Enhance a Generative Design Model with Event Simulation in Autodesk Fusion 360

IM501270

Jaesung Eom
Prn Research Engineer
@ Autodesk

John Holtz
Sr Technical Support Specialist
@ Autodesk

About Speakers

- 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.

Safe Harbor Statement

We may make forward-looking statements regarding planned or future development efforts for our existing or new products and services and statements regarding our strategic priorities. These statements are not intended to be a promise or guarantee of business results, future availability of products, services or features but merely reflect our current plans and are based on factors currently known to us. These planned and future development efforts may change without notice. Purchasing and investment decisions should not be made based upon reliance on these statements.

A discussion of factors that may affect future results is contained in our most recent Form 10-K and Form 10-Q filings available at www.sec.gov, including descriptions of the risk factors that may impact us and the forward-looking statements made in these presentations. Autodesk assumes no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made. If this presentation is reviewed after the date the statements are made, these statements may no longer contain current or accurate information.

This presentation also contains information, opinions and data supplied by third parties and Autodesk assumes no responsibility for the accuracy or completeness of such information, opinions or data, and shall not be liable for any decisions made based upon reliance on any such information, opinions or data.

Autodesk's partners frequently compete against each other in the marketplace, and it is critically important that all participants in this meeting observe all requirements of antitrust laws and other laws regarding unfair competition. Autodesk's long insistence upon full compliance with all legal requirements in the antitrust field has not been based solely on the desire to stay within the bounds of the law, but also on the conviction that the preservation of a free and vigorous competitive economy is essential to the welfare of our business and that of our partners, the markets they serve, and the countries in which they operate. It is against the policy of Autodesk to sponsor, encourage or tolerate any discussion or communication among any of its partners concerning past, present or future prices, pricing policies, bids, discounts, promotions, terms or conditions of sale, choice of customers, territorial markets, quotas, inventory, allocation of markets, products or services, boycotts and refusals to deal, or any proprietary or confidential information. Communication of this type should not occur, whether written, oral, formal, informal, or "off the record." All discussion at this meeting should be strictly limited to presentation topics.

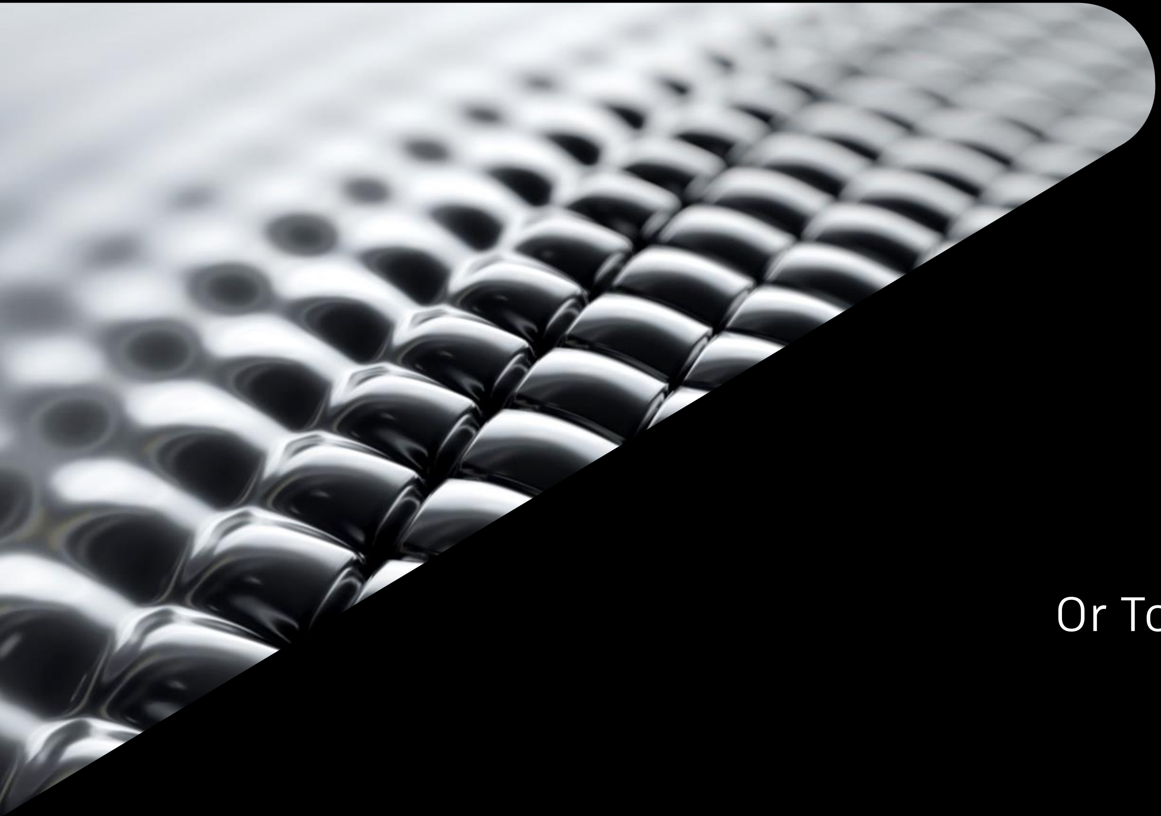
What we present:

1. Tips for Creating a Generative Design and Event simulation easily.

2. Improve designs that are potentially better solutions than other candidates.

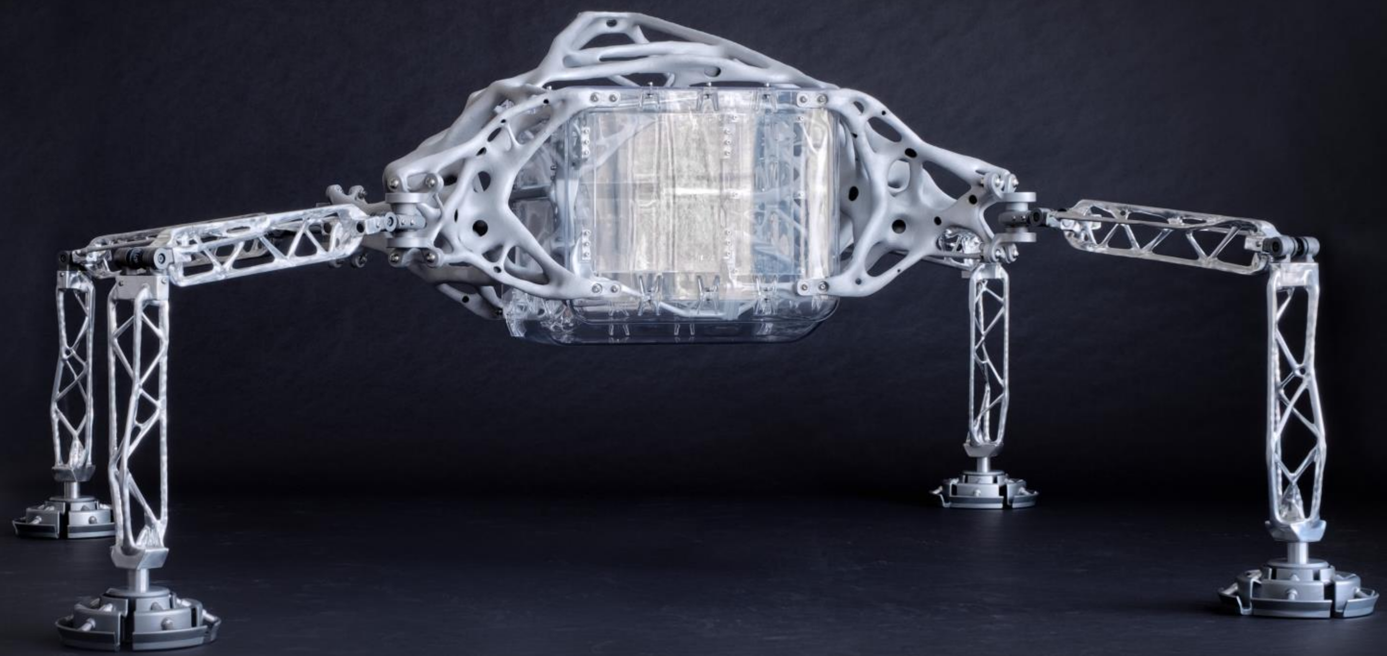
3. Analyze the chosen models with Event Simulation and tune Generative design parameters.

4. Evaluate the results to identify good features of the design and potential problems.



What is Generative Design

Or Topology optimization in 5 mins

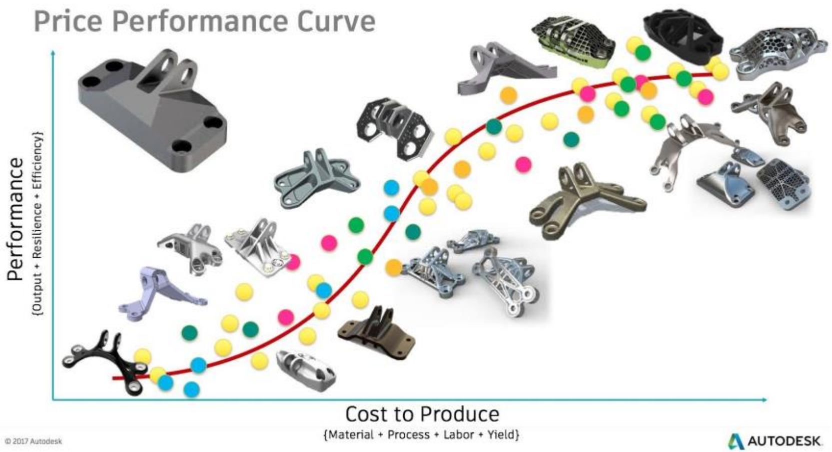


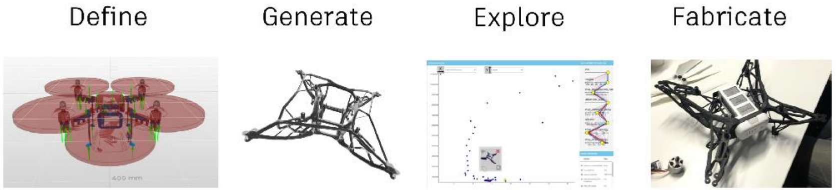
NASA JPL concept lander

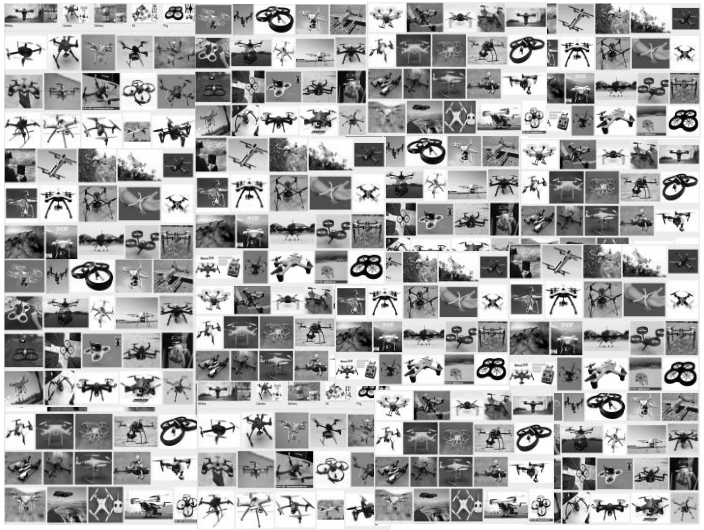
Immediate and future market needs

Promise and potential

- Reducing time and cost
- More, better designs with less material
- Complex Engineering problems
- More manufacturing constraints



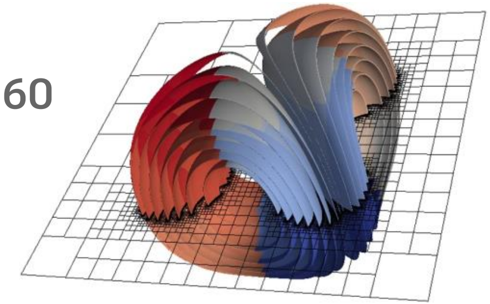


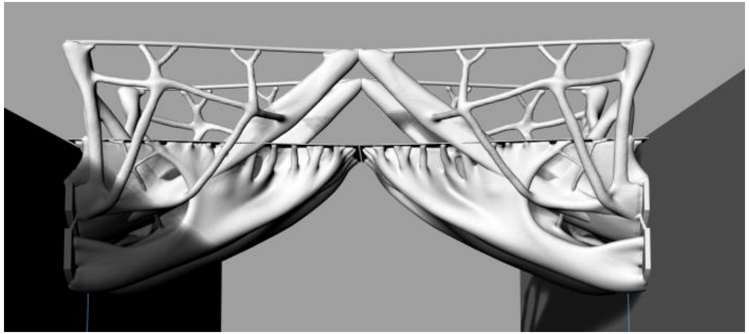


Background

Topology optimization – Generative Design in Fusion 360

- Levelsets for geometry operations.
- Voxel based simulation using GPU accelerated solver
- Various Boundary Conditions : Nodal forces, nodal restraints, element pressure, remote moments and forces
- Topology optimization using levelset algorithm subject to
  - volume constraints
  - Max VM constraints
  - Additive manufacturing
  - Displacement constraints
  - Milling manufacturing of 2/2.5/3/5 axis
  - Casting manufacturing constraints



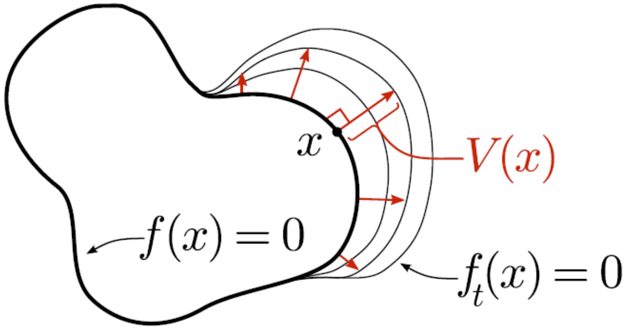


Shape Optimization by Level Set Evolution

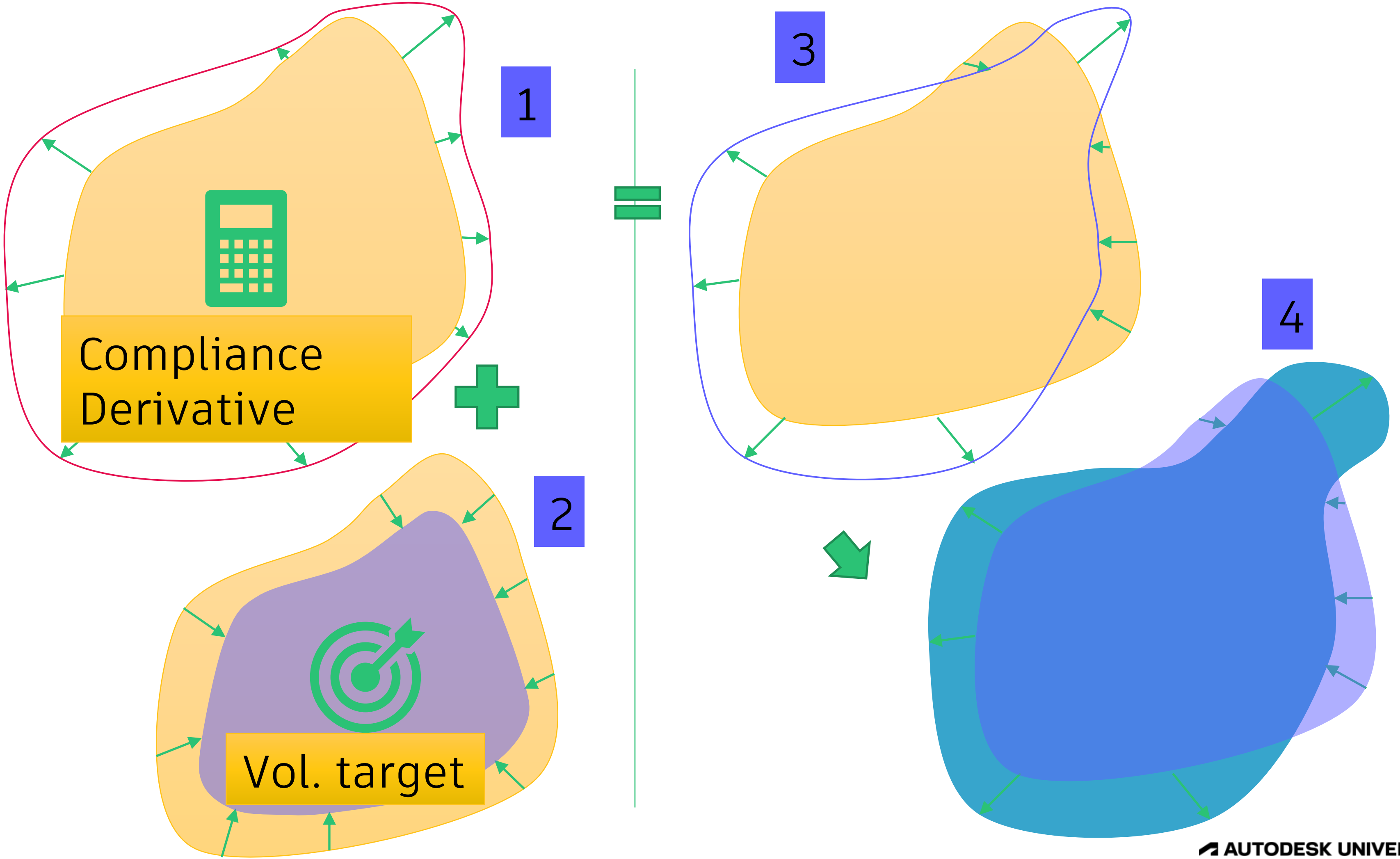
Idea: We would like to perform shape optimization by evolving the boundary of an object.

How:

- Model the evolving boundary by a family of level set functions $f_t : \mathbb{R}^3 \to \mathbb{R}$. Suppose normal velocity is *V*.



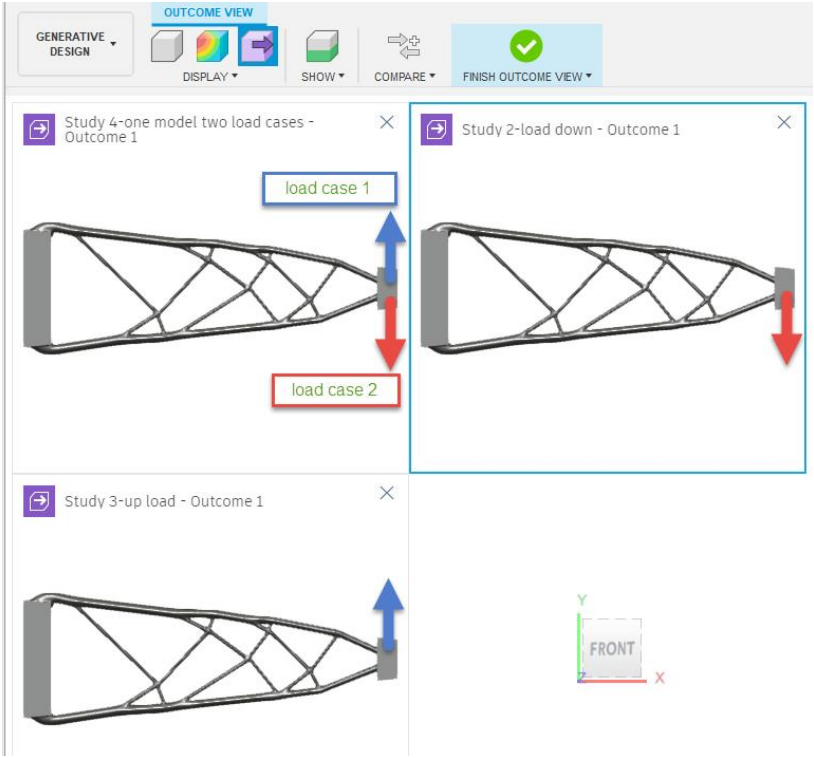
- Choose *V* to create the desired changes to the shape.



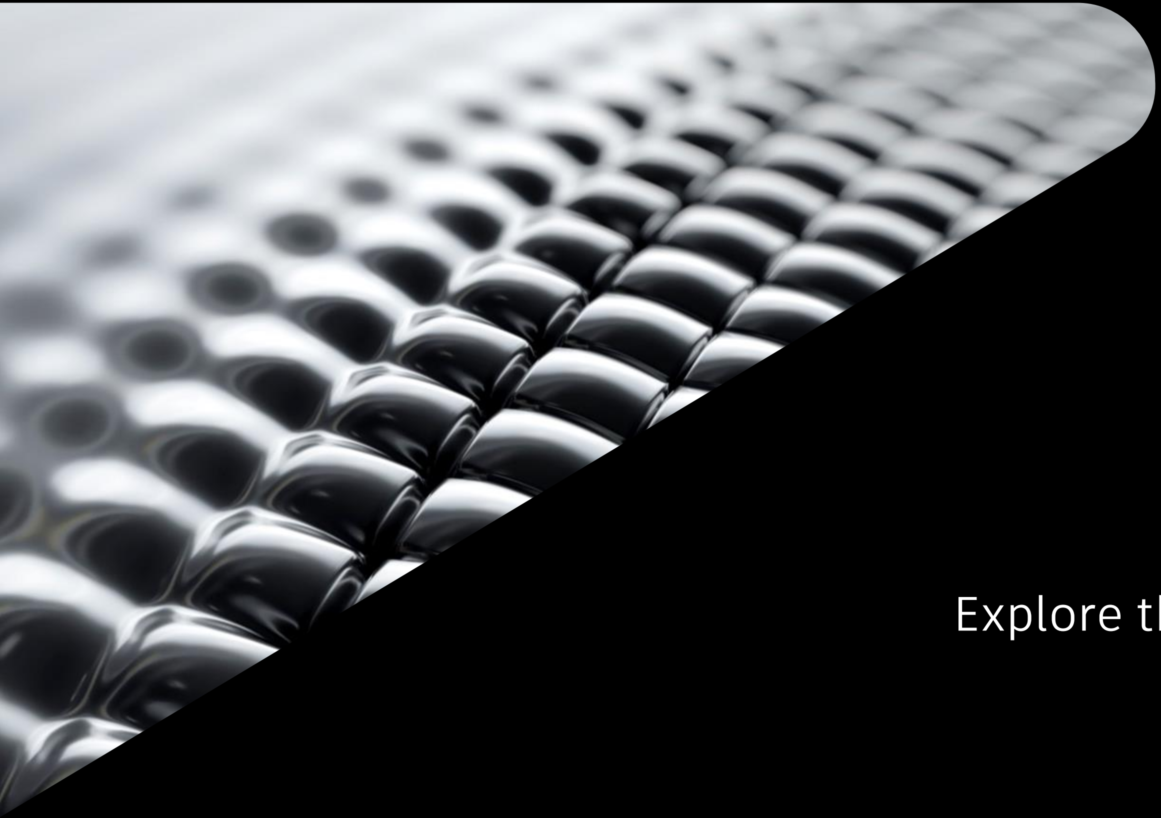
AUTODESK UNIVERSITY

What’s the catch?

Not all load cases matter



- The shape changes are driven by strain energy density field
  - Compliance derivative field = strain energy density field
- Strain energy density is SCALAR
- Be mindful on multiple load cases
- E.g. Loads in different load cases that are **equal** in **magnitude** but **opposite direction** are not necessary in a generative design simulation.

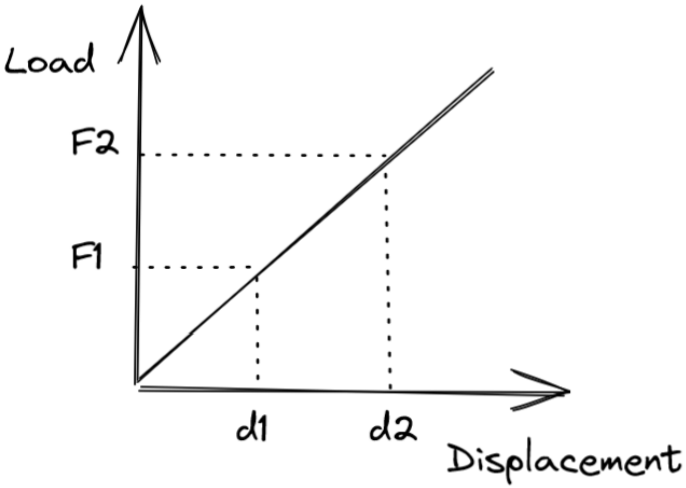


How Event Simulation helps GD

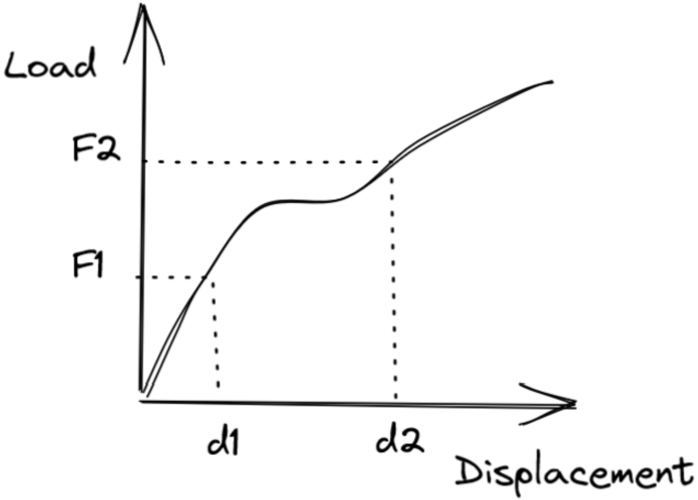
Explore the nonlinearity in the problem

What can we have more with Event simulation

Capture nonlinearity from material, geometric, contacts



Linear
F1/d1 = F2/d2



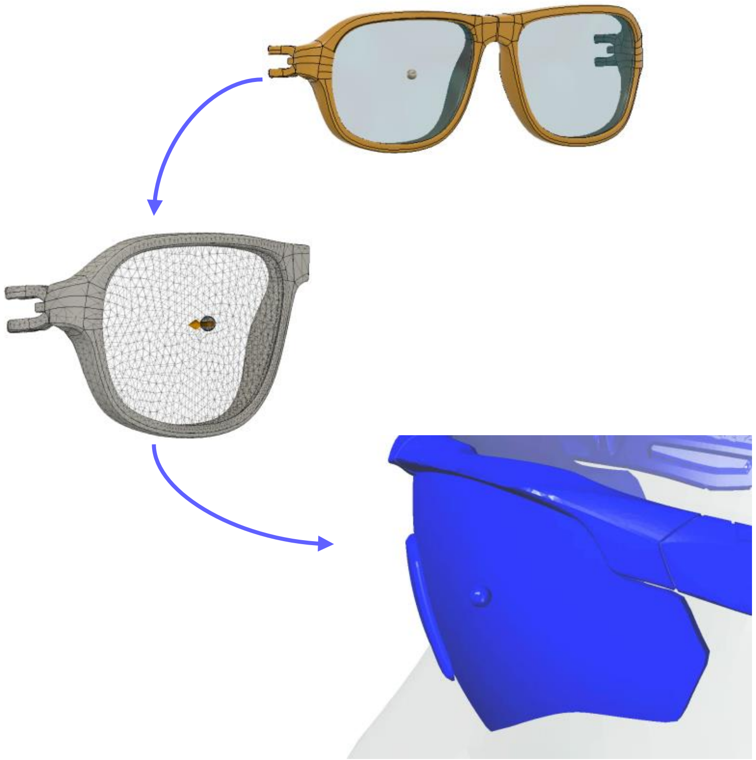
Nonlinear
F1/d1 != F2/d2

Event Simulation

- 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.

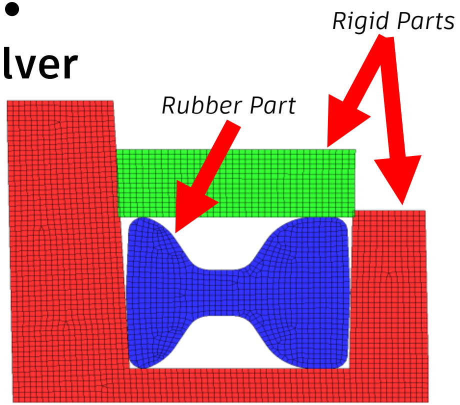
- A typical example is simulating the behavior of protective eyewear or helmets during an impact event.



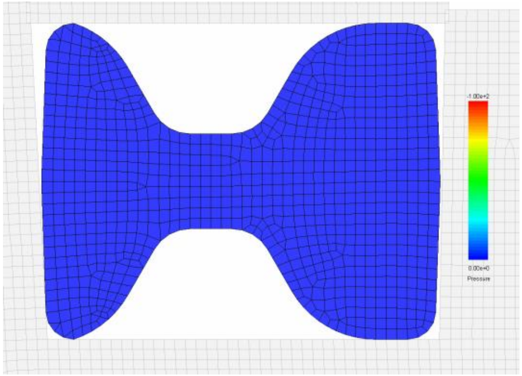
Why do we use an Event simulation?

Fusion 360 event simulation is running on Autodesk Explicit solver

- Autodesk Explicit is a general-purpose FEA solver with a large feature base of:
    - Large deformation and large rotation kinematics.
    - Nonlinear material models for plasticity and rubber elasticity.
    - Rigid Bodies
- An explicit solver forms no element stiffness matrices and does not require the solution of a set of linear algebraic equations. Therefore, it has <u>a very small memory footprint</u>.
- Explicit solvers are extremely robust; <u>they always converge</u>!
- The large feature base provides a pathway to future extensions: e.g. fluid structure interaction problems composed of complex assemblies of parts and gaskets.



Rubber Seal Model



Compression of Rubber Seal

What is so great about Explicit Dynamics?

Event simulation

- Finite Element method that has no solver:

Traditional Implicit Method:

$$[K]\{u\} = \{f\}$$

No Solution of Linear System of Equations in explicit dynamics method.

Explicit Dynamics Method:

$$\{a\} = [M]^{-1}\{f\}$$

Obtain Accelerations with Diagonal Mass Matrix.
Explicitly Integrate Velocities and Displacements.

- Excels at solving extremely large models.
- Nonlinear material behavior is a snap.
- Large deformation contact between bodies is natural.
- Models can be torn apart and create new contact surfaces.
- The solver picks the time step **automatically**.

What's the catch?

Small time step requires short duration

- The solver picks the time step **automatically**.
- Time step 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 time step. (Based on speed of sound in material.)

What's the catch?

Small time step requires short duration

- Fusion limits the runtime to 12 hours!

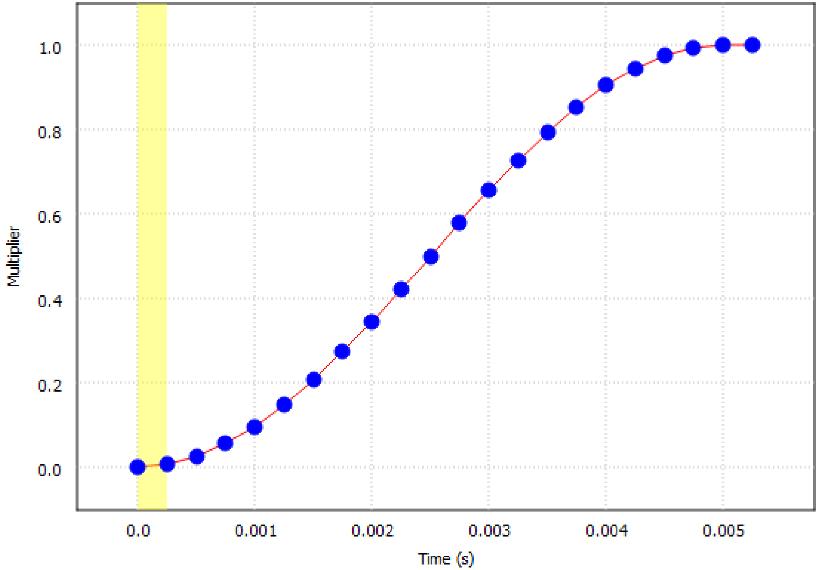
- Conclusion:
  - Eliminate sources of sliver mesh on the surface (tight corners).
  - Use realistic mass density and modulus of elasticity.
  - Start with a very short duration (1E-5 to 1E-3). Results will show if setup is correct and how long it takes to run.

(continued next slide)

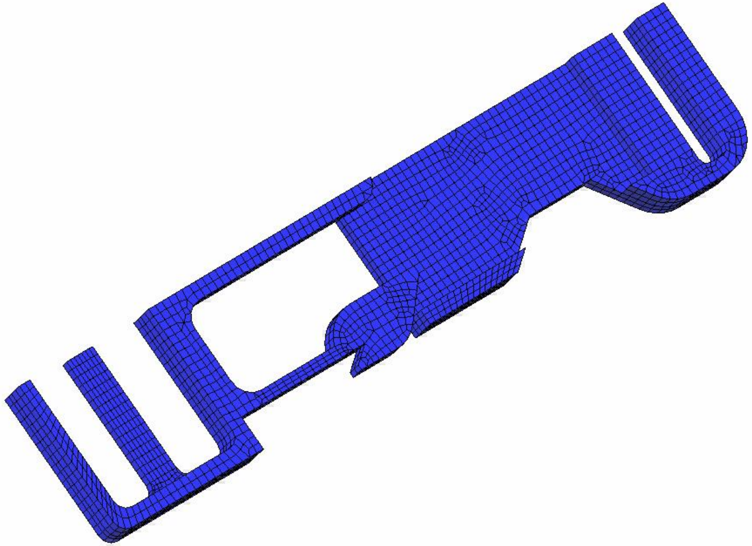
What's the catch?

Small time step requires short duration

- Conclusions: (continued)
  - Runtime approximately proportional to duration. If interested, increase duration based on the desired runtime.
  - To approximate a static condition, use a long duration and sine curve for the load.

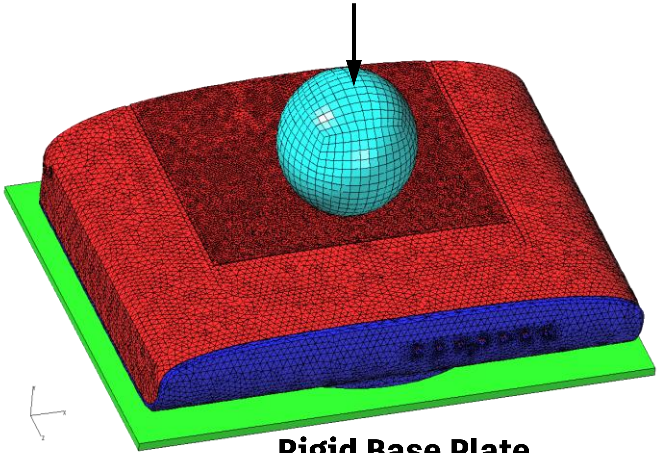


Simple Consumer product: buckle simulation

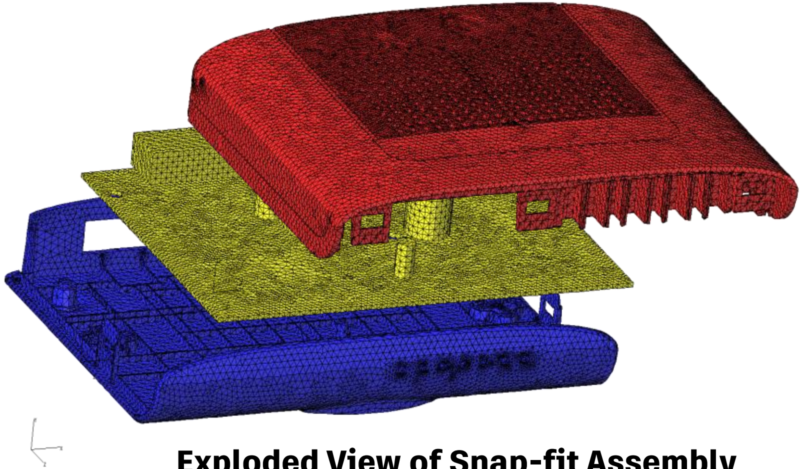


Impact Simulation on Router

Init Vel 4 m/s

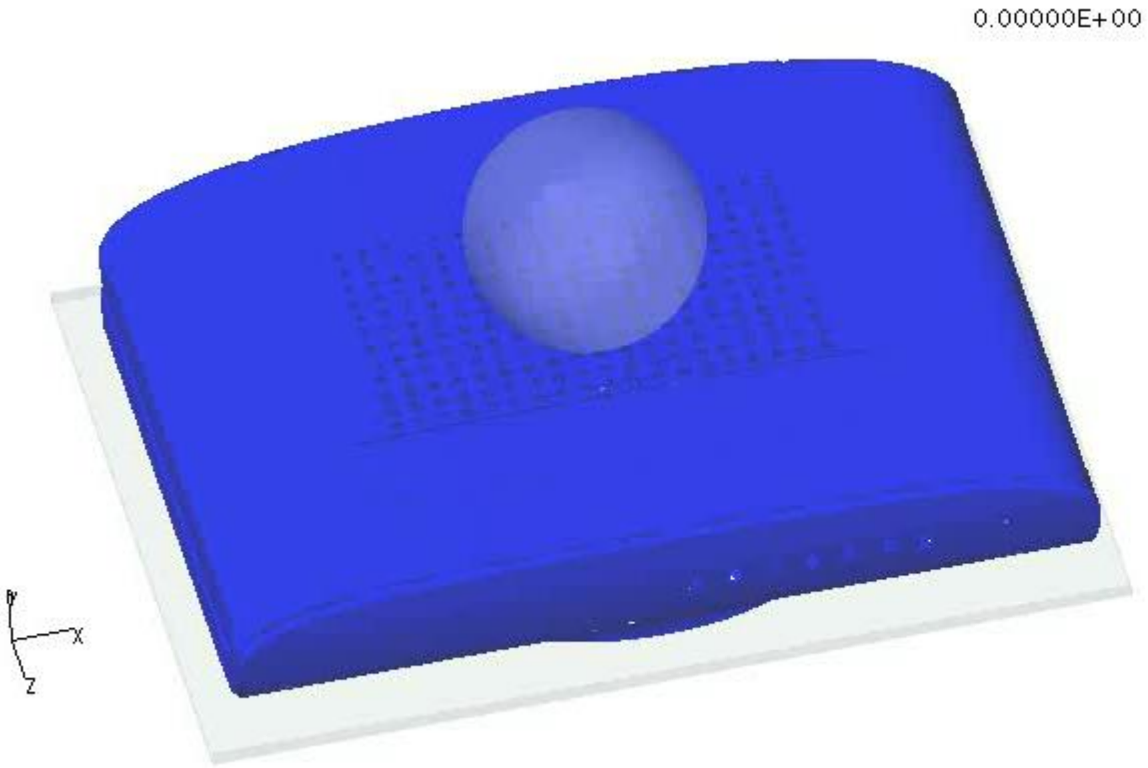


Rigid Base Plate

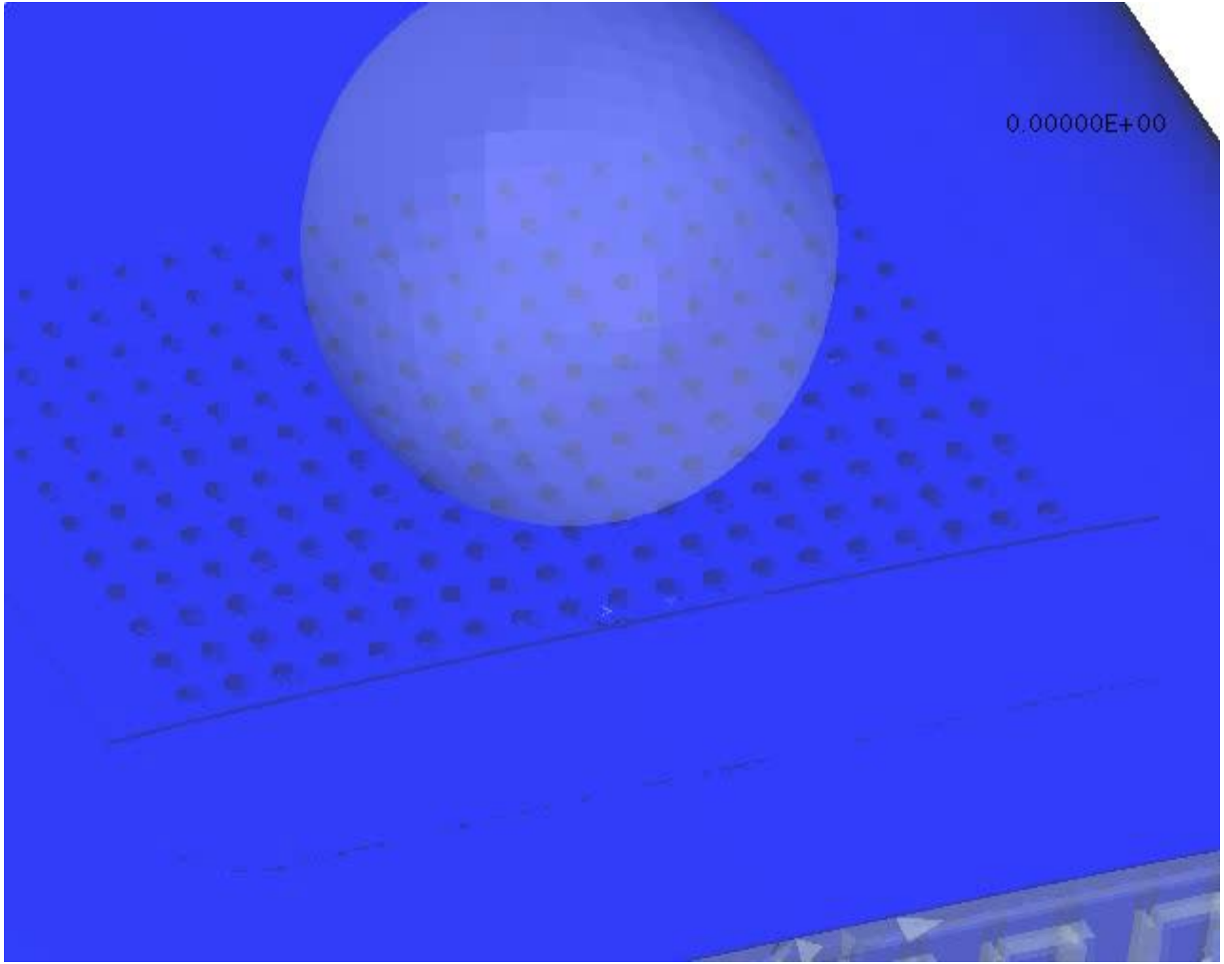


Exploded View of Snap-fit Assembly

- All parts elastic
- All TET mesh, 189K elements
- Automatic contact definition
- Failure defined as maximum principal strain value

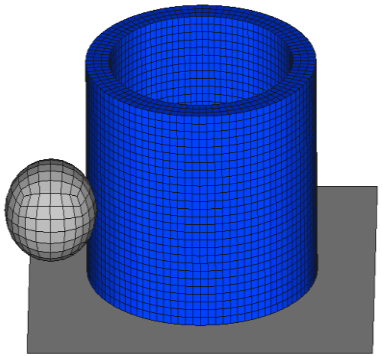


AUTODESK.

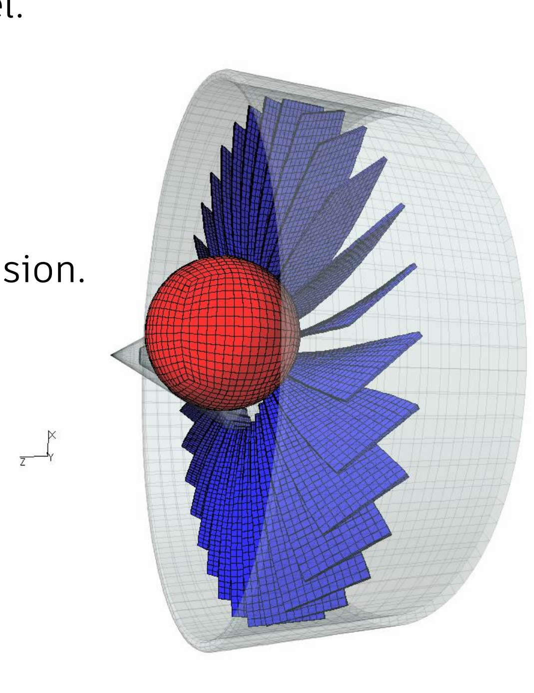

0.00000E+00

Event simulation is beyond elasticity

- **Plasticity, Buckling, Damage, Rupture…**
  - Automatic contact definition between all parts of the model.
  - Arbitrary contact with friction for large deformations.
  - Contact between deformable and rigid parts
  - Element deletion under various material failure criteria.
  - Automatic rebuilding of contact surfaces under surface erosion.



Contact Between Large Number of Parts



Bird Strike on Turbine

Quasi-static Event Simulation

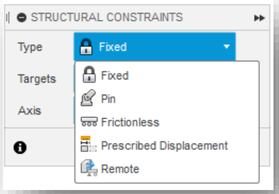
- Fusion 360's automatic quasi-static analysis uses explicit dynamics algorithms to solve highly nonlinear simulations. These nonlinear simulations often do not run successfully with an implicit solver using Newton’s method.

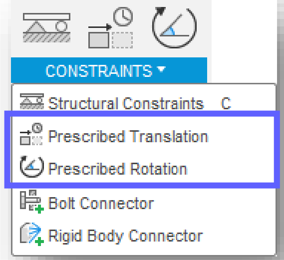
- In a quasi-static analysis, the concept of time is dimensionless. Time is simply a pseudo time that measures the application of the transient loads and prescribed boundary conditions.

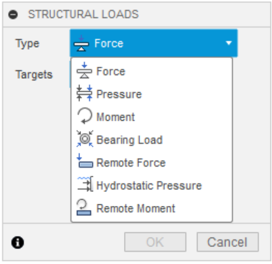
- **Quasi-static analysis examples:**

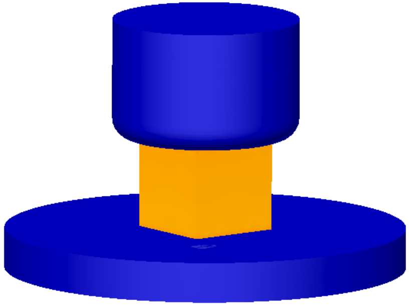
- Large deformation contact problems that involve large sliding motions and friction.

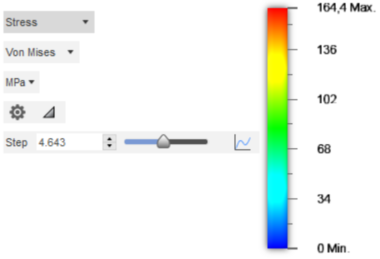
- Nonlinear material behavior such as large plastic deformations.



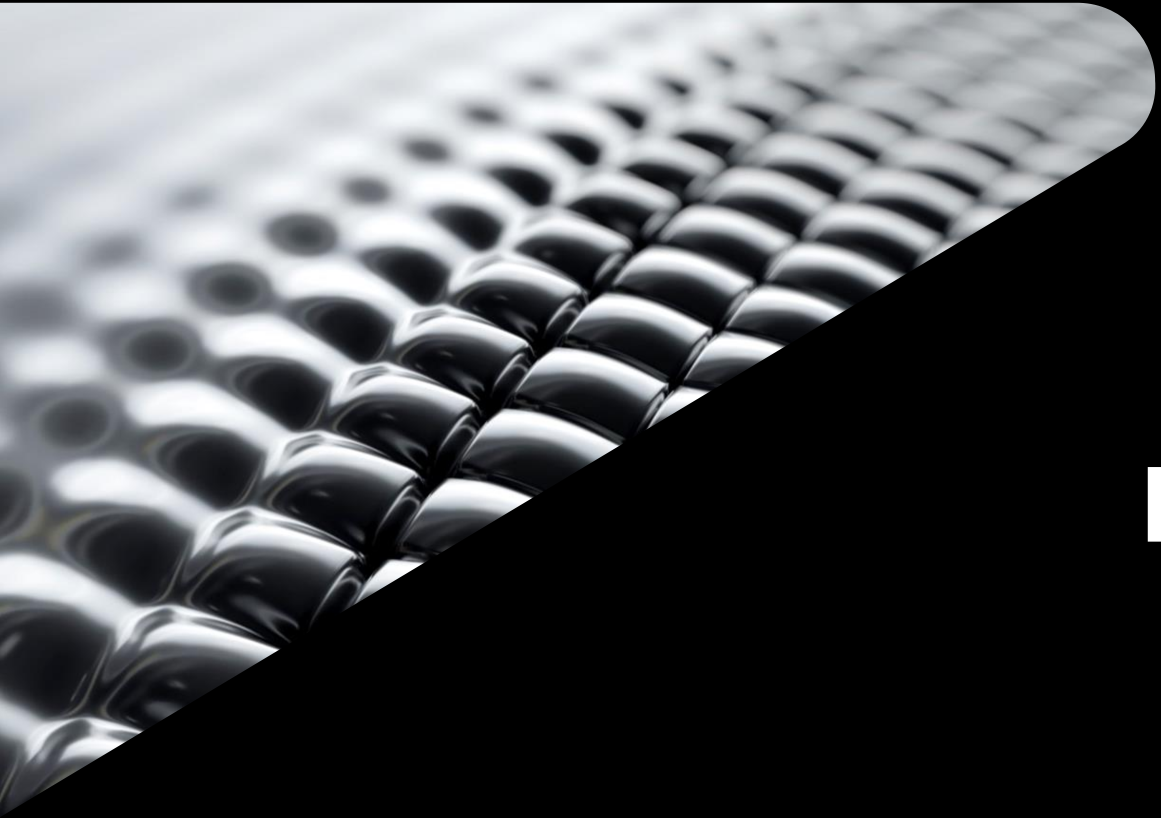








AUTODESK UNIVERSITY



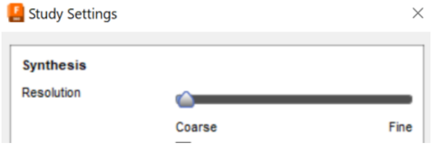
Tuning Generative Design model

Tips and tricks
to get better alternatives

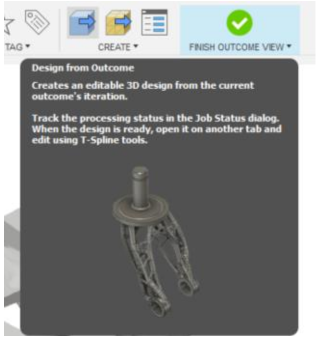
Quick tips : Experiment more!

Polishing in Generative design setup

- Start with
  - Coarse resolution
  - Simple boundary condition and adding more load cases



- Checking with Linear static analysis and Event simulation
- Pick any outcomes you like and refine with:
  - Add load cases and boundary conditions
  - Applying constraints
    - Displacement constraints– local or global
    - Additive manufacturing constraints for thickness
  - Changing resolution as the preserving feature sizes allow
    - Fine resolution => membrane/shell dominant shape
    - Coarse resolution => beam/truss dominant shape



Quick tips (continued)

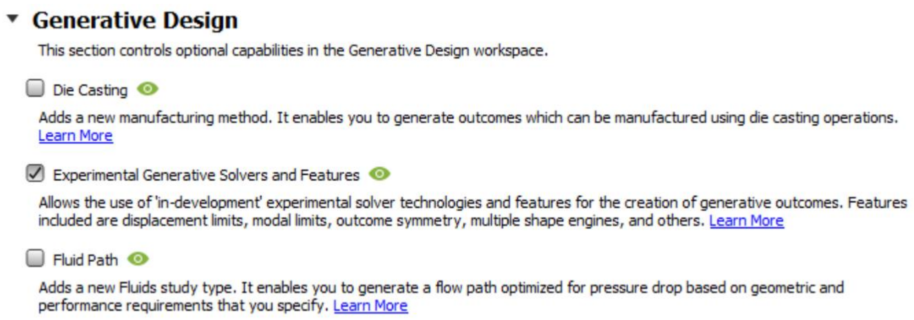
How to quickly pick the right loading magnitude

- Loading (Boundary condition) = Direction + Magnitude
- Add Multiple load cases
- Force Magnitude 💪

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

https://help.autodesk.com/view/fusion360/ENU/?guid=GD-LOADS-MAGN-REF

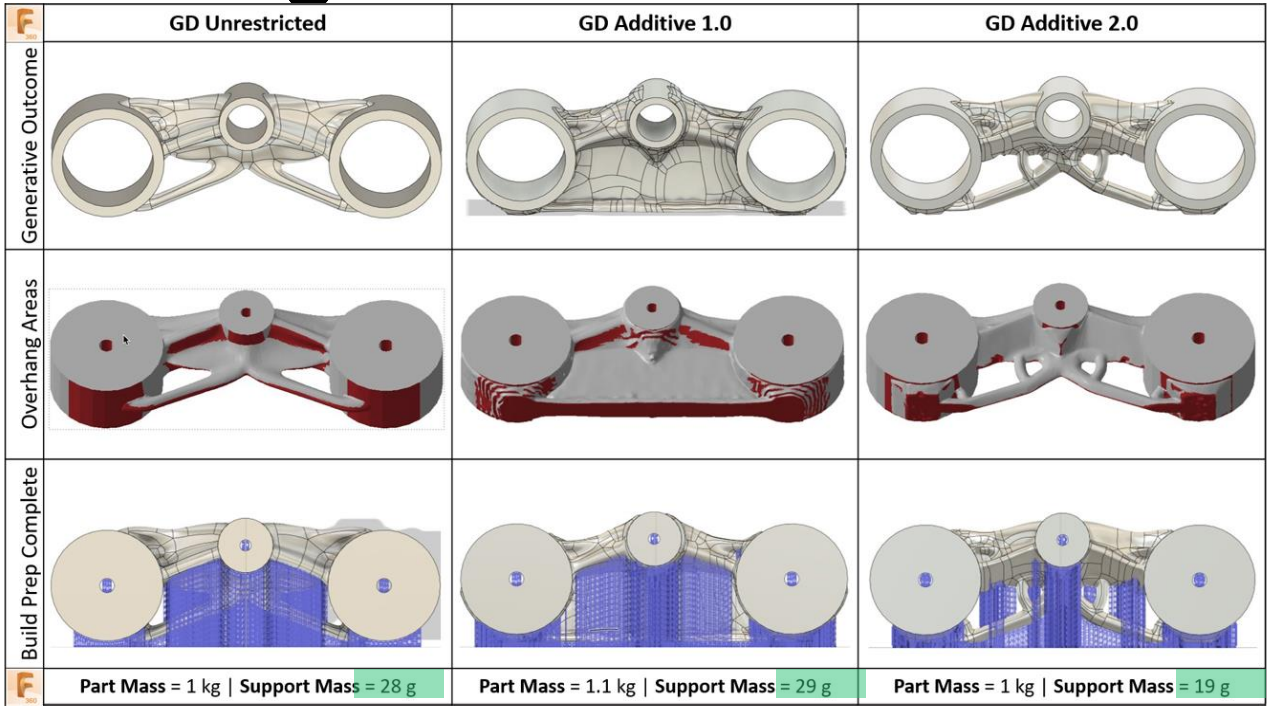
Explore constraints from experiment solver features



- Refine the model with
  - Local and global displacement constraints
    - https://help.autodesk.com/view/fusion360/ENU/?guid=GD-EXP-SOLVER-LIMITS
  - Thickness control by additive manufacturing constraint
    - https://help.autodesk.com/view/fusion360/ENU/?guid=GD-EXP-SOLVER-MFG

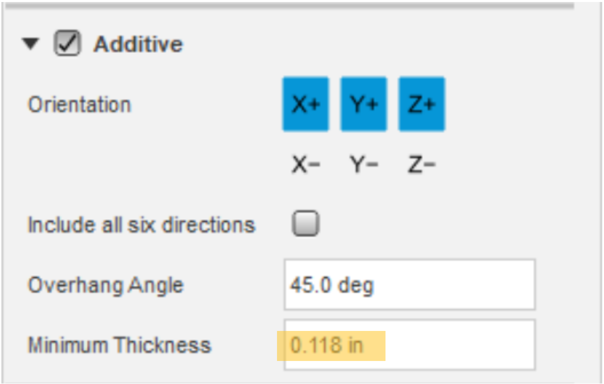
Additive Manufacturing

- Support structures designed by Additive Manufacturing expert
- Additive constraints ensure that the support mass is reduced significantly
- Yet there are other use



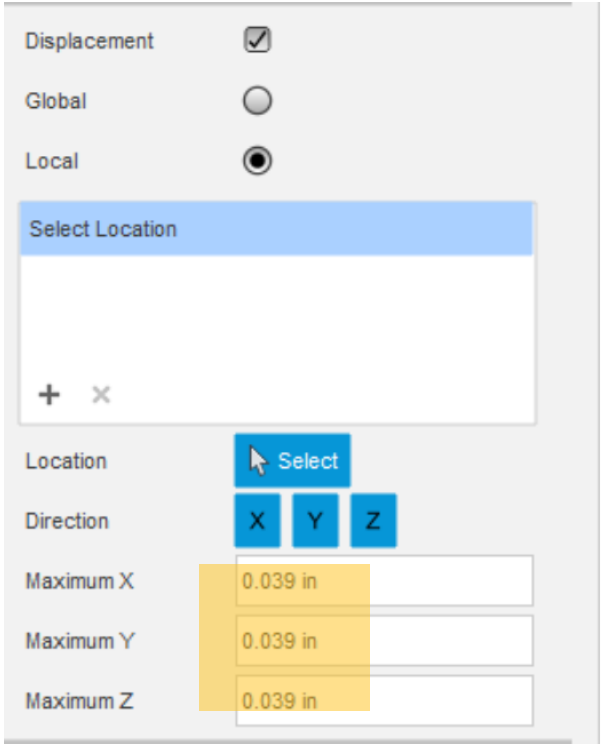
Additive Manufacturing

- Suitable for 3D Printing
- Overhang angle constraint ensures that the part can be 3D printed
- Not always possible to satisfy overhang angle
- Minimizes the support structures needed
- Minimum thickness ensure that part is strong enough be 3D printed



Displacement Constraints

- Generates a shape whose deformation under loading is limited by user's requirements
- Control over global displacement
  - Along X, Y, Z global axes directions
- Control over regional displacement
  - Choice on the region where the displacements needs to be limited
  - Along X, Y, Z global axes directions



Displacement Constraints : Global

Without

Mass (kg)	0.168
Max von Mises stress (MPa)	1,000
Factor of safety limit	1
Min factor of safety	1
Max displacement global (mm)	2.47

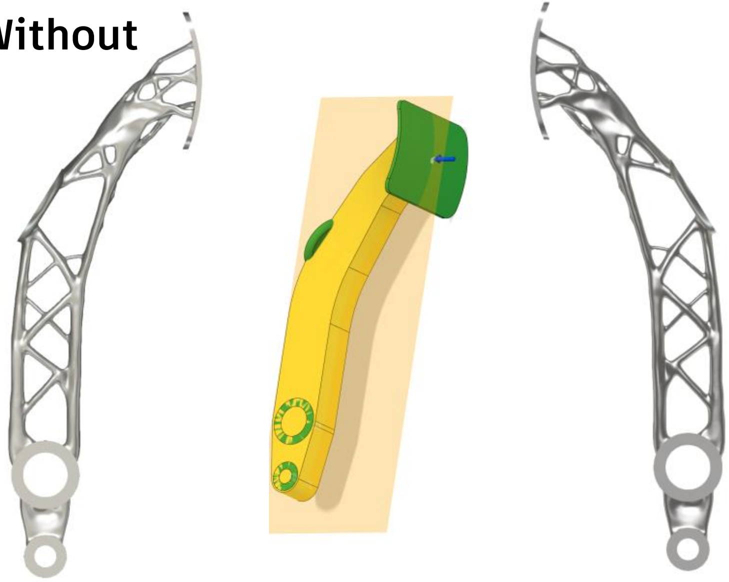
With

Mass (kg)	0.234
Max von Mises stress (MPa)	674.5
Factor of safety limit	1
Min factor of safety	1.48
Max displacement global (mm)	1.53
Max displacement X (mm)	1.5
Max displacement Y (mm)	0.01
Max displacement Z (mm)	0.87

Displacement	☑
Global	◉
Local	○
Direction	X Y Z
Maximum X	1.50 mm
Maximum Y	1.50 mm
Maximum Z	1.50 mm

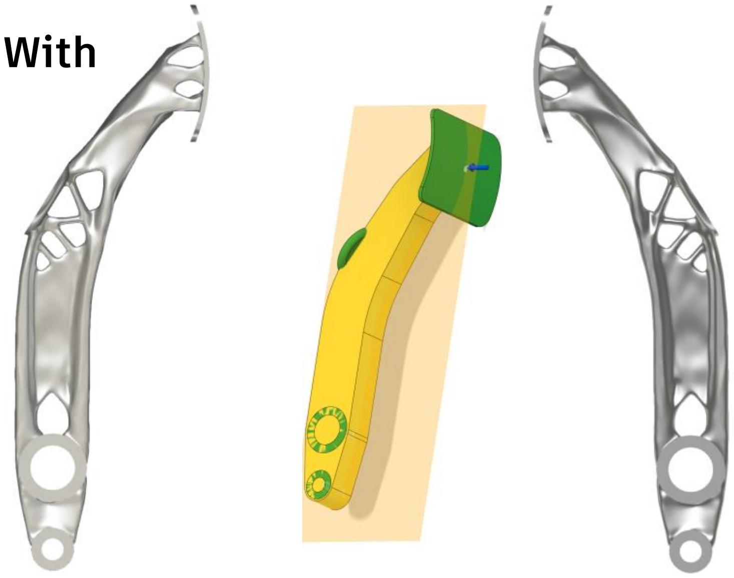
Displacement Constraints: Local

Without

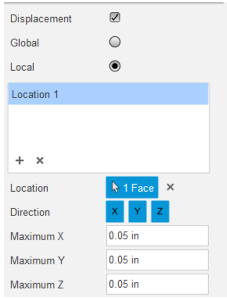


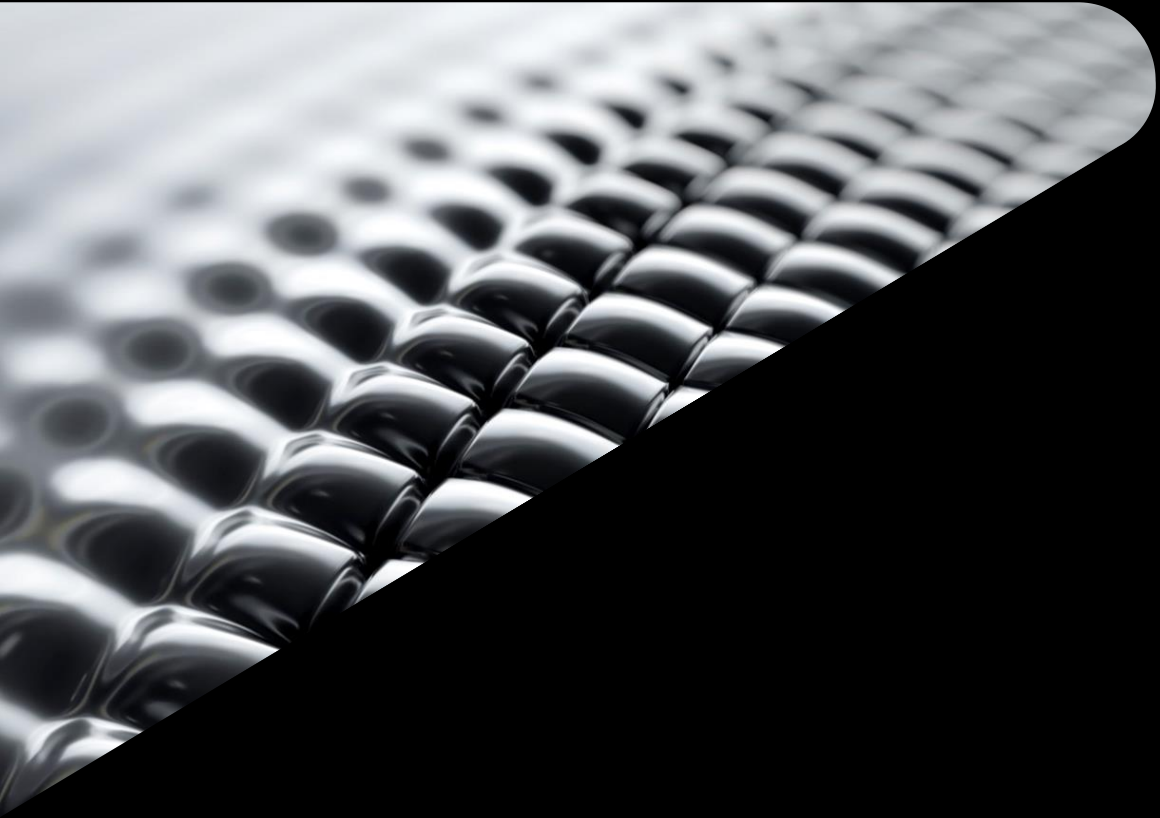
Mass (lbmass)	0.154
Max von Mises stress (psi)	17,525.4
Factor of safety limit	1.2
Min factor of safety	1.2
Max displacement global (in)	0.11

With



Mass (lbmass)	0.204
Max von Mises stress (psi)	12,075.4
Factor of safety limit	1.2
Min factor of safety	1.74
Max displacement global (in)	0.05

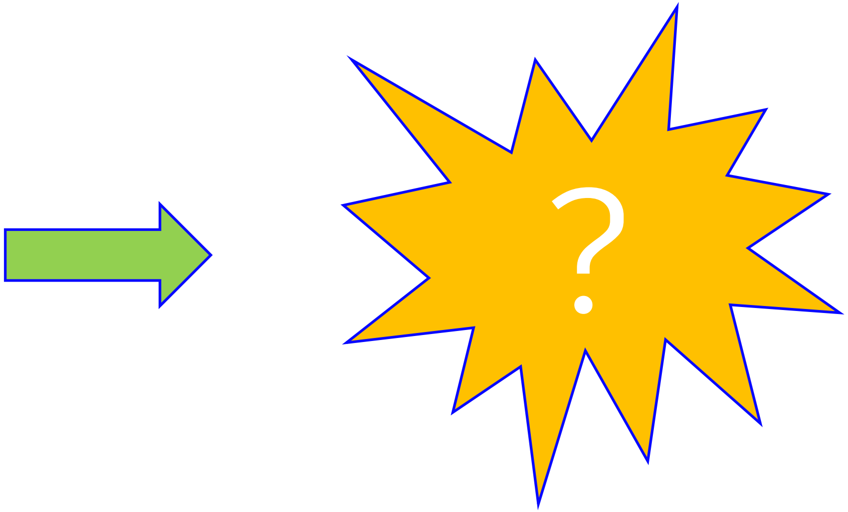




Demo

Compound bow
Bicycle saddle

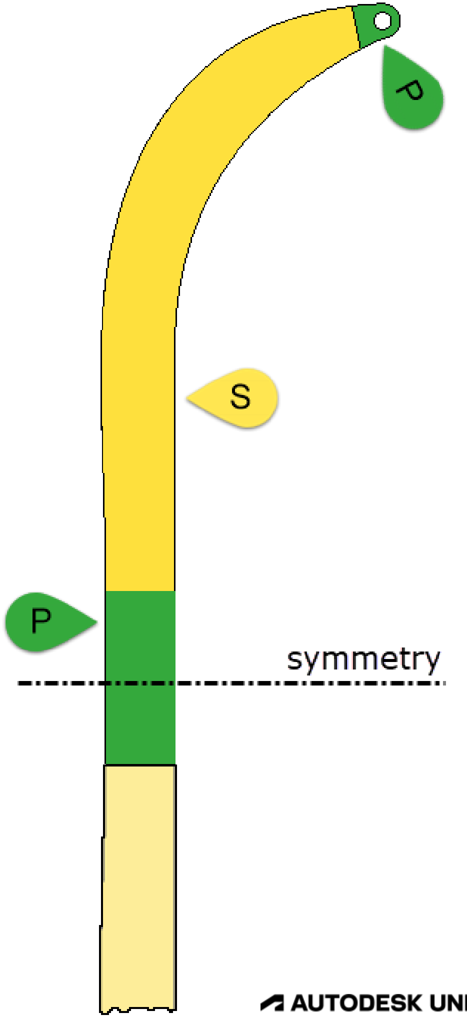
Invitation for next AU for pulley design contest



Generative Design Example

Compound Bow

- Types of Geometry:
  - Preserve (P) - volumes to keep
  - Starting Shape (S) - where new volume is created and shaped
  - Obstacles (O) - where not to create new volume (none in this example)

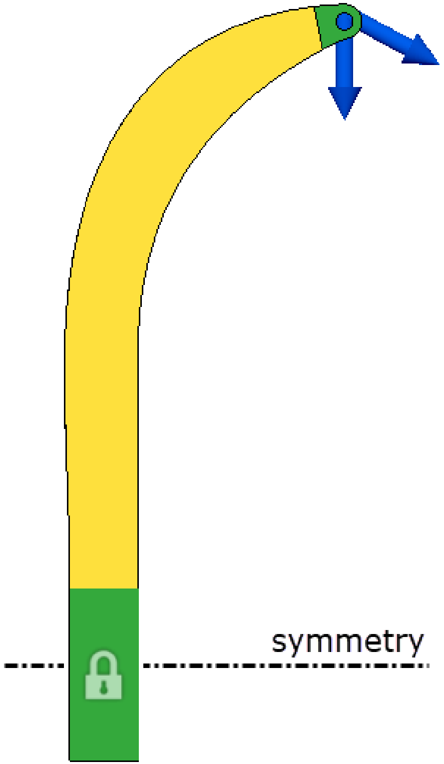


Generative Design Example

Compound Bow

Static stress analysis.

- Types of Loads:
  - Force
  - Pressure
  - Moments
- Type of Constraints:
  - Fixed
  - Pinned
  - Frictionless
- Multiple subcases:
  - Yes, but not necessary to use excessive number.



Generative Design Example

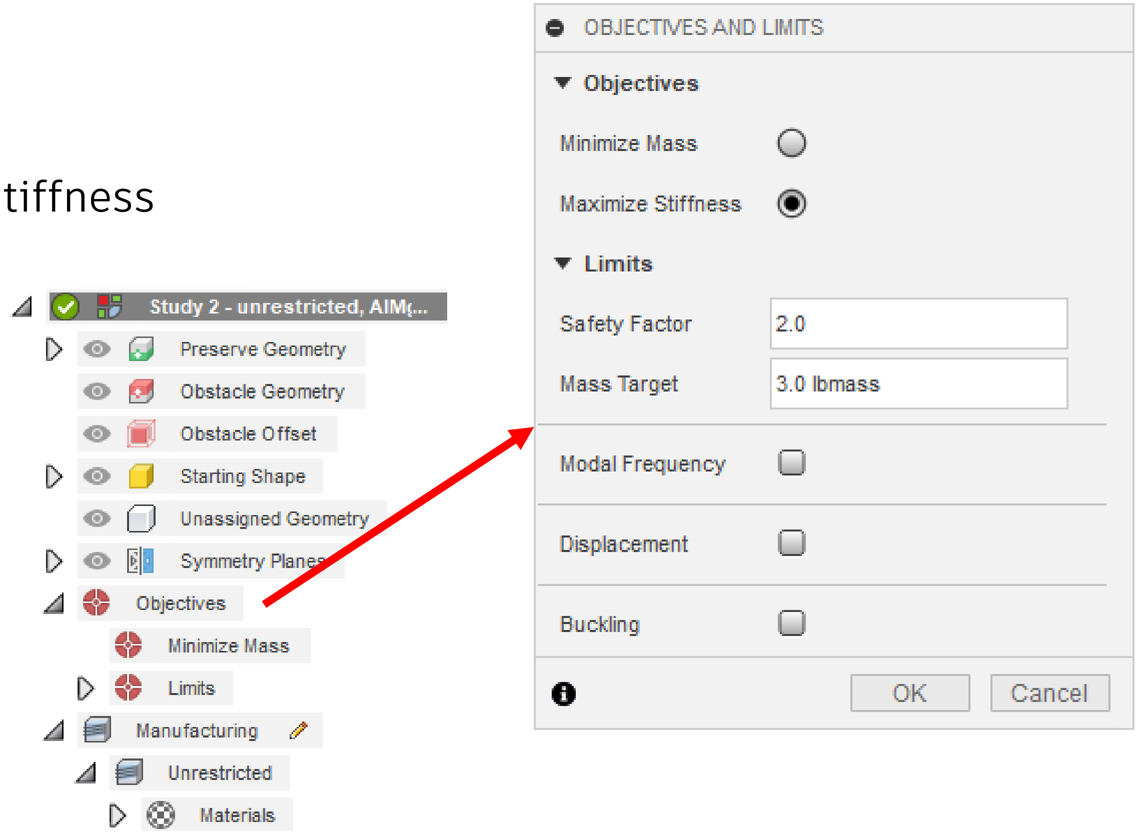
Compound Bow

Objectives:

- Minimize mass or maximize stiffness

Limits:

- Safety Factor
- Mass
- Frequency
- Displacement

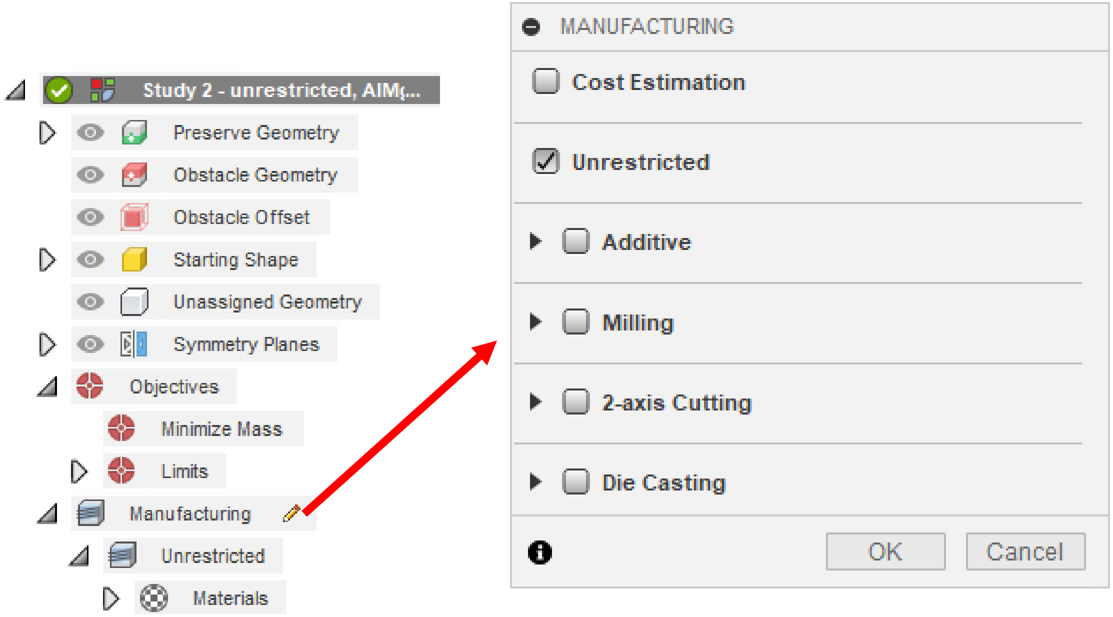


Generative Design Example

Compound Bow

Manufacturing Methods:

- Unrestricted most free-form shapes.
- Other methods if dictated by reality.

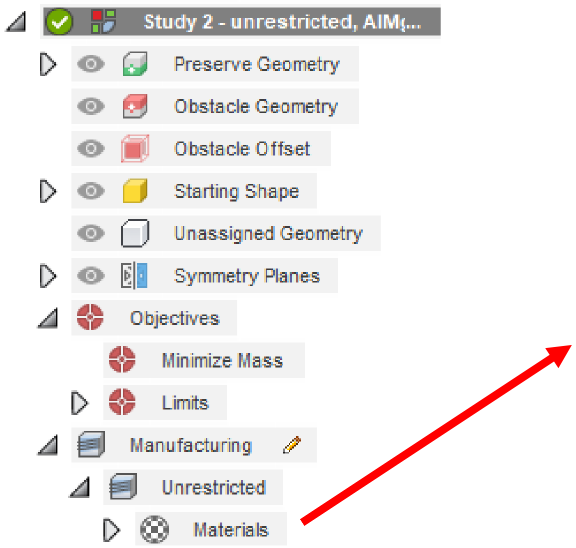


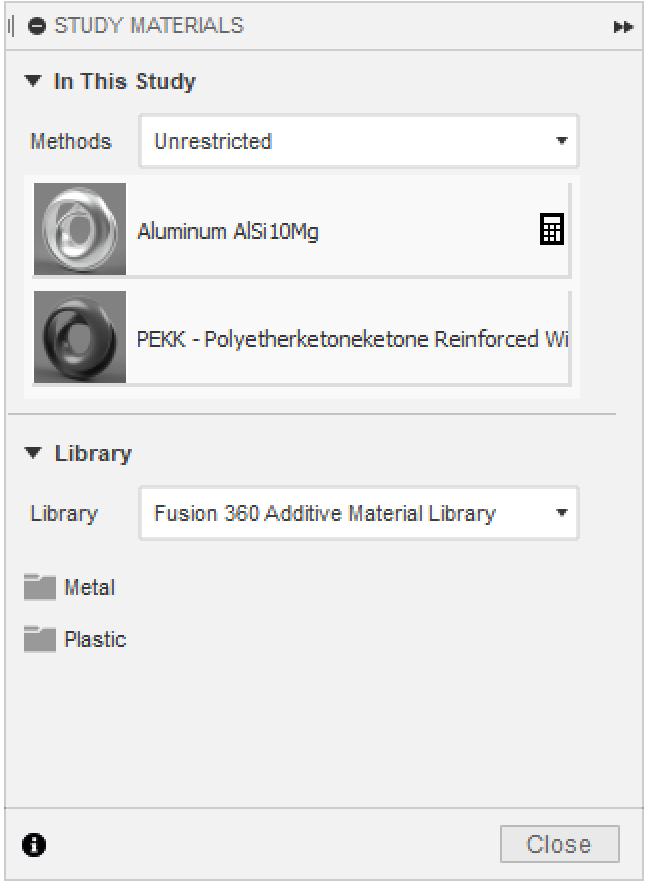
Generative Design Example

Compound Bow

Materials:

- Choose from library.
- Drag and drop in Study.



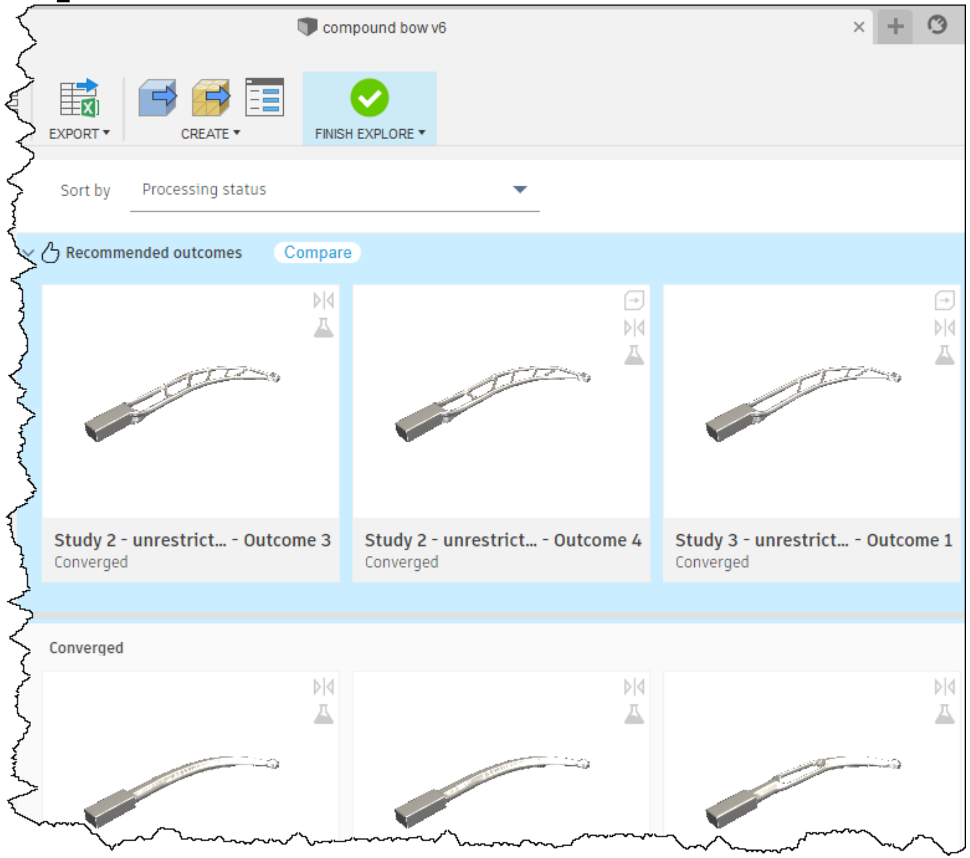


Generative Design Example

Compound Bow

- Results ("Outcomes") are shown in the Explore window while analysis is in progress.

- Click an Outcome to see details.



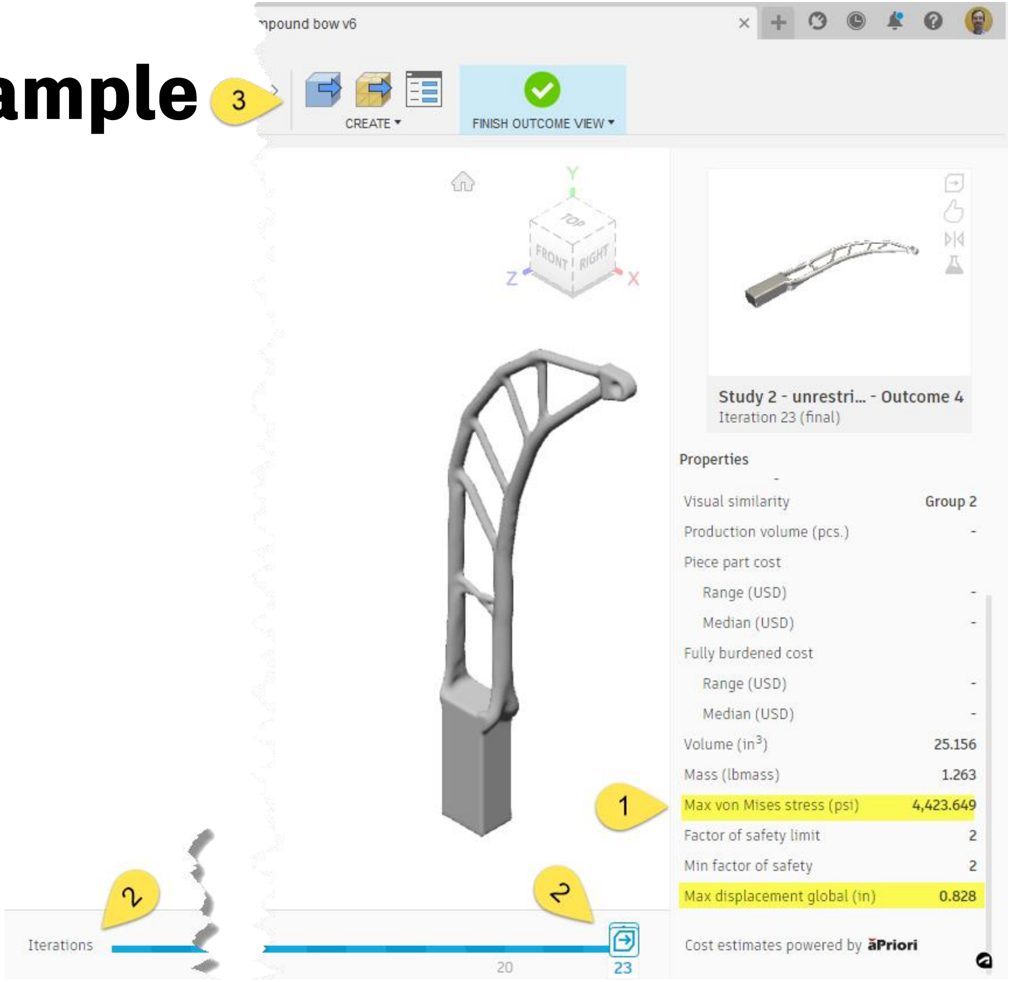
Generative Design Example

Compound Bow

1. Results are approximate.

2. Different “Iterations” of the outcome are available. All are valid but may not meet the criteria.

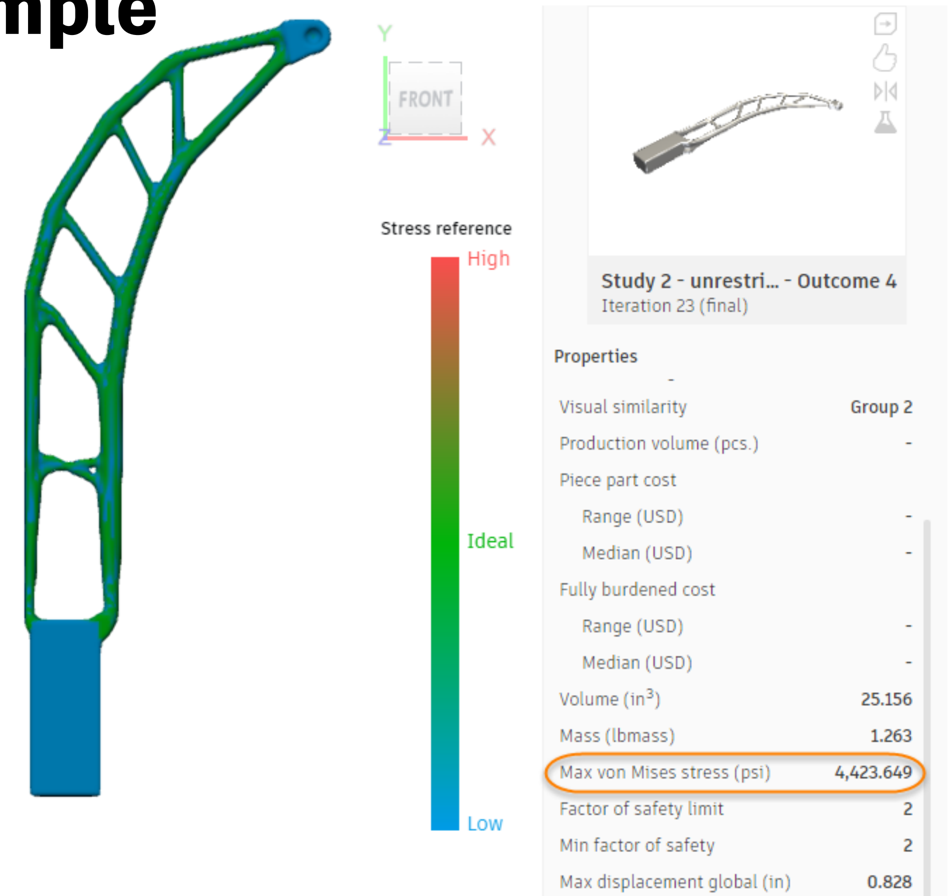
3. Design can be exported to a model for further analysis. Exported model can be edited as desired! (Trim material, add material, etc.)



Generative Design Example

Compound Bow

- Minimal details are shown for the result contour.
- Need to create a model and perform a simulation to get details.

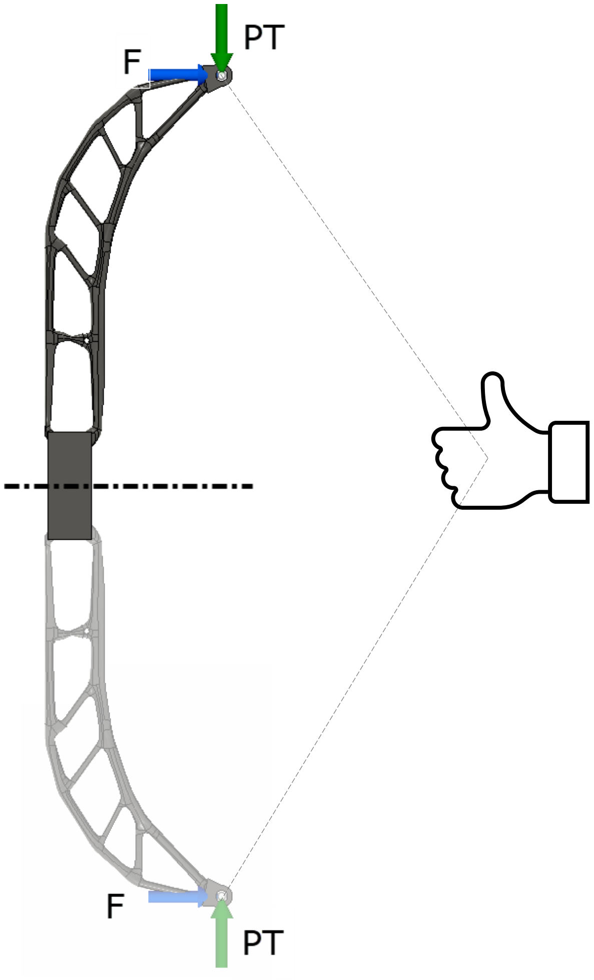


Event Simulation Example

Compound Bow

Conceptual analysis:

- Symmetry
- Force (F) for horizontal tension in string.
- Prescribe Translation (PT) for vertical tension in string and cables.

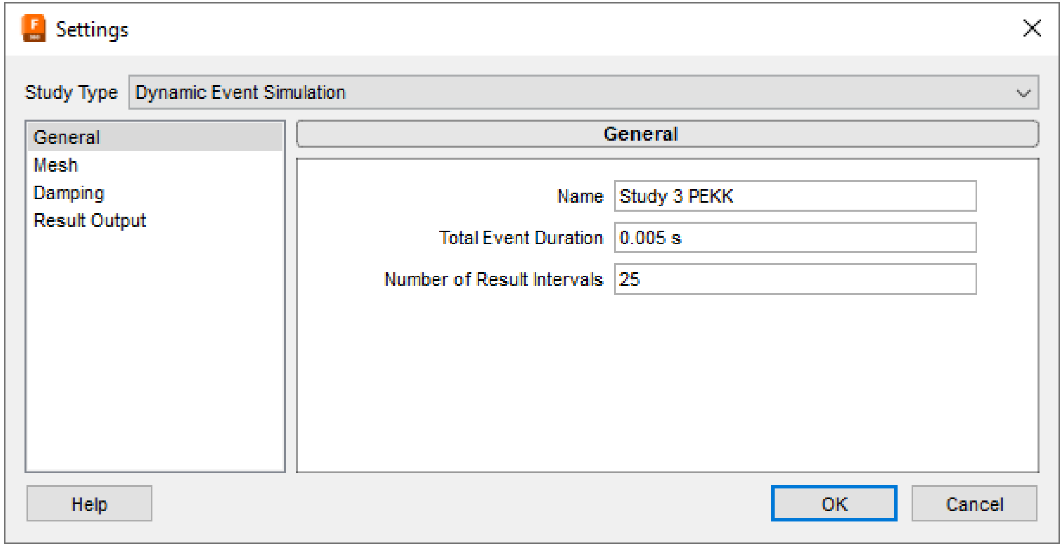


Event Simulation Example

Compound Bow

Remember: the time step is calculated by the solver.

- Duration determines total analysis run time time.
- Number of interval *only* determines how many results, not the time step size.

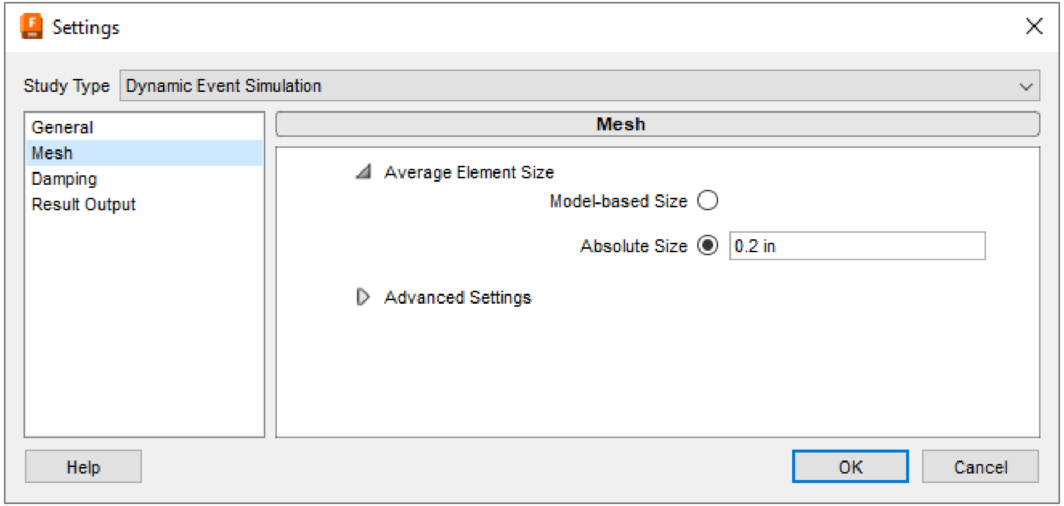


Event Simulation Example

Compound Bow

Remember: time step is dependent on smallest element size.

- In an assembly, if using “Model-based Size”, check the mesh to confirm excessively small elements are not created!

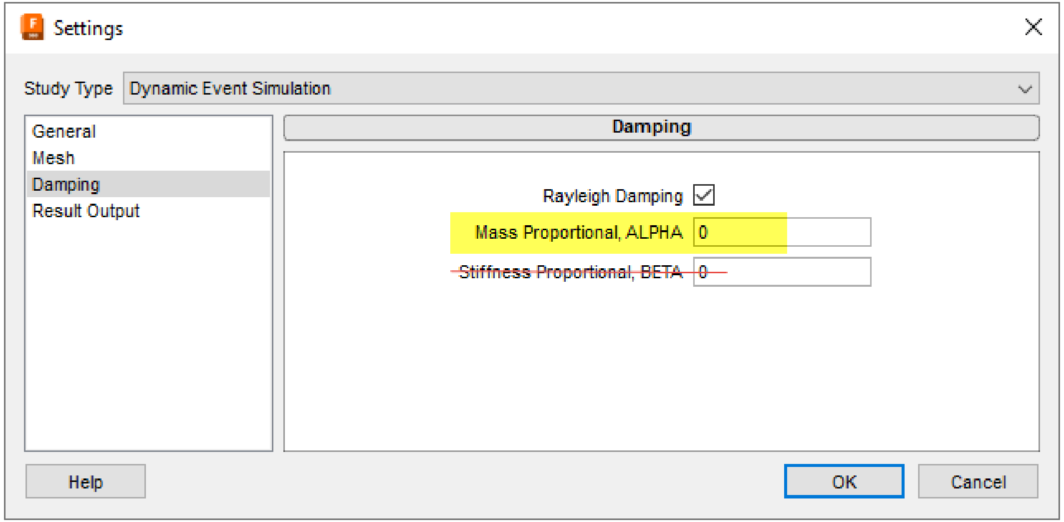


Event Simulation Example

Compound Bow

If damping is used, use mass proportional.

- Mass proportional does not affect the time step size.
- Stiffness proportional *does* reduce the time step size.

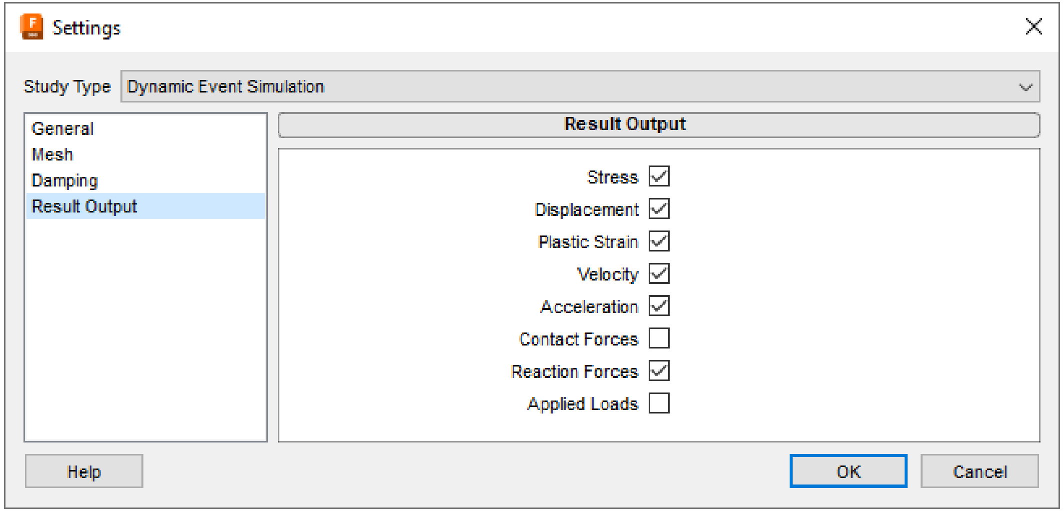


$$\text{ALPHA} = 4\pi \cdot \text{frequency} \cdot (\text{fraction of critical damping})$$

Event Simulation Example

Compound Bow

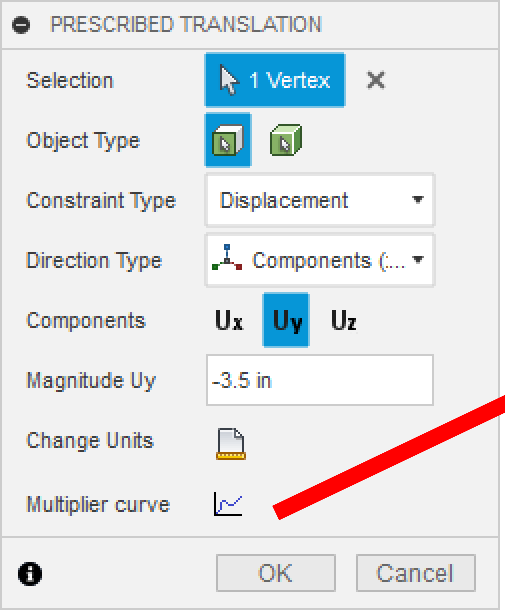
Select which results are to be saved.

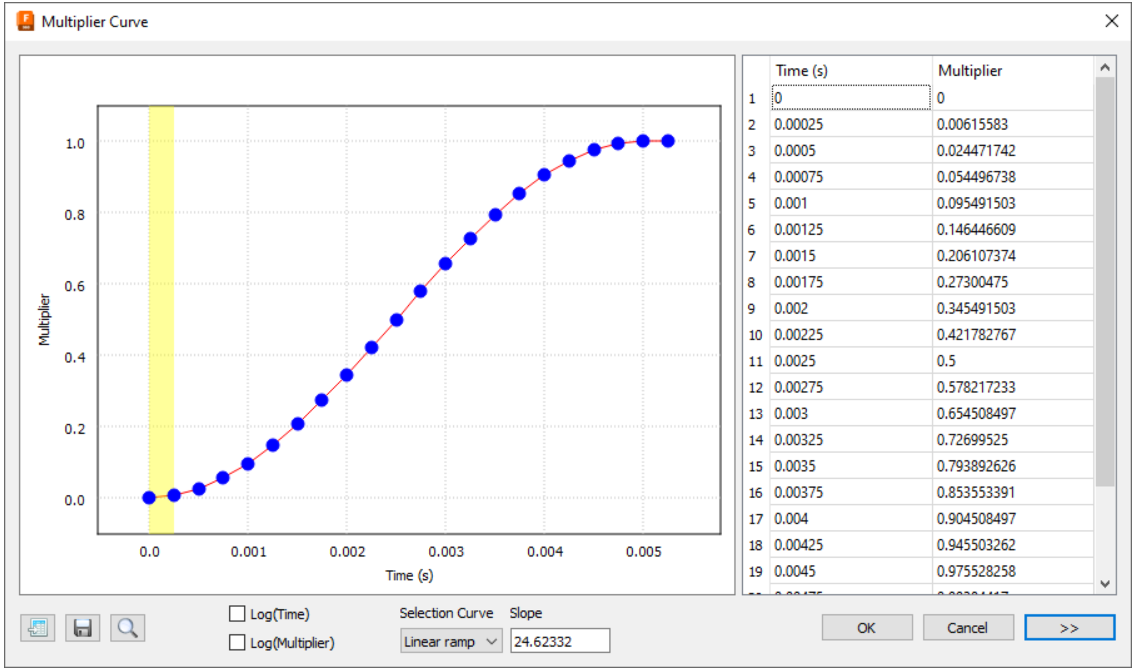


Event Simulation Example

Compound Bow

Remember: Loads are transient. Use Multiplier Curve to describe how the load changes with time.





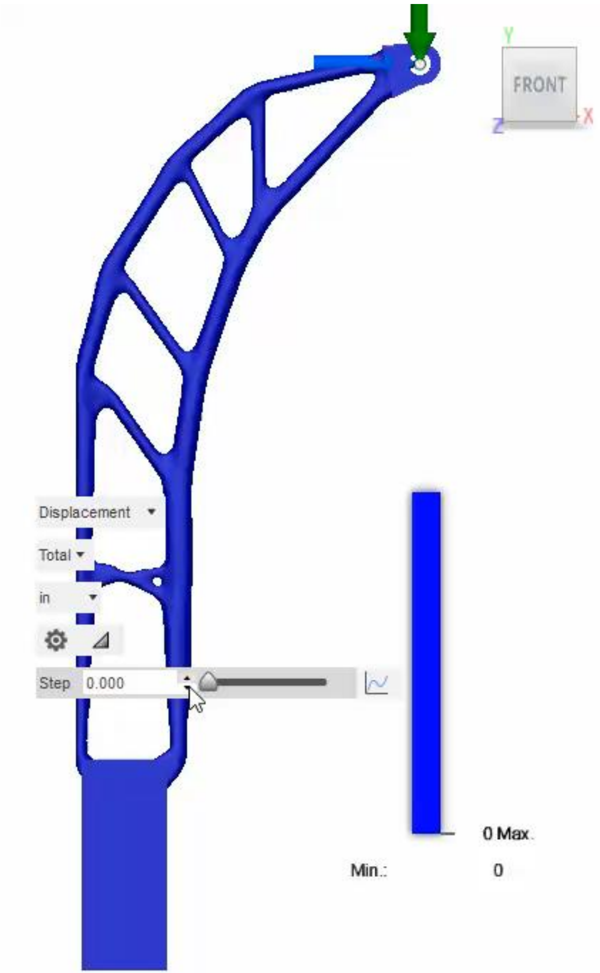
Event Simulation Example

Compound Bow

Review the results:

- Results more accurate since based on actual mesh (and not the approximation used by Generative Design).

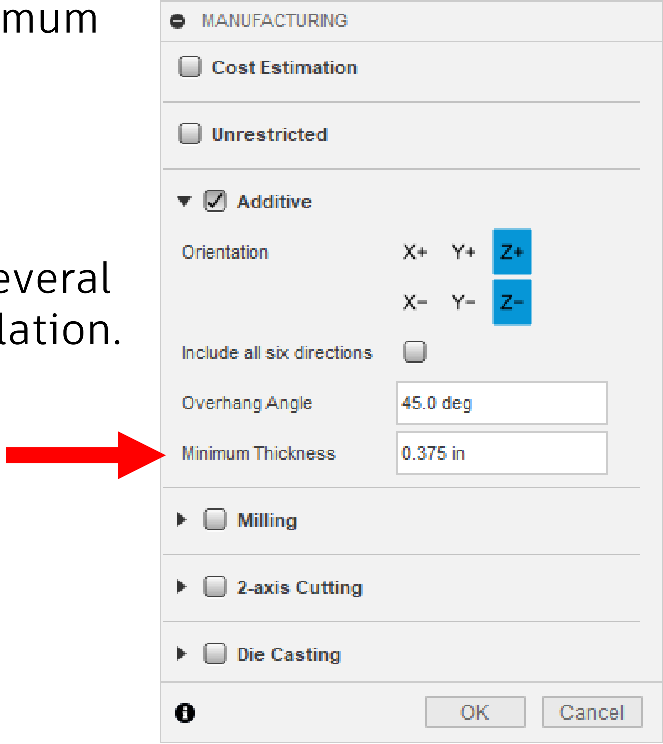
- Ignore stress concentrations.



Generative Design 2

Compound Bow

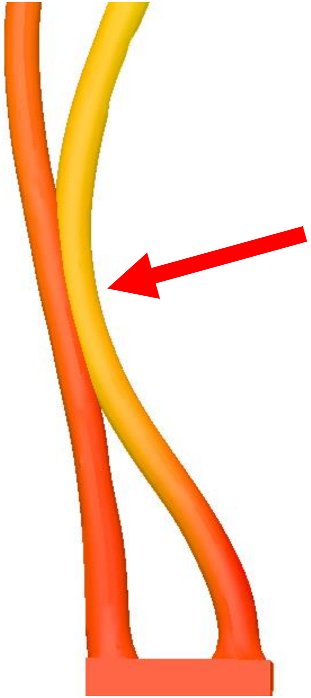
- Enforce a limit on the minimum thickness.
- Re-generate the model.
- Choose one (or more) of several outcomes for further simulation.

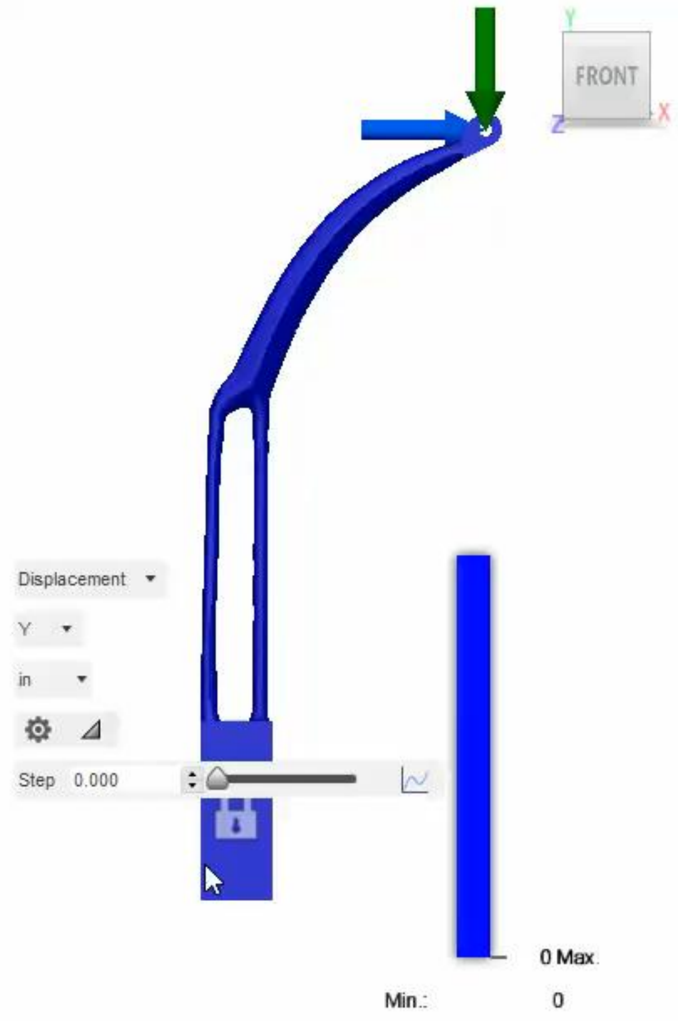


Event Simulation 2

Compound Bow

Review the results:





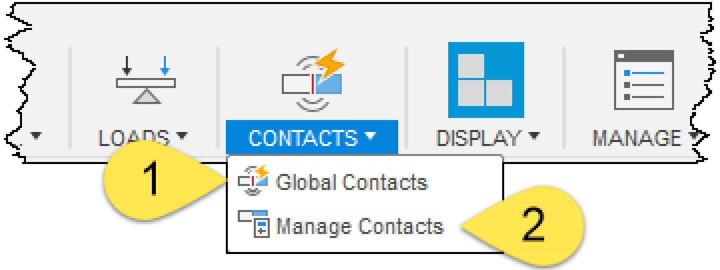
Event Simulation 2

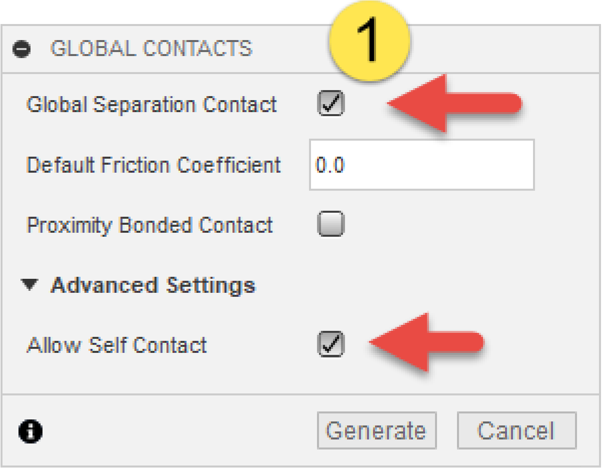
Compound Bow

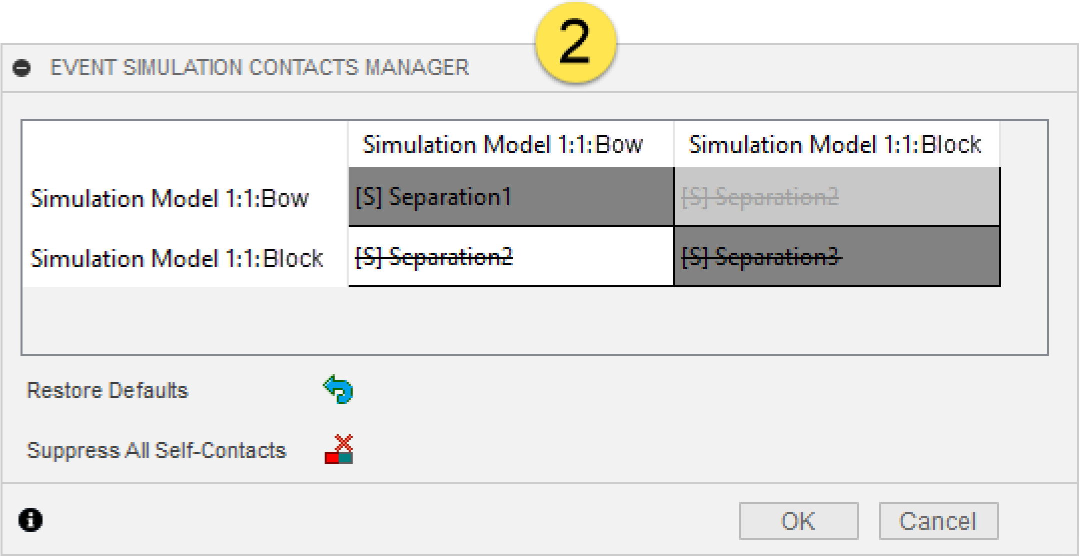
Add contact.

1. Global Contacts to create defaults.

2. Manage Contacts (to make any changes)



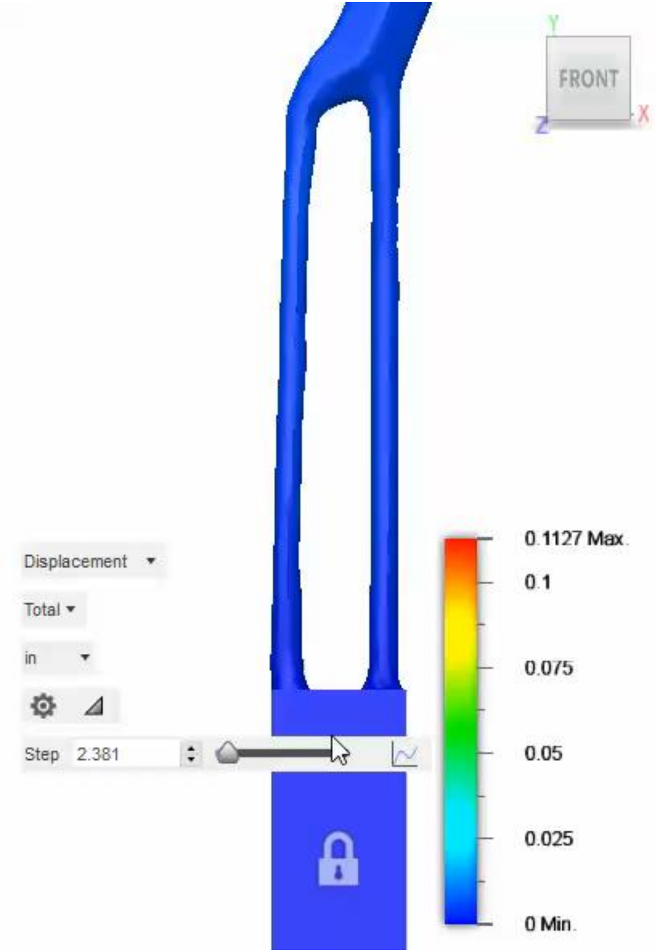




Event Simulation 2

Compound Bow

Results



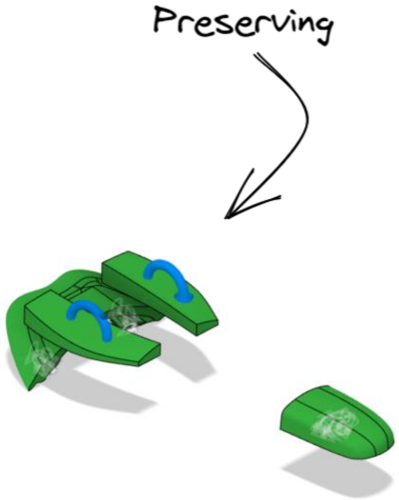
AUTODESK UNIVERSITY

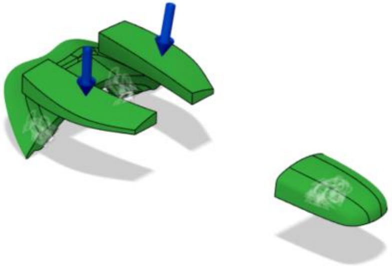
AUTODESK UNIVERSITY

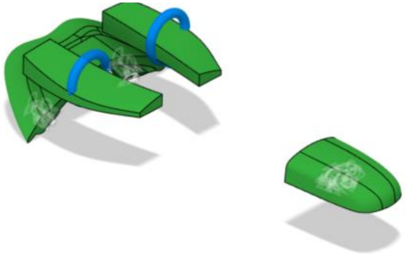
Designing Bike Saddle

Expecting material nonlinearity

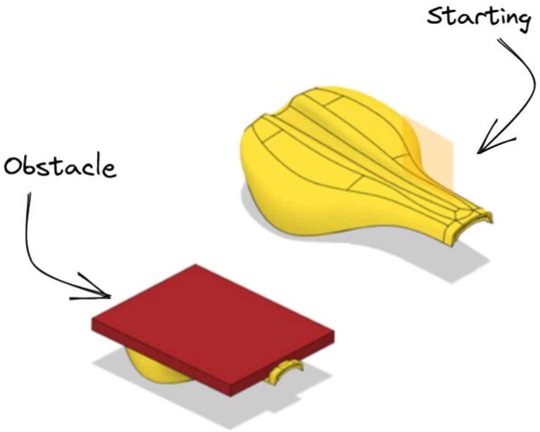
- Design requirements
- Modeling information
  - Material : Foam - Polyethylene
  - Boundary conditions
    - Body weight and moments loads
    - Fixed on rail-seat post connector





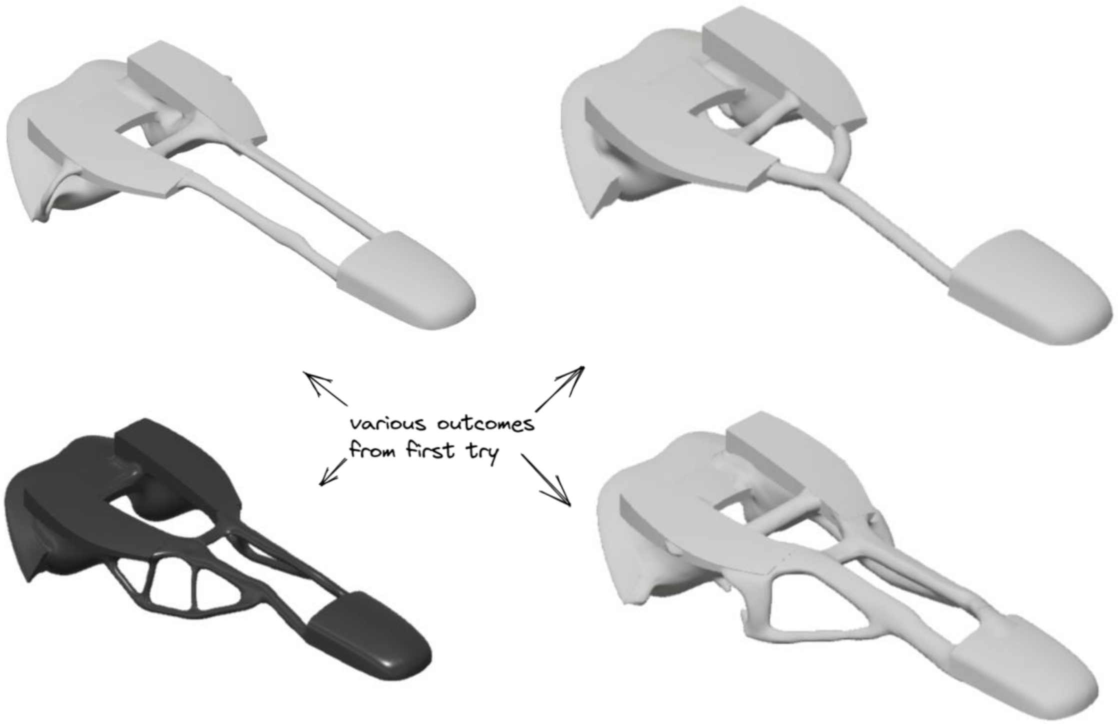


Courtesy of Evan Smith



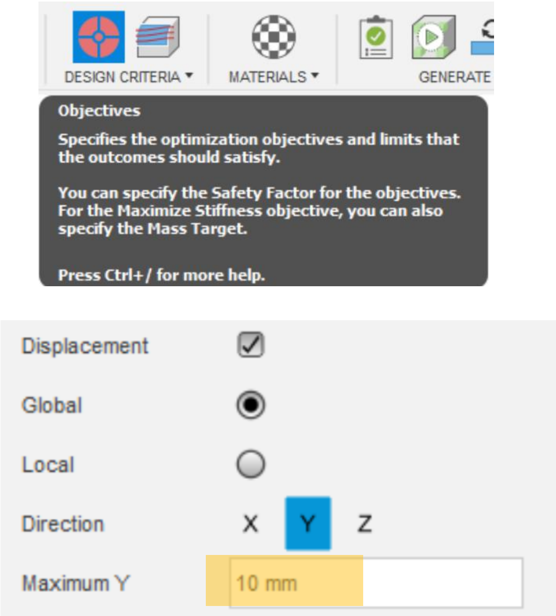
Procedure: GD -> Event Sim -> GD

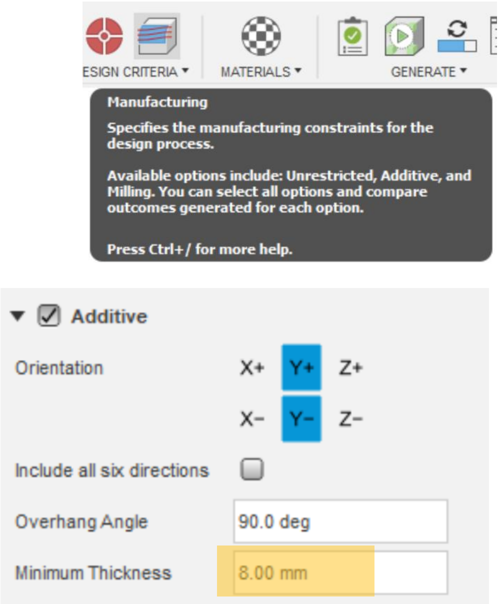
1. Run naive Generative Design
2. Run Event simulation analysis on outcomes
3. Tune the parameters in Generative Design
4. Assess again with Event simulation



Tuning the model

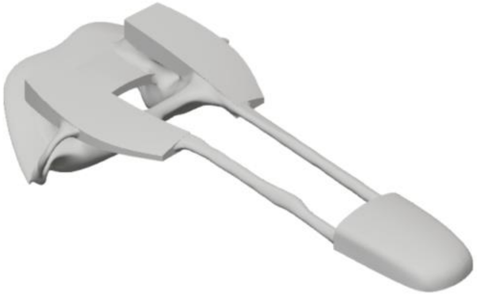
- How to tame excessive displacement and attain proper thickness for saddle’s internal beam networks





Approaching desirable outcome with iterations

Naïve GD

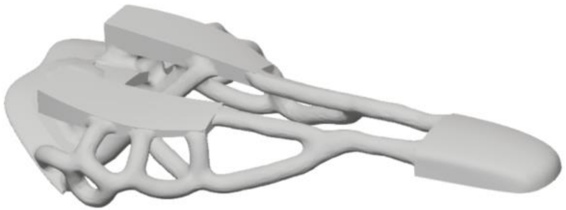


Mass (kg)	0.149
Max von Mises stress (MPa)	5.398
Factor of safety limit	2
Min factor of safety	2.001
Max displacement global (mm)	10.995

w/ Displacement Constraint

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

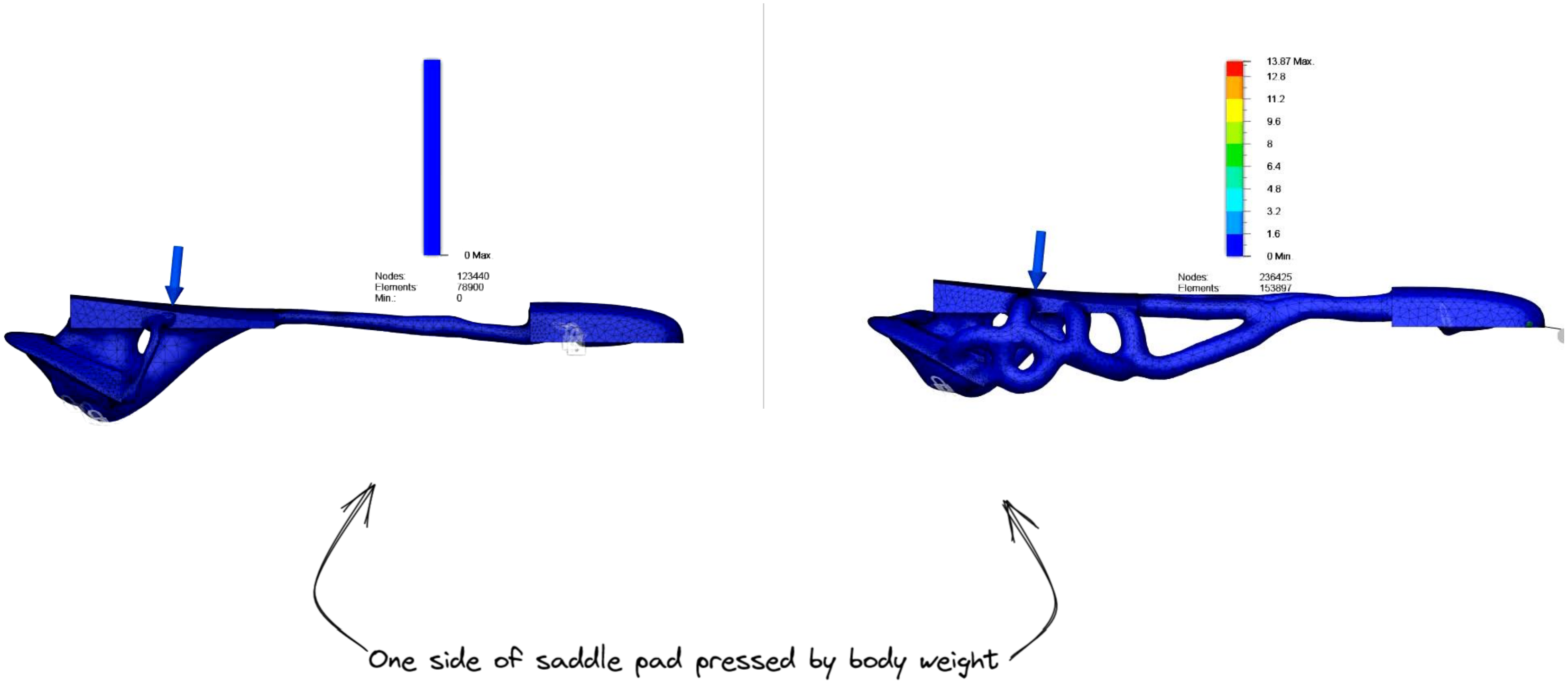
w/ Thickness constraint



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

Better shapes with proper constraints

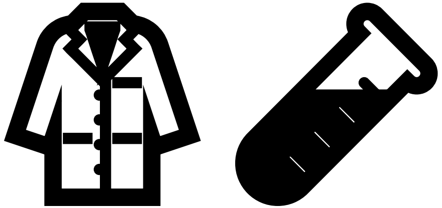
Evolve to the proper deforming feature with more interesting shape



Summary

Using both Event simulation and Generative design for better outcomes

- Event simulation can cover the blindside of assumptions in Generative Design
  - Nonlinearity – Geometric, Material, Contact induced.
- Tips for better Generative design and Event simulation/Quasi-static analysis in Fusion 360
  - Start small
  - 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



Do Experiments!

AUTODESK UNIVERSITY