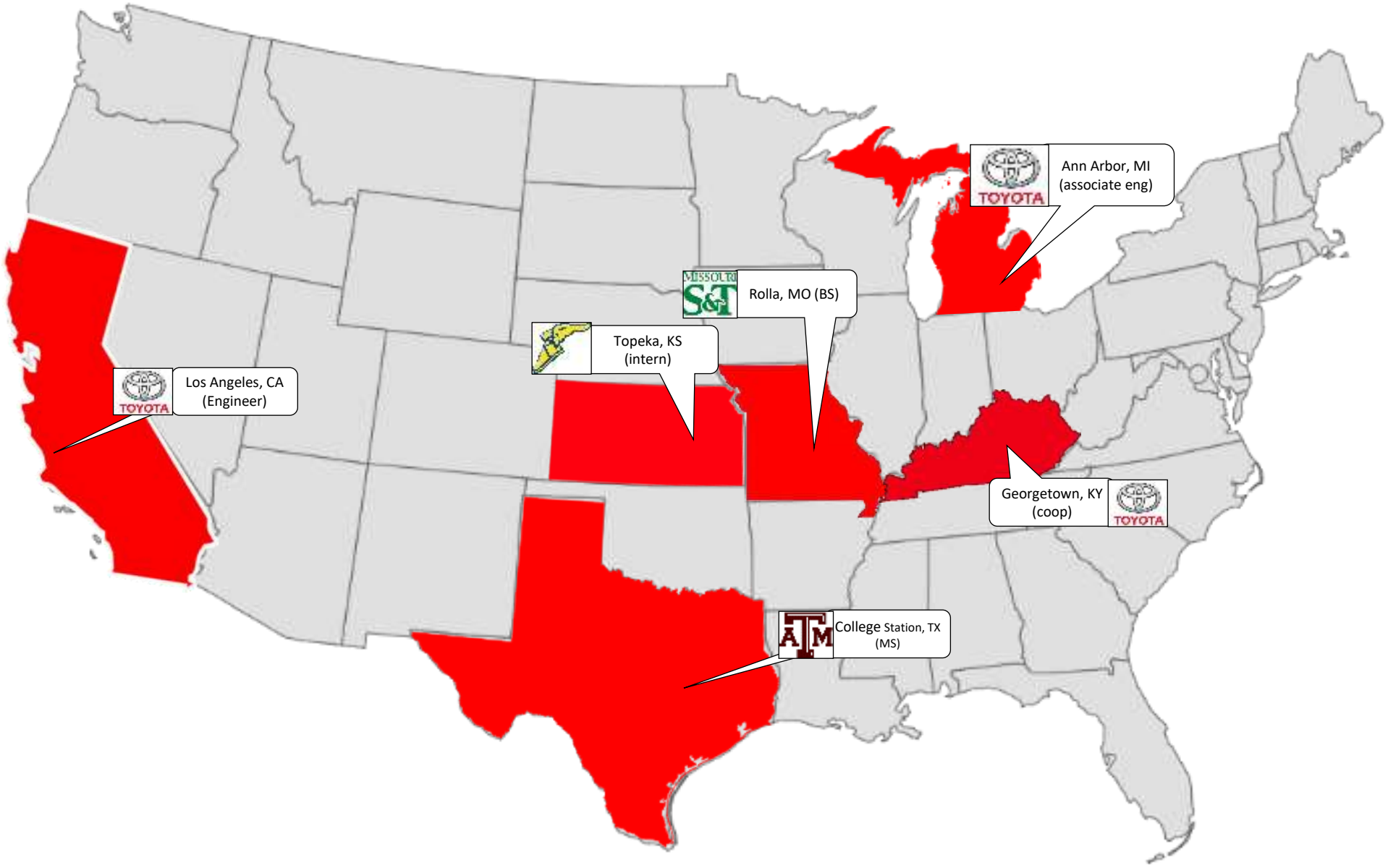
Summer school
ADDITIVE MANUFACTURING

TITLE: Practical Applications for Plastic & Metal AM

Speaker: David Malawey, Texas A&M University

My Background



My Lab at Texas A&M

Project Laboratory for Engineering Technology
Capstone Teams

Team Workspace

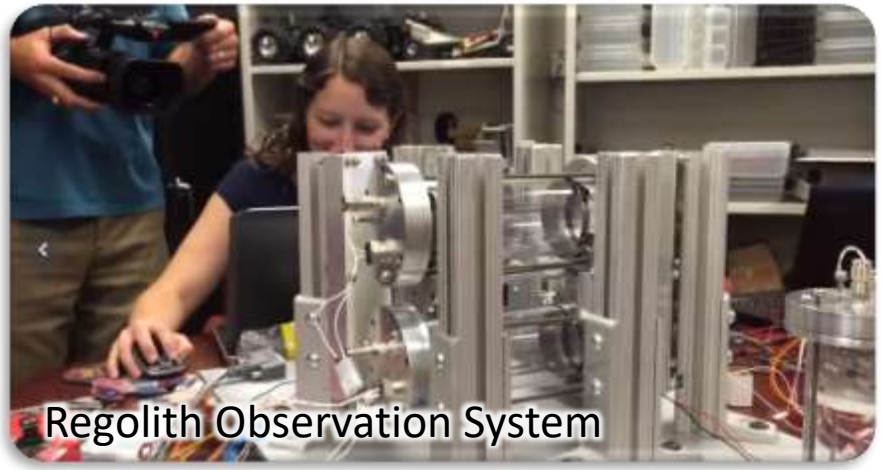
Electronics
Fabrication

Mechanical
Fabrication

My Lab at Texas A&M

"DSTR robot for outreach & tech demonstration"

Rover-monitoring System



Regolith Observation System

"Articulated Suspension Exploratory Platform"

My Lab at Texas A&M


Underwater ROV


Internet-of-Things House


“Reggie” Mini-digger robot


Pipe Inspection Lens/light system


Underwater Thruster

Goals

Goals of Plastic AM in my Job:

- Reduce iterations required in printing
- Improve the success of the application
  - (successful print ≠ successful part)
- Acknowledge limitations of AM
  - Constrain designs or adopt a postprocess.

Not included in this presentation:

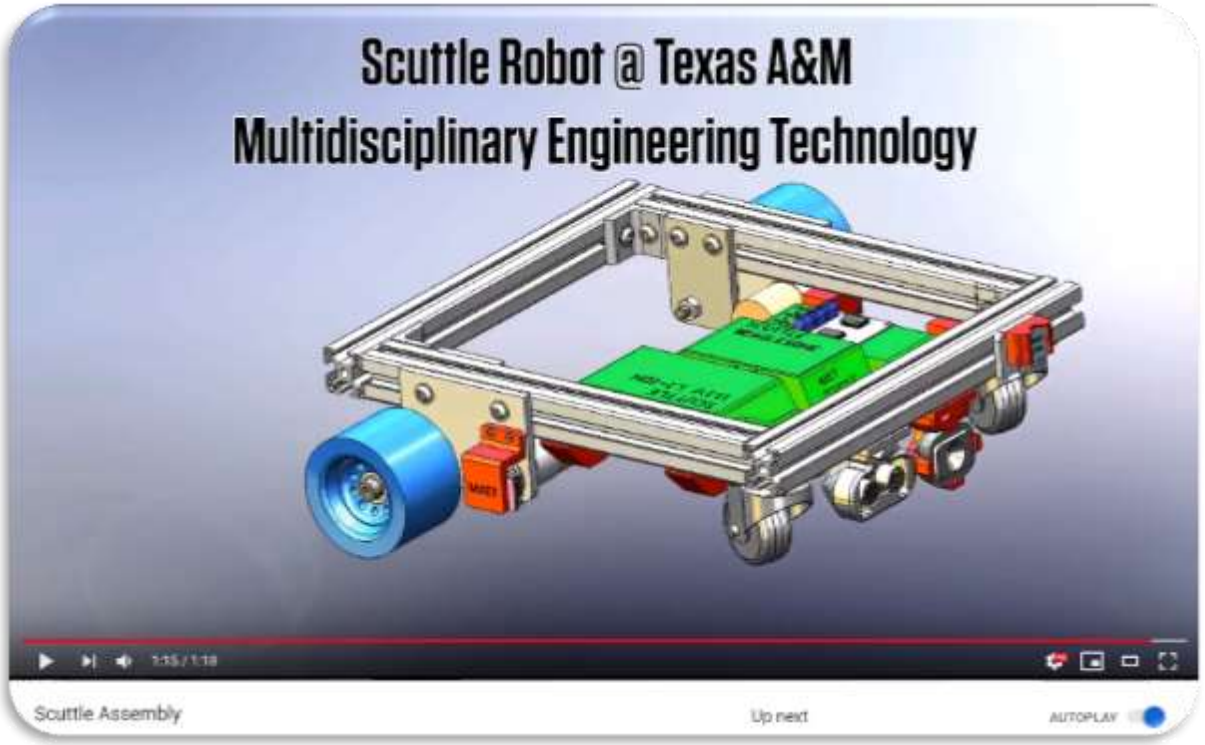
- How to operate your 3D printer.
- Various kinds of plastic printers.
- Parameters to use in your 3D printers.

Goals for this Presentation:

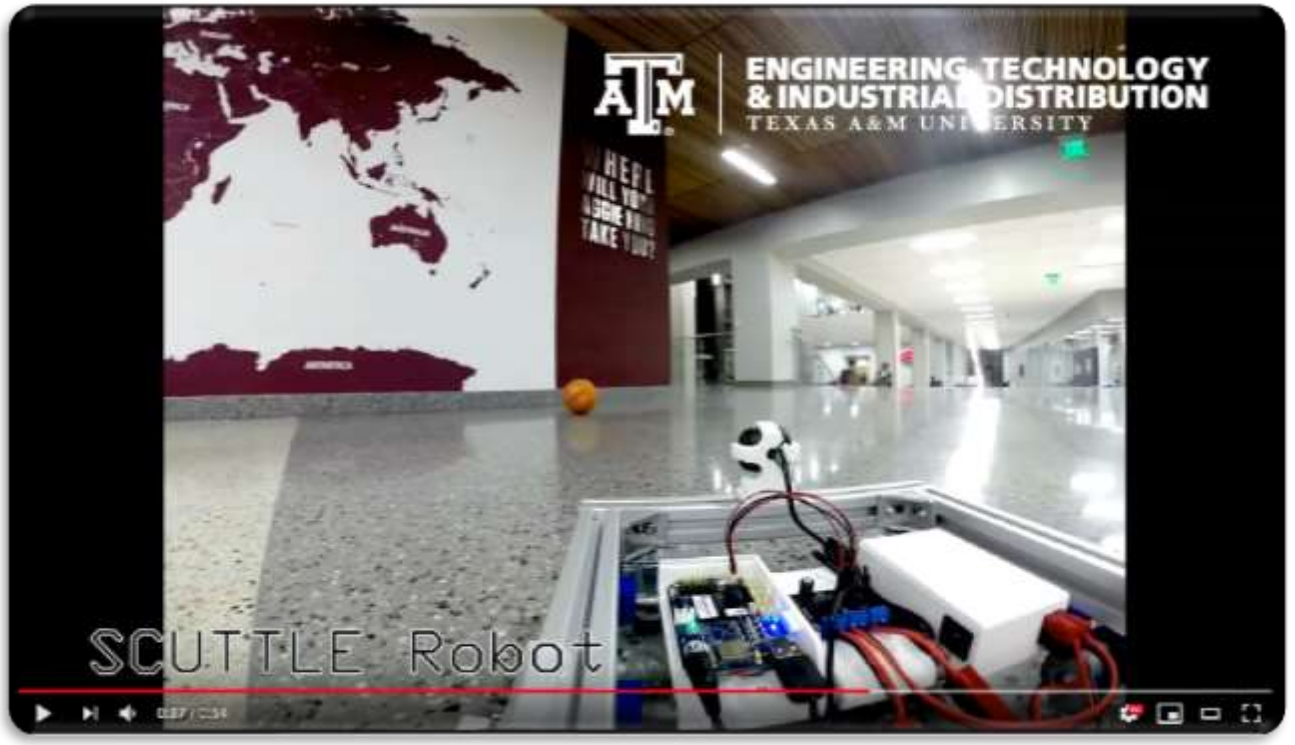
- Share **key learning points** that support applied AM.
- Share **applications** that benefit strongly from AM
- Share **tools** that we have discovered to enhance AM
  - (Links are provided in slides or PDF)

Robot with Examples Onboard

- Attempting to create the most affordable payload-carrying mobile robot
- Most of the parts are made from 3D printing or off-the-shelf
- Some components are examples for this presentation.



Parts Assembly on the robot

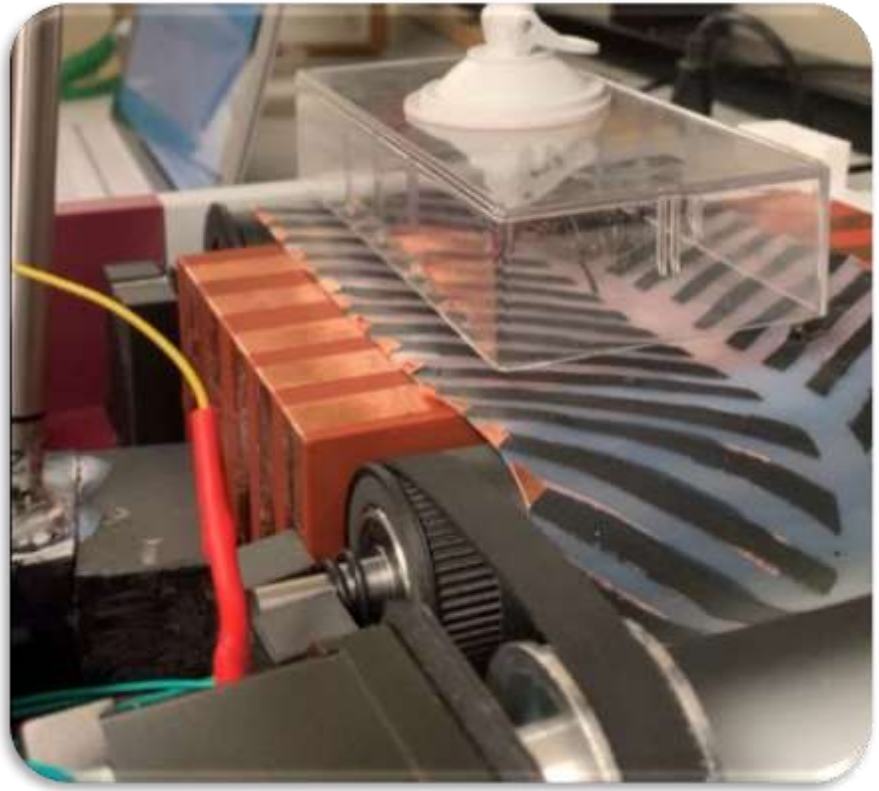


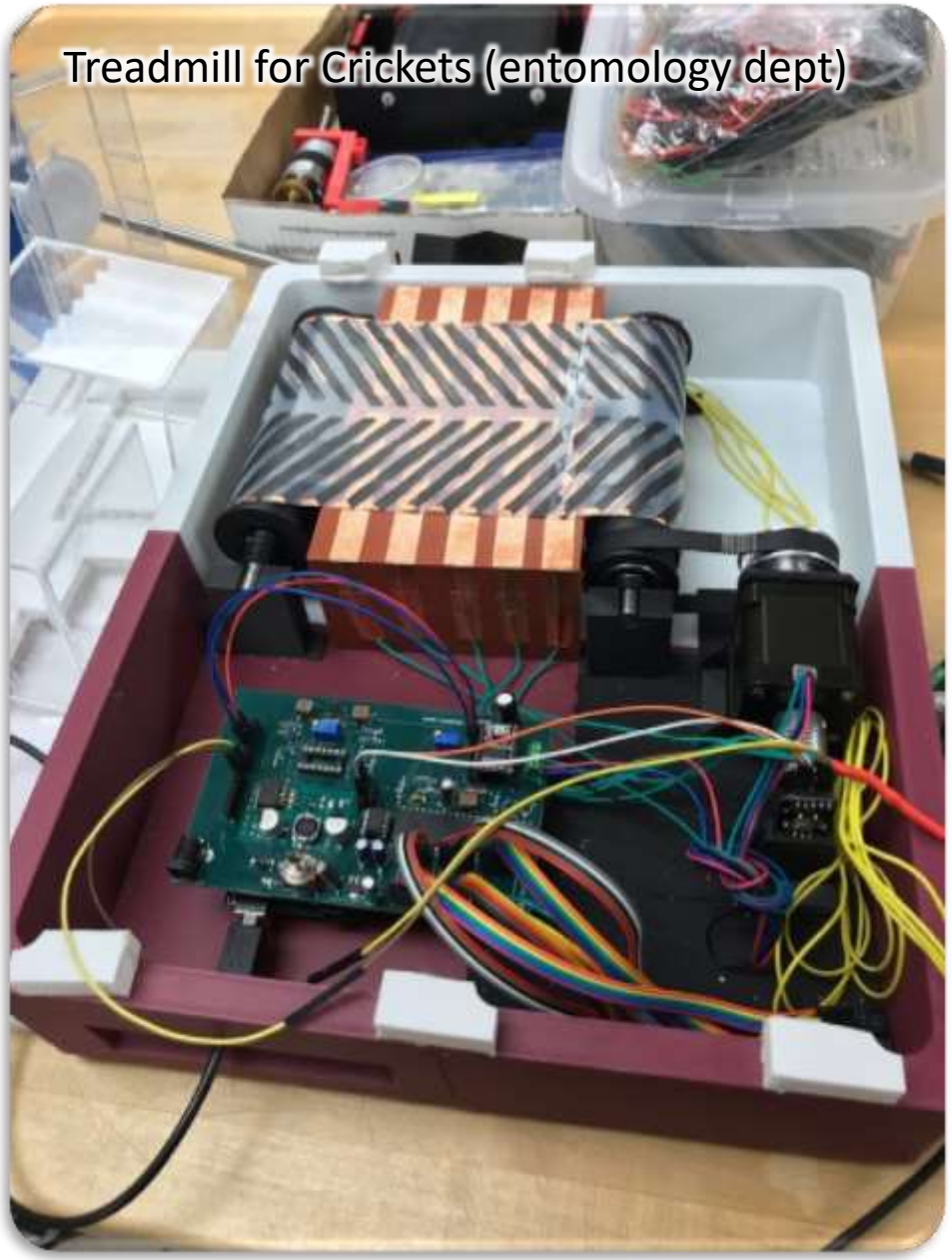
Autonomous Ball-Chasing

Modular Designs

Modular designs are the No.1 Recommendation

- If 1 module fails – only reprint 1 module.
- Multiple team members work simultaneously
- Printing results are faster
- Incremental results help the project team.



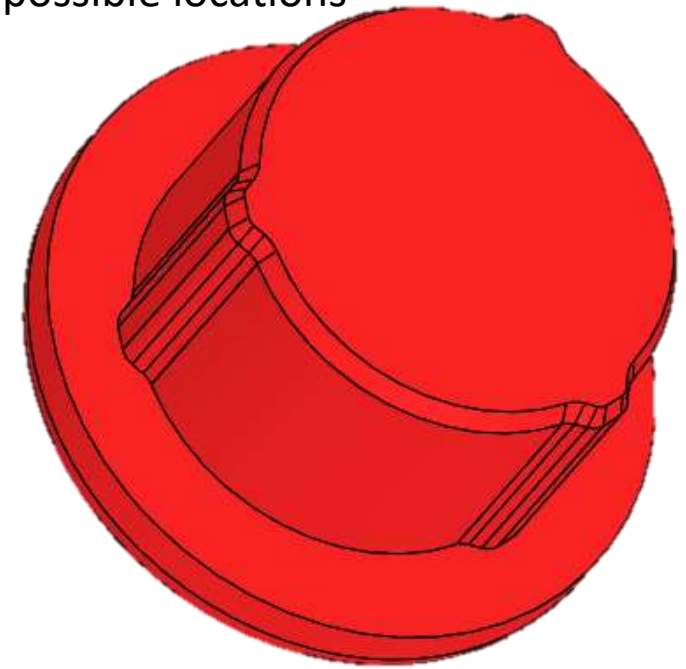


Mating Fitment – Plan for Variance

- Tolerance of printer varies (+0mm to +0.5mm)
- Printer model, material, parameters will impact the tolerance (unpredictable)
- Allow for filing without reprint
- See example part

Photo Credit: i-Solids.com

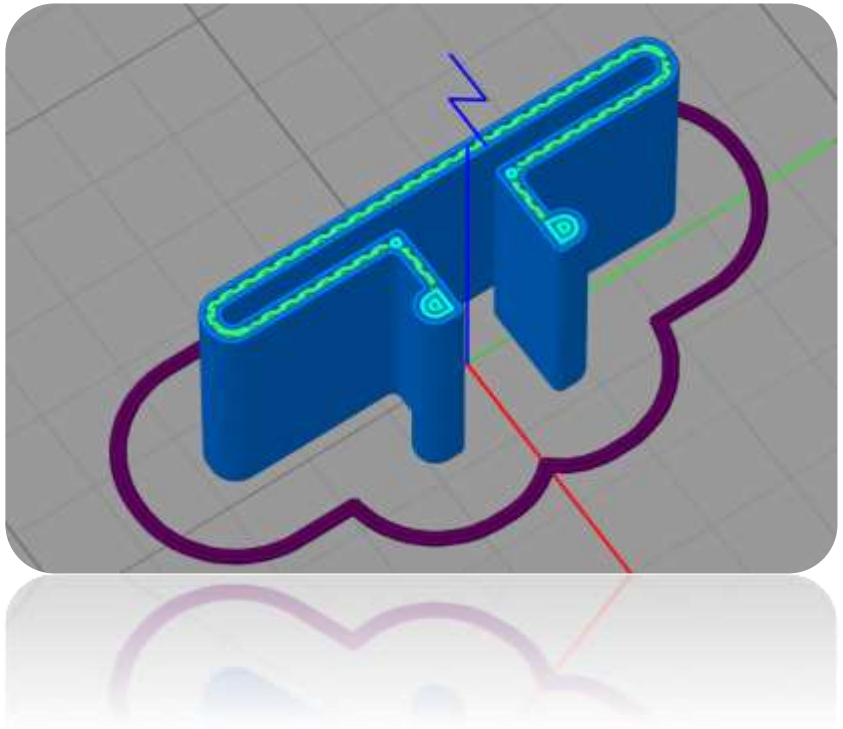
An interference fit isolated to fewest possible locations

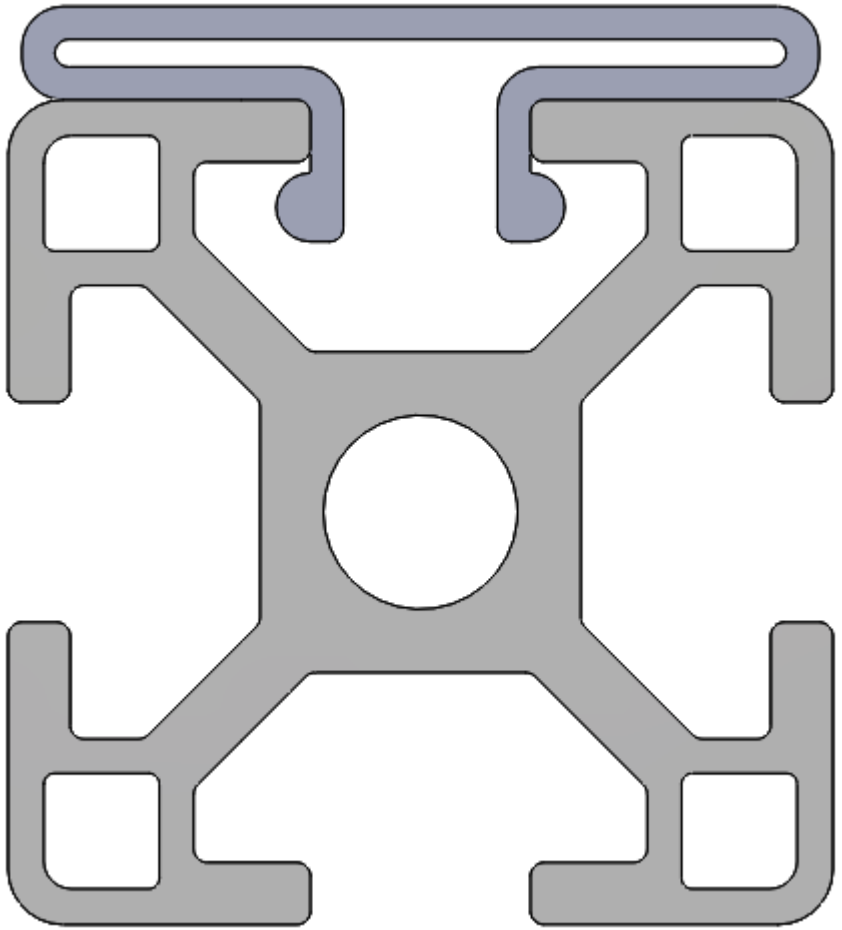


Compliant Designs

Print thin profiles to achieve compliant mechanisms.

- If you choose “no infill”, Make sure your outline size is a factor of your extruder width.
- see example part





Adhesives – PVC Glue

PVC, ABS, and ACRYLIC bond great with superglue but PVC glue is cheaper.

- PVC cement is ***gap filling***
- PVC cement is ***cheaper***
- Superglue is ***NOT gap-filling***

Safety Datasheet for "Loctite SuperGlue"

3. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous Component(s)	CAS Number	Percentage*
Ethyl 2-cyanoacrylate	7085-85-0	60 - 100
Methyl methacrylate polymer	9011-14-7	5 - 10

Safety Datasheet for "Medium Clear PVC Cement"

3. Composition/information on ingredients

Mixtures

Chemical name	CAS number	%
Furan, Tetrahydro-	109-99-9	30-50
Acetone	67-64-1	10-25
Methyl ethyl ketone	78-93-3	10-25
Ethene, chloro-, homopolymer, Polyvinyl chloride; PVC;	9002-86-2	12-20
Cyclohexanone	108-94-1	10-20
Fumed Silica	112945-52-5	1-5

All concentrations are in percent by weight unless ingredient is a gas. Gas concentrations are in percent by volume.

Safety Datasheet for "Medium Black ABS Cement"

3. Composition/information on ingredients

Mixtures

Chemical name	CAS number	%
Methyl ethyl ketone	78-93-3	40-60
ABS Resin	9003-56-9	30-40
Acetone	67-64-1	10-20
Other components below reportable levels		2.41

*Designates that a specific chemical identity and/or percentage of composition has been withheld as a trade secret.

Adhesives – Gel Superglue

Modify off-the-shelf parts by bonding with 3D prints.

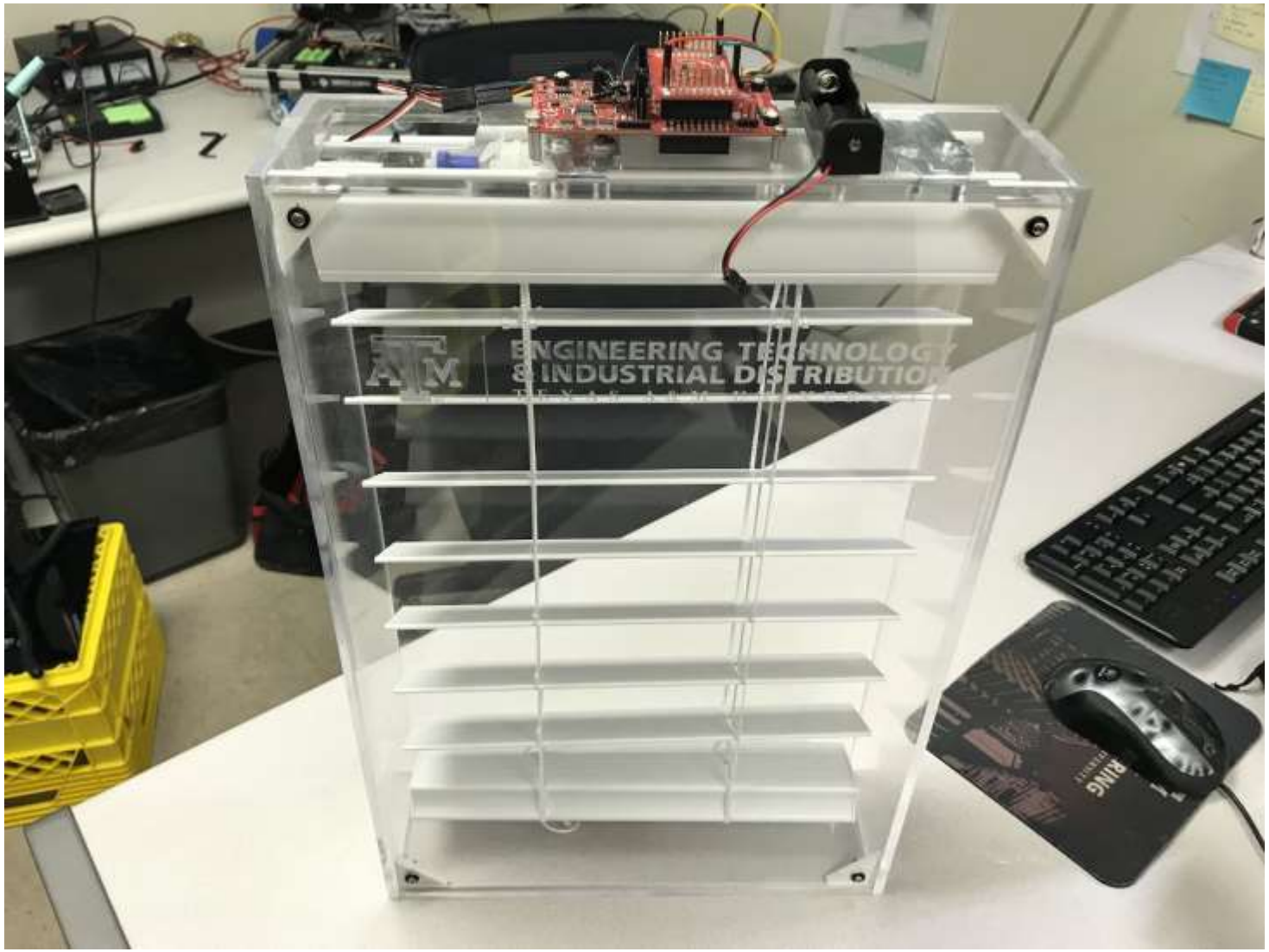
- see video - 2:32 to 3:43

Adhesives – For Small Gaps

Solvents can be used as adhesives

- They do not fill gaps
- They perform “wicking”
- Check chemical compatibility

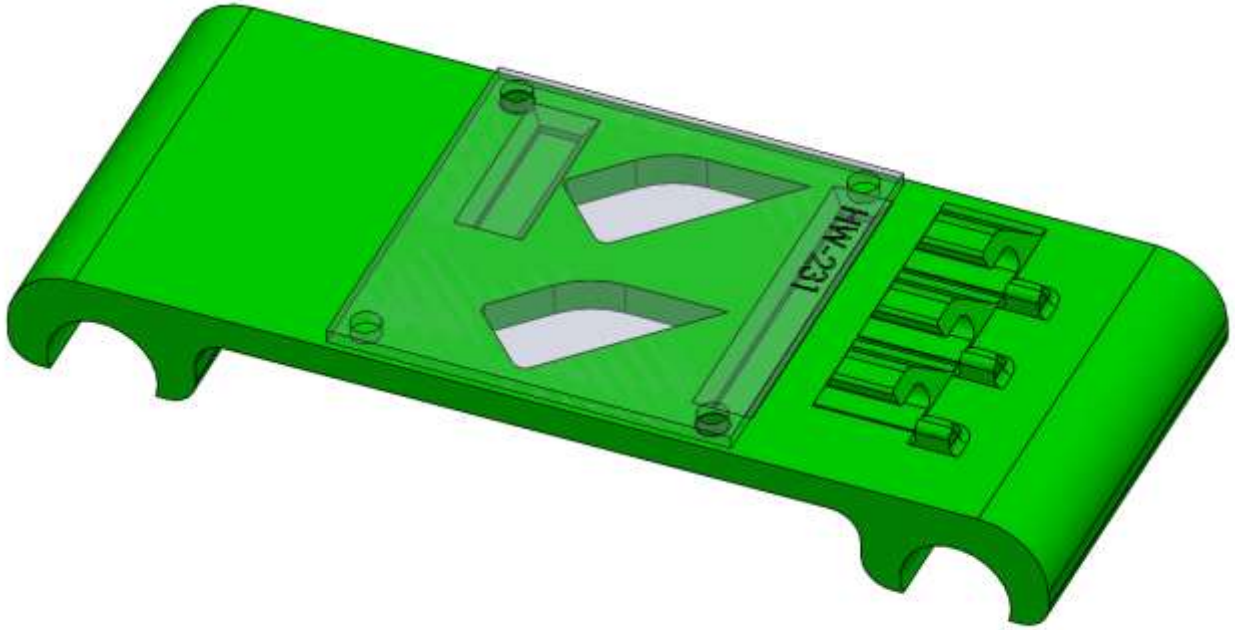
See video – See example part



This technique was used for an ***IoT Window Blinds*** enclosure

More Planning - Less printing

- Utilize Designs Online
- double-check designs by amateurs
- Check versions of parts
- It always pays to model mating parts
- See example part

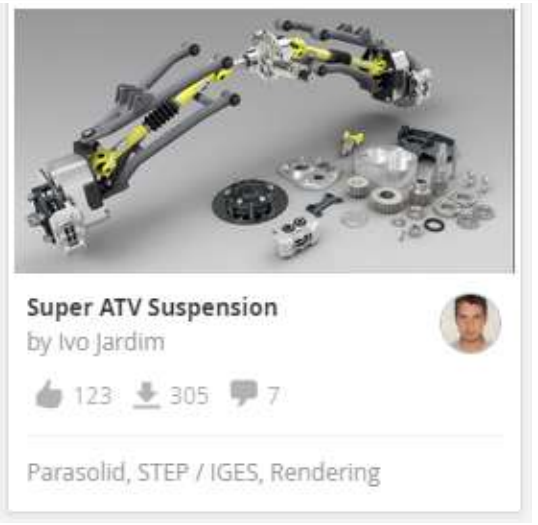


Motor driver bracket for SCUTTLE robot - designed with mating features as constraints

Thingiverse

Free online design – without cooling PCB

GRABCAD COMMUNITY Library

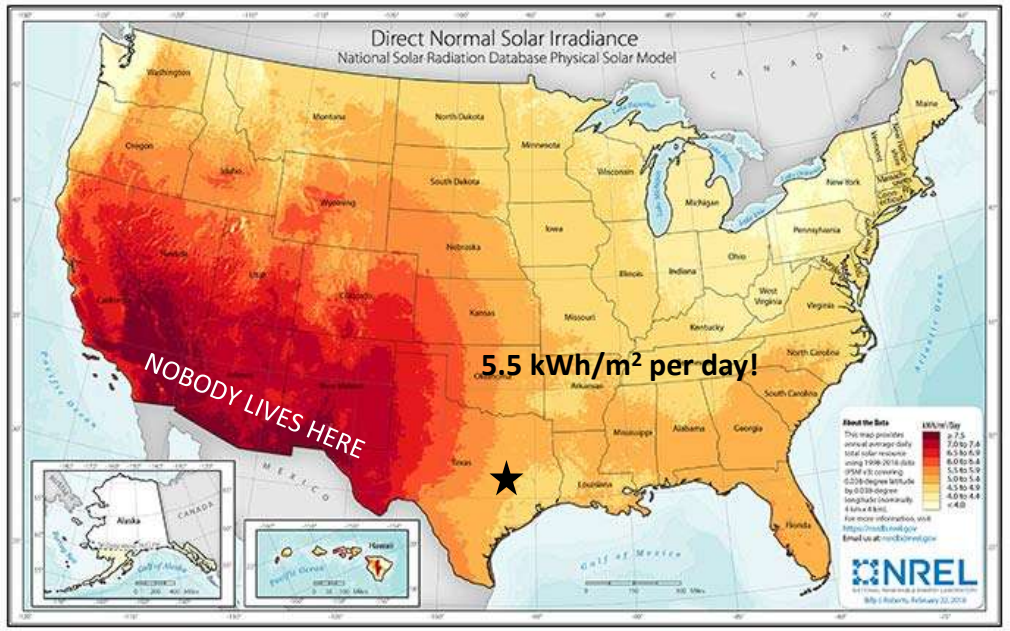


Some very professional designs on GrabCAD

ABS heat/UV Performance

I created an ABS handle grip for my Harley

- It has been working for 2 years
- Receives direct sunlight of texas

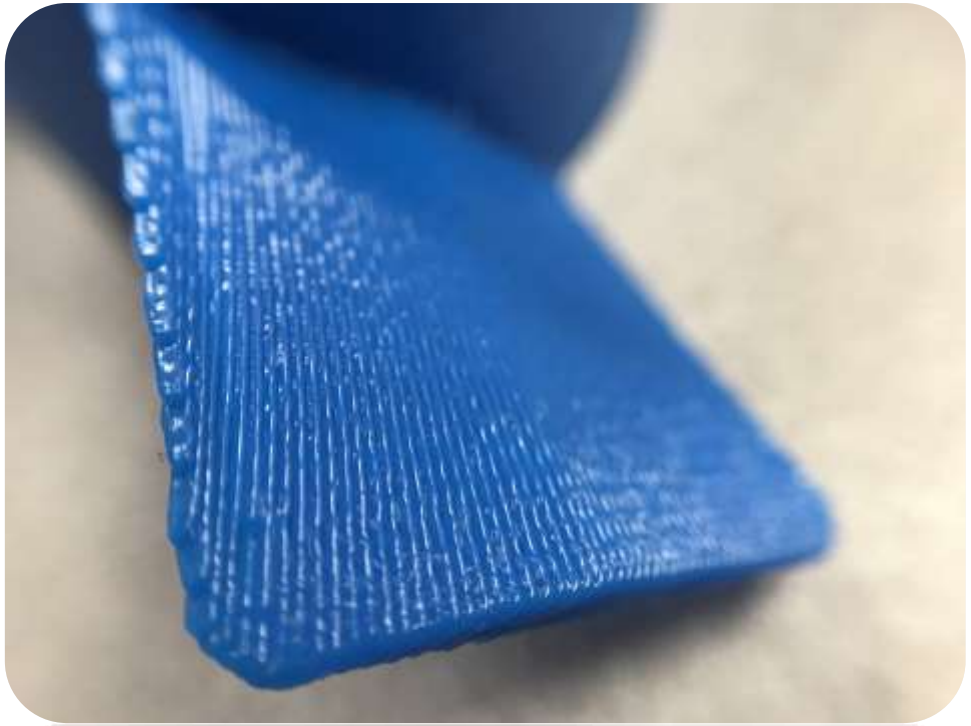


ABS handle grip survived 2 years so far!

Surface finish treatment

Method: acetone vapor polishing (this works on ABS but not PLA).

- See example part



Propeller blade before surface treatment

Propeller blade after surface treatment

- increased smoothness
- loss in dimensional accuracy

Surface finish treatment

My vapor treatment setup. (Enclosure is more elaborate than necessary)

- suspend the part to reduce contact
- surround the part with acetone vapor, and cover it
- raise the temperature to about 35C
- Leave for about 40 minutes
- Container is metal or HDPE (chemical resistance)

Surface finish treatment (continued)

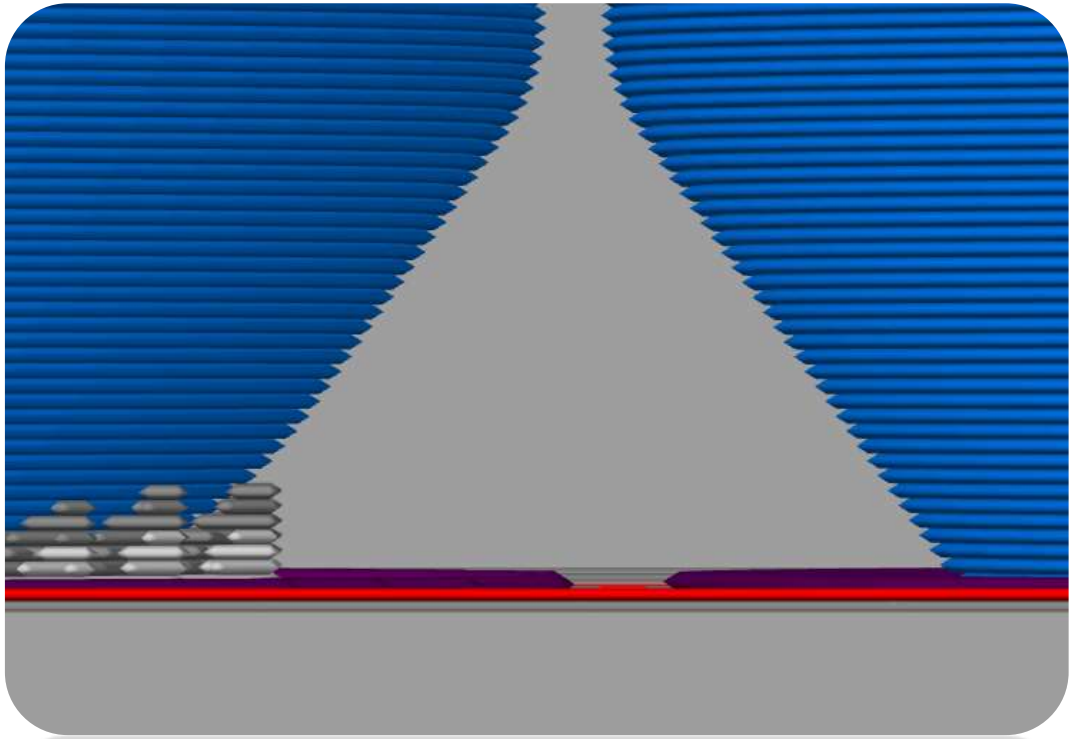
Method: Gap-Filling primer & sanding

- Spray Filler, Primer Filler, or Sandable Primer
- See video (if time allows)

Do not Fillet Lower Edges

A fillet on the bottom edge will create an overhang.

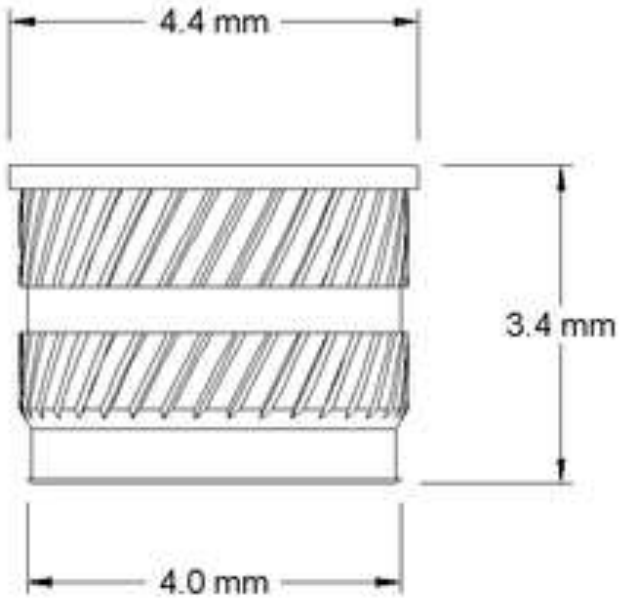
- Part below has a 60 degree wall and just a 7mm fillet.
- This will require supports or just build poorly

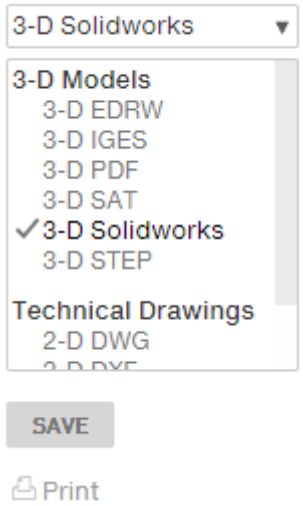


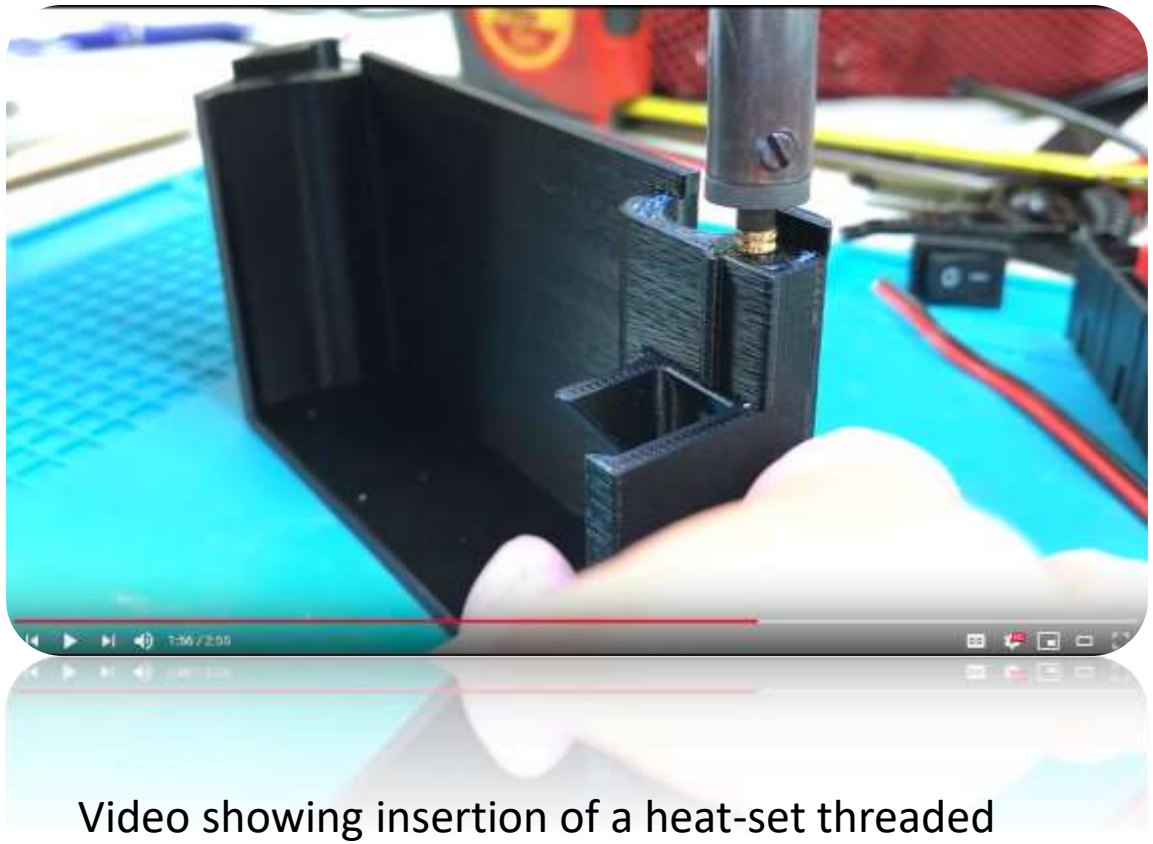
Fasteners: Heat-Set Threaded Inserts

Heat Set Threaded Inserts are very reliable for fine threads.

- In Texas we order from Mcmaster Carr (example parts)
- 3D CAD is available for most fasteners
- Drawings are provided
- Specialized iron die is available.





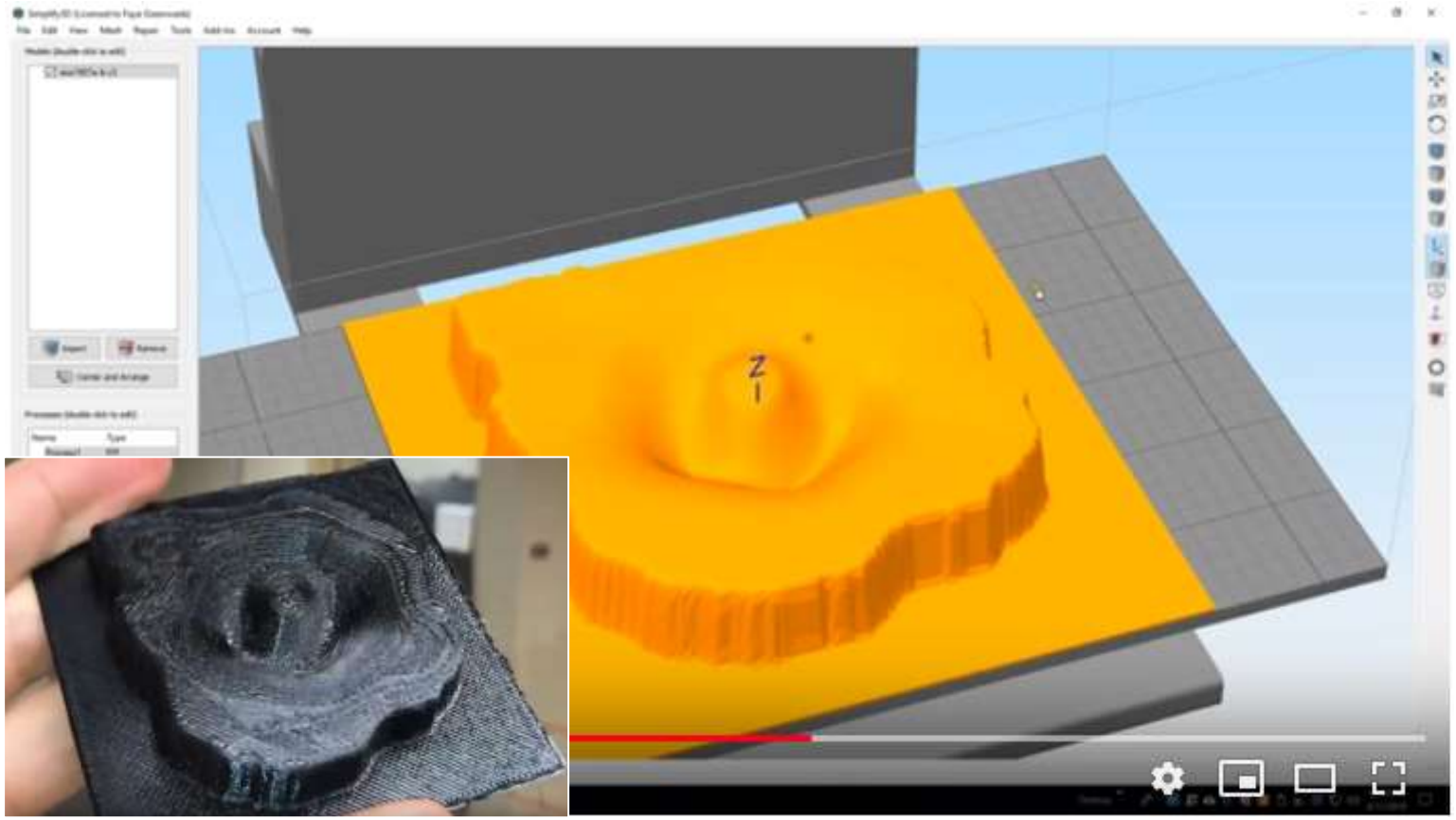


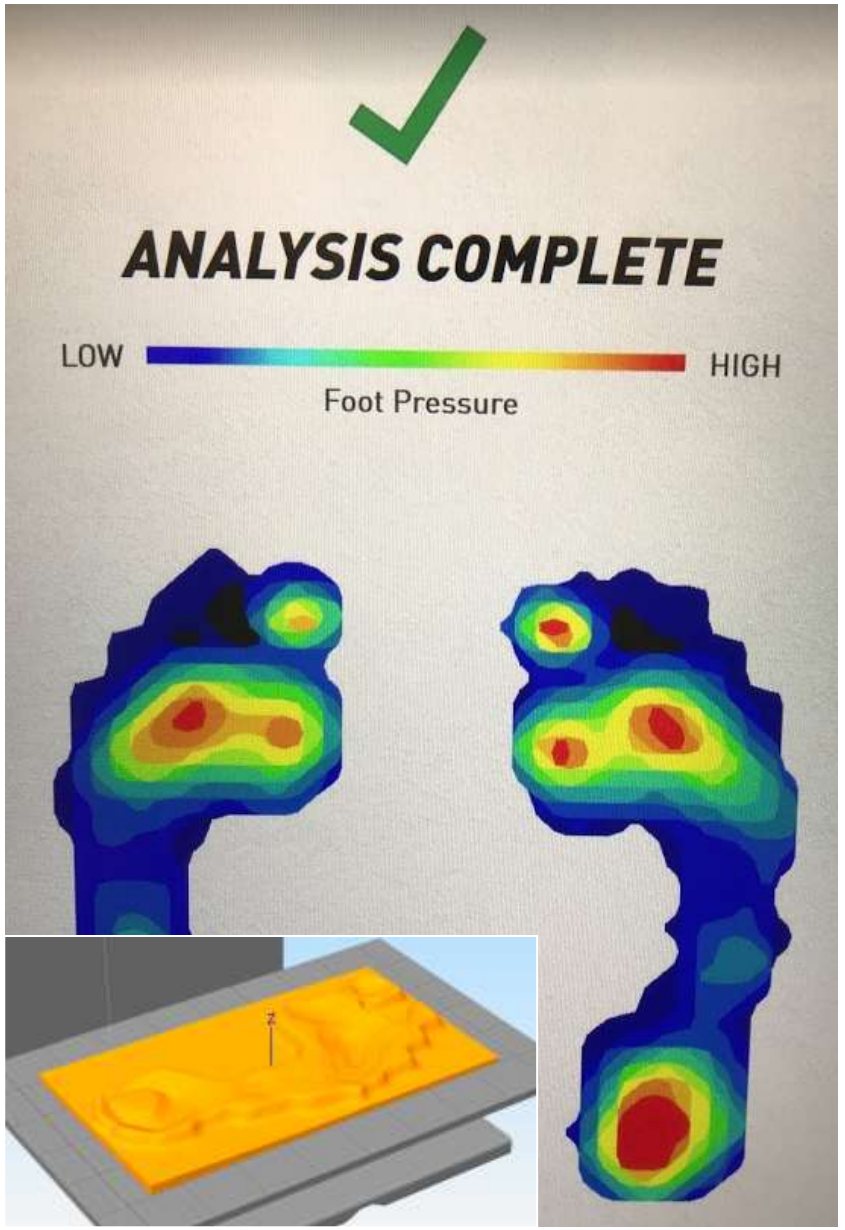
Video showing insertion of a heat-set threaded insert

Color Mapping

Easily convert a color photo into a 3D print

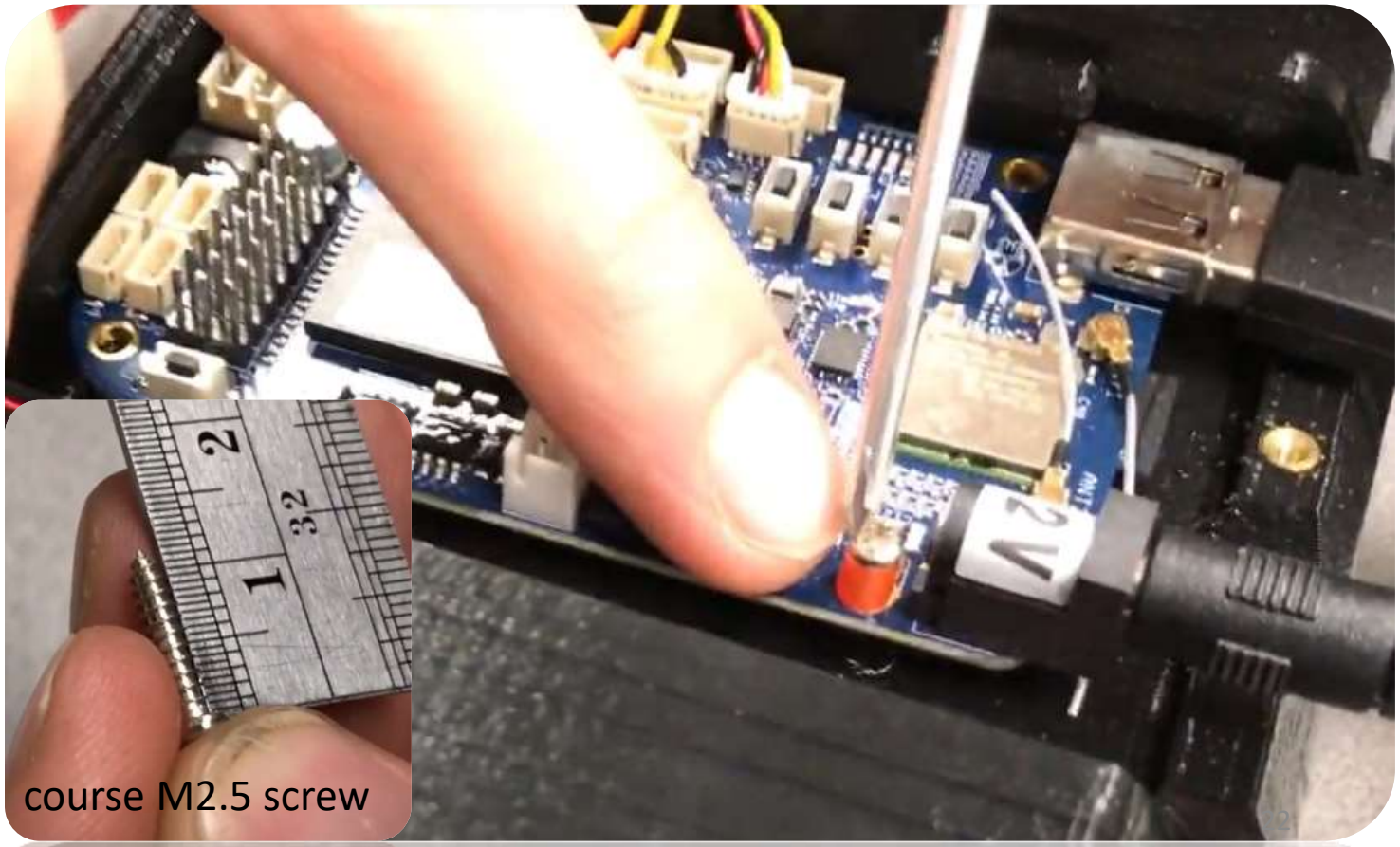
- Video: how to 3d print a black hole
- Potential Application: difficult-to-measure parts, non-mating parts





Fasteners: Heat-Set (continued)

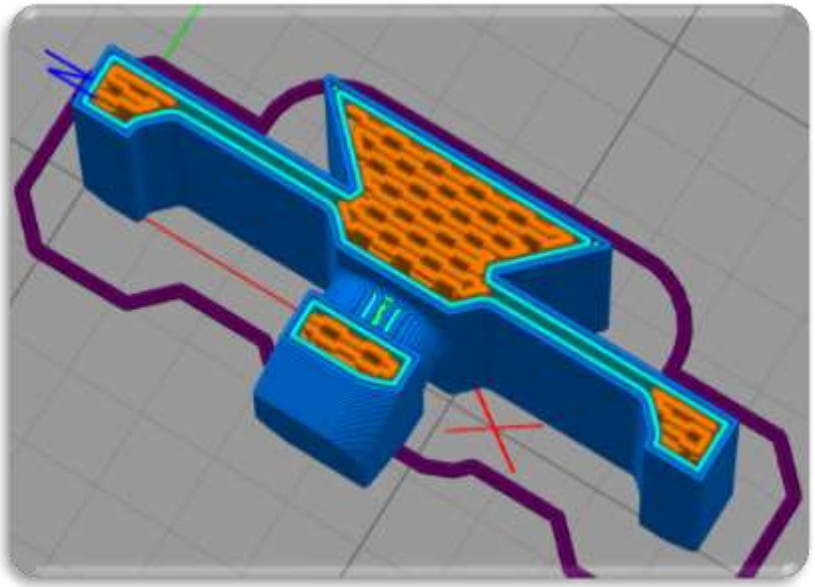
Application: Adjustable cutter for plastic tubes.
Create your own spacers.



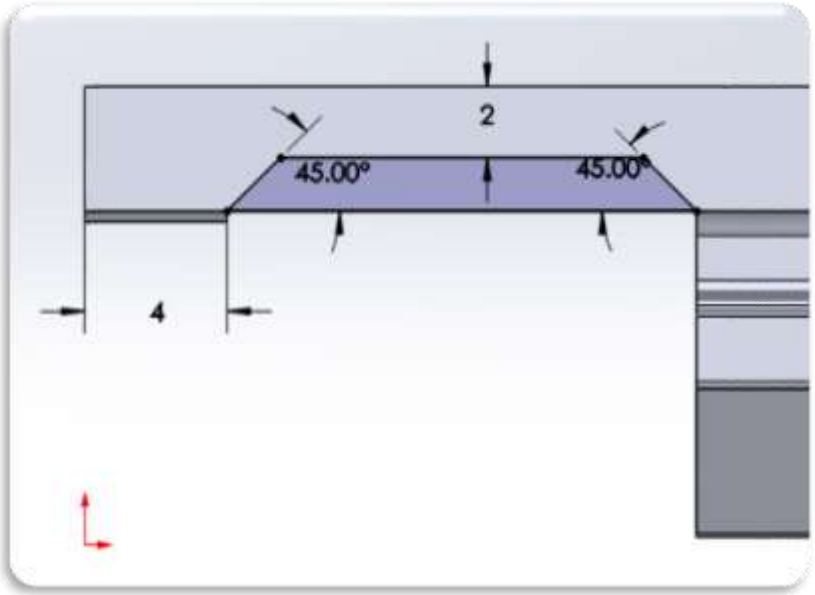
Extruder Width & Wall Gap

The slicer may create a gap between walls in some cases

- Compare your nozzle diameter to wall thickness and check the slicer model.
- Nozzle on common FDM desktop printers is 0.4mm
- See handout example with wall gap



0.4mm nozzle
2.0mm wall
100% infill
2 “perimeters”

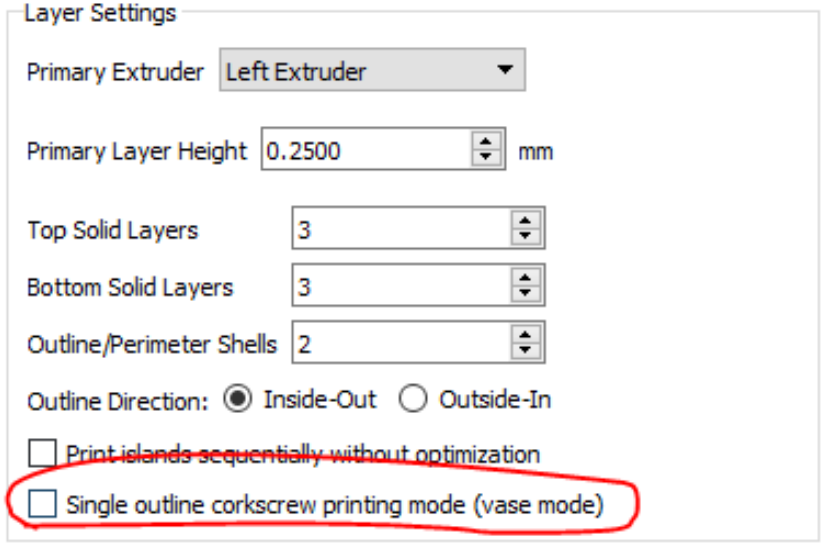


Vase Mode

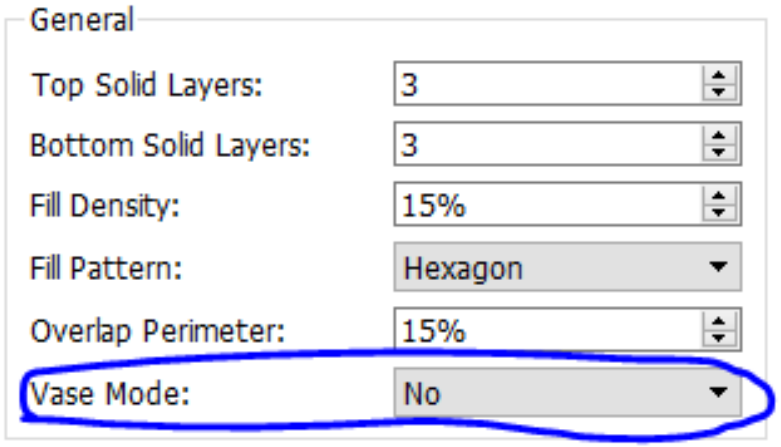
Vase mode or Corkscrew Mode in FDM

- Saves time because the printer nozzle moves continuously
- Very few parts are suitable for this method
  - Vases
  - Cups
- See example part

Vase Mode Setting in Simplify3D



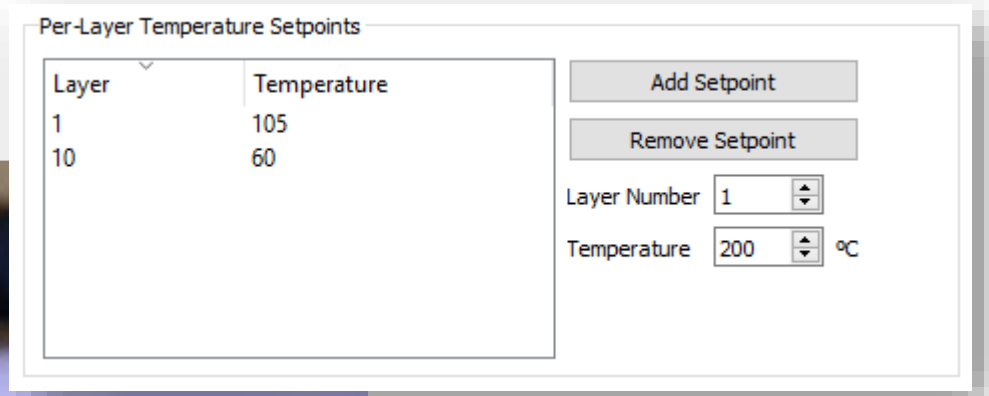
Vase Mode Setting in FlashPrint



Successful Overhangs

Reduce the bed temperature after the initial layers.

- On Flashforge Dreamer, we use 105C and transition to 60C

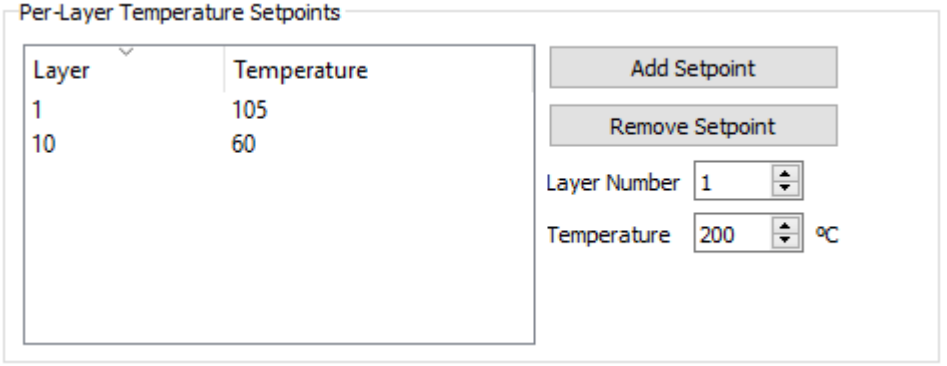


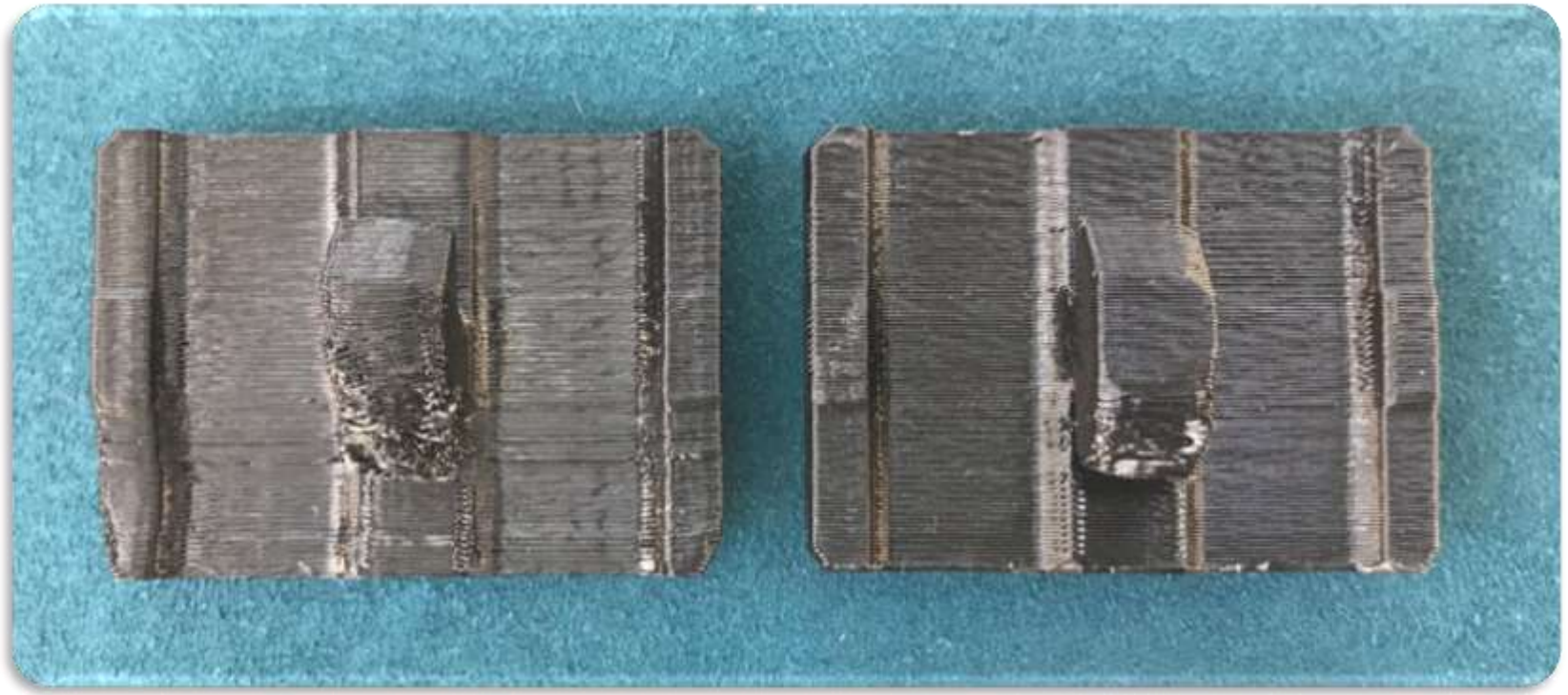
Parameters in Simplify3D

Successful Overhangs (continued)

Reduce the bed temperature after the initial layers.

- On Flashforge Dreamer, we use 105C and 60C
- see example parts





1 Design Combining Strategies

An example part featuring:

- using rubber o-ring
- internal passages
- built-in threads
- gap-filling adhesive
- wicking adhesive
- heat-set inserts
- “vase mode” component
- bonding dissimilar materials (ABS-PVC)
- bonding same materials (ABS-ABS)

My laminar flow valve attempt

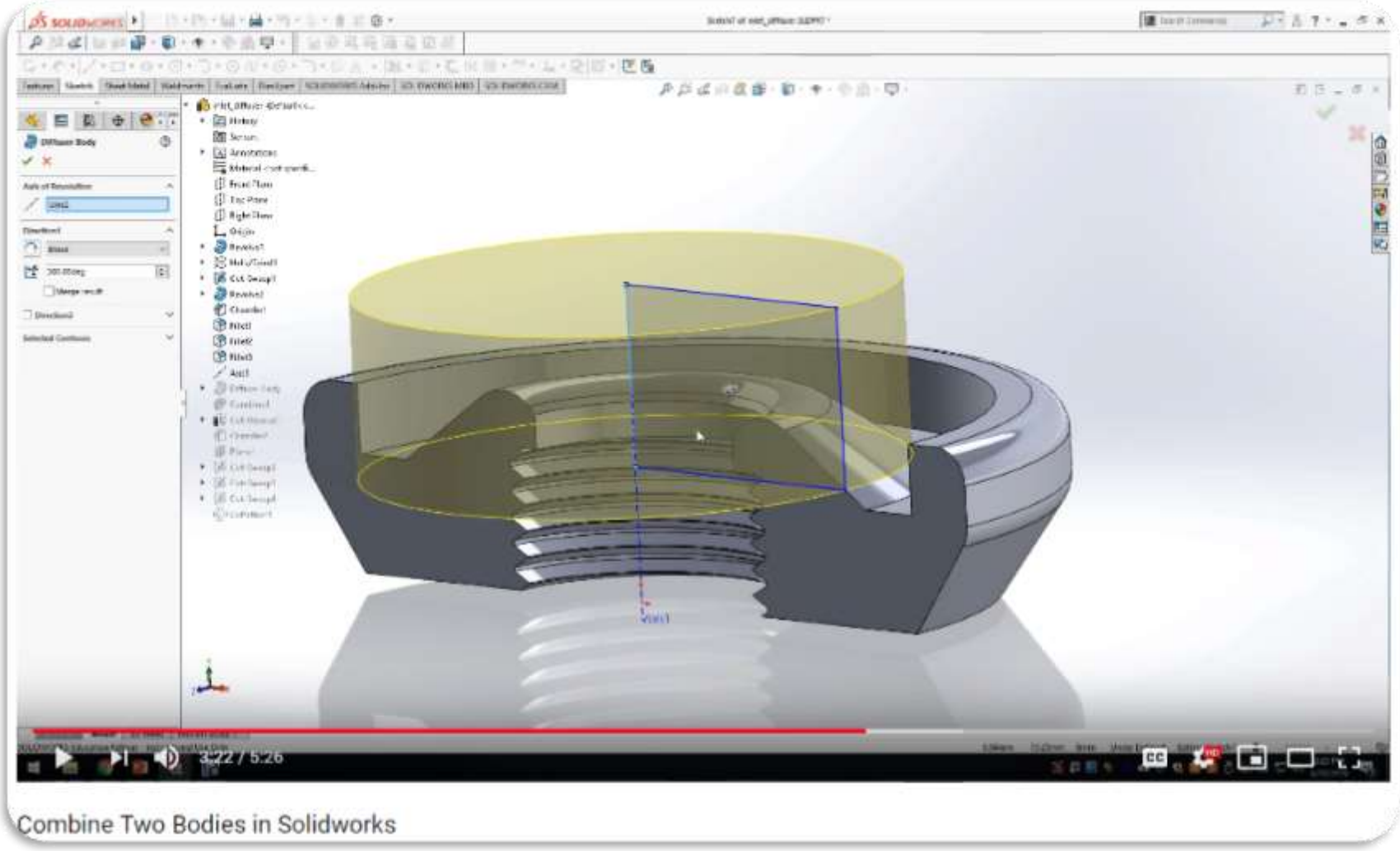
CAD assembly is available at GrabCAD.com HERE

My Benchmark: City Creek Center, Salt Lake City, Utah, USA

Strategy – Subtracting Parts

Some models have features not suitable for 3d printing.

- How to *subtract* two bodies in Solidworks
- see video

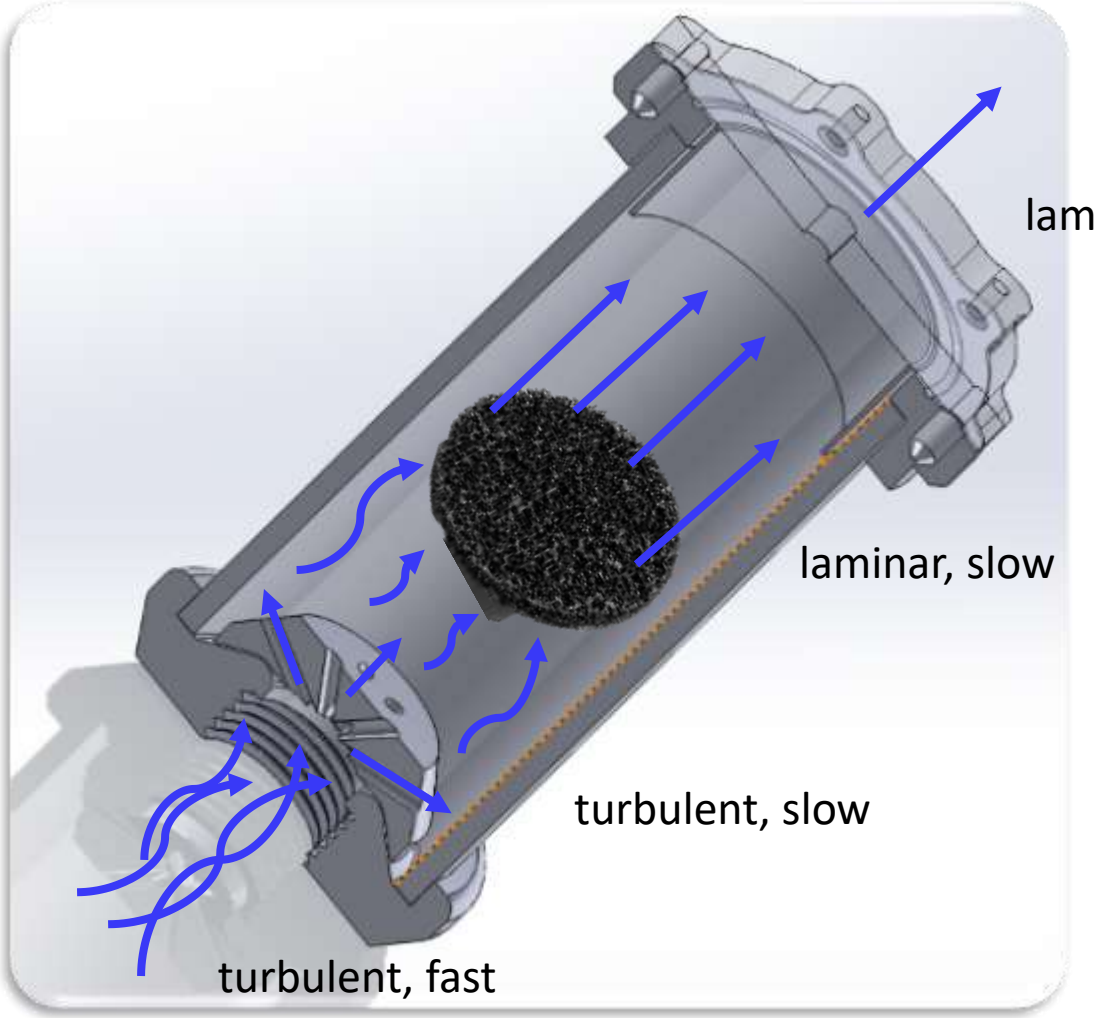


1 Design Combining Strategies

Some models are not suitable for 3d printing.

- They can be split and printed in 2 parts
- Glue these parts back together for function

CAD assembly is available at GrabCAD.com HERE



1 Design Combining Strategies

An example part which combines strategies.

- See video: construction of laminar flow valve

Section 1 End - Questions

Questions for Section 1?

Goals

Goals of Metal AM in my Job:

- Help Grad/Undergrad teams design for AM
- Support research in parameter selection
- Protect the Equipment
- Attempt to make the lab sustainable/economical

Goals for this Presentation:

- Share **key learning points** that support applied AM.
- Share **applications** that benefit strongly from AM
- Share **tools** that we have discovered to enhance AM
  - (Links are provided in slides or PDF)

ETID Metal AM Lab

Requirements for Metal AM Lab:

- Argon Supply
- Laser chiller
- Air dryer
- High-performance A/C in-lab
- Dedicated Computer
- Sieve (dedicated closet)

ETID Metal AM Lab

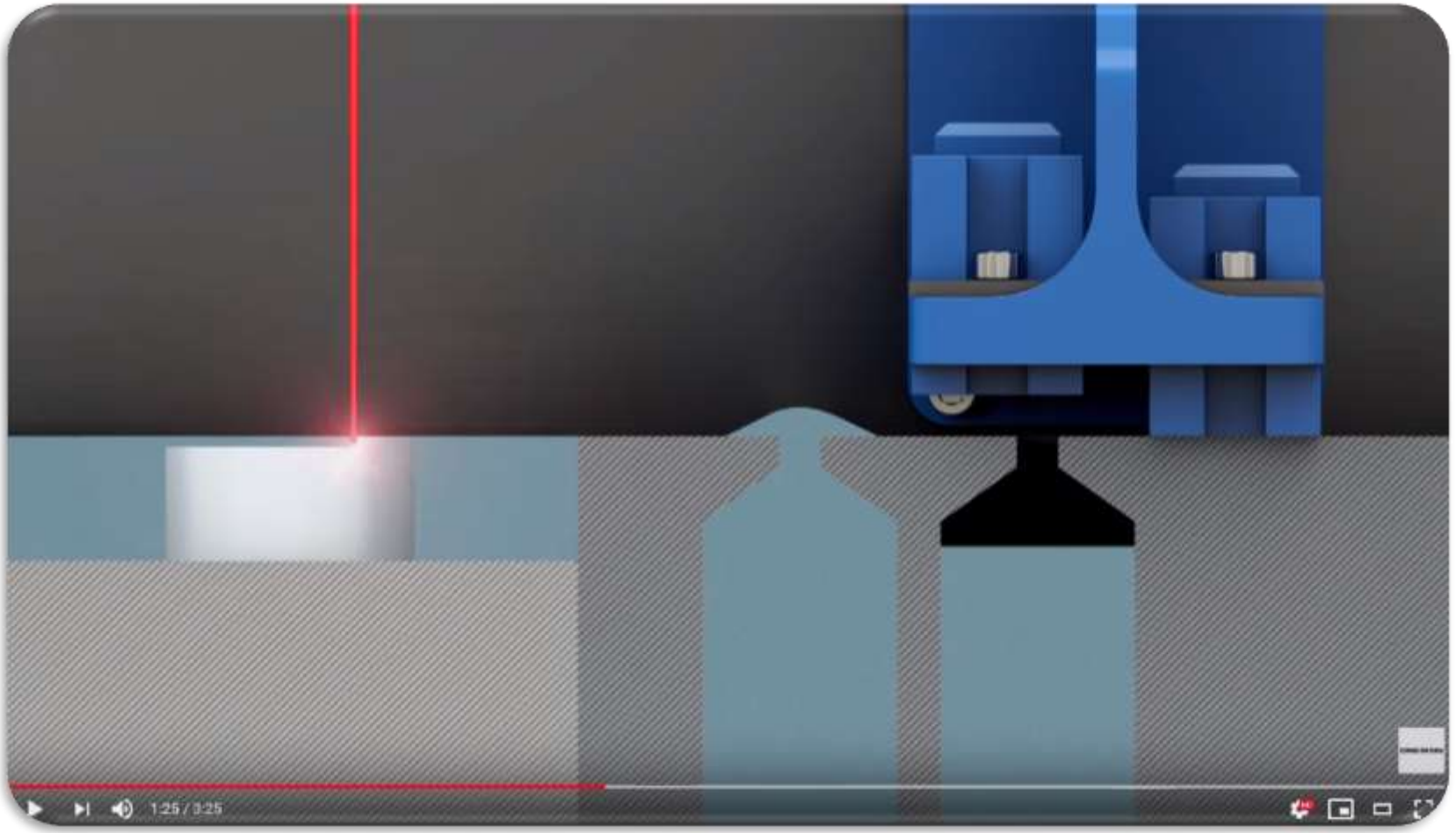
Sieve Room:
Mechanical shaker
Fine screens
Inert gas supply (for Al, etc)
Fancy vacuum

Metal AM – Process Overview

How the Layers are Formed
(Skip this slide if audience has seen)

What you can call this process:

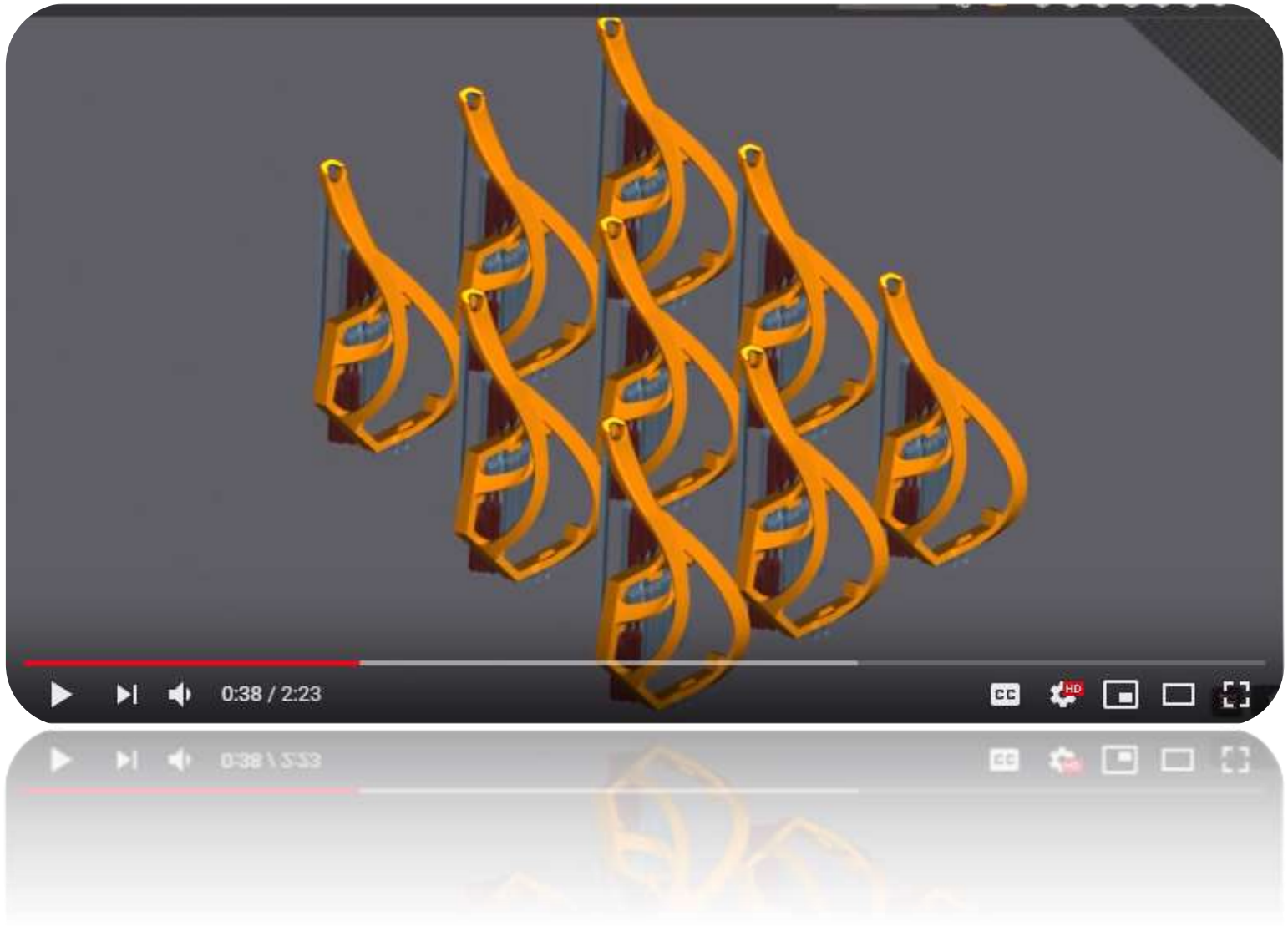
- Selective Laser Melting
- Direct Metal Laser Sintering
- Laser Powder Bed Fusion
- See video – 0:55 through 2:15



Metal AM – Process Overview

Our Machine: Renishaw AM400

- Brief overview of design and build
- See video of our process



Metal AM –Constraints

What makes a part not suitable for metal AM?
See video: Compilation of Challenges in Metal AM

Warping and Practical Solution

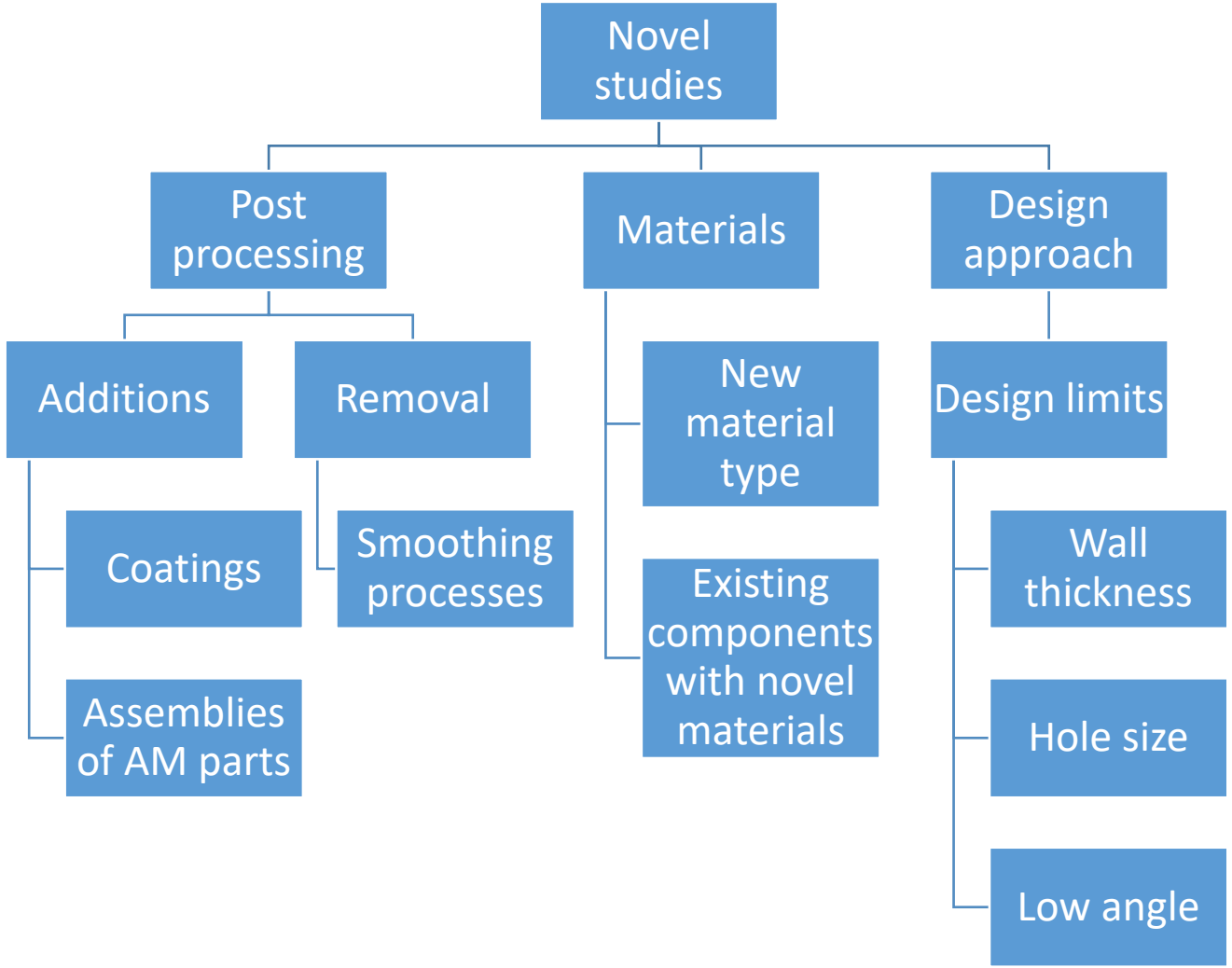
Proof that plates can warp severely

- Application: repairing a screw

Reconstructed Bolt for Substrate – KGSBO company, Katy, TX

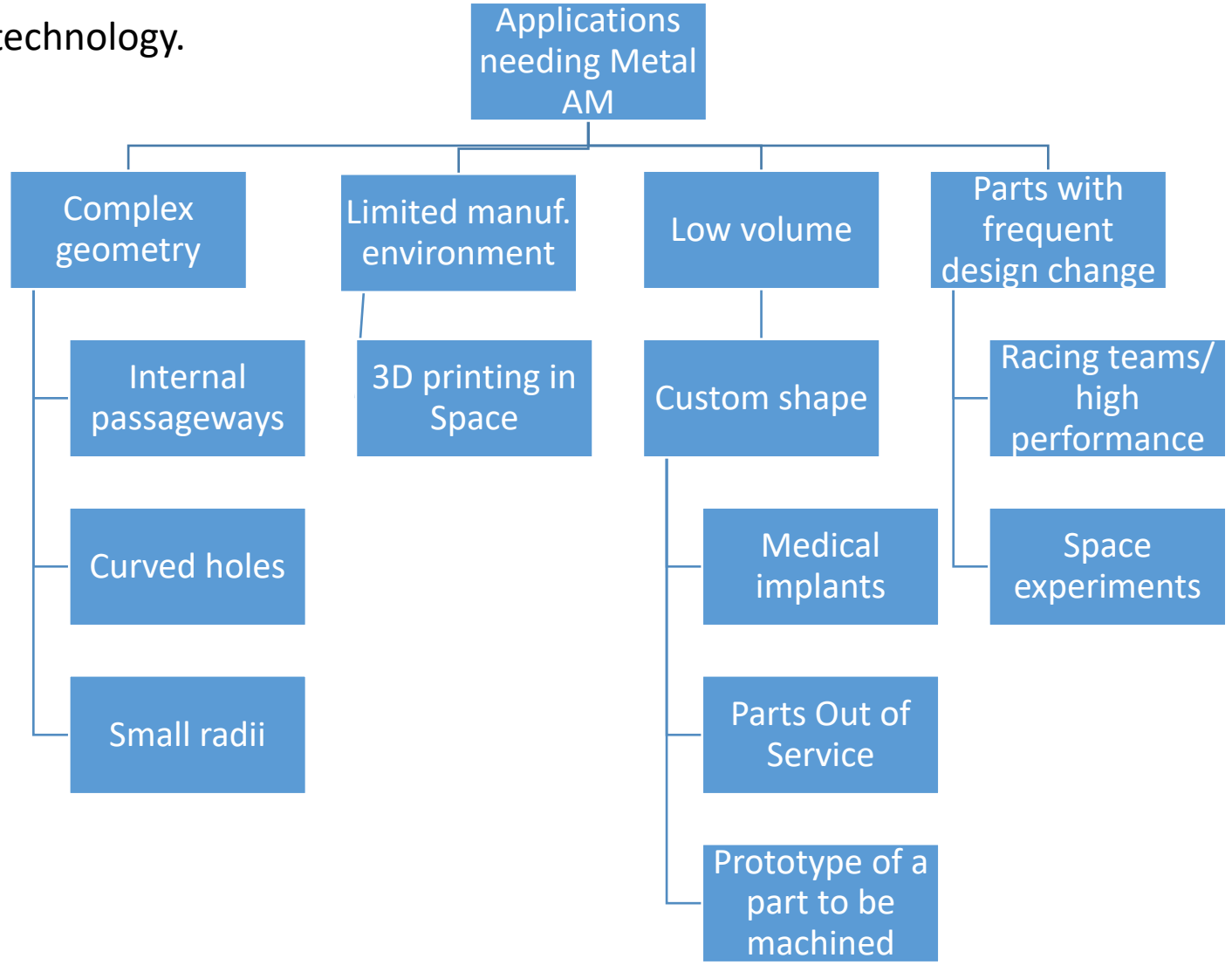
Metal AM Brainstorm

Research exploration in improving metal AM to meet the needs of current designs.



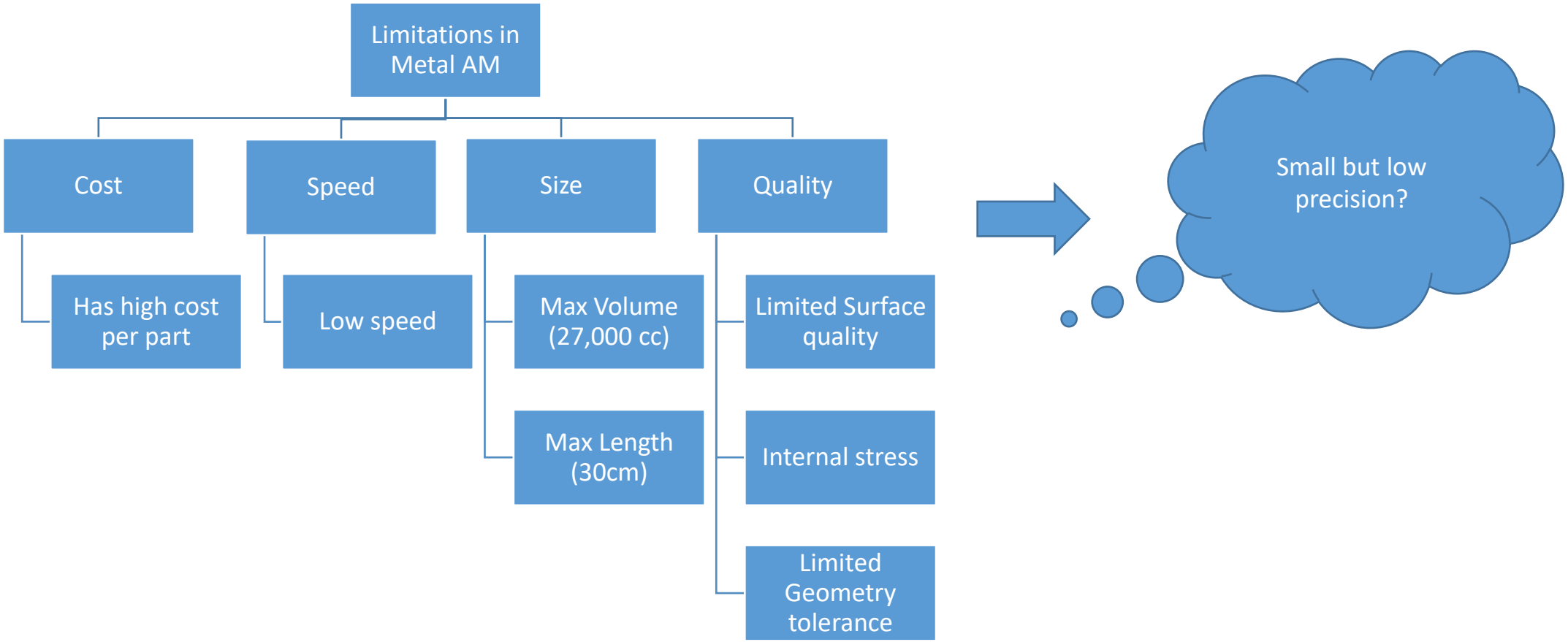
Metal AM Applications Exercise

Considering suitable parts for the technology.



Metal AM Applications Exercise

Qualitative limitations



Section 2: Metal AM Applications

Some Small & Low Precision Applications

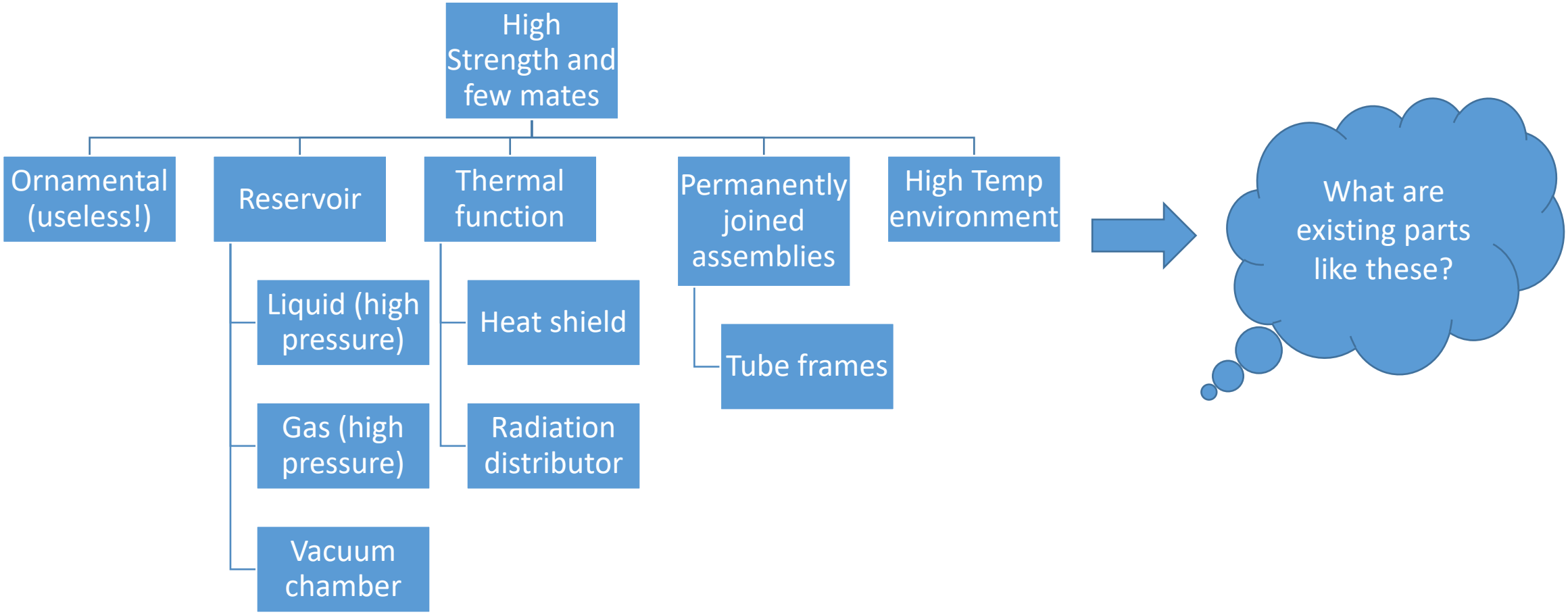
- Small but low precision
  - Ornamental
  - Functional
    - Parts that lose geometry as they work
      - Hammers, grinding, cutting
    - Parts that mate with low precision requirement
      - Springs
      - Parts separated by gasket
    - Chaotic function
      - Filters, diffusers
      - Blades (turbine)
      - Musical instruments
    - Compliant parts
      - Wires
      - Springs
    - Parts with post-machining
      - Fewer mates = less machining (turbine)

High strength but few mates?

Downhole boring head

Sintered metal exhaust silencer

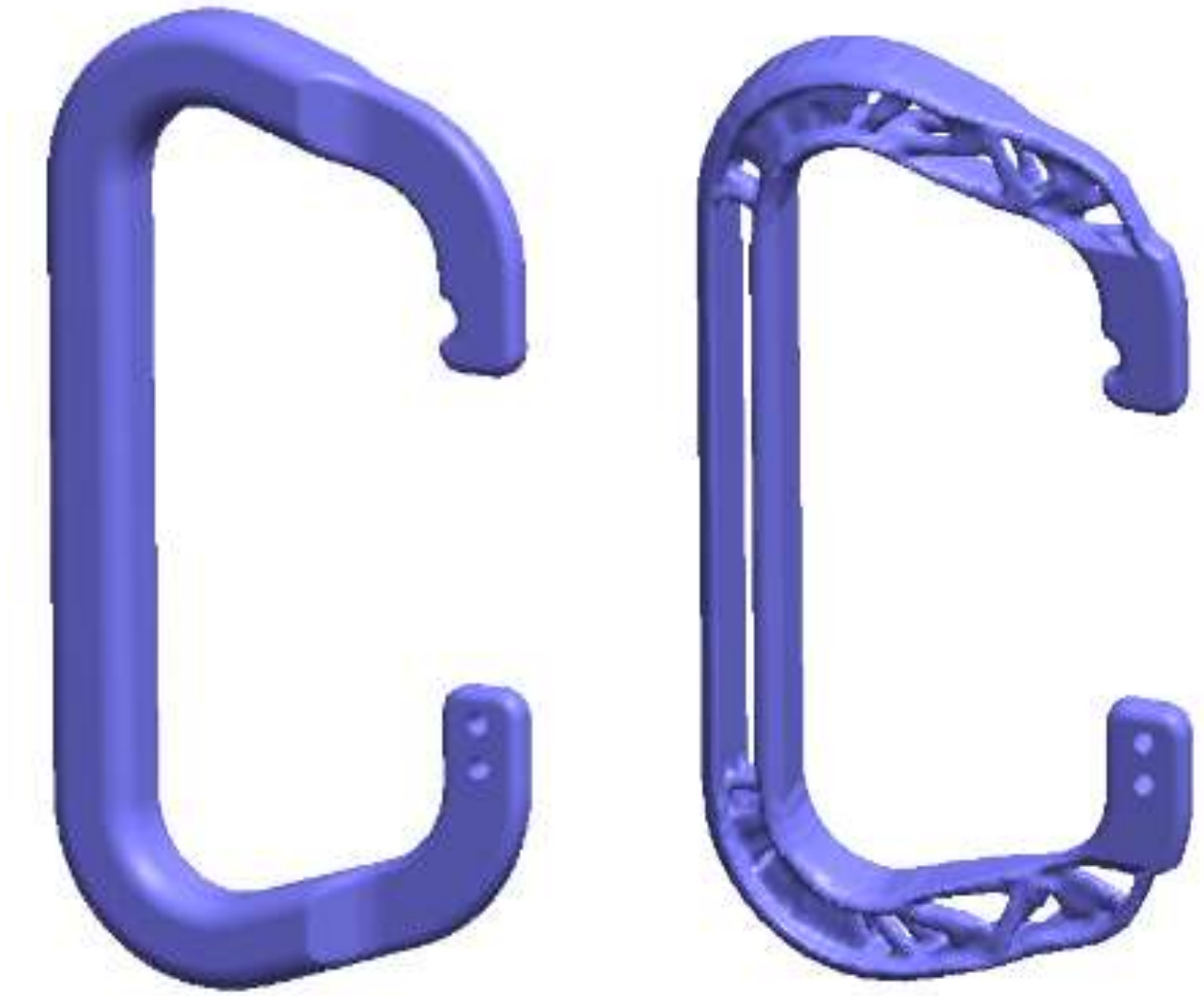
Metal AM Applications Exercise



My Topology Optimization Attempt

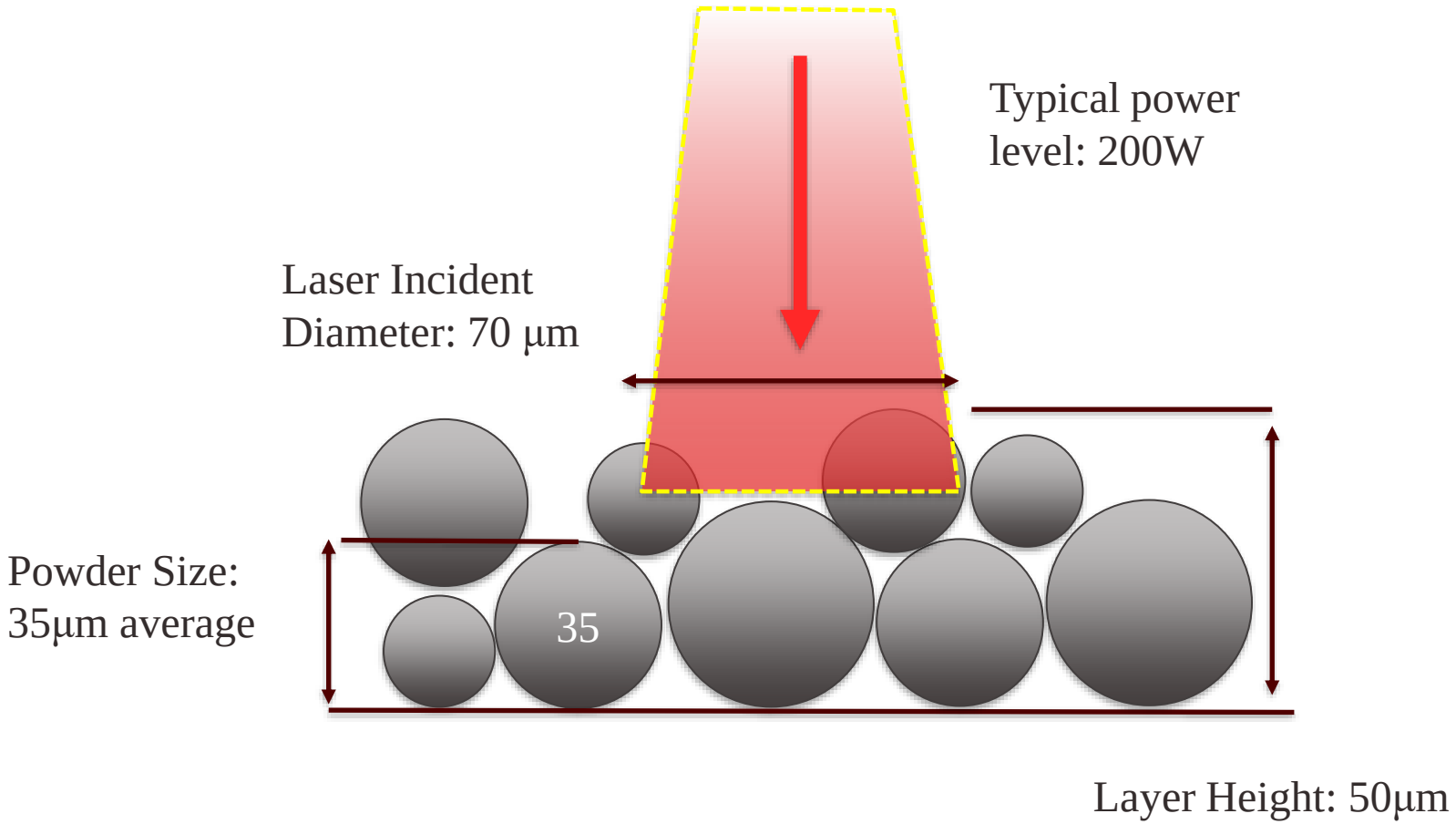
Caribiner (such as those for climbing)

- successfully decreased weight 30%
- decreased strength only 10%
- Built/tested plastic parts
  - Success
- Built Metal parts
  - See example
  - supports are too difficult to remove



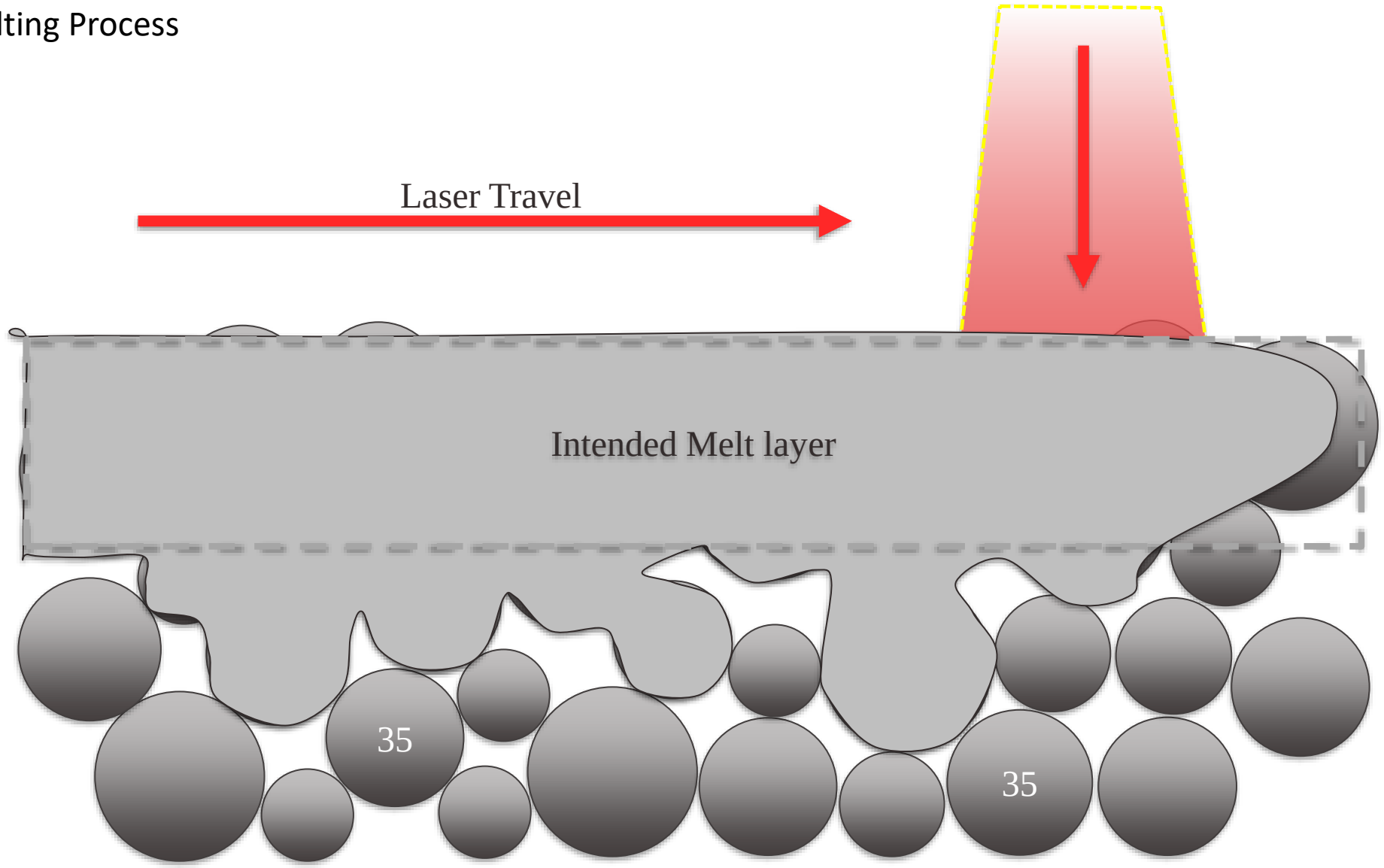
Melting Process Details

Insight on Melting Process



Melting Process - Overhang

Insight on Melting Process



MAM – Overhang

Another example of Overhang

- Even these photos are superior performance to our typical overhangs.

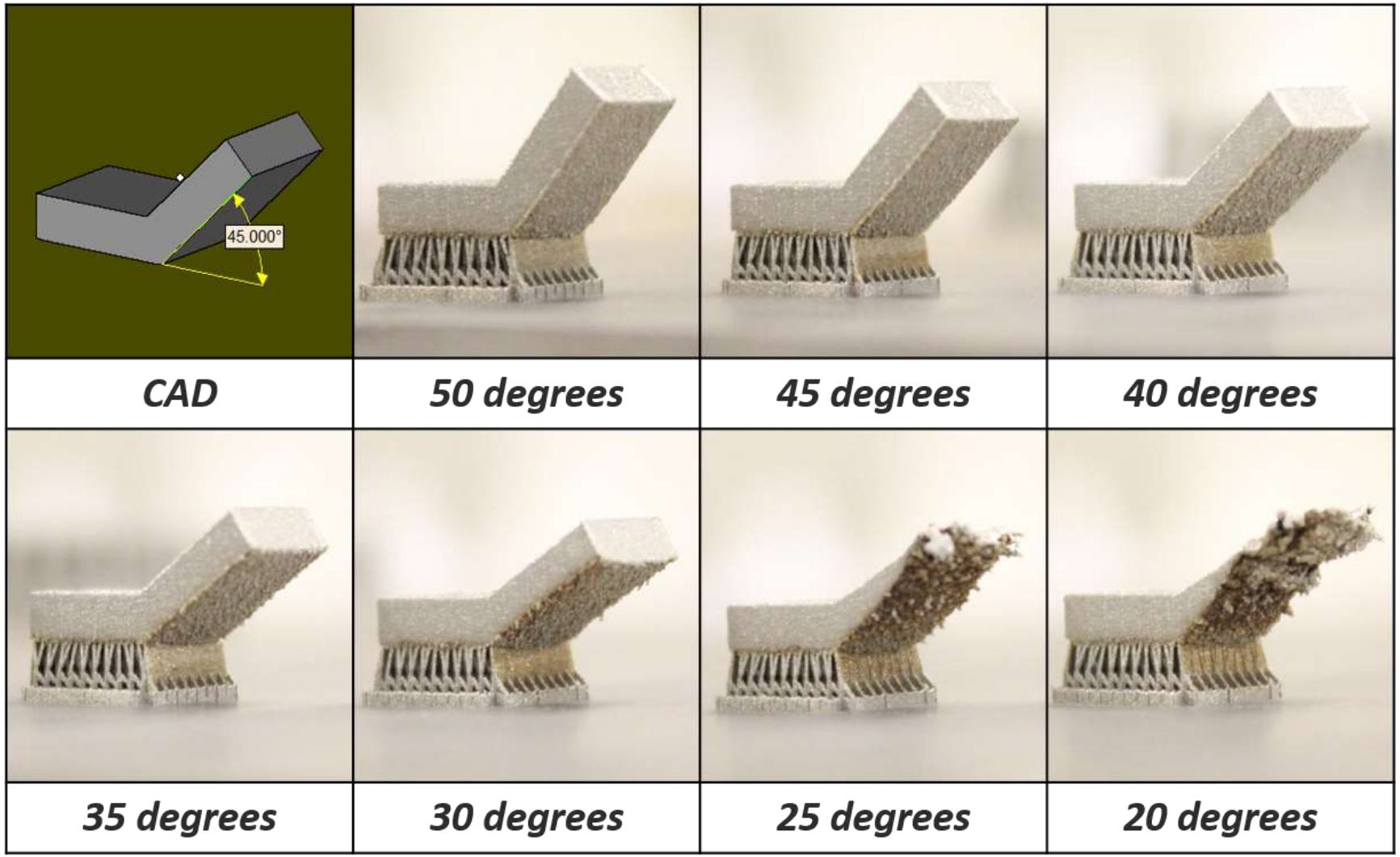


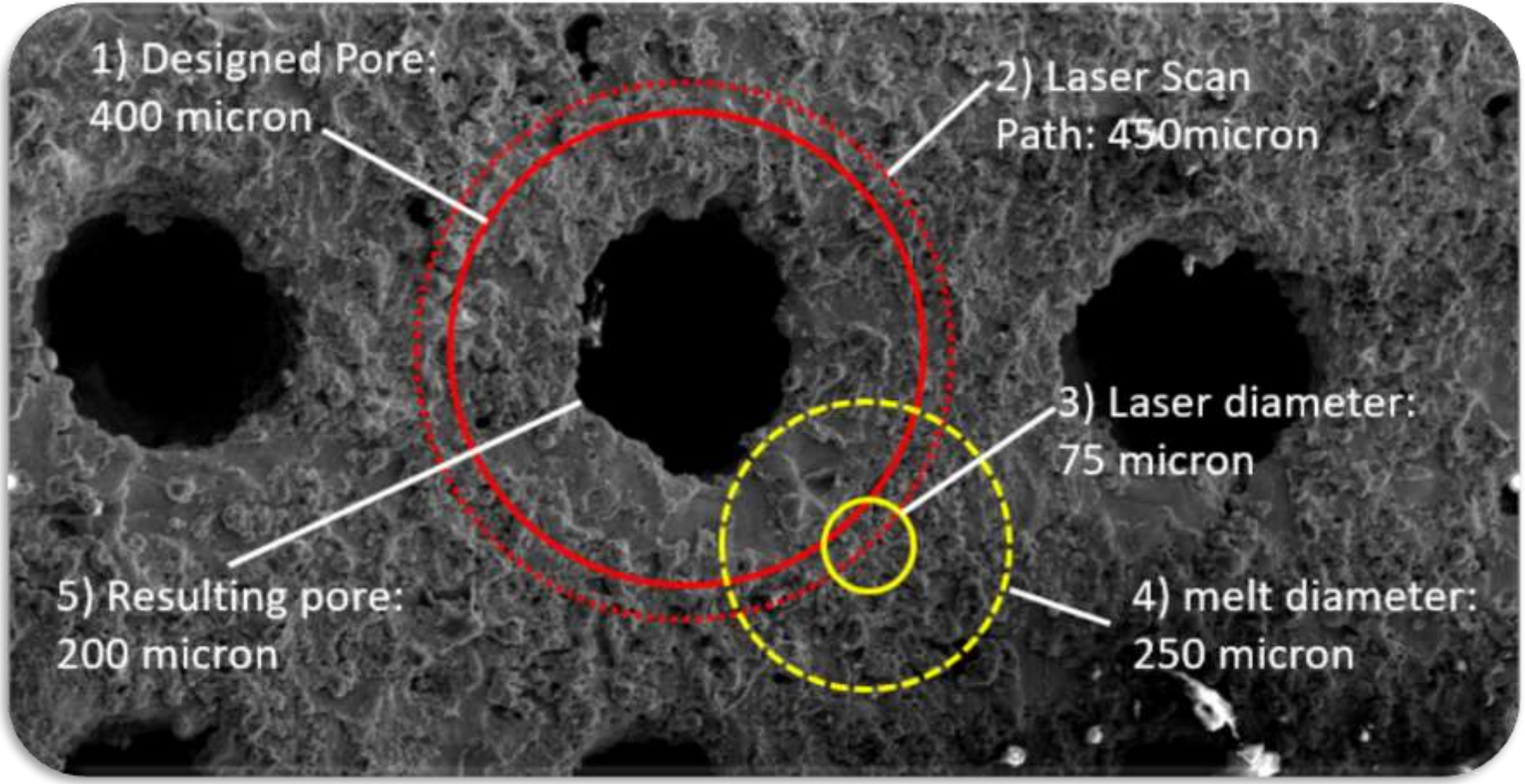
Photo credit: Dassault Systems SolidWorks Corporation

MAM – Clearance & Overmelt

Measuring the overmelt of a circular "pore."

- For tight tolerance regions, consider overmelt
  - In our case, design should be undersized by 100 microns at each wall

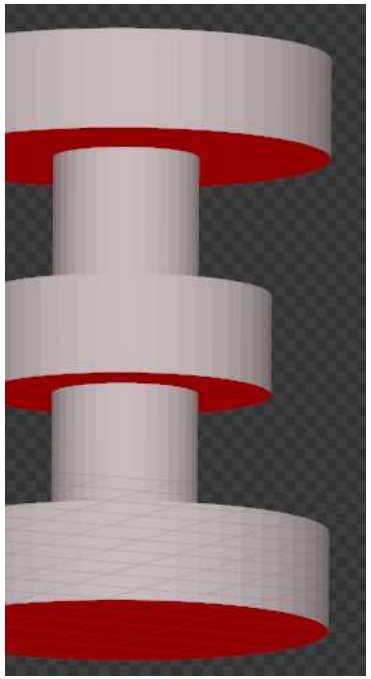
Or, design the geometry for machining after build.

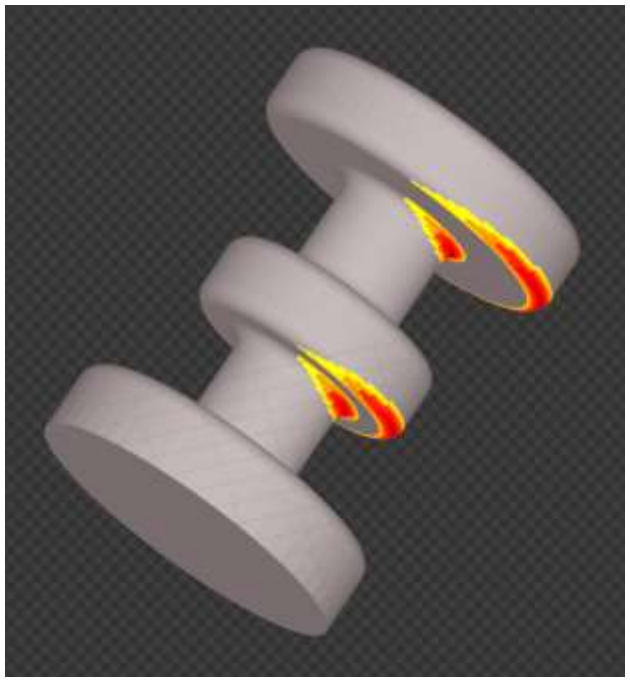


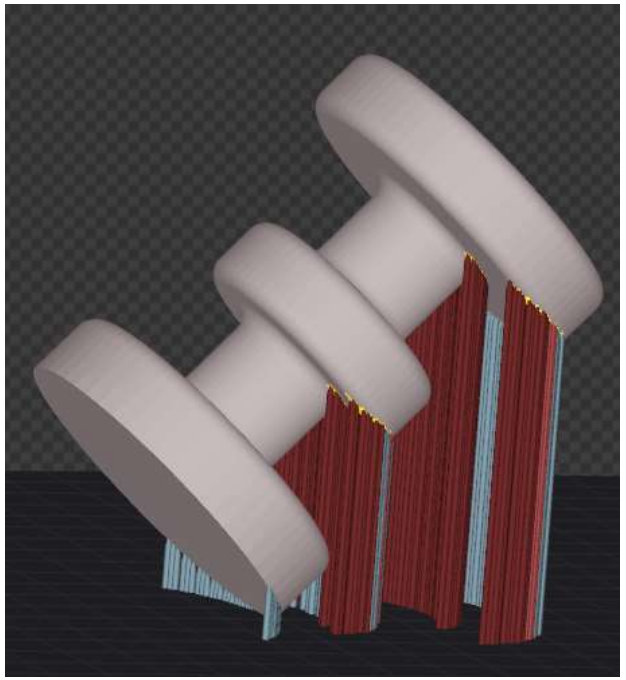
Unintuitive Support Requirements

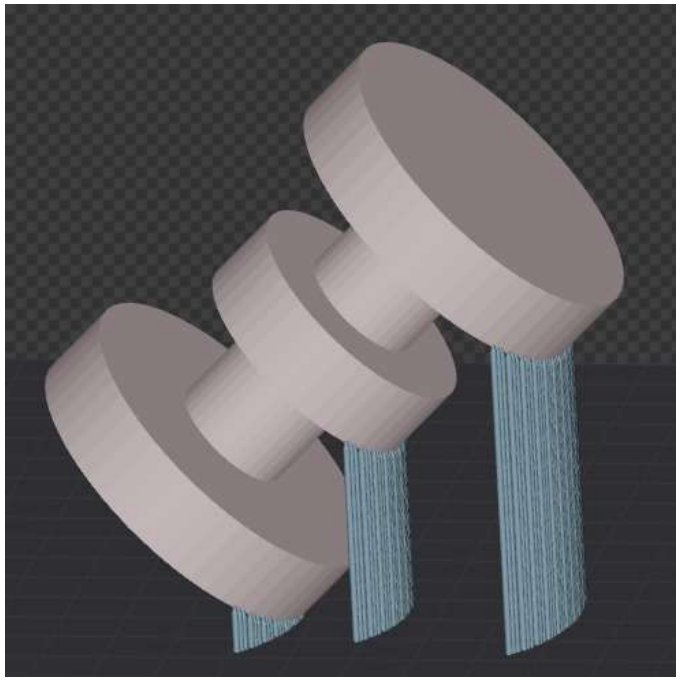
Unintuitive Support Requirements

- Fillets are FREE
- They help with transitions in cross-section
- Can create more difficulty printing - check your slicer









Overhang Angle

45 degrees is a recurring rule-of-thumb

- Stronger overhangs may deteriorate the net shape (not just increase roughness)
- See example parts

Video on Overhang Experiment

The Story of the Welded Parts

When the build pauses:

- continuous heat input from the laser stops and allows parts to cool
- this part shrunk in height by about 1mm.
- The laser must melt 20x more powder in order to successfully build

Postprocessing Example Part

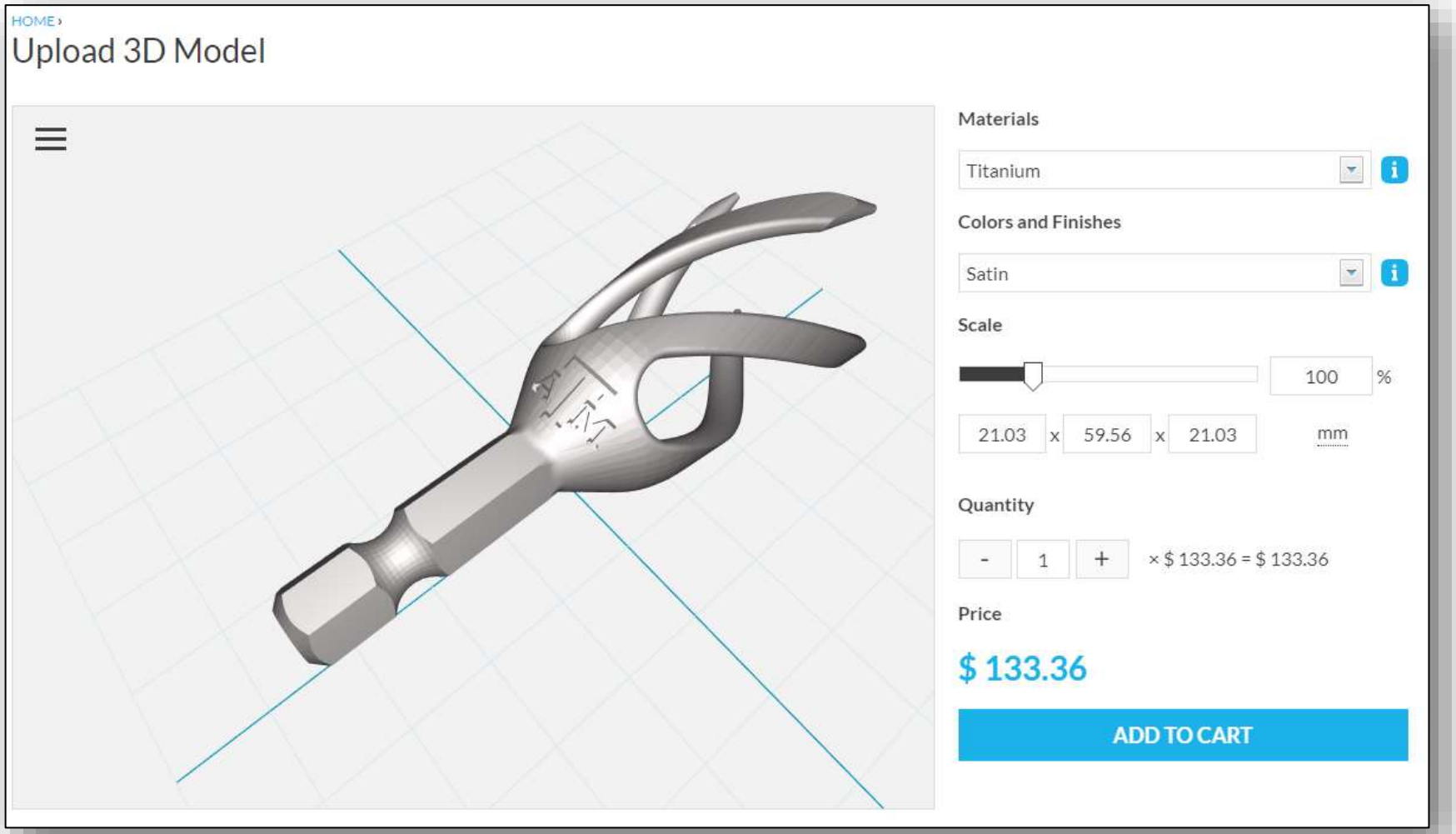
Video: postprocessing of the fruit spike

- Achieving smoothness is a major effort & cost.

3D Printing Money

Services are available for Metal AM

- Lead times as little as 4 weeks
- New opportunities for small businesses
- Knowledge can be monetized



Parts Estimation page from i-materialise.com

Reduced Build Volume

Renishaw Reduced Build Volume (RBV)

- Only need 0.5 Liters of powder
- No need to clean machine (can be 2 day process)
- No need for 50kg of material

Disadvantages:

- Cannot heat build plate
- Cannot control dosing amount

End of Part 2

Questions?

Multiple Choice Questions

#56

What will offer better performance bonding plastic with rough surfaces:

- Adhesive containing only solvent
- Adhesive containing both solvent and polymer (CORRECT ANSWER)
- Adhesive containing only polymer

Based on today's presentation, what is NOT a recommended way to achieve mating fitment?

- Carefully measure the mating part and add a 0.5mm clearance into your design (CORRECT ANSWER)
- Build your first part, check fitment, and adjust the design.
- Overbuild, but isolate your contact to a few points. Then file down as needed.
- Design a significant interference into your parts, but create compliance

Which technology name is not synonymous?

- SLM – Selective Laser Melting
- EBAM – Electron Beam Additive Manufacturing (CORRECT ANSWER)
- DMLS – Direct Metal Laser Sintering
- LPBF – Laser Powder Bed Fusion

What amount of overmelt was measured in our Pore design study in metal SLM?

- 0.25mm
- 0.10mm (CORRECT ANSWER)
- 0.05mm
- 0.01mm