

IM501270

Enhance a Generative Design model with Event Simulation in Fusion 360

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Learning Objectives

- Create a Generative Design model.
- Identify designs that are potentially better solutions than others.
- Analyze the chosen models with Event Simulation.
- Evaluate the results to identify good features of the design and potential problems.

Description

Generative Design (GD) in Fusion 360 creates hundreds of innovative optimized design options within a short period of time. However, there is no free lunch. When it comes to engineering, users need to think about the assumptions and limitations of GD. GD models are often slender which do not behave linearly in real life, material may not be linear elastic over the loading cycle, and the model may need to contact other parts. Event Simulation (Fusion 360) and/or Explicit Dynamics analysis (Inventor Nastran) can help confirm the acceptability of the GD model by including all the nonlinear effects that may be encountered during actual use: nonlinear displacement, plasticity, and contact.

This session will cover multiple aspects of creating the GD and performing a simulation with Event Simulation or Explicit Dynamics.

Speaker(s)

About Jaesung Eom

Jaesung is a Principal Research Engineer of Product development and Manufacturing solution Group. He is working on the levelset optimization of Generative Design and the FEM solver in Fusion 360. After Ph.D. on computation mechanics at KAIST, he is an active reviewer of several technical journals and conferences.

About John Holtz

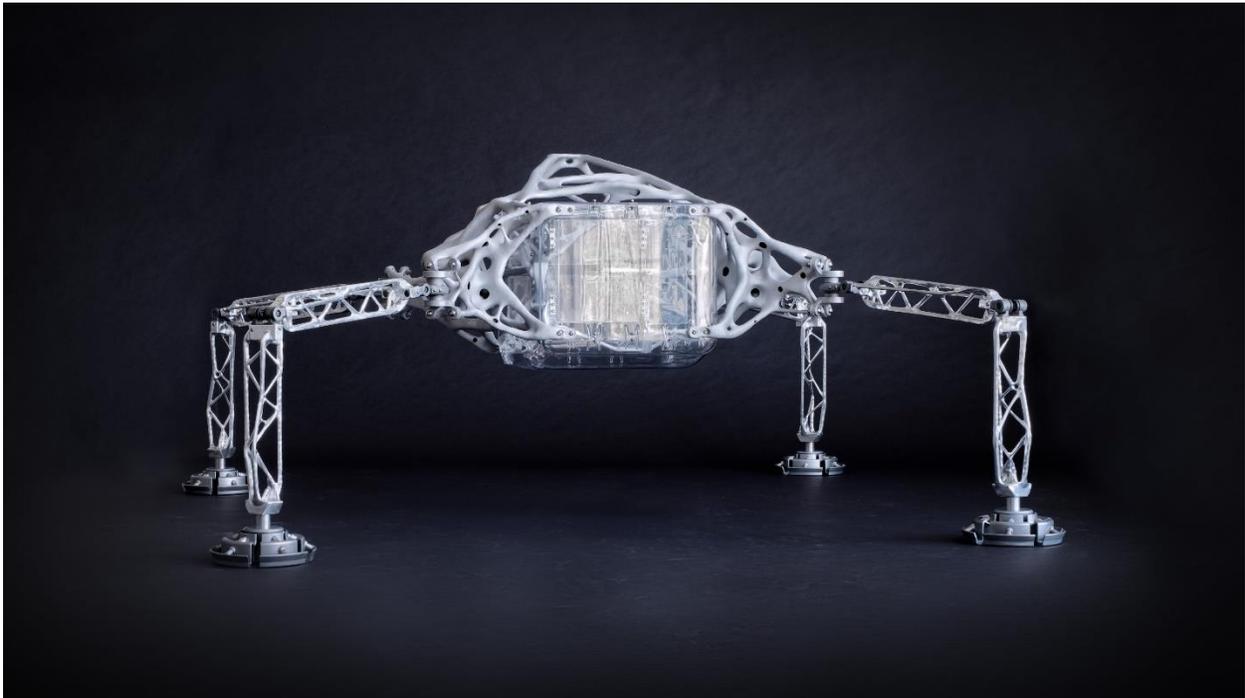
John is a Senior Technical Support specialist with over 30 years of FEA experience designing steel mill equipment for various engineering firms and providing technical support and software design for FEA software. He currently provides support for the Inventor Nastran and Fusion simulation.

Introduction

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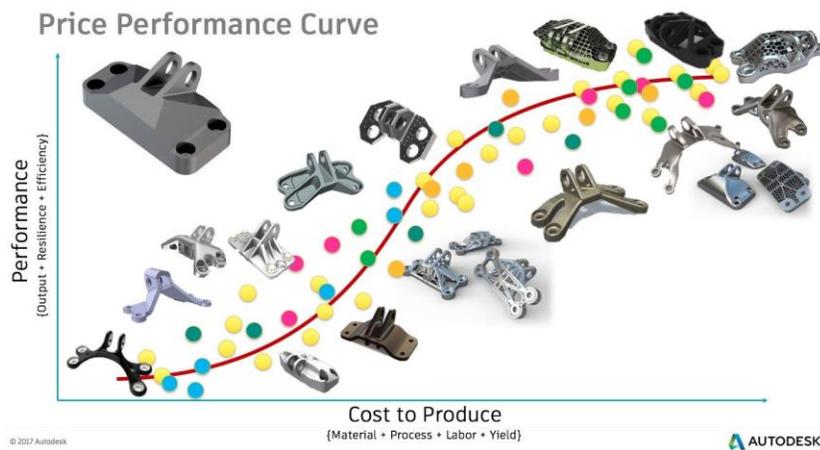
AUTODESK SOFTWARE LETS NASA JPL DESIGNERS BALANCE SEVERAL PERFORMANCE GOALS AGAINST MISSION CONSTRAINTS WHILE REAPING THE BENEFITS OF CLOUD COMPUTING AND MACHINE INTELLIGENCE.

Fast forward of Generative Design

What is Generative Design

Autodesk Generative design has received immediate attention from the market since it promises:

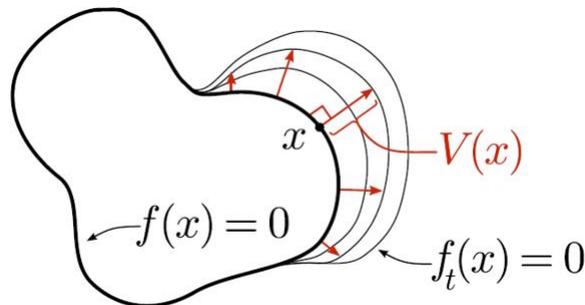
- Reducing time and cost
- More, better design with less material
- Holistic approach to the complex engineering problems



GENERATIVE DESIGN EMPOWERS USER TO EXPLORE AND MULTIPLE DESIGN OPTION IN THE SINGLE SPOT

Levelset topology optimization

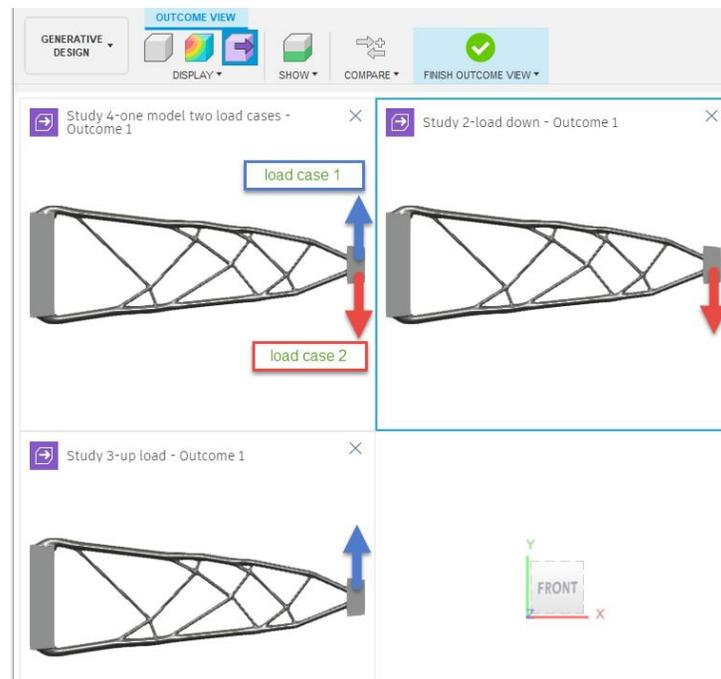
Generative design is a design exploration process. Designers or engineers input design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints.



LEVELSET TOPOLOGY OPTIMIZATION: MODEL THE EVOLUTION OF BOUNDARIES BY A FAMILY OF LEVELSET IMPLICIT FUNCTIONS $F(x)$ AND $V(x)$ CREATES THE DESIRED CHANGES TO THE SHAPE

To conjure the shape from input design goal, Generative design in Fusion use a popular method of Levelset topology optimization. It incorporates an implicit representation of the boundary, commonly as a signed distance function. Voxel based finite element simulation runs on the GPU for fast and accurate structural solutions. Computed finite element response drives the levelset velocity field as form of 'scalar' strain energy field.

A set of structural constraints and loads that act on the generative model at one time. Load cases simulate model behavior under different loads and constraints. You need to define at least one load case for the model. You can define multiple load cases for the same geometry. Here's a catch to define the non-redundant load cases; since the scalar strain energy field drives the topology evolution, applying the same amount of loads in two opposite direction becomes duplication of two equivalent strain energy field and eventually leads same shape.

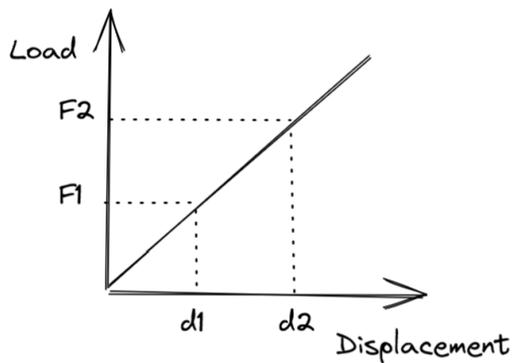


THE SHAPE CHANGES ARE DRIVEN BY THE SCALAR, STRAIN ENERGY DENSITY FIELD.

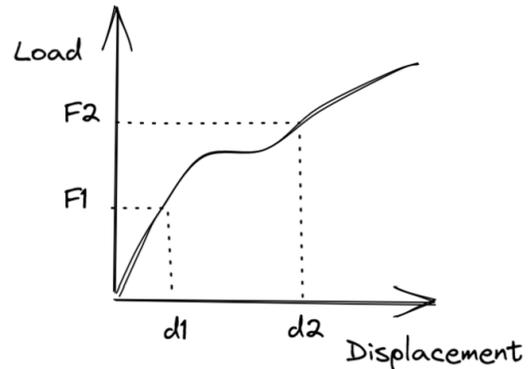
Use Event simulation with Generative Design

Linear versus Nonlinear

Many generative designs (GD) are thin wall or "spindly" structures. These designs are susceptible to nonlinear effects due to the small cross-section compared to the overall size.



Linear
 $F1/d1 = F2/d2$



Nonlinear
 $F1/d1 \neq F2/d2$

In linear analysis, displacements vary linearly with applied loads. Likewise, stress and strain are linear with the applied load all the way to infinite stress.

- Material: Linear elastic with no yielding, single modulus of elasticity.
- Geometry: change in geometry due to deformation are assumed to be small. Therefore, the stiffness of the structure does not change from the unloading stiffness.
- Contact: displacements are assumed to be small. Otherwise, separation-type contact is the one situation where the results may not be linear (due to the changing contact area as the load is increased).

In nonlinear analysis, the stiffness varies as a function of load.

- Material non-linearity occurs when the material deviates from a straight line modulus of elasticity. Nonlinear material properties occur due to plasticity, rubber-like elastic material, viscoelasticity, and viscous material properties.
- Geometric nonlinearity occurs when the deformation is very large relative to the dimensions of the model under load. When the shape of the model changes, the stiffness of the structure changes. Nonlinear displacement can include effects such as buckling, etc.
- For contact/boundary nonlinearity, it is caused by contact between two objects. This is because when contact occurs, the load conditions and constraints that were initially applied change.

Nonlinear effects (materials, geometry, contact) do not have to be applied simultaneously when performing nonlinear analysis. Therefore, the user must always understand the dominant nonlinear mechanism in the structure of interest.

Why do we use an Event simulation in Fusion 360

Event simulation is used to simulate time-dependent, dynamic events, such as impact analysis, where load curves control the magnitude of applied loads and prescribed displacements as a

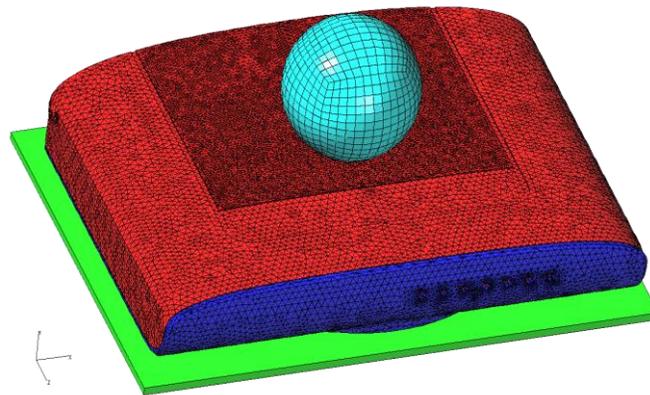
function of time. Event Simulations generally involve very small time increments and short overall event durations. A typical example is simulating the behavior of protective eyewear or helmets during an impact event.



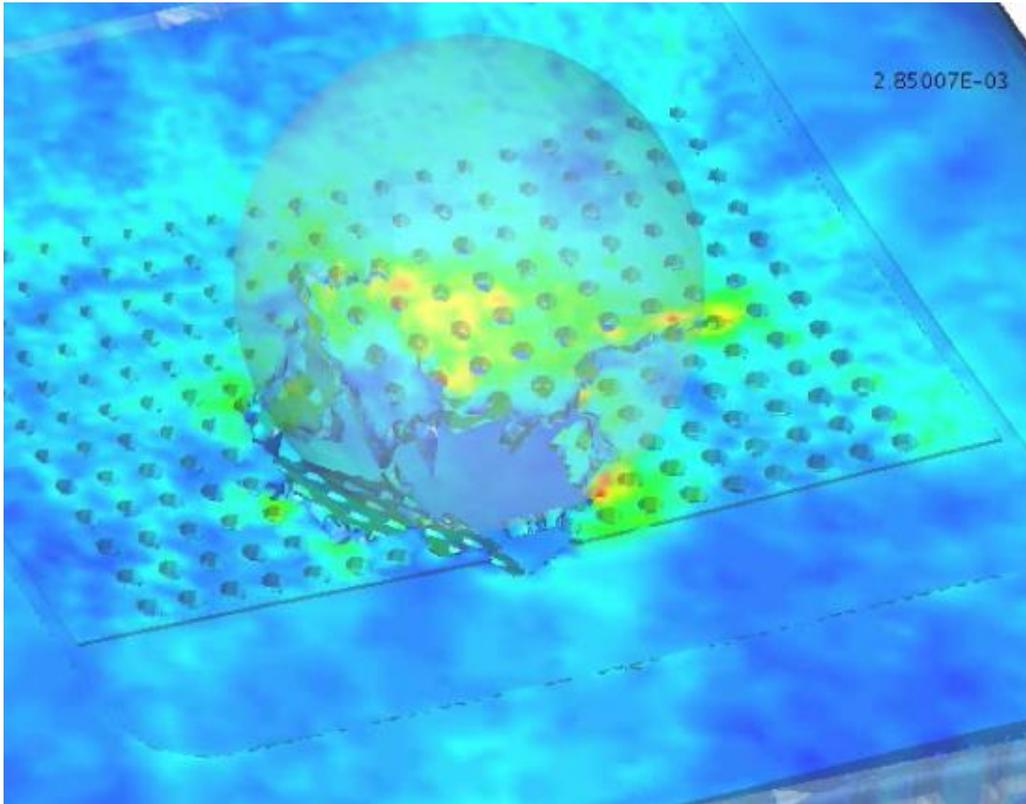
IMPACT ON SAFETY GLASSES

Event simulation includes the nonlinear effects above, but it also has the following features:

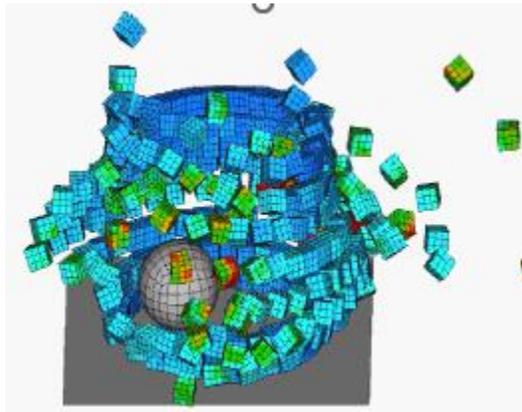
- Uses an explicit solver which forms no element stiffness matrices. It does not require the solution of a set of linear algebraic equations. Therefore, it has a very small memory footprint. A larger model in event simulation uses less RAM than the equivalent nonlinear static model.
- Explicit solvers are extremely robust; they always converge!
- Models can “break” and be “torn apart”. The solver creates new contact surfaces on each step.
- The solver picks the time step **automatically**.



IMPACT OF A WI-FI ROUTER WITH A BALL.



ROUTER CASE BREAKING DUE TO IMPACT. (BALL SHOWN TRANSLUCENT FOR CLARITY.)



A TOWER OF BLOCKS WITH CONTACT UPDATING AS THE BLOCKS FLY APART.

What's the catch in Event simulation

If event simulation is “so great”, why is it not used for everything?

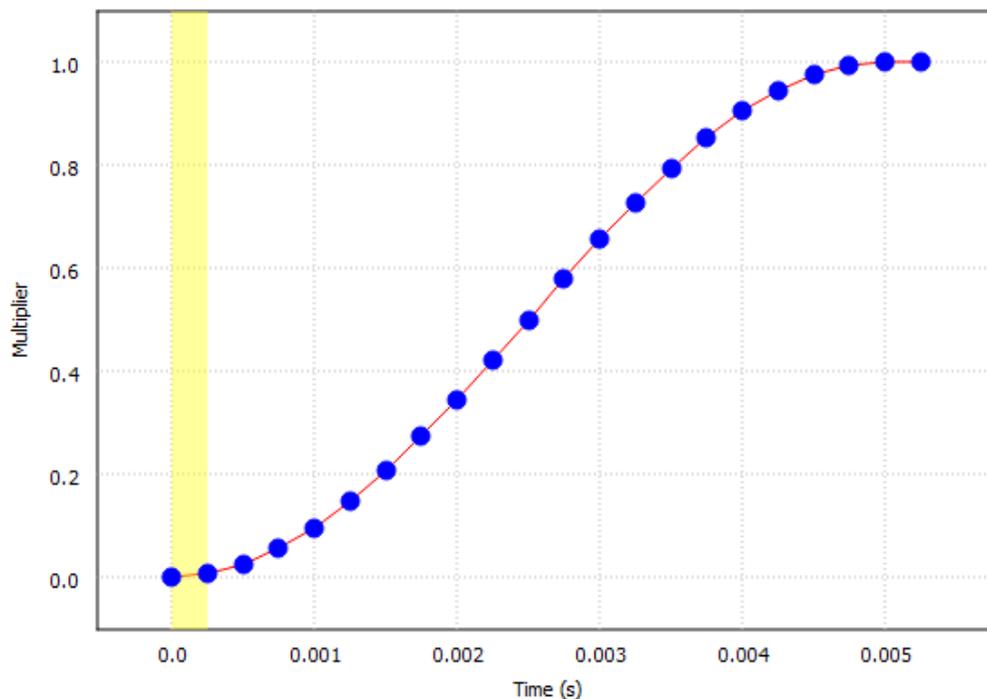
- The solver picks the time step **automatically**.

Since event simulation is a transient analysis, the time is incremented in steps from time 0 to the duration. The “catch” is an explicit solver requires the time step to be a certain size based on the speed of sound in the material.

- Time step size typically on the order of 1E-6 to 1E-8 seconds.
- To calculate an event 1 second long requires 1- to 100-million time steps.
- That can lead to a long runtime in a large model.
- Mass, stiffness, and minimum dimension control the automatic time step size.
- Fusion limits the runtime to 12 hours.

The time step size can be a hindrance for “long” duration events, but the robust “convergence” also provides an advantage that can be exploited. To get the best from an event simulation analysis, follow these guidelines:

1. Eliminate sources of sliver mesh on the surface such as tight corners.
2. Use realistic mass density and modulus of elasticity.
3. Start with a very short duration (1E-5 to 1E-3). A short duration will reduce the runtime, and getting quick results will show if setup is correct and how long it takes to run.
4. The runtime is approximately proportional to duration. If a longer duration is of interest, increase the duration based on the desired runtime. For example, if an event duration of 1E-5 seconds solves in 5 minutes, a duration of 1E-3 seconds (100 times longer) will solve in 500 minutes (=8.3 hours, 100 times longer).
5. If a static result is desired, use the longest duration practical, and ramp the loads using a sine curve.



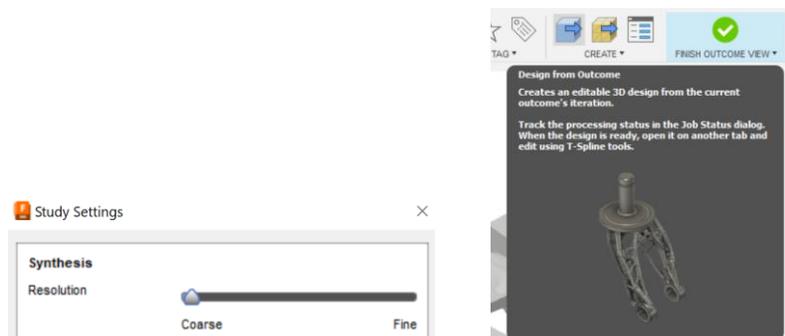
A SINE CURVE TO START THE LOAD GRADUALLY (REDUCING THE SHOCK) AND RAMP THE LOAD TOWARDS THE FINAL VALUE (REDUCES THE KINETIC ENERGY) CAN BE USED TO BETTER APPROXIMATE A STATIC CONDITION IN AN EVENT SIMULATION.

Tuning Generative design model

Be an experimentalist

For successful use of the Generative Design, being an experimentalist helps. The users need to be open-minded on the various traditional tools and even non-conventional tool. Here are a number of tips you can start with:

1. Starting small: please start with coarse resolution with very simple boundary conditions
2. Iterating design with the simulation: the right assessment of working design is essential, even FEM under the hood drives Generative design
3. Refining the model by:
 - a. Use the previous outcome as a starting geometry
 - b. Add more load cases and boundary condition; this will suppose on the top of previous boundary conditions
 - c. Apply max. displacement or manufacturing constraints
 - d. Change the Synthesize resolution



A FEW TIPS: 1) STARTING COARSE RESOLUTION WITH SINGLE SIMPLE LOAD CASE HELPS TO GUIDE THE DIRECTION OF MODELING WITH QUICK RESULTS 2) EXPORTING DESIGN OUTCOME FOR SIMULATION ASSESSMENT OR STARTING SHAPE FOR NEXT GENERATIVE DESIGN OPENS THE POSSIBILITY BETTER DESIGN.

Real-life loads examples

Real-life Loads	Est. magnitude in N
Smart phone weight	1-2 N
Breaking chicken egg	50 N
Human grip	225-500 N
Human bite	720 N
Standing Human	1k N
Load on Seatbelt/Airbag at 100 km/h car crash	100k N

Explore more features and parameters

▼ Generative Design

This section controls optional capabilities in the Generative Design workspace.

Die Casting 

Adds a new manufacturing method. It enables you to generate outcomes which can be manufactured using die casting operations. [Learn More](#)

Experimental Generative Solvers and Features 

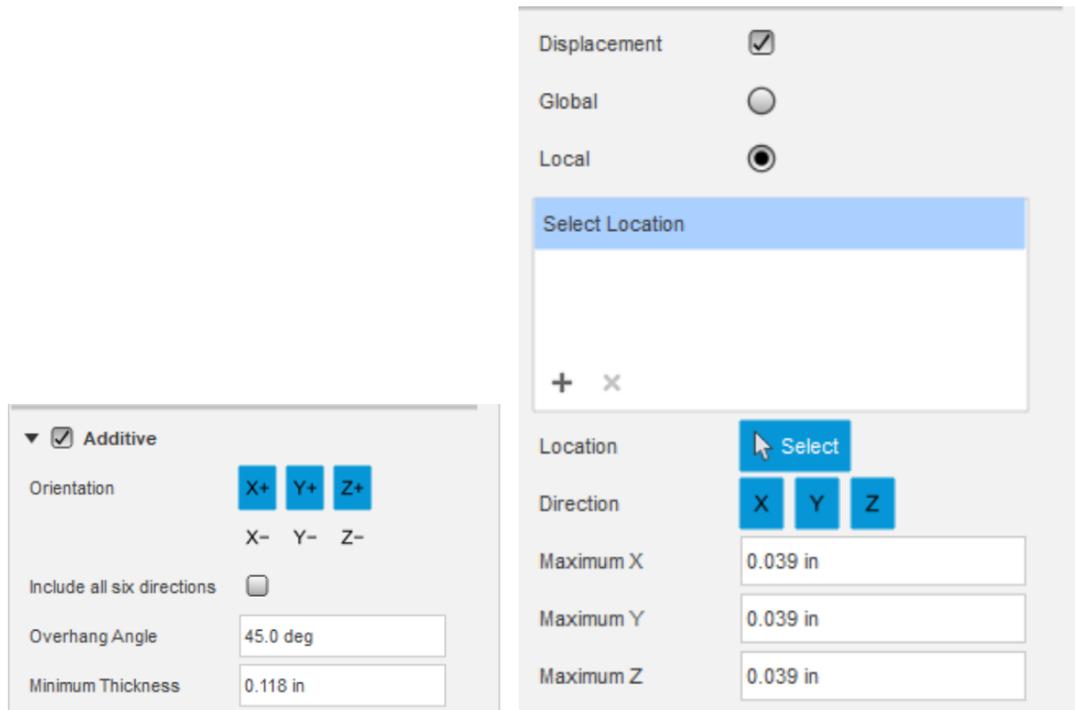
Allows the use of 'in-development' experimental solver technologies and features for the creation of generative outcomes. Features included are displacement limits, modal limits, outcome symmetry, multiple shape engines, and others. [Learn More](#)

Fluid Path 

Adds a new Fluids study type. It enables you to generate a flow path optimized for pressure drop based on geometric and performance requirements that you specify. [Learn More](#)

ACTIVATE EXPERIMENTAL GENERATIVE SOLVER FEATURES

On the top of minimal setup of generative design, users can impose various design constraints to prescribe the design intentions – weight limit, manufacturing method, displacement limit and symmetry. Generative design in Fusion offers more options to improve your model as an open preview for experimental features.



ADDITIVE MANUFACTURING CONSTRAINTS AND DISPLACEMENT CONSTRAINTS

Additive manufacturing constraint offers the generated shape requires minimal supporting structure during 3d printing by regulating the overhang angle and minimum thickness of the shape. Use this method to generate outcomes which can be manufactured using additive

manufacturing processes. For this method, manufacturing constraints include three printing build directions (X+, Y+, Z+). You can select one or more build directions using the Orientation buttons. Each selected build direction generates a separate set of outcomes. Additive enables manufacturing of complex parts. It is easy to change a part through changes in the CAD file. It can help reduce material costs and waste.

Displacement constraints enables you to include displacement limits in the generative design process. You can specify global or local displacement limit.

- **Global** - determines the maximum global displacement of your design.
- **Local** - determines the maximum local displacement of a part of your design. You can define it for one or more locations in your design that belong to the preserve geometry, such as a face, edge, or vertex.

Unlike conventional CAD, user can only indirectly engage the outcome of the generative design. With these two design constraints, user can regulate the generic thickness of organically generated part and maximum allowable deformation by the structural load.

Demo1 : Compound bow

Outline

As an example, the bow in a compound bow will be analyzed. The pulleys are not included in this example.

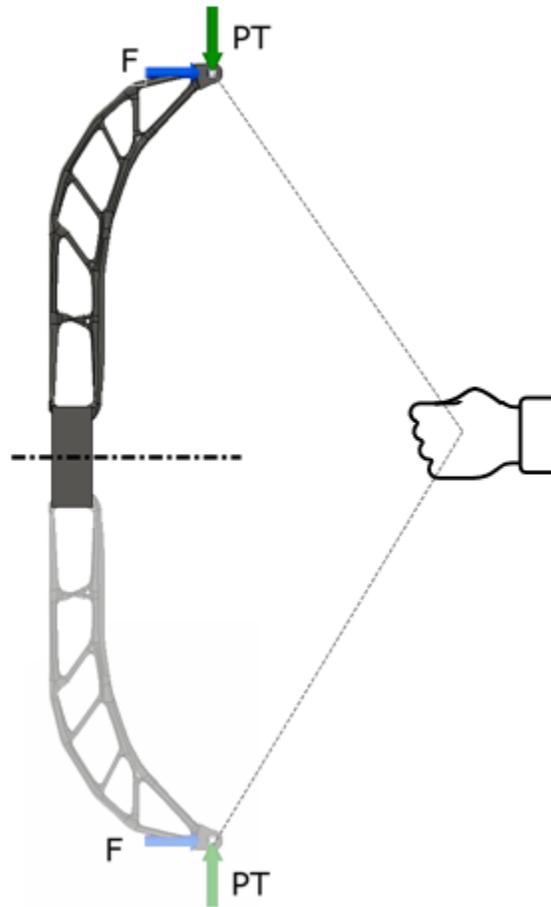


EXAMPLE: USE GENERATIVE DESIGN AND EVENT SIMULATION FOR A BOW.

Disclaimer: this example shows how to use Generative Design and Event Simulation using a bow as an example. This is not how to design a bow!

Generative design modeling

Because of symmetry, only the top half of the bow needs to be created.



SCHEMATIC OF ANALYSIS. ONLY THE TOP HALF NEEDS TO BE MODELED.

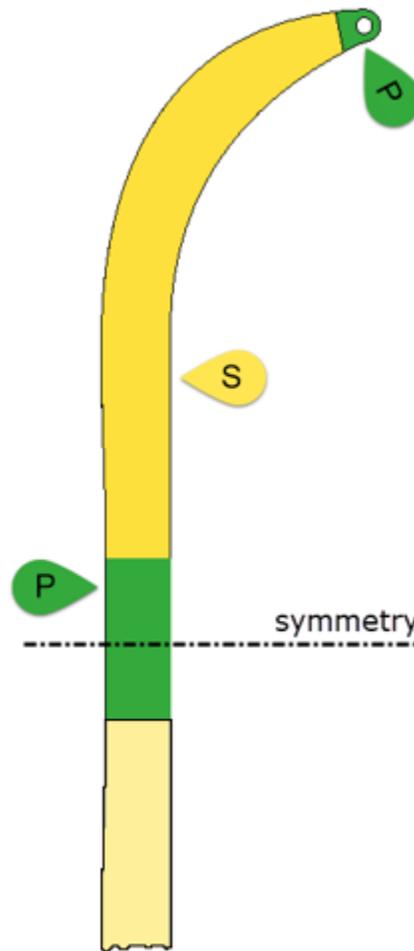
Geometry Types

A GD model is similar to other simulation models except for the obvious differences; namely, GD creates and adjusts the shape! However, there are three types of geometry that can be created or need to be created (see the figure below):

- Preserve (P) – These are volumes to keep and must be created and selected as preserves. Preserves are areas where loads and constraints are applied. Additional material can be created around the preserve, but the shape of the preserve will remain the same.
- Starting Shape (S) - where new volume is created and shaped. These regions are optional. If not provided, GD will create what it thinks is the optimal shape between the preserves. If provided, the shape will generally be confined to the starting region, mainly

because GD tries to minimize the volume, and the volume will not be minimized if it extends greatly outside the starting shape.

- Obstacles (O) - where not to create new volume. Obstacles are optional, and none are provided in this example. An obstacle body could have been included in the region of the pulley to prevent GD from creating the bow where the pulley needs to be.



GD MODEL WITH PRESERVES (P) AND STARTING SHAPE (S)

Loads and Constraints

Generative Design is a static analysis and includes the loads and constraints typical of a static simulation:

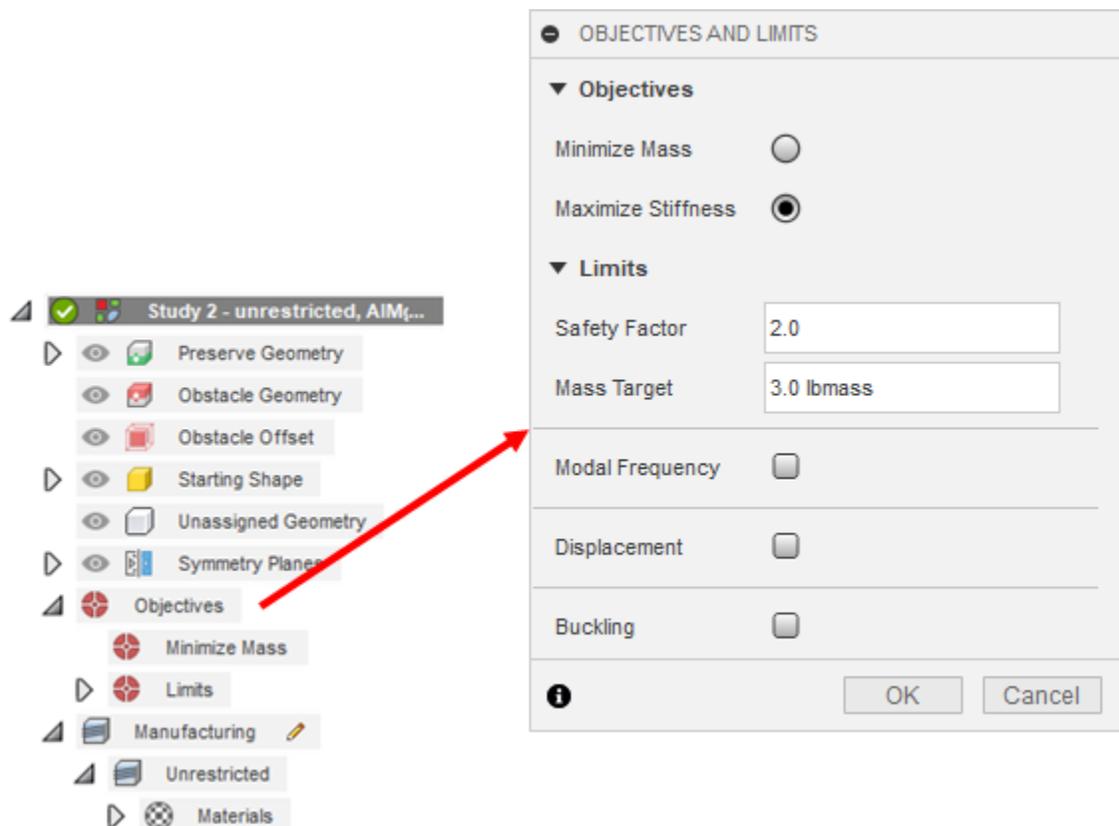
- Types of Loads:
 - Force
 - Pressure
 - Moments
- Type of Constraints:
 - Fixed
 - Pinned

- Frictionless
- Multiple load cases:
 - Yes, but not necessary to use excessive number of load cases. Only the loads that capture the extremes are needed.

Objectives and Limits

Objectives and limits of the GD are set from the browser (see Figure below) or the ribbon.

- Objectives include minimizing the mass or maximizing the stiffness.
- Limits include the safety factor, mass, natural frequency, displacement, or buckling load multiplier.

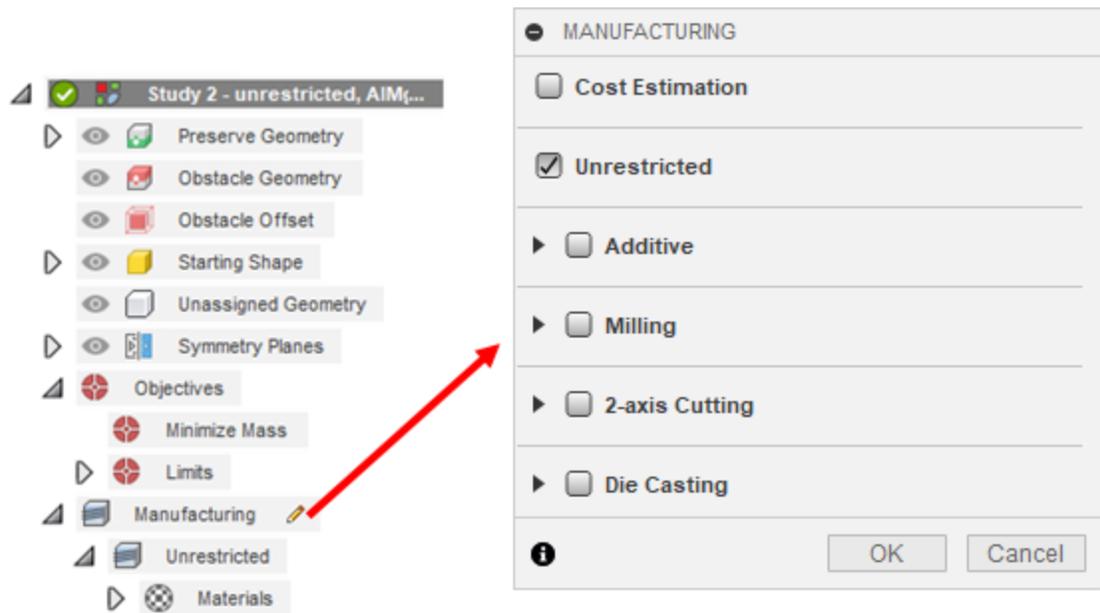


OBJECTIVES AND LIMITS

Manufacturing Methods

Manufacturing methods include Unrestricted, Additive, Milling, 2-axis Cutting, and Die Casting. Unrestricted gives the most free-form shapes and is a good option to begin with. It is like brainstorming!

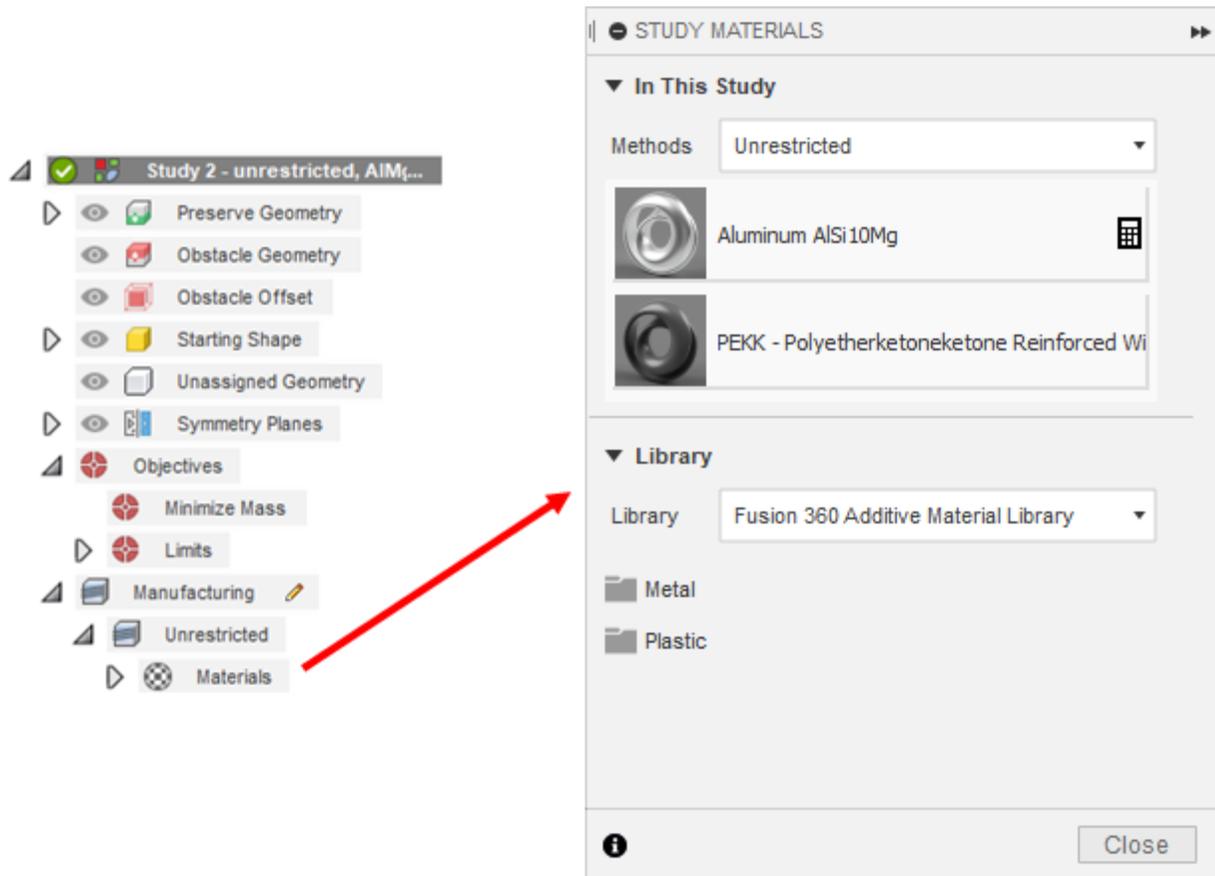
Of course, choose a specific method if it is known that the choices are limited to X-Y-Z.



MANUFACTURING METHODS

Materials

Multiple materials can be selected. Choose the library (bottom half of the Study Materials dialog, see the figure below) and then drag the material to the “In This Study” (top half of the dialog). All selected materials will be used in all manufacturing methods. Do not use an excessive number of materials and manufacturing methods; otherwise, the combination will result in a huge number of outcomes which takes time to compute and time to go through. Use the KISS principle: Keep It Super Simple.



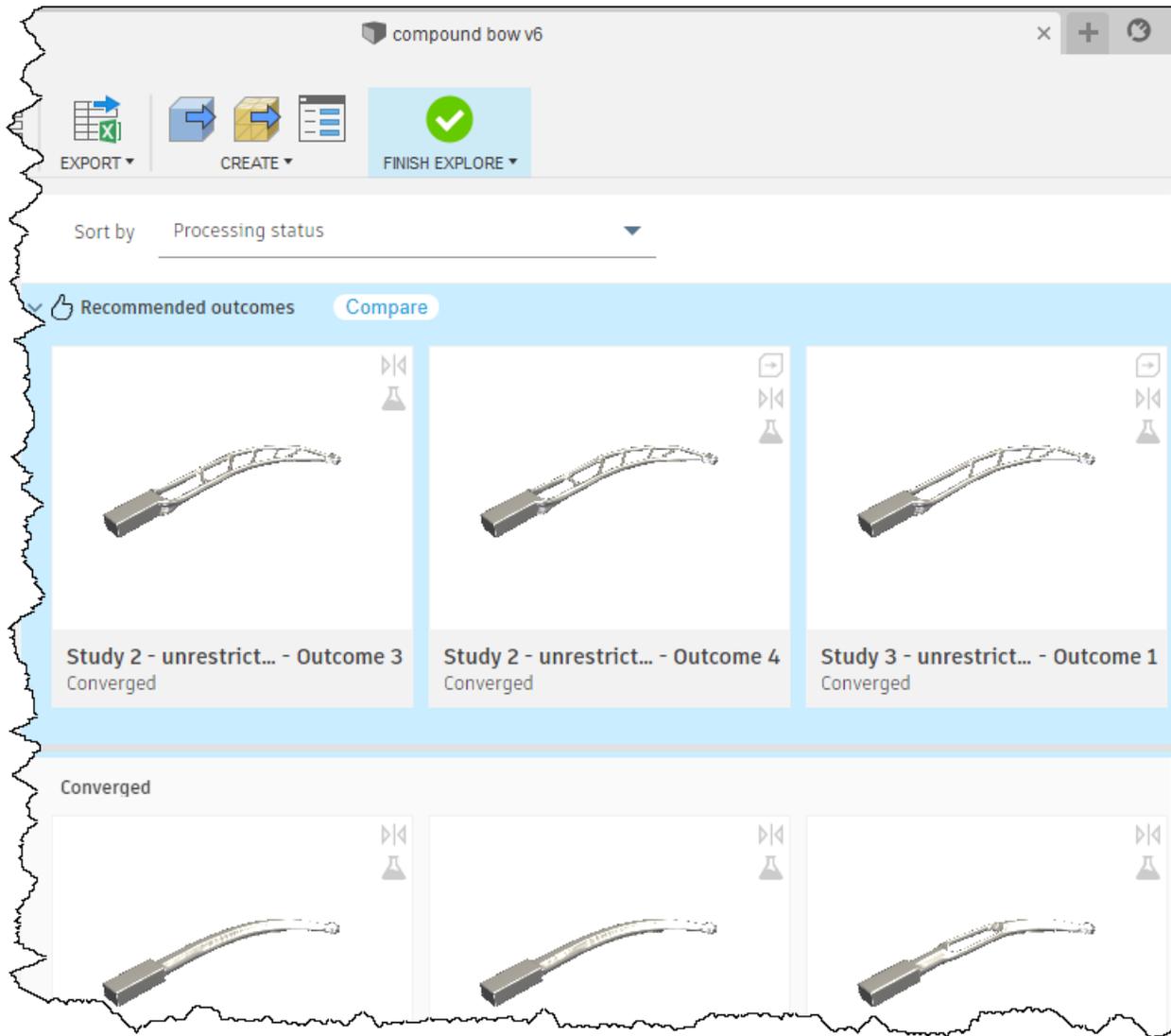
SELECTING MATERIALS FOR GD

Explorer (Outcomes)

While the GD is running, results will be shown in the Explore tab as they are created. This provides the opportunity to watch the creation while it runs.

Click an Outcome to see details about the design (See the figures below). There are three main regions of the Outcome View to pay attention to:

1. Results are shown under the preview. Note that the stress and displacement results are approximate. The stress is approximate because sharp edges that create a stress concentration or “singularity” are overlooked by GD. The stress and displacements are approximate because of the element size.
2. Each outcome has different “Iterations”. All iterations are valid but may not meet the criteria. Use the slider to review the different iterations.
3. The chosen iteration can be exported to a model for further analysis. The exported model can be edited, too, such as trimming material, adding more geometry, and so on.



EXPLORE OUTCOMES AS THEY ARE GENERATED.

Compound bow v6

CREATE FINISH OUTCOME VIEW

Study 2 - unrestrict... - Outcome 4
Iteration 23 (final)

Properties

Visual similarity	Group 2
Production volume (pcs.)	-
Piece part cost	-
Range (USD)	-
Median (USD)	-
Fully burdened cost	-
Range (USD)	-
Median (USD)	-
Volume (in ³)	25.156
Mass (lbmass)	1.263
Max von Mises stress (psi)	4,423.649
Factor of safety limit	2
Min factor of safety	2
Max displacement global (in)	0.828

Iterations 20 23

Cost estimates powered by aPriori

OUTCOME VIEW SHOWS THE DETAILS FOR THE SELECTED OUTCOME. EACH OUTCOME MAY INCLUDE MULTIPLE RESULTS. SCROLL THROUGH THE RESULTS TO FIND A DESIGN OF INTEREST.

While viewing an Outcome View, the stress contour plot can be displayed. Note there are minimal details shown – low stress, medium, and high stress regions. You need to create a model and perform a simulation to get details.



STRESS RESULTS IN GD ENVIRONMENT

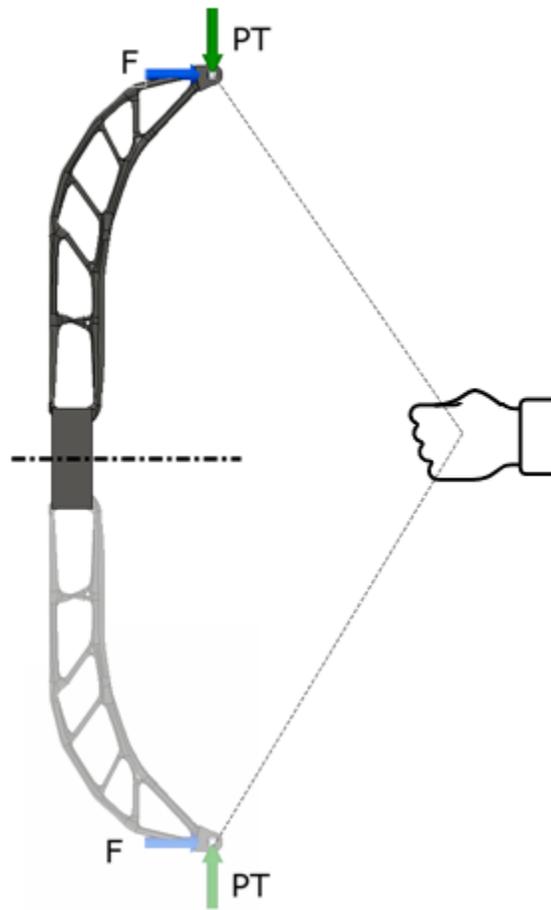
Event simulation setup

Once a generative design is chosen and output as a model, an in-depth simulation can be performed. In this example, an Event Simulation is performed because of the anticipated large displacement effects. (The ends of a compound bow may move several inches (hundreds of mm) toward each other.)

The concept used here is shown in the figure below. These aspects are typical of most types of analyses, not just Event Simulation:

- Symmetry is used since the geometry and results are expected to be symmetric about the handle.

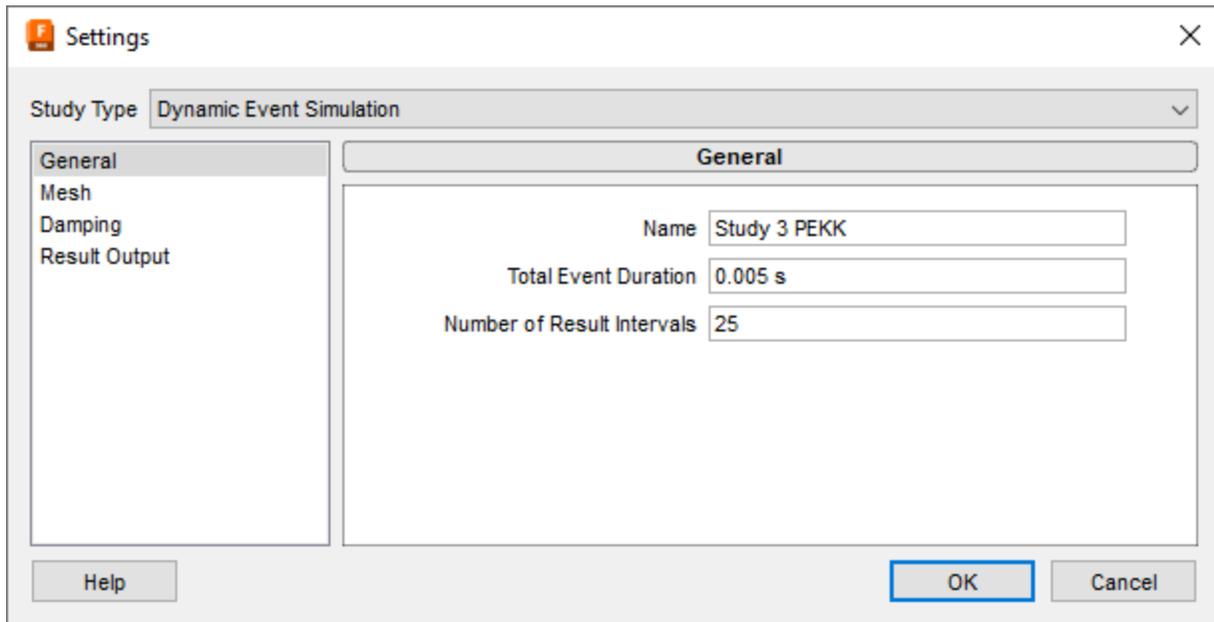
- A horizontal force “F” is used to simulate the tension of the bow string.
- A prescribe translation “PT” is used to simulate the action of the control cables (not shown in the diagram) acting on the cams. This is a known dimension that changes the vertical axle-to-axle dimension.
- A constraint is applied to the handle to hold the bow.



SCHEMATIC OF EVENT SIMULATION.

Event Simulation Settings

The input that is unique to Event Simulation is the Settings (“Manage > Settings”).

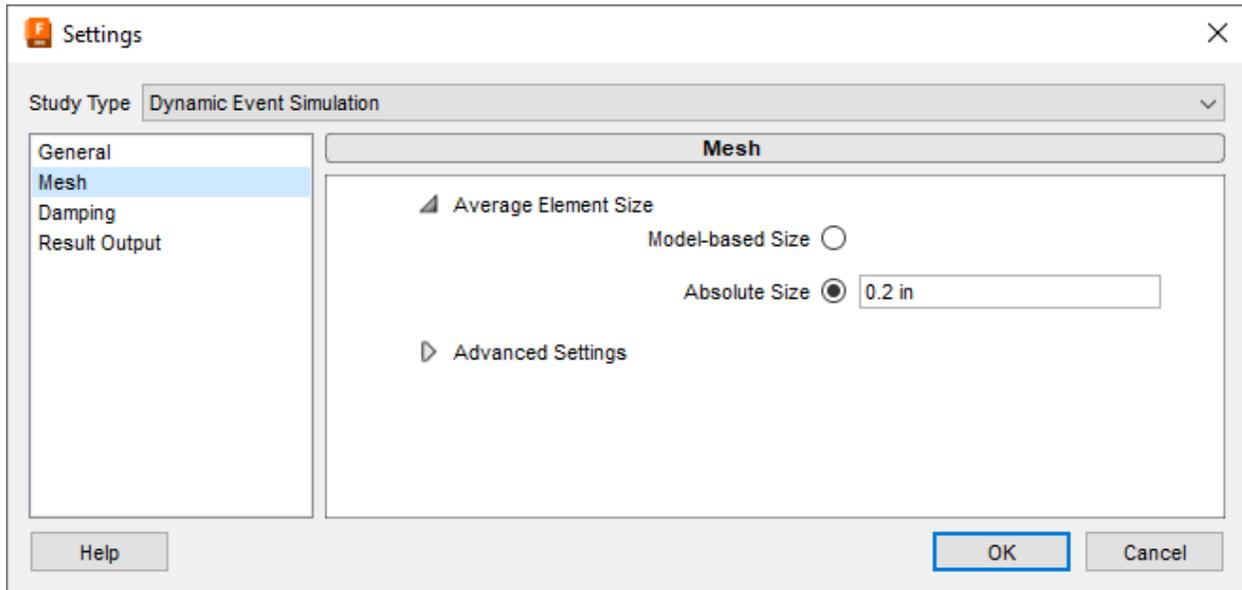


DURATION INPUT

Remember: the time step size is calculated by the solver.

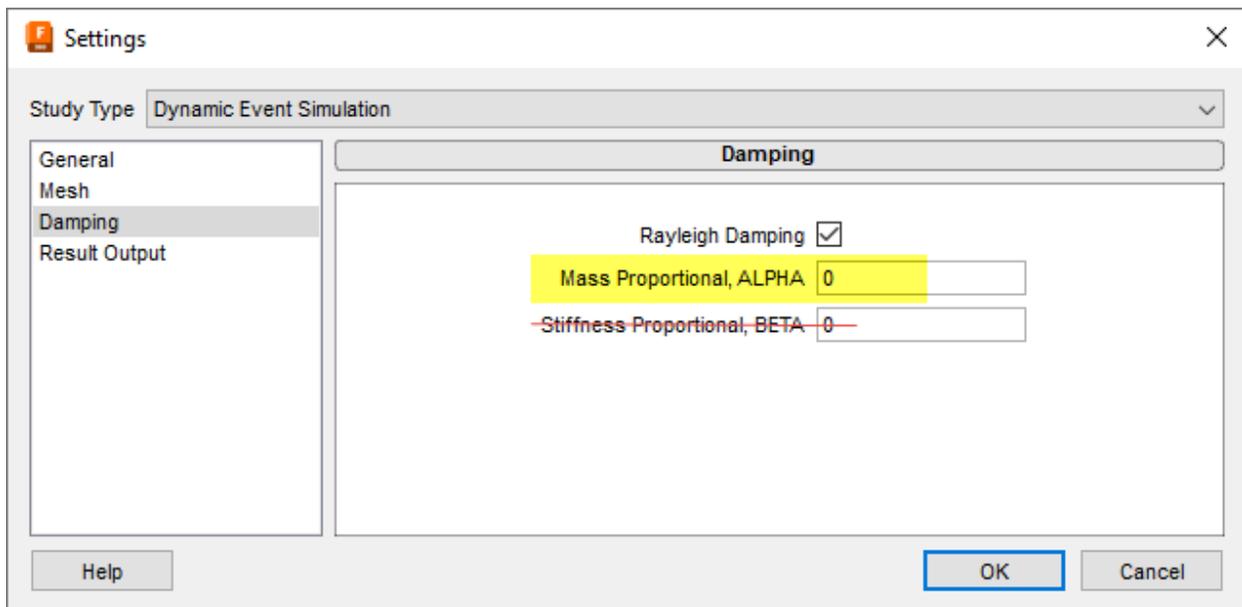
- The “Total Event Duration” (along with the solver determined time step size) determines how long the analysis will run. The true duration of pulling the bow string may be on the order of 0.5 seconds. As described previously, this needs to be exaggerated (shortened) to reduce the overall runtime.
- The “Number of Results Intervals” only determines how many results are output. This value does not affect the time step size. In fact, the number of results has only a negligible effect on the runtime. Use more output steps to see more results as the loads build from 0 to full load.

Note: If this were an impact analysis, the duration needs to be long enough to capture the impact and rebound. This cannot be shortened to reduce the overall runtime.



MESH SIZE

Since the solver calculated time step size is related to the smallest element in the model, use the largest mesh size possible – provided such a mesh size does not create distorted elements. When working with an assembly that includes a mix of “large” parts and “small” parts, use an “Absolute Size” so that the small parts do not generate excessively small elements.



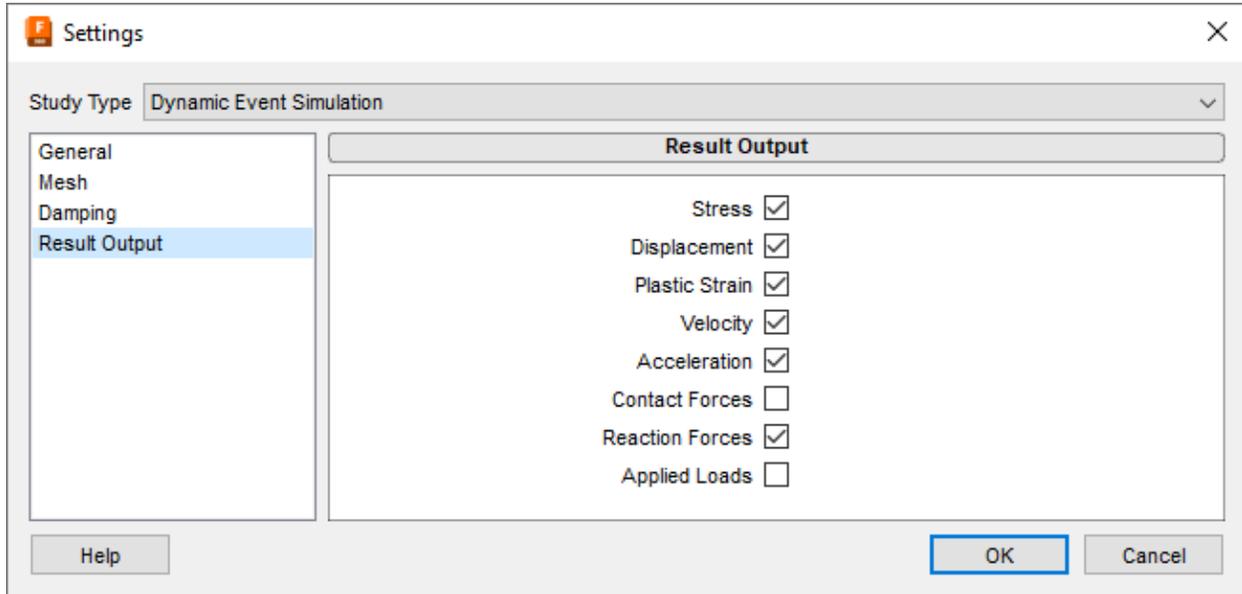
DAMPING

If damping is used in the analysis, use mass proportional damping if possible.

- Mass proportional damping does not affect the time step size.

$$ALPHA = 4\pi \cdot (\text{fraction of critical damping})$$

- Stiffness proportional damping does reduce the time step size which increases the runtime.



RESULT OUTPUT

Select which results are desired to be save before running the analysis.

Event Simulation Load Curves

Since the Event Simulation is a transient analysis, all loads can be assigned to a “Multiplier curve” which describes how the load changes with time. In this example, the duration is faster than real life, so the goal of the multiplier curve is to reduce the dynamic effects (and kinetic energy) due to the reduced duration.

Select the “Multiplier curve” button on the load dialog and enter a sine curve. The data points can be created in Excel and Copy+Paste into the Multiplier Curve table. Use approximately 20 points or more over the duration and calculate the multiplier versus time as follows:

$$Multiplier = A \sin \left(2\pi \cdot \frac{time}{(2 \cdot duration)} + Phase \right) + offset$$

where

- A is the amplitude of the sine curve (use 0.5 in order to have a maximum multiplier of 0.5)
- Phase is the phase offset (use $-90^\circ = -1.5708$ radians in order to start the sine curve at the minimum value)
- Offset shifts the curve up or down (use 0.5 to start the curve with a multiplier of 0).

PRESCRIBED TRANSLATION

Selection **1 Vertex**

Object Type 

Constraint Type Displacement

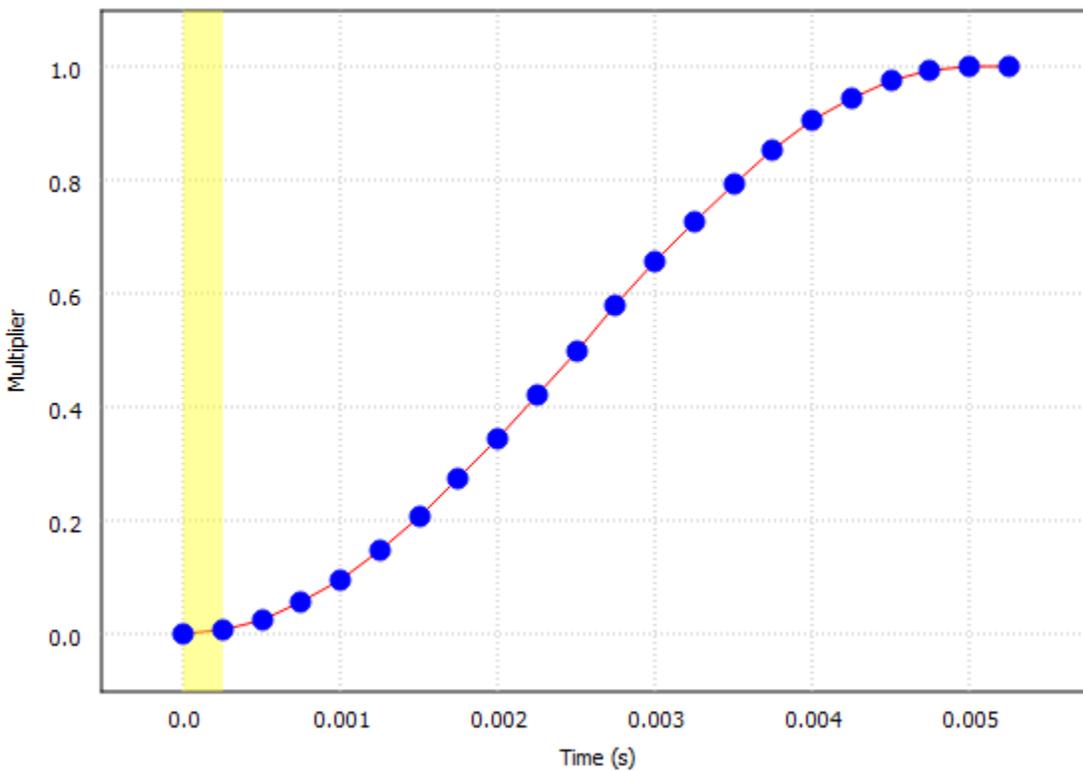
Direction Type Components (...)

Components **U_x** **U_y** **U_z**

Magnitude U_y -3.5 in

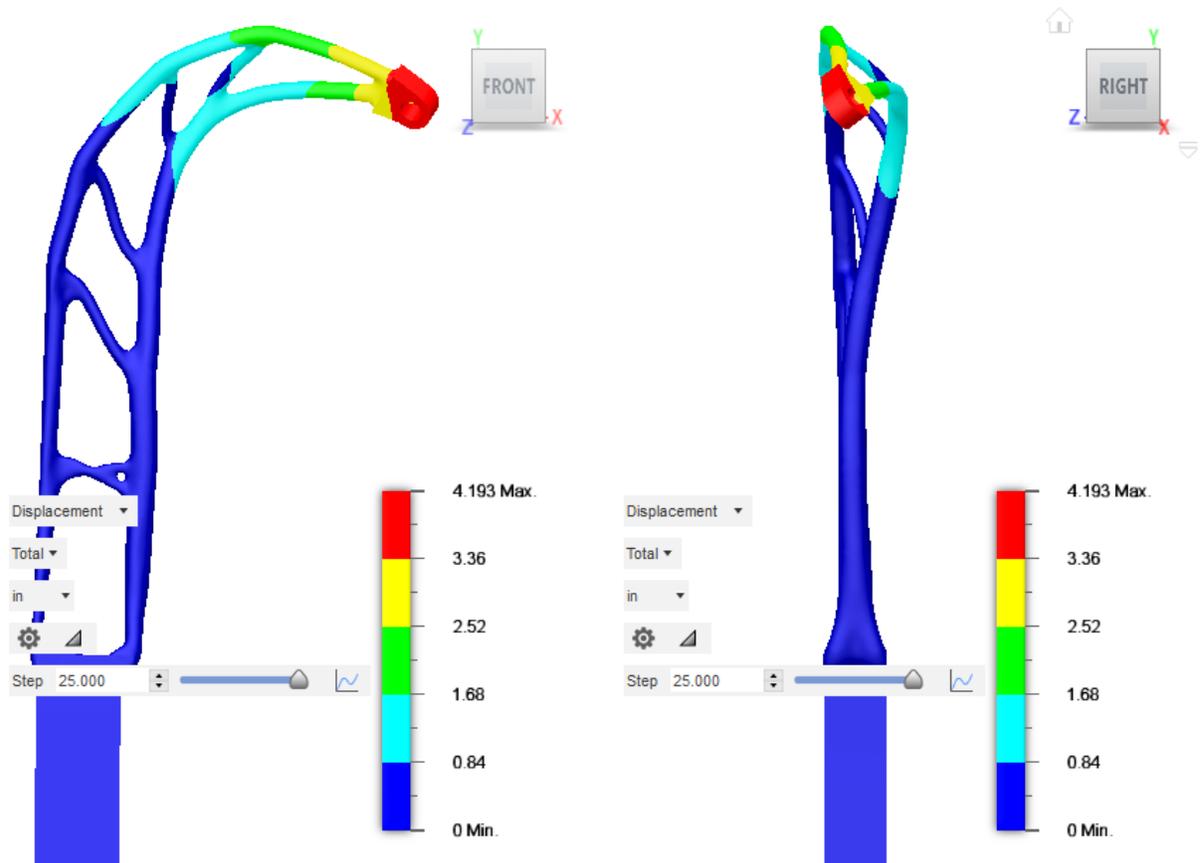
Change Units 

Multiplier curve 



SINE CURVE INPUT FOR PRESCRIBED TRANSLATION

First try



THE NONLINEAR DISPLACEMENT OF THE "SPINDLY" FIRST DESIGN IS NOT GOOD: THE BOW TWISTS/BUCKLES AT THE MAXIMUM DRAW.

Next try

A "beefier" design is required to avoid the possibility of buckling. For the second GD, it was decided to use the Additive manufacturing method. This method allows a limit to be enforced on the minimum thickness. Since the original design included members on the order of 0.25 inch, a 0.375 inch minimum was specified.

MANUFACTURING

Cost Estimation

Unrestricted

Additive

Orientation X+ Y+ **Z+**
 X- Y- **Z-**

Include all six directions

Overhang Angle 45.0 deg

Minimum Thickness 0.375 in

Milling

2-axis Cutting

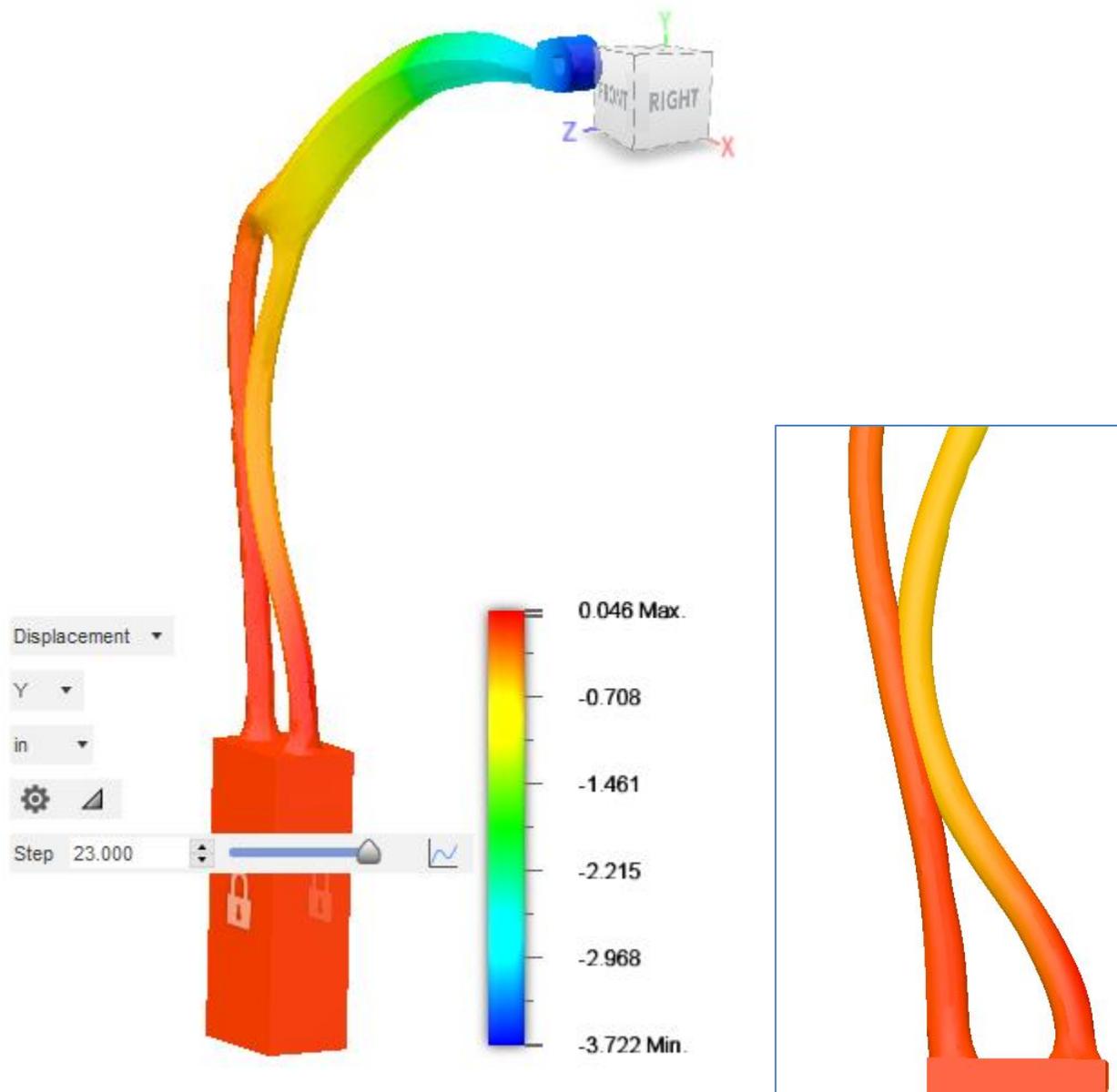
Die Casting

i OK Cancel



ADDITIVE MANUFACTURING WITH MINIMUM THICKNESS SPECIFIED AND OUTCOME.

The new design performs better; at least it does not buckle. However, another potential problem is noted that was unanticipated.

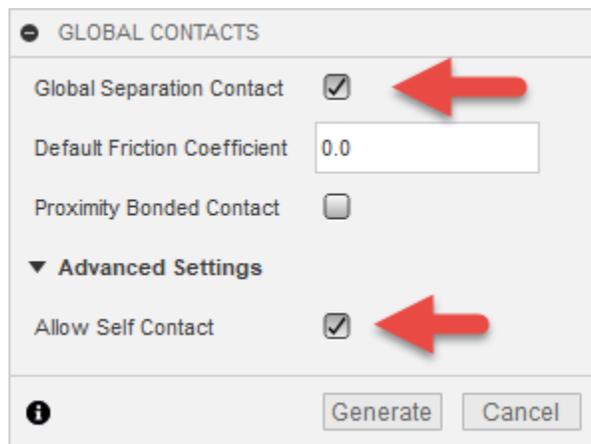
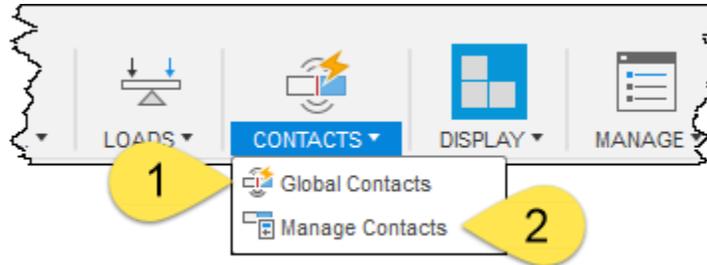


THE DISPLACEMENT IS LARGE ENOUGH THE PIECES TOUCH EACH OTHER.

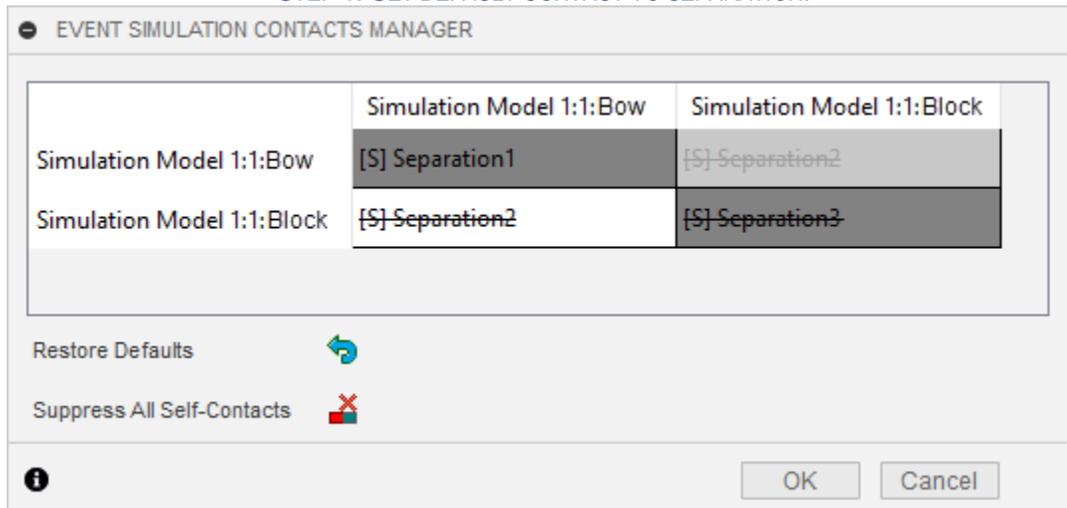
To account for the self-contact, contact is activated in the model:

1. Use "Contacts > Global Contacts" to generate the desired type of default contact.
2. Use "Contacts > Manage Contacts" to adjust the default contacts if desired. In this example, two bodies are included in the analysis: the bow, and a dummy block used to apply the prescribe translation. The only contact is the self-contact of the bow.
 - a. The contact between the dummy block and bow is not needed. Right-click and suppress that contact pair.

- b. Contact between the block and itself is not needed. Right-click and suppress that contact pair.



STEP 1: SET DEFAULT CONTACT TO SEPARATION.



STEP 2: SUPPRESS CONTACT PAIRS THAT ARE NOT NEEDED.

With the contact, the arms of the bow come into contact but do not pass through each other.

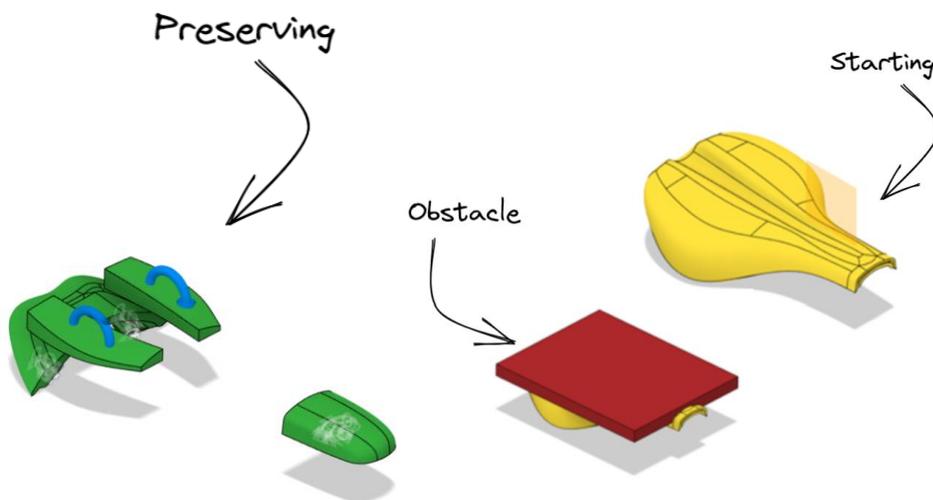
Demo2 : Bike saddle

Outlines



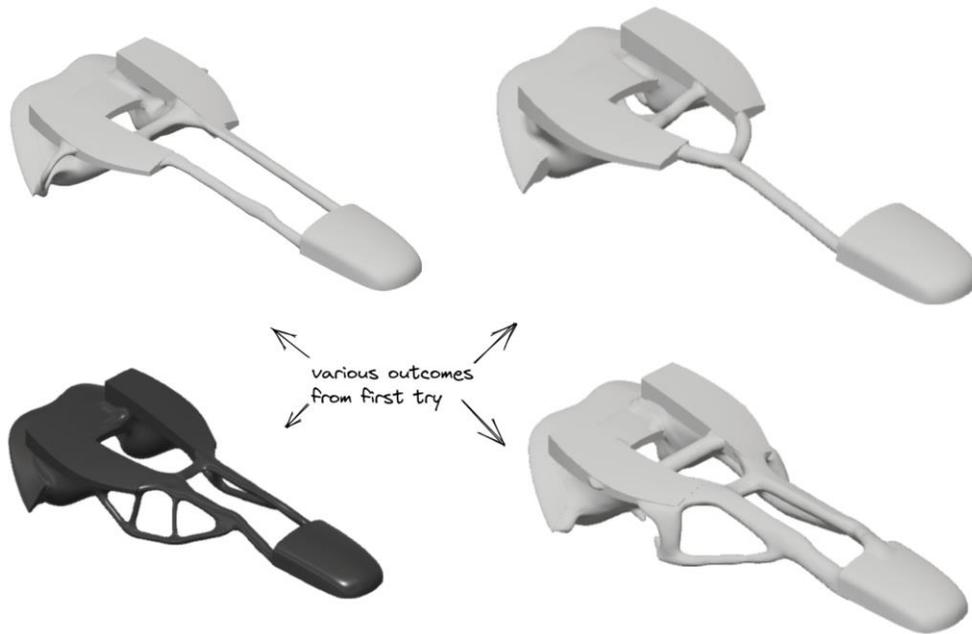
BIKE SADDLE

The second demo of this talk is designing the new bike saddle. The function of bike saddle is deforming by rider's weight and absorb the shock from road to comfort the rider. We select the hyper foam material to deform enough to absorbing impacts while riding. The load is 1k N as pressure where pelvic bone seats and two tangential moments are applied. The fixed displacement constraint is applied for holding the saddle with the seat post rail.



GENERATIVE DESIGN SETUP: PRESERVING, OBSTACLE, STARTING GEOMETRIES

Tuning the model into the better shapes with proper constraints



THE SHAPES FROM GENERATIVE DESIGN WITHOUT THE DESIGN CONSTRAINTS

By the variations of mix matching boundary conditions, we can get four types of design outcome without any GD constraints: the connectivity between the preserving geometries depends on the boundary conditions.

Following iterations of running simulation and generative design we can improve the outcome to reach our specific goals:

1. Run naive Generative Design
2. Run Event simulation analysis on outcomes
3. Tune the parameters in Generative Design
4. Assess again with Event simulation



Naïve GD



w/ Displacement Constraint



w/ Thickness constraint



Mass (kg)	0.149
Max von Mises stress (MPa)	5.398
Factor of safety limit	2
Min factor of safety	2.001
Max displacement global (mm)	10.995

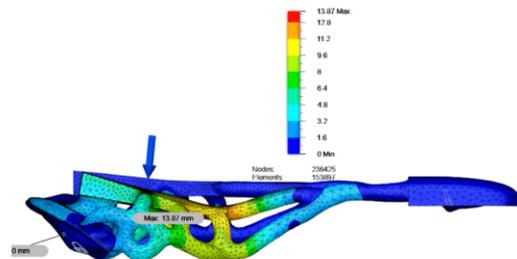
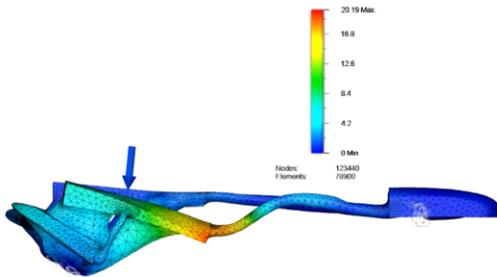


Mass (kg)	0.212
Max von Mises stress (MPa)	2.639
Factor of safety limit	2
Min factor of safety	4.093
Max displacement global (mm)	2.817
Max displacement Y (mm)	2.717



Mass (kg)	0.137
Max von Mises stress (MPa)	3.876
Factor of safety limit	2
Min factor of safety	2.786
Max displacement global (mm)	7.461

TUNING THE NAÏVE GD (LEFT) INTO CONTROLLED DEFORMATION (MIDDLE) OR TARGETED DEFORMATION WITH FAVORABLE THICKNESS (RIGHT)



One side of saddle pad pressed by body weight

EVENT SIMULATION OF NAÏVE GD OUTCOME VS THICKNESS CONTROLLED GD OUTCOME

Summary

- **Event simulation can cover the blindside of assumptions of linear elasticity in Generative Design**
 - Considering Nonlinearity of the given design problem from Geometric, Material, Contact induced nonlinearity.
- Tips for better Generative design and Event simulation/Quasi-static analysis in Fusion 360
 - Start small and coarse
 - Evaluate Design outcomes from GD with Event simulation
 - Improve Generative Design from Event simulation analysis
 - Use Symmetry
 - More load cases
 - Displacement constraints
 - Thickness control in Additive manufacturing constraint