the preview option is turned on, the additional options appear in the Objectives and Limits dialog.

Global displacements

The first constraint is related to global displacements, which are total motions of nodes in a model considered in a global coordinate system.

Model Setup

1. On the Define tab, click Design Criteria > Objectives
2. Click Displacement and select Global
3. Choose from one up to three directions
4. Specify the maximum displacement value for X, Y, and/or Z directions
Setup for constraining global displacements.

To limit global displacements in the considered model we set the allowable maximum value 0.1 mm in all three orthogonal directions.

Then we compare two final outcomes - without displacement constraints and with global ones.

As the result, we can see that the final outcomes have shape optimized in a similar way. For the one with limited displacements, there are fewer members but stockier.

Comparing these properties, we can see that the Factor of Safety for both is the same. However, maximum global displacement was reduced from 0.28 mm to 0.1 as it was constrained.
The outcome with global displacements constraints set to 0.1mm.

Properties of the outcome without displacement constraints.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max von Mises stress (MPa)</td>
<td>85</td>
</tr>
<tr>
<td>Factor of safety limit</td>
<td>2</td>
</tr>
<tr>
<td>Min factor of safety</td>
<td>2</td>
</tr>
<tr>
<td>Max displacement global (mm)</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Properties of the outcome with global displacements constraints set to 0.1mm

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<tr>
<td>Min factor of safety</td>
<td>2</td>
</tr>
<tr>
<td>Max displacement global (mm)</td>
<td>0.1</td>
</tr>
<tr>
<td>Max displacement X (mm)</td>
<td>0.02</td>
</tr>
<tr>
<td>Max displacement Y (mm)</td>
<td>0.1</td>
</tr>
<tr>
<td>Max displacement Z (mm)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Local displacements

We can get even more control over by setting constraints of local displacements. There we are limiting the motions of nodes from a particular object of a defined preserve geometry.

**Model Setup**
1. On the Define tab, click Design Criteria > Objectives
2. Click Displacement and select Local
3. Select a location in your design such as face, edge, or vertex that belongs to the preserve geometry.
4. Choose from one up to three directions
5. Specify the maximum displacement value for X, Y, and Z directions.
To limit this time, local displacements in the considered model we set the allowable maximum value 0.1 mm in all three orthogonal directions and additionally we selected top face of a preserve geometry cuboid.

Then we compare two final outcomes - without displacement constraints and with local ones.

As the result, we can see that the final outcomes have shape optimized in a similar way. For the one with limited local displacements, members are even stockier than in a case of global constraints.

Comparing these properties, we can see that the Factor of Safety still stays the same However, maximum displacement was reduced to 0.1 mm as well.
The outcome with local displacements constraints set to 0.1mm.

Properties of the outcome with local displacements constraints set to 0.1mm

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</tr>
<tr>
<td>Max displacement global (mm)</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Following manufacturing methods are supported for displacements constraints:
- unrestricted,
- additive,
- 2D cutting,
- 3 axis milling,
- 5 axis milling.
Symmetry constraints

Symmetry
Symmetrical design in many cases is highly desirable not only due to visual value but also due to the engineering aspects (uniform stress distribution, manufacturing process, etc). Unfortunately, sometimes due to reasons beyond the user’s control final design can be unsymmetrical. Outcome can be influenced by numerical errors that can cause a non-uniform distribution of loads. The use of symmetry constraint enforces symmetry on every outcome from Generative Design.

Model Setup
1. Prepare symmetry plane(s) - depending on the need you can use one or many symmetry planes.
   - Use global symmetry planes (1)
   - Create your own symmetry planes in the Edit Model contextual environment (2)

2. Define symmetry planes
   - Using Define Tab (1)
   - Using Browser (2)

3. Choose at least one symmetry plane (3)
Define symmetry planes

4. Generate study
5. Explore your results. Results with symmetry constraints will be marked

Requirement
Symmetry constraints require a proper study setup. All geometries (Preserve, Obstacle, Starting Shape) used in the study need to be symmetrical to used planes. Using an asymmetrical setup can lead to a violation of constraints.
Boundary conditions can be asymmetrical.

Example
The symmetry example below shows the influence of used constraints.
The model at the top was defined without constraints. It shows an asymmetrical final shape while the same model but with the use of three symmetry planes (visible at the bottom) has no such issues.

**Frequency constraints**

**Frequency**

Every object (building, engine, beam etc.) has its own set of natural frequency modes and corresponding values.

Knowledge about natural frequency is essential during the design process. It allows preventing the occurrence of resonance phenomena that can be damaging to design. In most cases, engineer's secures constructions by assuring that the first natural frequency mode higher than the frequency at which resonance occurs. Knowing that every other natural frequency is higher than first assures safety from resonance.

Generative Design allows setting the minimal allowable value of first natural frequency mode. This constraint will be enforced on every created outcome.

**Model Setup**

1. Open Objectives and Limits dialog
   - Using Define Tab (1)
   - Using Browser (2)
2. Check Modal Frequency limit (3)
3. Enter allowable Frequency value for first mode (3)
4. Generate Study
5. Explore results

Enabling frequency constraints

Example
The below example shows the difference in results with and without the use of Frequency constraints.

Example of frequency constraints
Results on top do not contain frequency constraints. The simulation of this outcome shows that the first natural mode oscillates around the X axis and has a value of 168.8 Hz. Assuming that resonance might occur at 300 Hz, the frequency limit was set to 350 Hz. Results on the bottom show outcome from constrained setup. It’s worth noting that the result changed significantly; the material was added to stiffen the outcome in direction of bending, around X axis. The value of the first mode increased to 356.2 Hz what satisfies our requirements.

**Buckling constraints**

**Buckling**

Slender shapes can be affected by a sudden change of shape that is called buckling. Deformation can result in loss in load capacity, plastic deformation or break of other parts. During the engineering process, it is useful to consider buckling as a safety factor. Experimental Solvers and Features gives that possibility.

**Model Setup**

1. Objectives and Limits dialog:
   - Using Define Tab (1),
   - Using Browser (2).
2. Check Buckling option (3),
3. Enter allowable Buckling FoS value (3),
4. Generate Study,
5. Explore results

Enabling buckling constraints
Example
Example below, shows difference in results with and without use of Buckling constraints.

First from the top is model view. It consists of two preserve geometries, one loaded and second fully constrained.
Result without buckling constraint shows slender design that connects both preserves. It satisfies stress constraint however after validation done in Simulation workspace, we can see risk of buckling.
Applying buckling constraint to initial setup increases Buckling Safety Factor. Notice that shape is thicker and not as slender as before.

Remove Rigid Body Modes
Remove Rigid Body Modes
Typical Generative Design setup require a fully constrained model in order to start calculations. User needs to apply displacement constraints that prevent movement of the model.
Remove Rigid Body Modes allows us to create designs without that requirement.
In practice this means user can calculate models that are not constrained.

Model Setup
1. Check option Remove rigid body modes in study settings,
2. Generate study,
3. Explore results.
Enabling Remove Rigid Body Modes feature

Requirement
Remove rigid body mode features should not be used together with classical constraints.

Example
The first example shows two unconstrained rings. Smaller is loaded with a force that would affect in lack of convergence. With Remove Rigid Body Modes study was able to produce a reasonable design.
First example of Remove Rigid Body Modes

The second example shows two rings connected with a cylindrical starting shape. Both cylinders are loaded with opposite forces of equal value. Due to a lack of constraints such setup would not generate any result. With Remove Rigid Body Modes study was able to produce a reasonable design.

Second example of Remove Rigid Body Modes