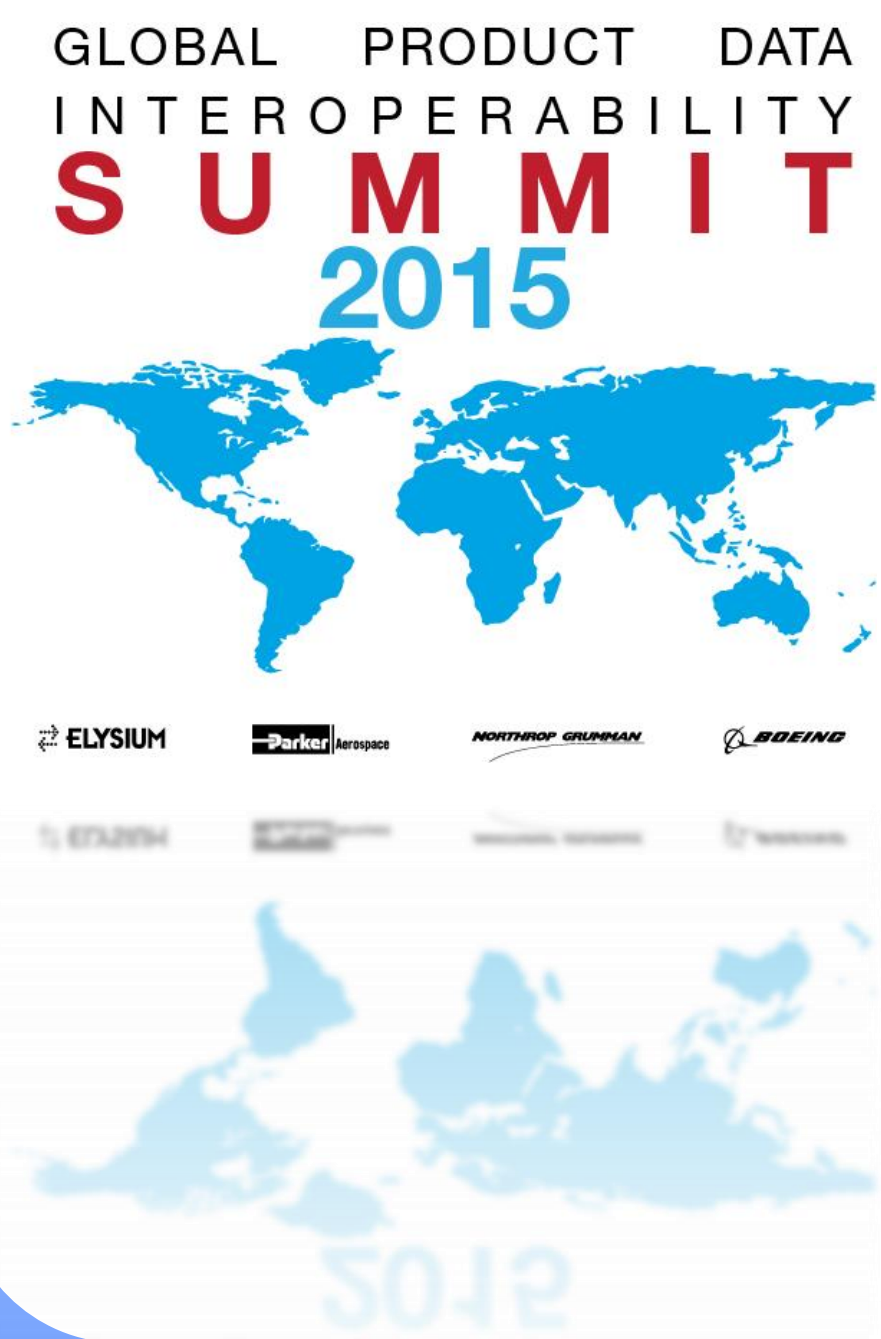
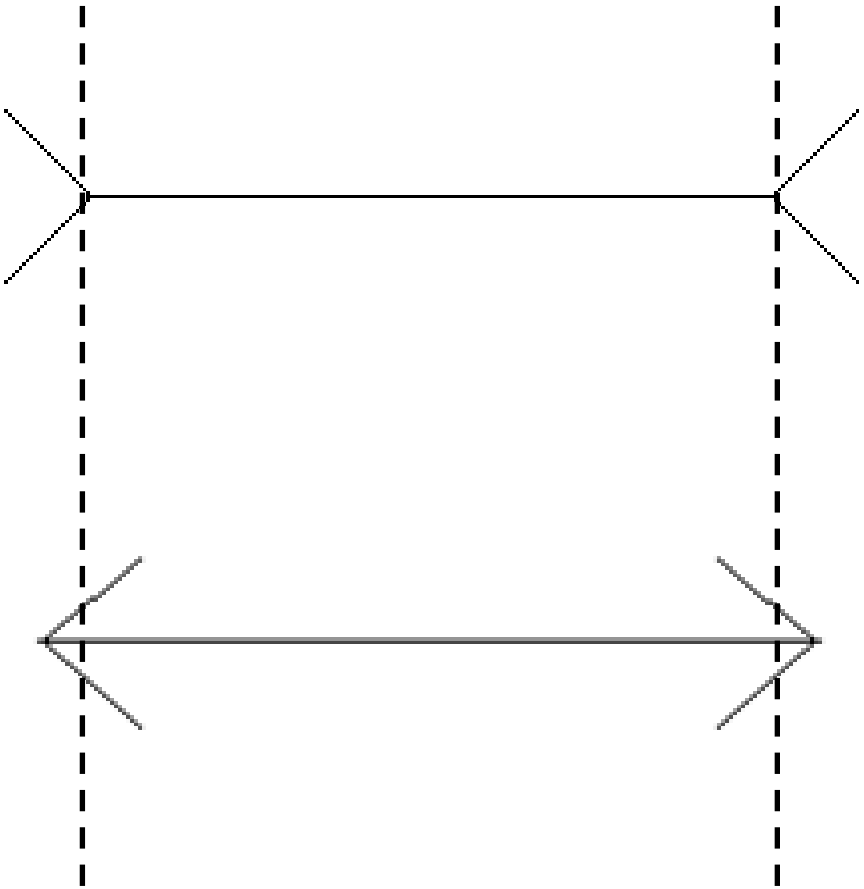
Six Stages of Additive Engineering

Richard Murrish –
Technology Management Services
316-461-7238



Parallax

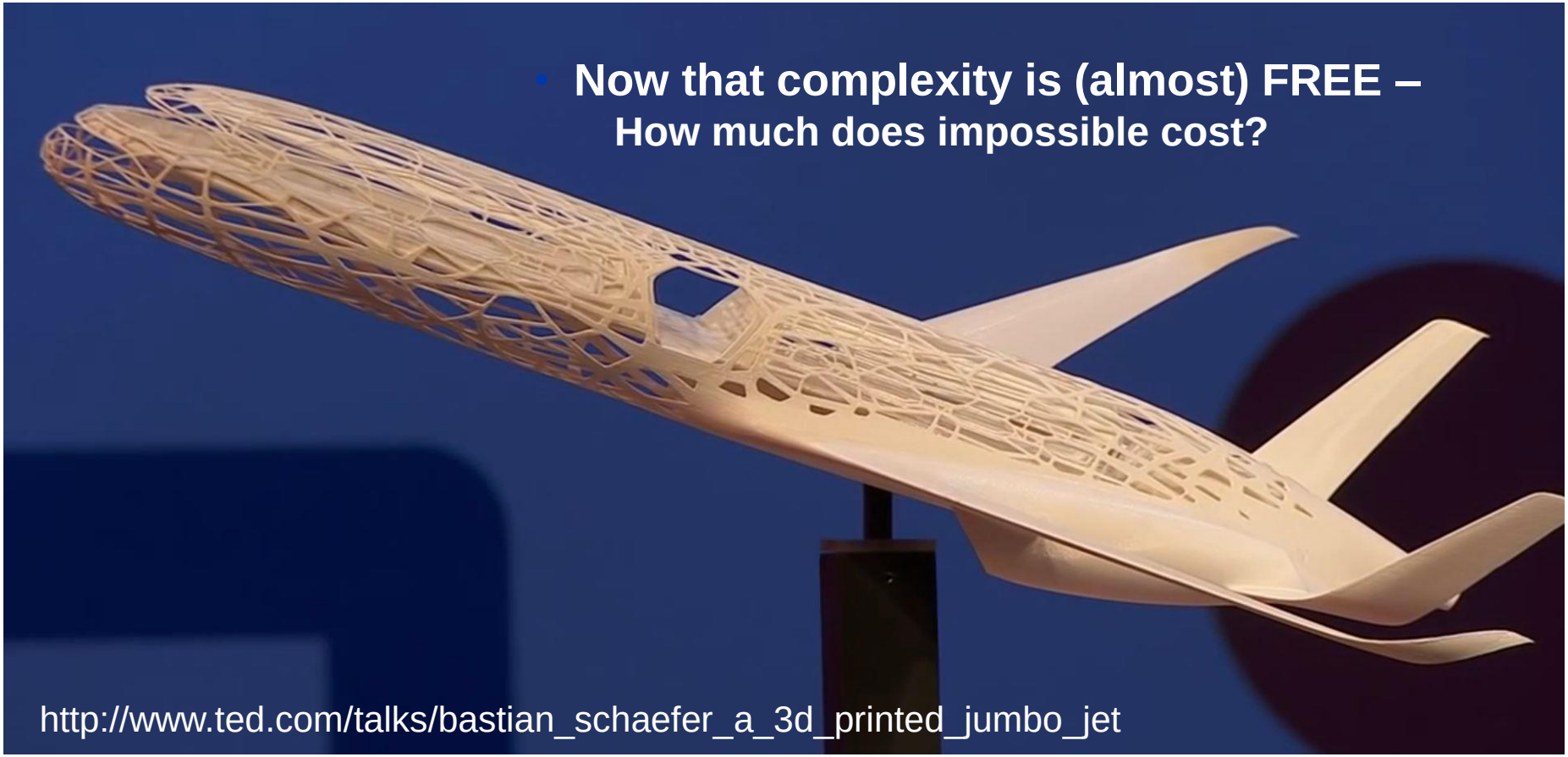


“Look at the world differently!”

Neural Plasticity Reduces with Age

You Cannot Ride This Bicycle !!

Things you need to know and Limits you need to challenge



What's in a name?

Additive Manufacturing

aka – Accelerated Digital Manufacturing

aka – Additive Layer Manufacturing

aka - Solid Freeform Fabrication

aka – Rapid Prototyping

aka – Digital Fabrication

aka – 3D Printing

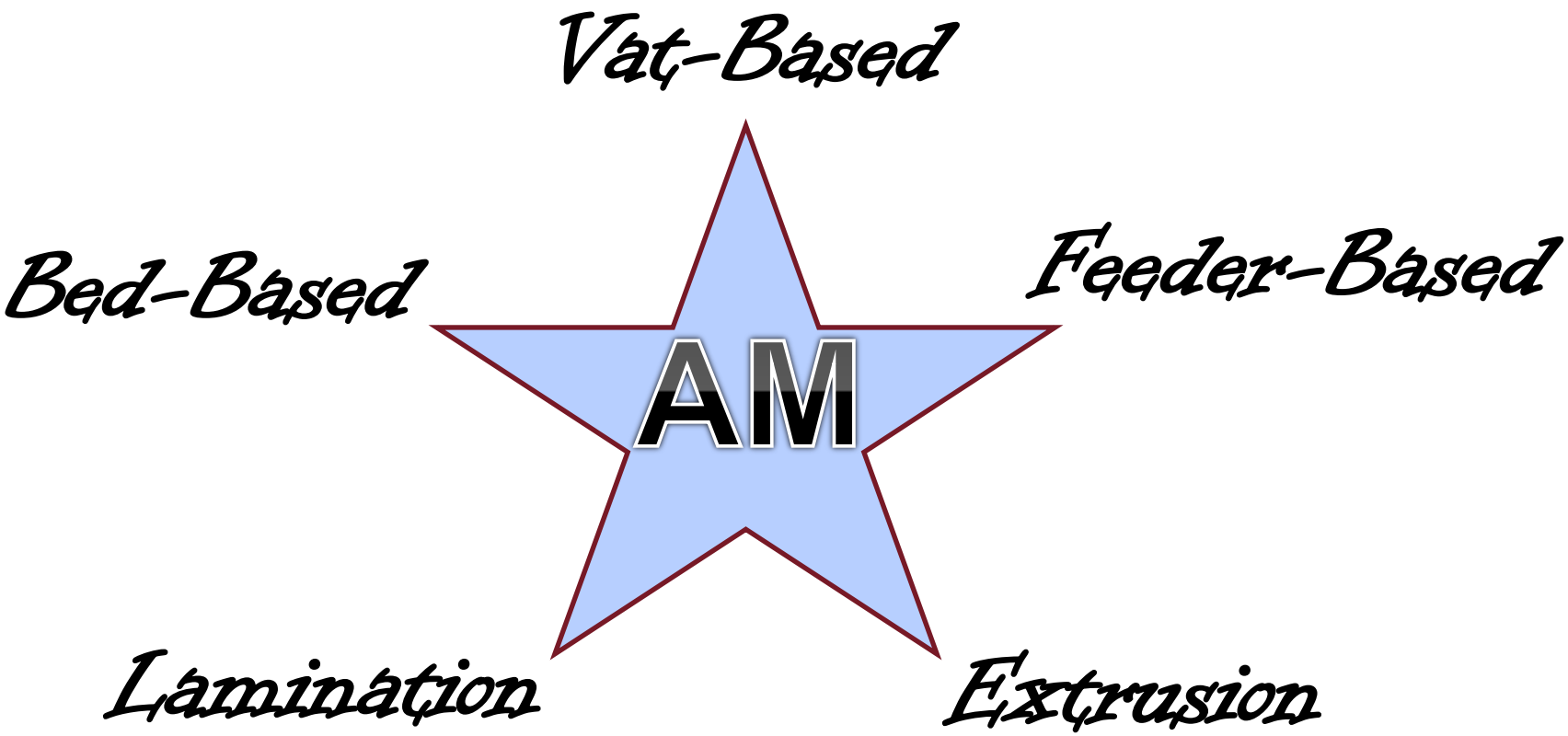
aka – .....

Technology – More Names

Powder bed fusion
Selective Laser Sintering
Directed energy Deposition
Electron Beam Direct Mfg
Ballistic Particle Mfg
VAT photo-polymerisation
Two-photon Lithography
Fused Deposition Modeling
Liquid Jet Metal Print
Continuous Liquid Interface Production
…….

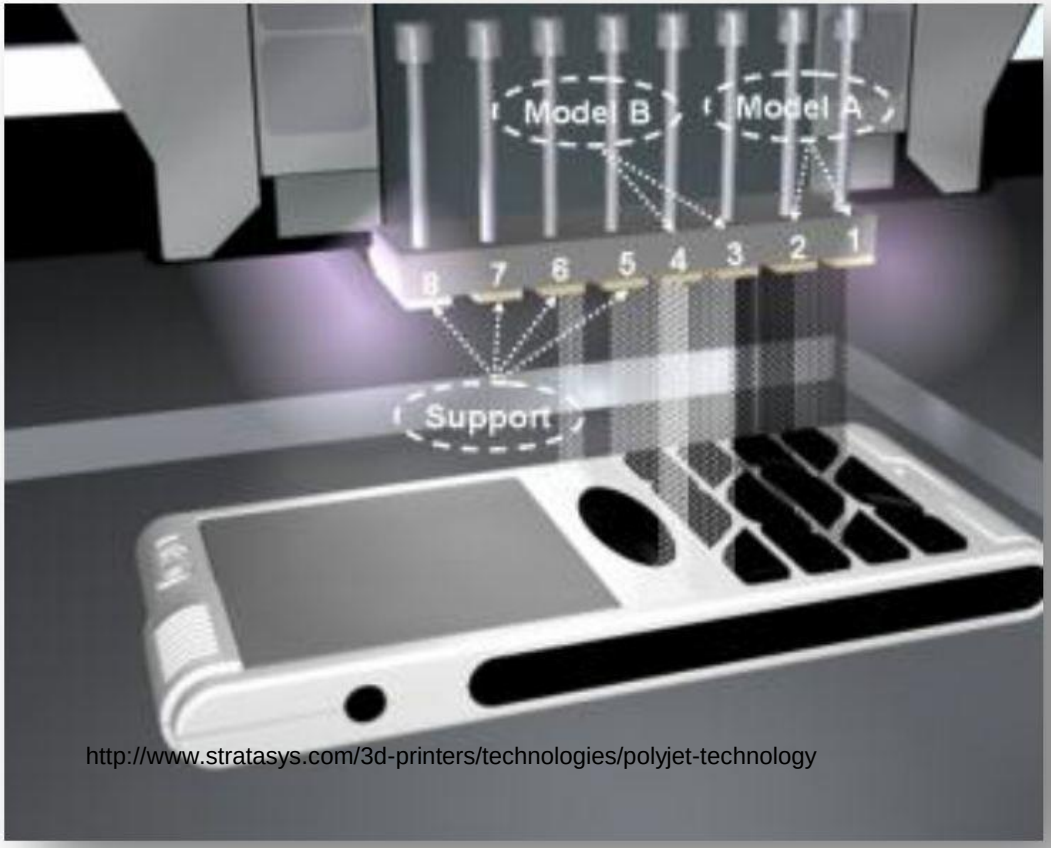
Stereo-Lithography
Sheet lamination
Layer Object Mfg
Material jetting
Binder jetting
3D Doodling
Material extrusion
Polyjet
Bioprinting
FreeForming
……..

AM Processes – Types - 5? 7? 9? More?



Processes – Polyjet

Or - Ballistic Particle Manufacturing and Stereolithography



http://www.stratasys.com/3d-printers/technologies/polyjet-technology

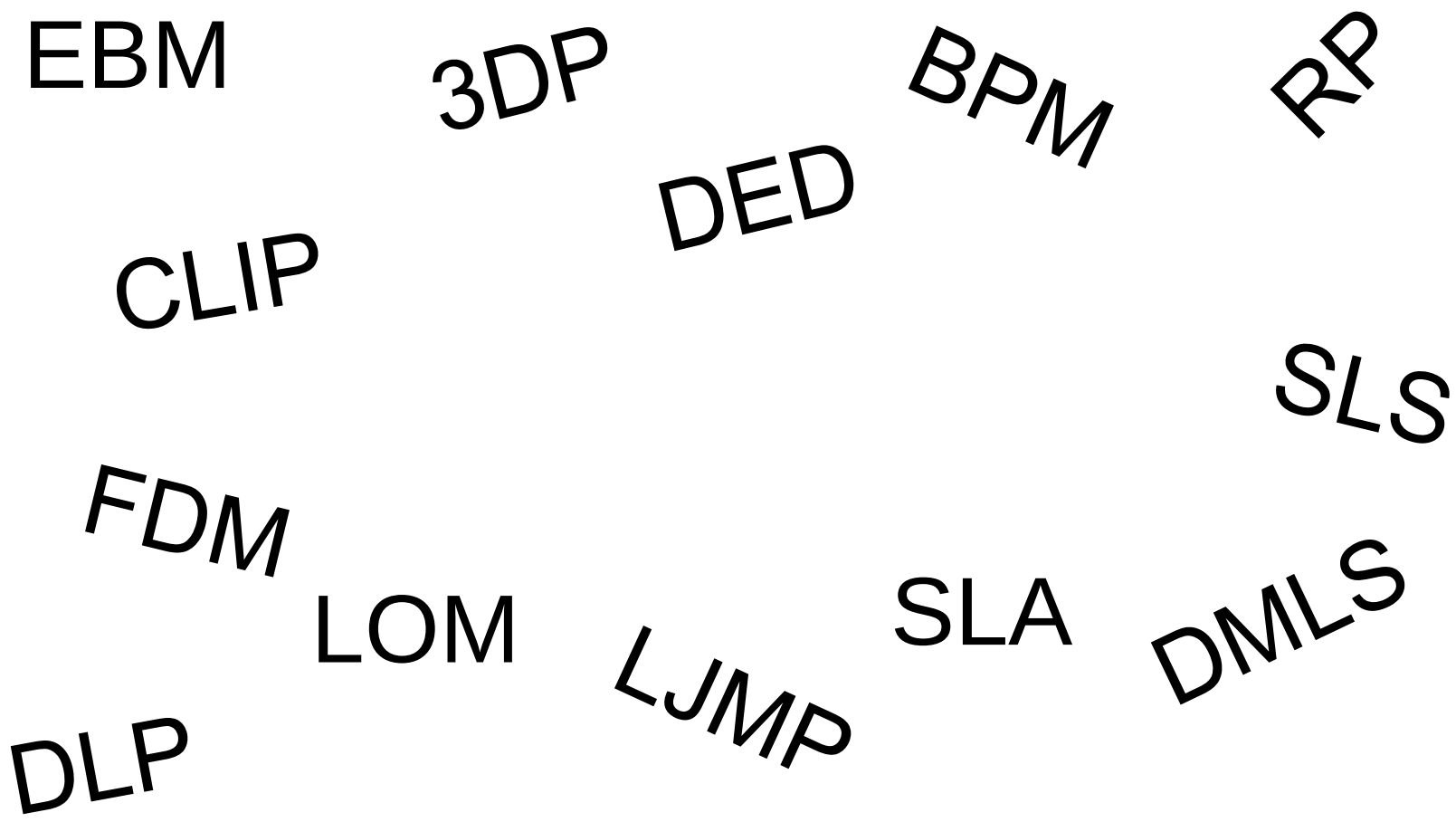
Objet 3D printing block, consisting of 8 printing heads:

- Heads 1 & 2 jet material A

- Heads 3 & 4 jet material B

- Heads 5 - 8 jet the support material

Design For Additive Technologies



Six Stages of DeFAT

Ask yourself why?

Is it really the right way to go?

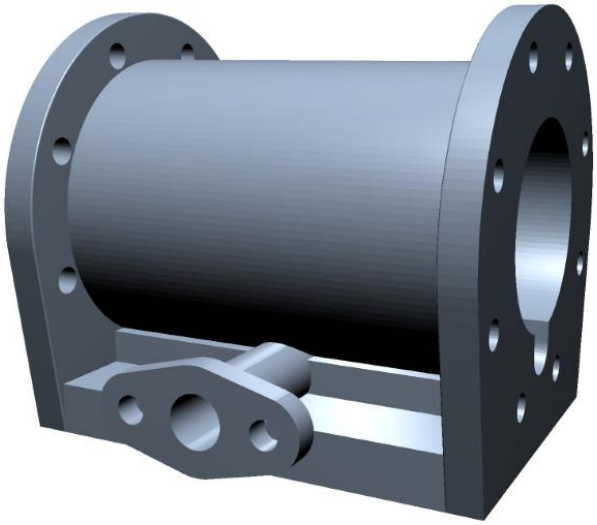
Or are you just wanting to play?

Or need a paperweight for desk?

Stage ZERO

- **<u>AM is still expensive</u> – usually more than other "production" methods**
- **<u>You need to take the entire product life cycle into account to establish value</u>**
  - **Cut lead time**
  - **Performance Improvement**
  - **Weight improvement**
  - **Production rates**
  - **Reduced inventory**
  - **Cut Tooling**
  - **Environmental impact**

Six Stages of DeFAT



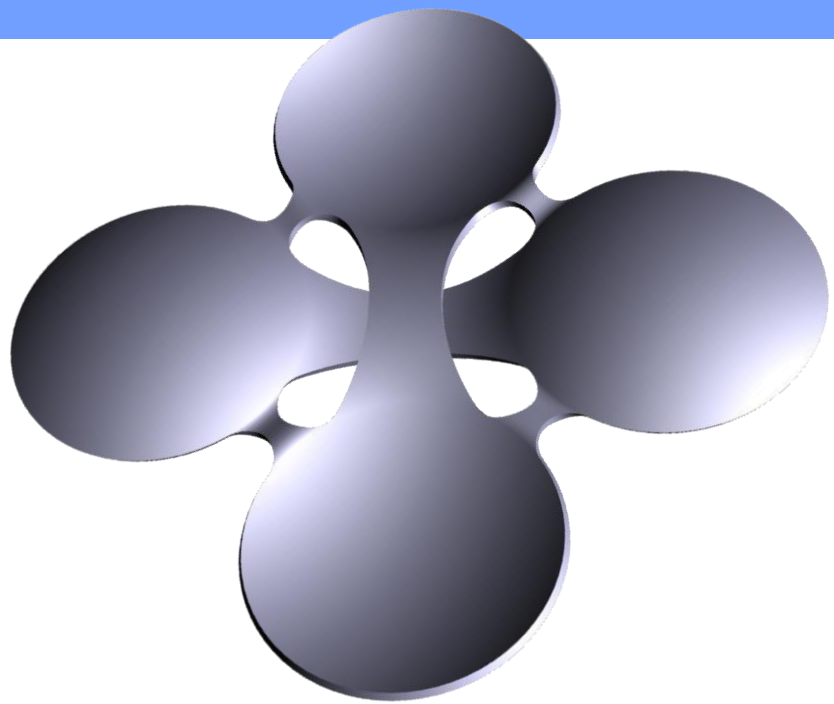
COE 2014 Certification Model

Stage One — Prototyping or AM for Metalheads

Stage Zero

Take a CAD Solid and Print it – No Thinking

Six Stages of DeFAT



Stage Two

Stage One

Stage Zero

Saving money or Metalheads on a budget/schedule

- Sparse Fill - automatic
- Orientation Options
- Material Options
- Process Options

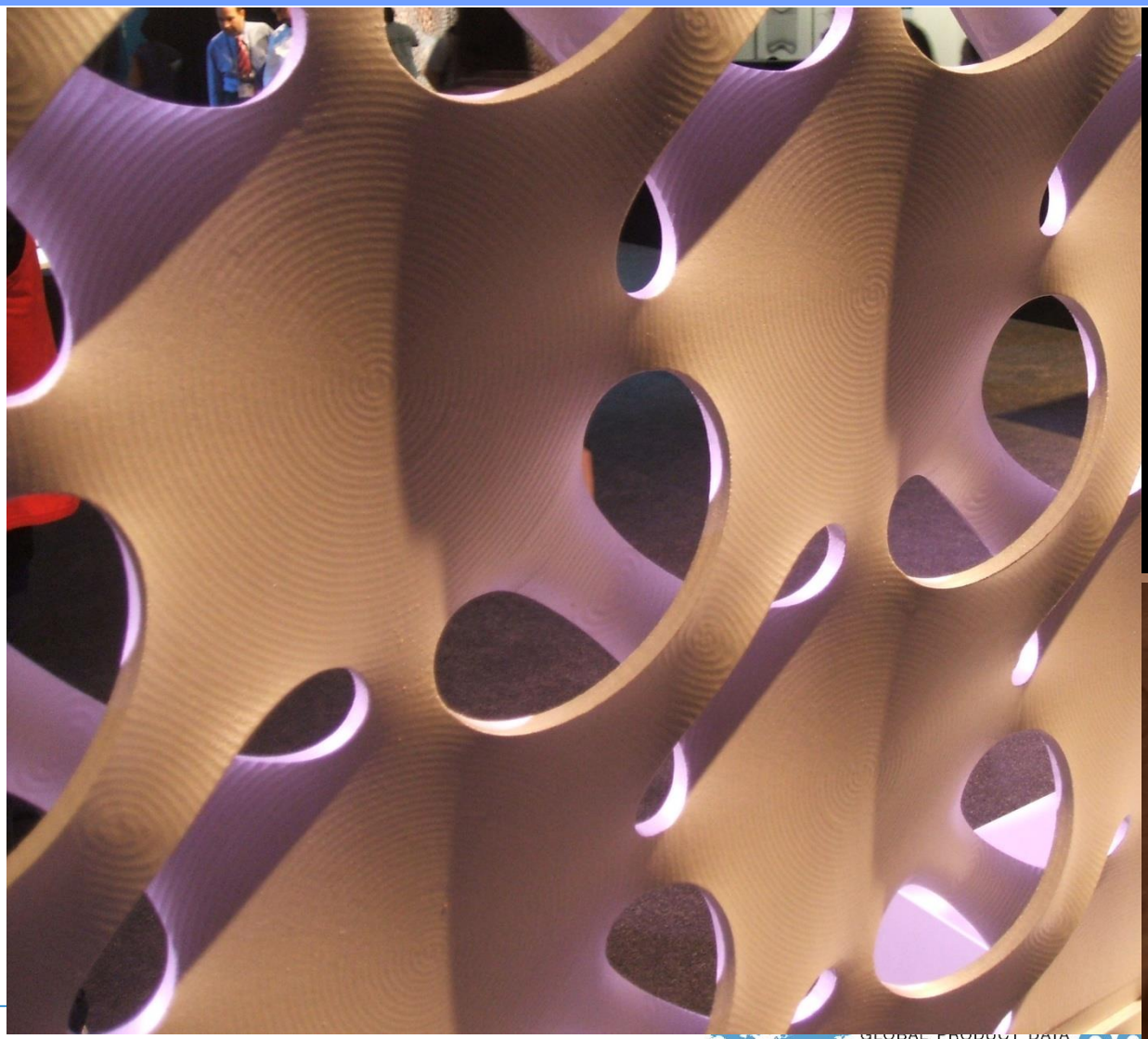
Sparse Fill – Automatically Generated

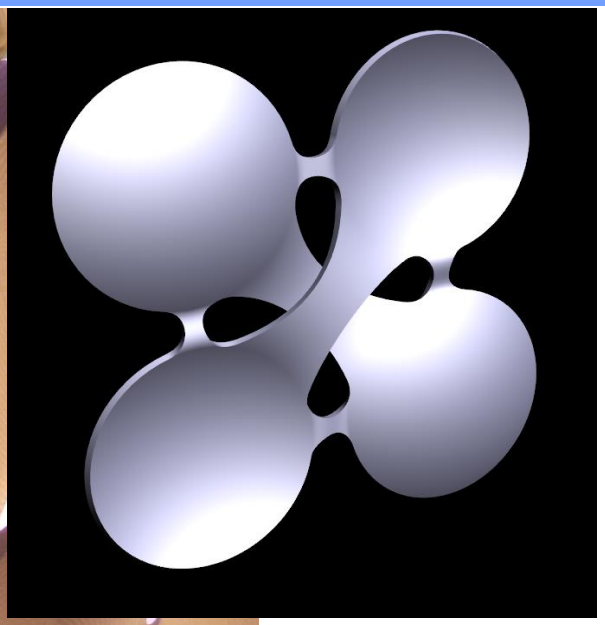
Interior not part of Design Intent

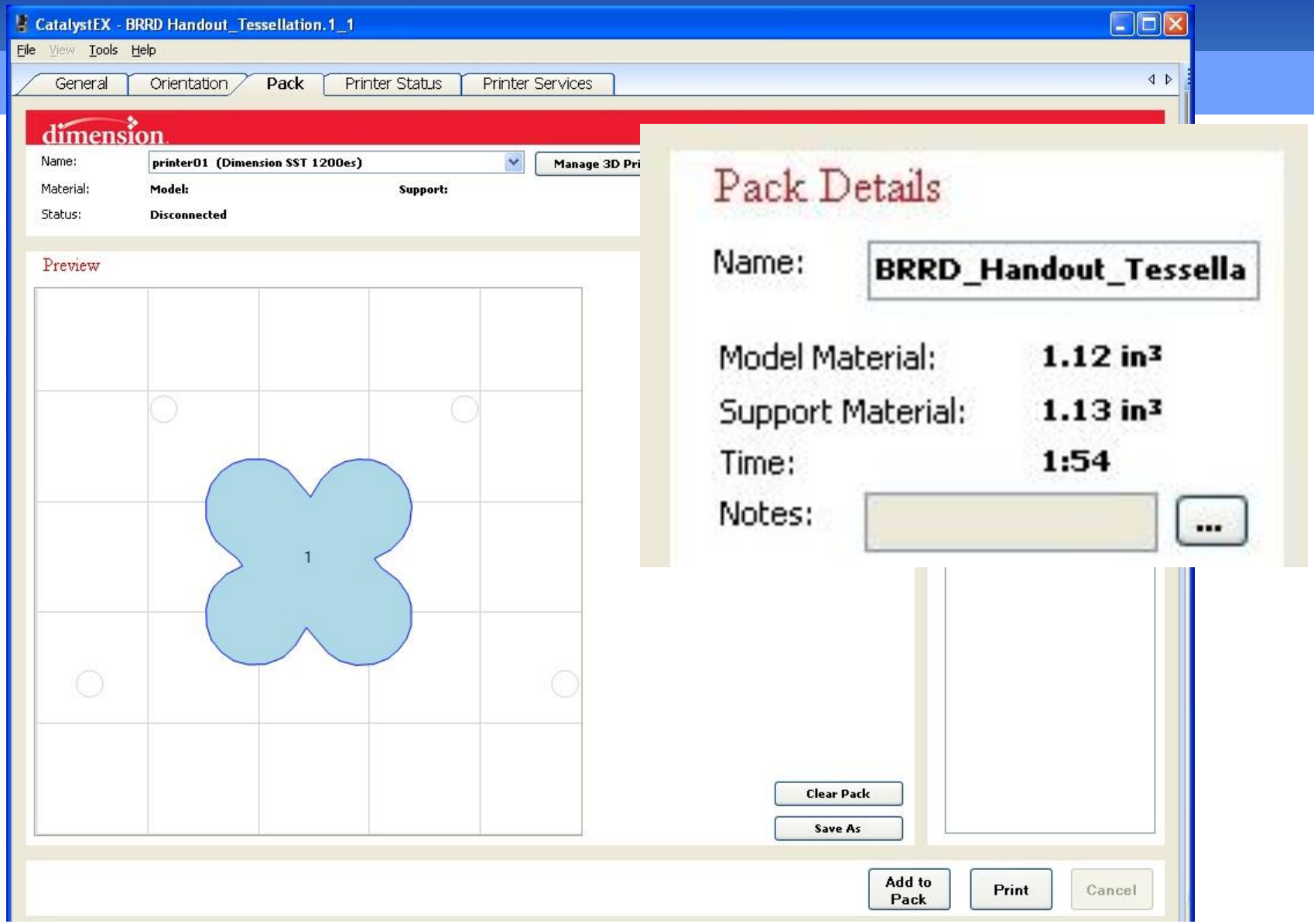
Simplify3D infill patterns

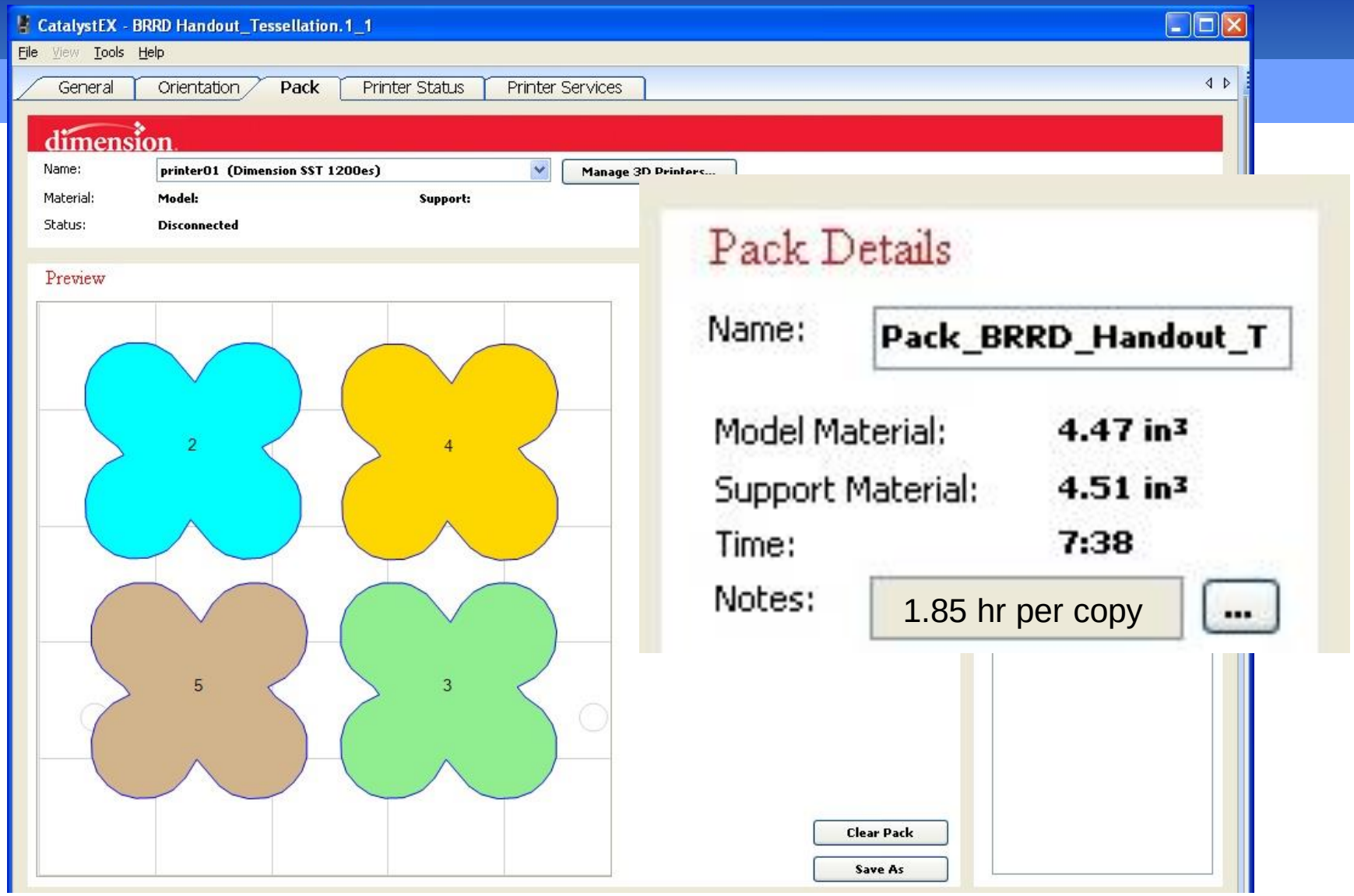
Example – Time, Space and Orientation

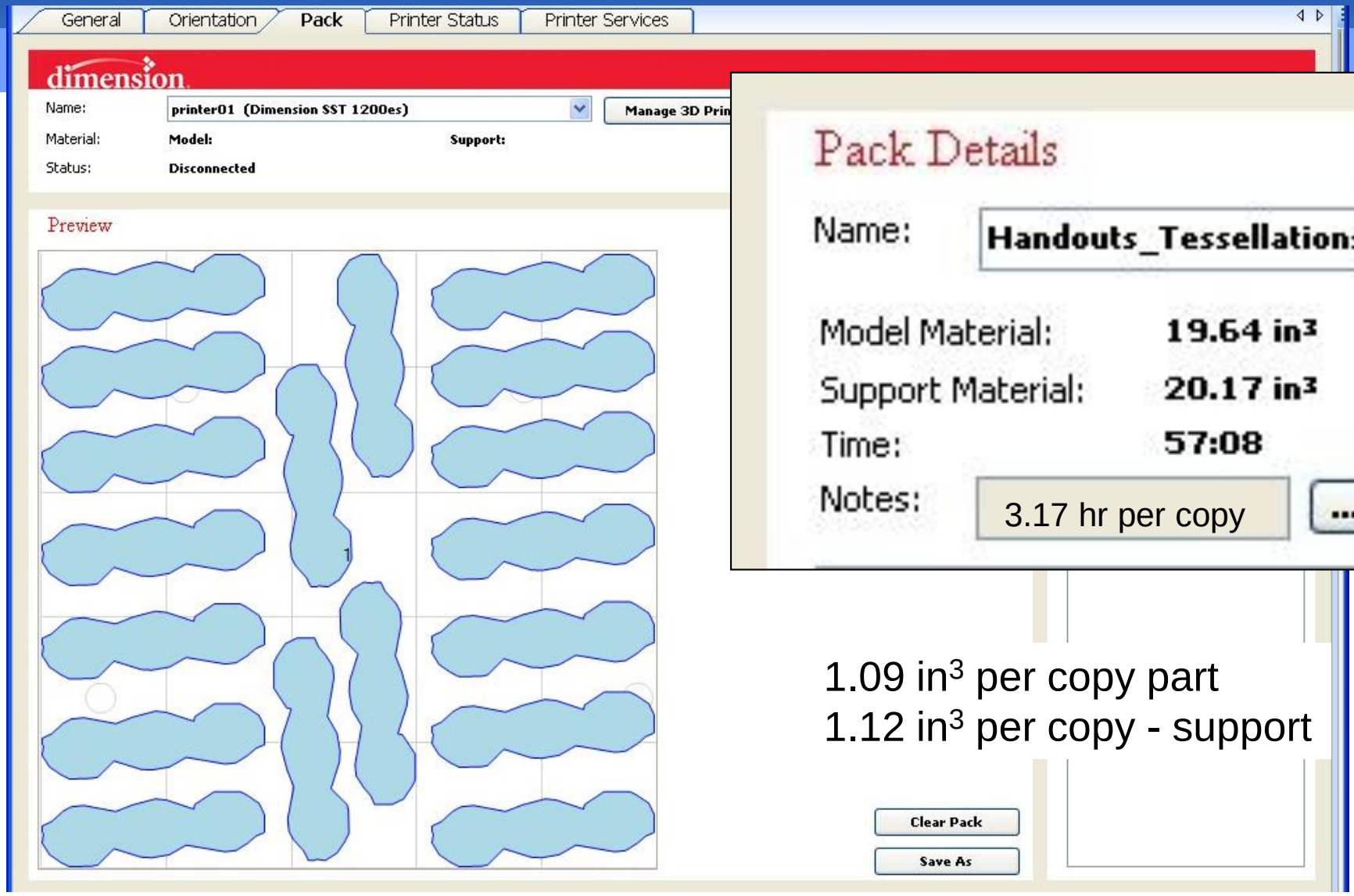
Inspiration @ Siggraph ‘08

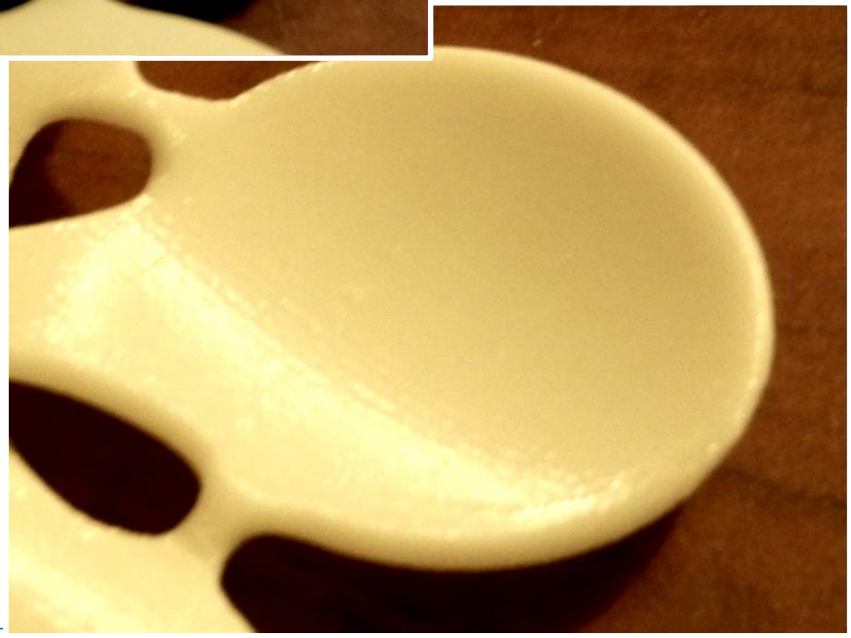












What's Different?
Material and Process

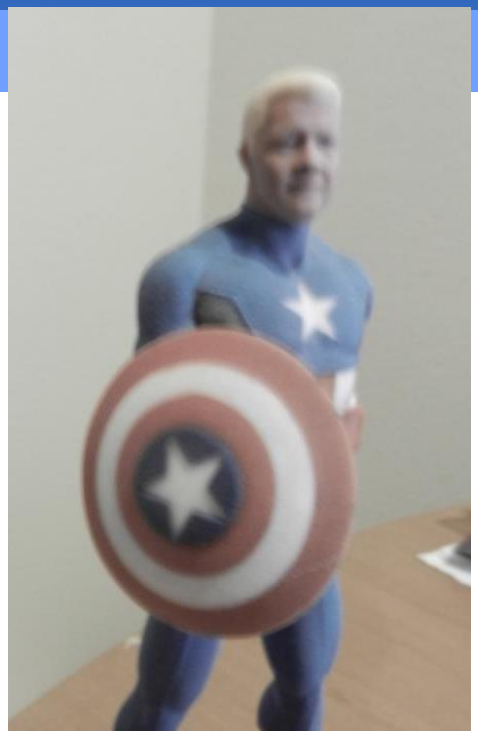
Six Stages of DeFAT

Material Selection?

Durability?

Color Required?

Size?



Stage Three

Stage Two

Stage One

Stage Zero

Design Considerations

Decision Tree

Complexity is (almost) Free

Training is not

Topology Optimization (automatic)

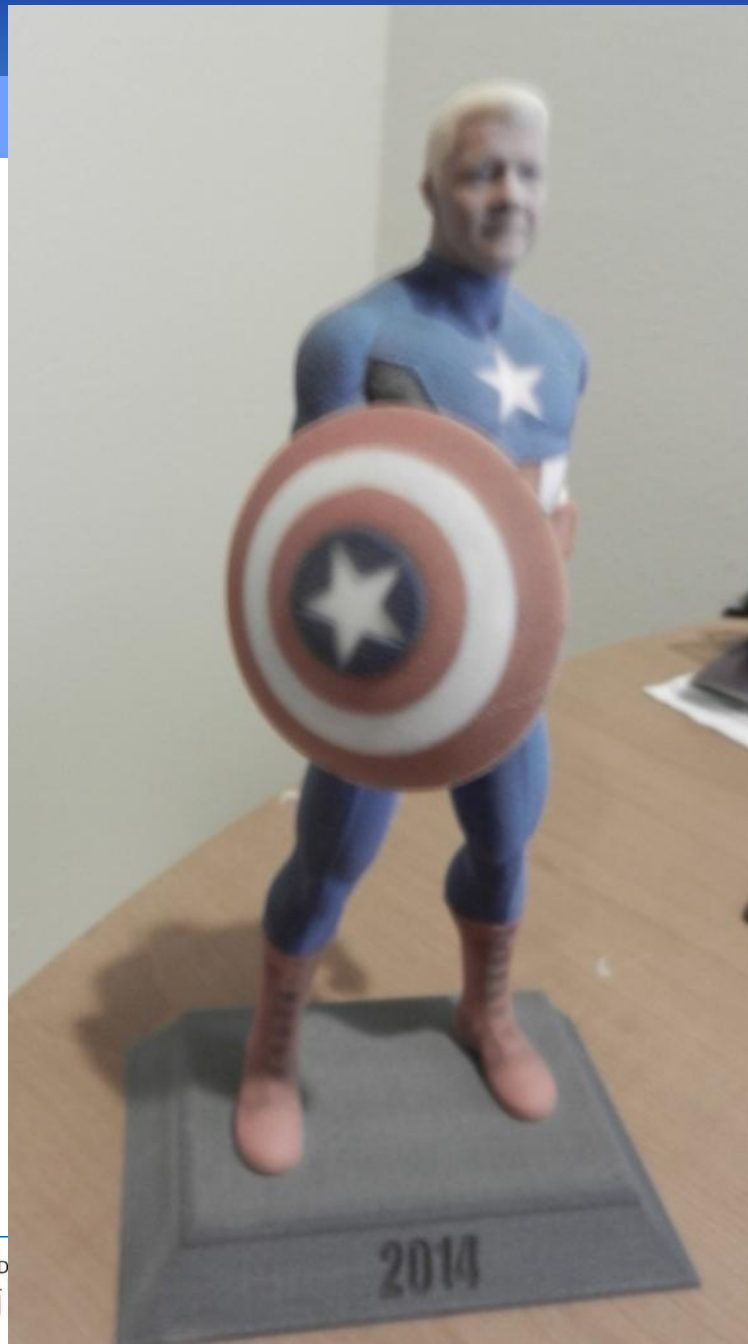
Attention to other “Design For”

Technology Overview – Decision Tree

Processes – Material Cost and Color

Process – 3D Printing

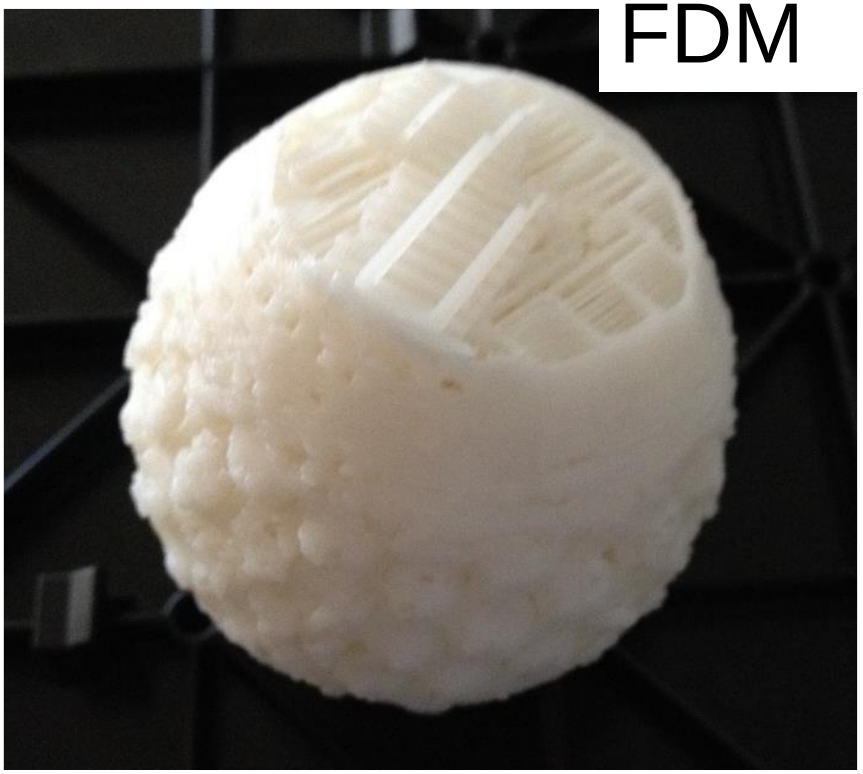
Note – you never see me and Captain America at the same place and the same time???



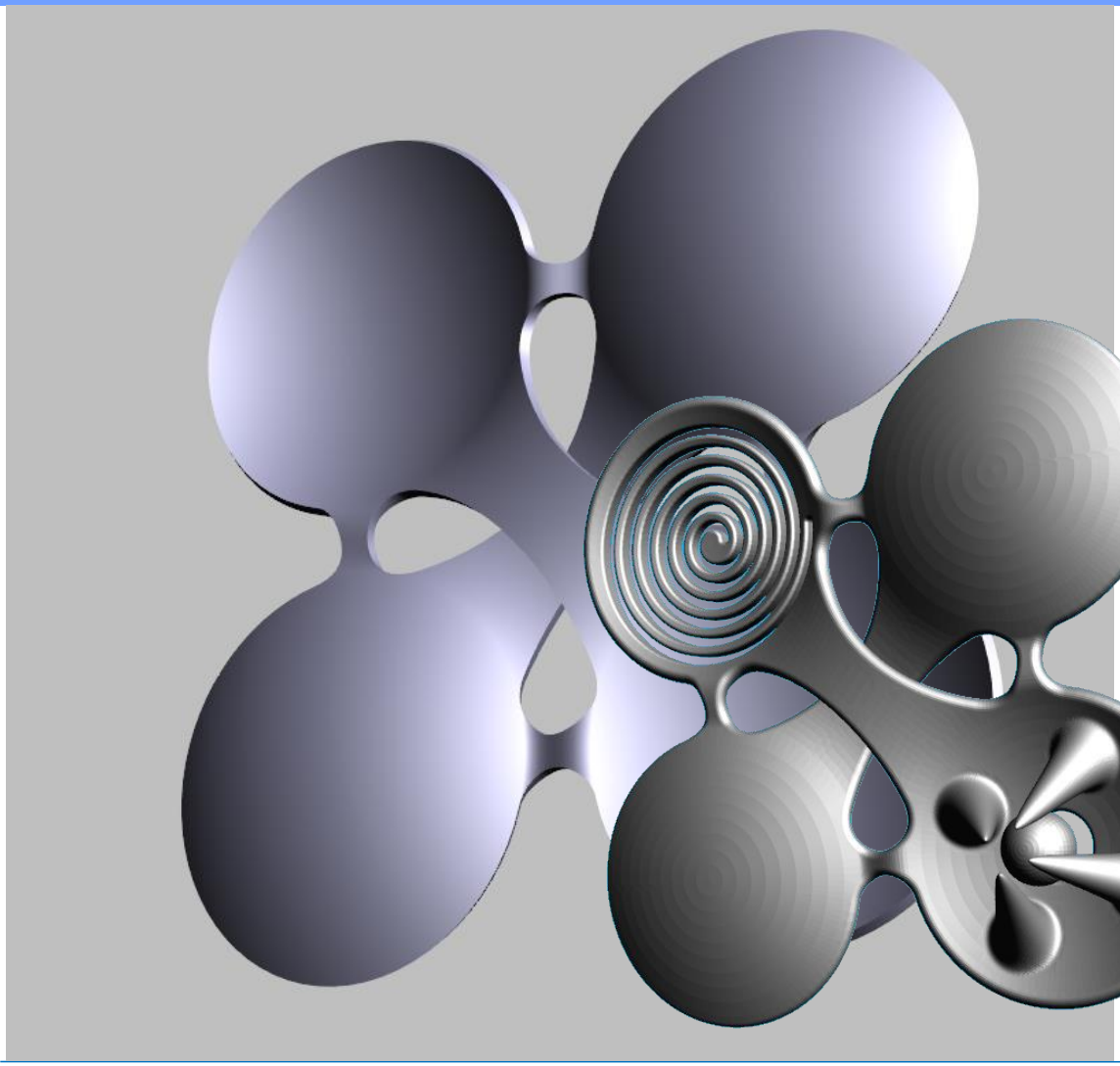
Process – Support Costs

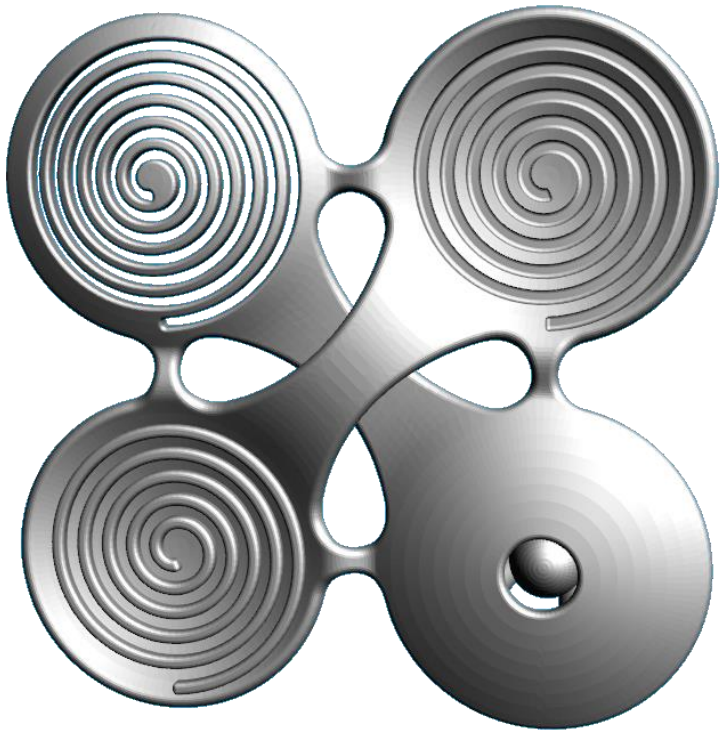
SLS

FDM

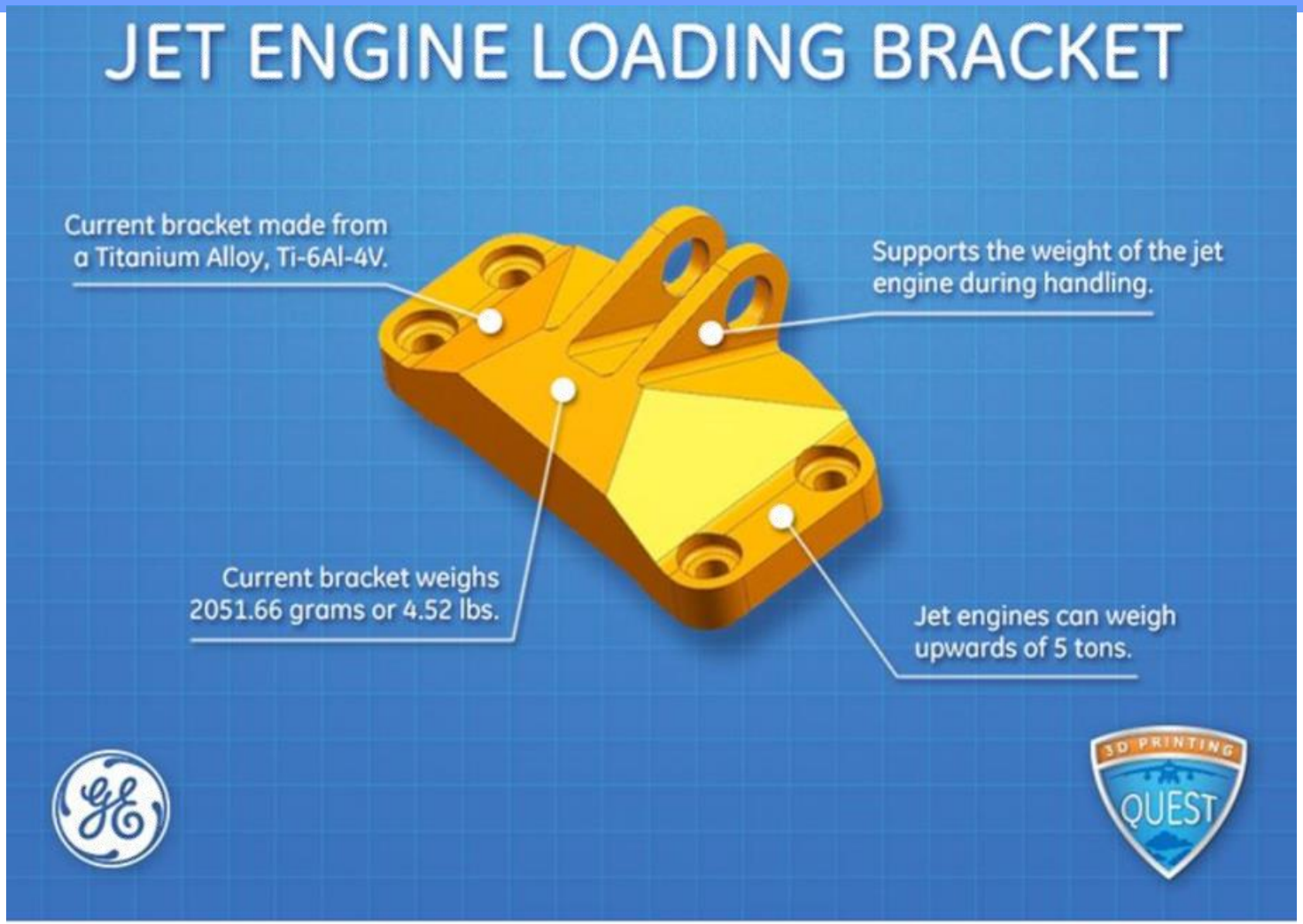


Complexity is (almost) Free – Training is NOT!





Typical COE “Top Gun” Challenge?



Found on invent.ge

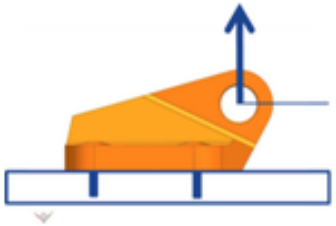
Typical COE “Top Gun” Challenge? Plus some -

Load Conditions 1

Static

Vertical

8000 lbs up

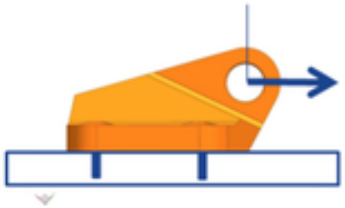


Load Conditions 2

Static

Horizontal

8500 lbs out

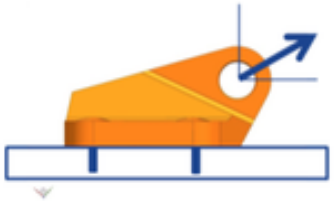


Load Condition 3

Static

42 degrees from Vertical.

9500 lbs out



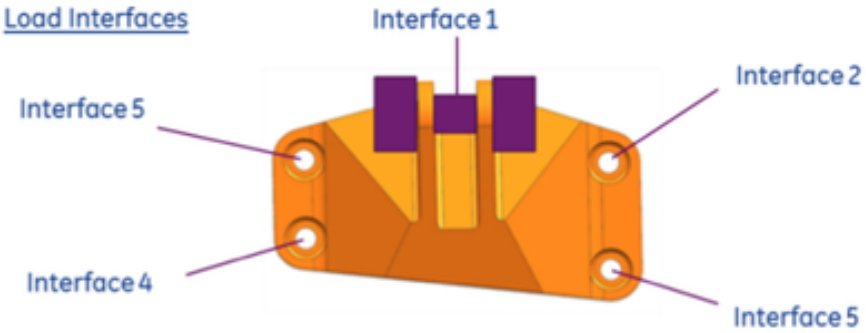
Load Condition 4

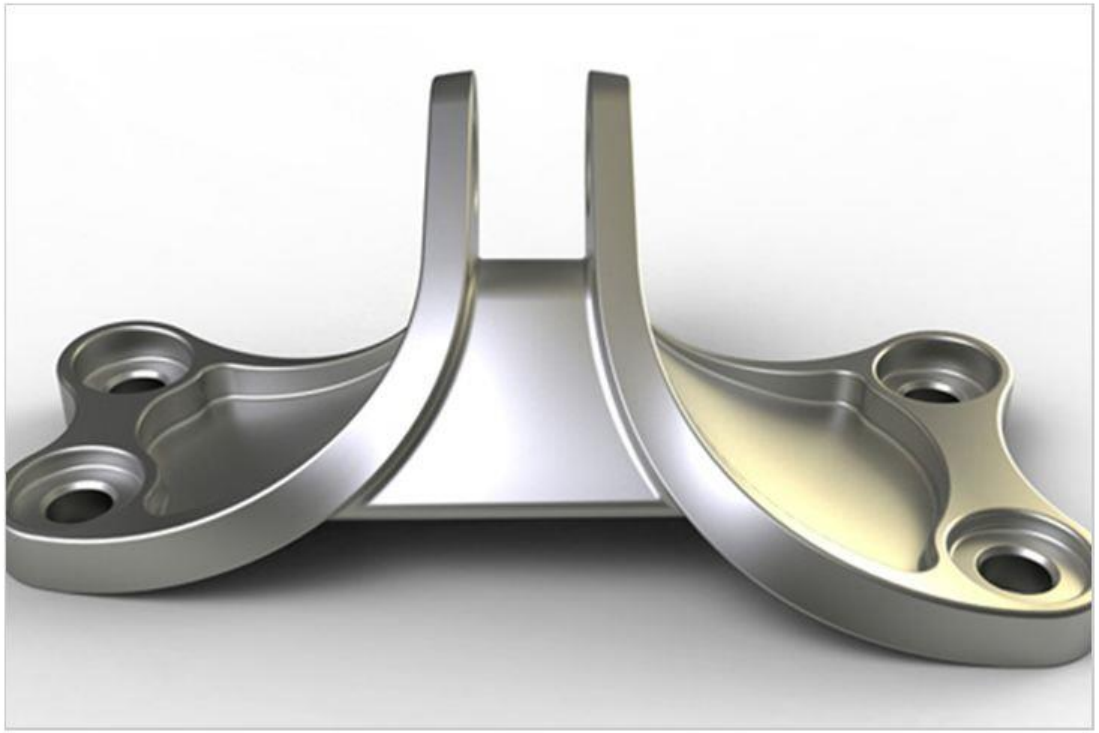
Static Torsional

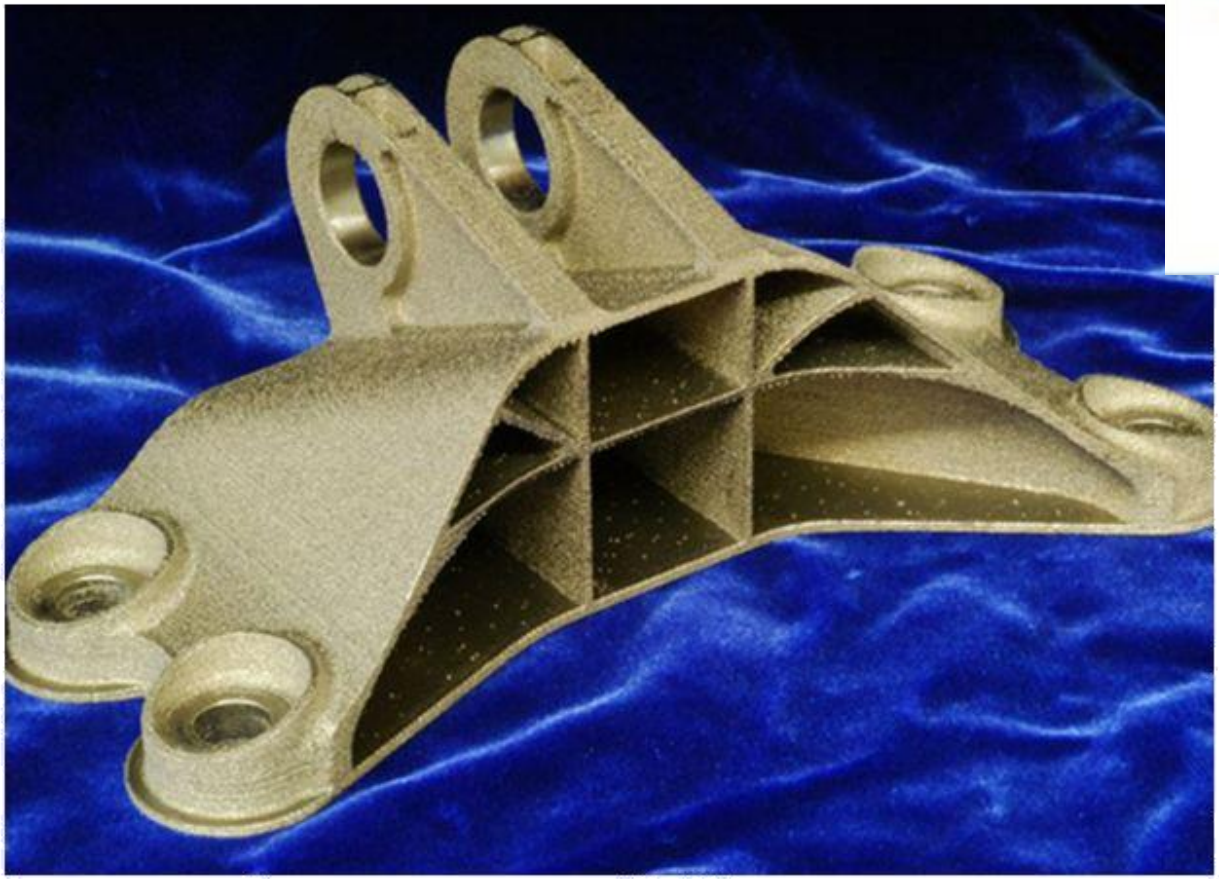
Horizontal plane at centerline of clevis.

5000 lb-in

Load Interfaces







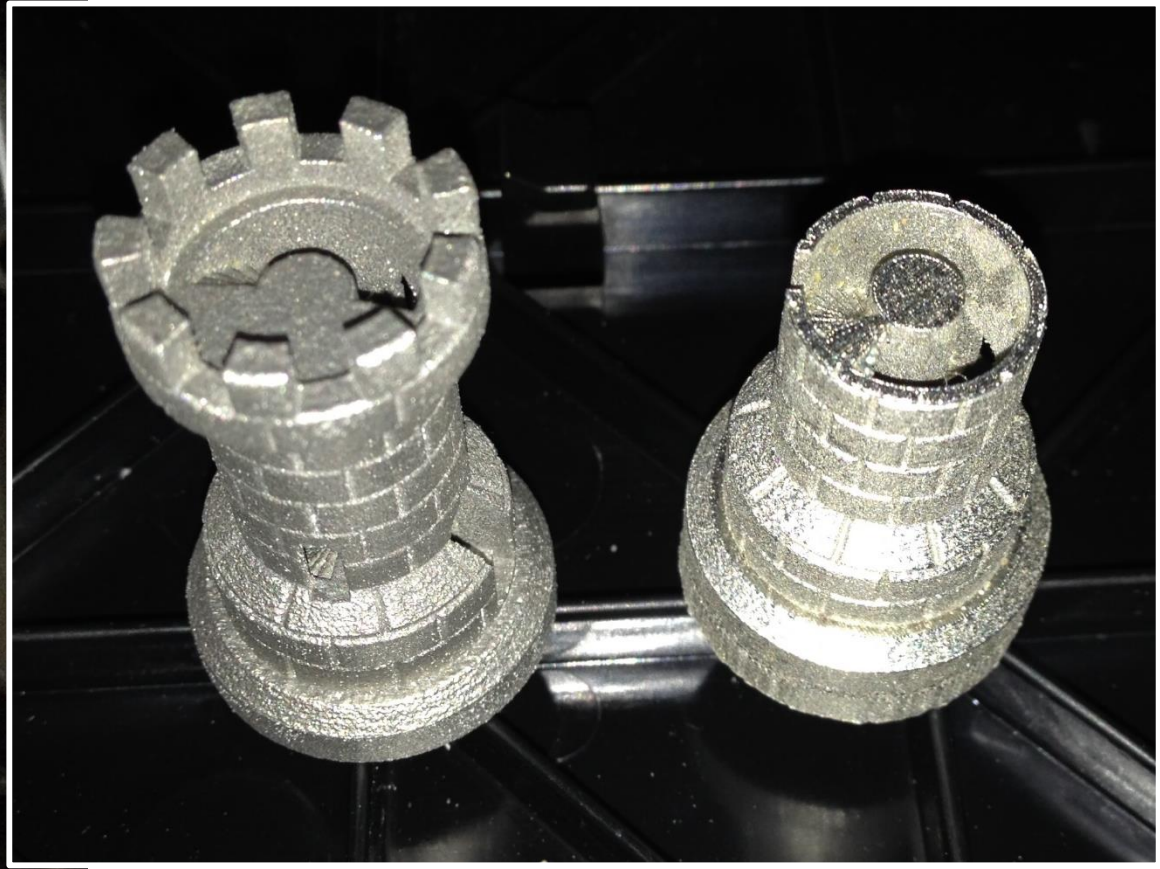
M Arie Kurniawan was able to slash the original bracket weight by nearly 84 percent to just 327 grams (0.72 pounds). His design is inspired by the H-beam profile. (Photo Courtesy of GE and GrabCAD)

Process – Part Consolidation

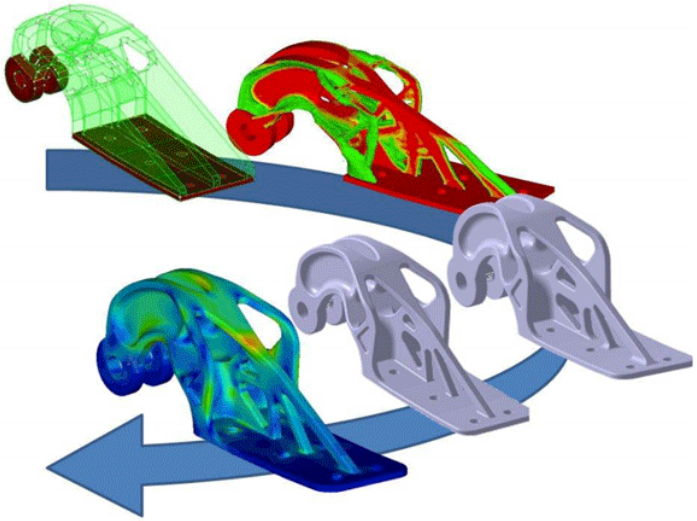
Process – Resolution

Process – Material Selection

Process – Post Processing



Design Considerations - Topology Optimization



simulatetoinnovate.com

2015

- Not specific to AM
- AM allows geometry to be manufactured that could not be machined
- FEA determines where material is needed based on loading and boundary conditions

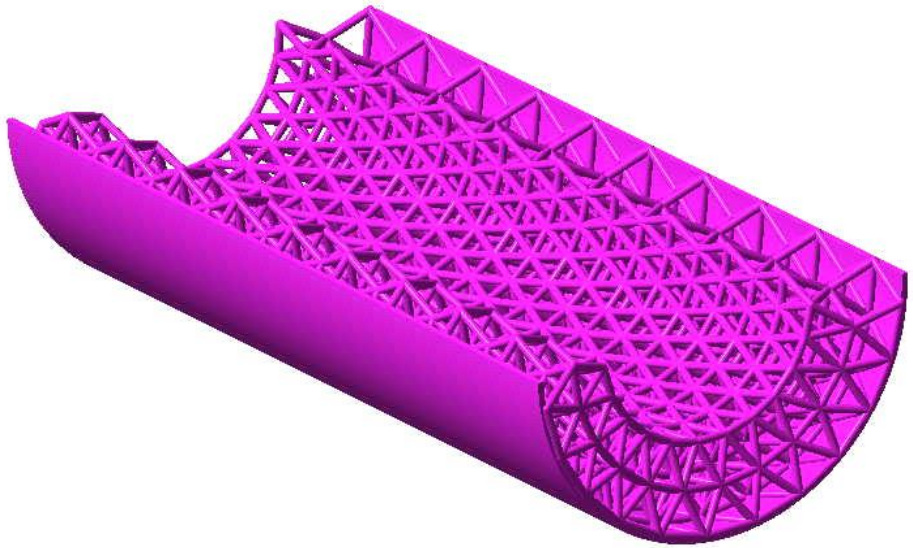
Airbus A320 Hinges

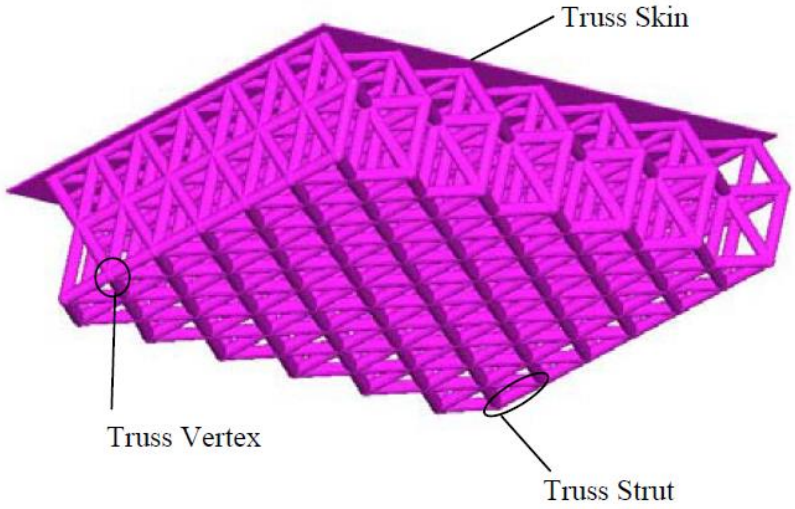
Airbus A380 Bracket

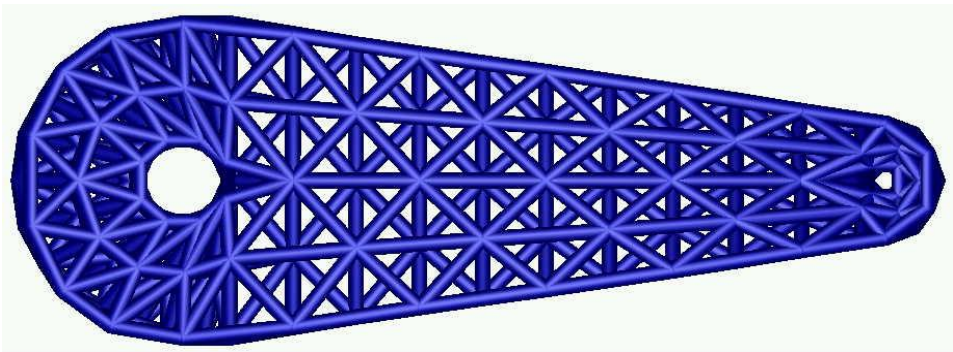
Within Technologies

Design Methodologies: Truss Structures

- **Conformal truss structures**





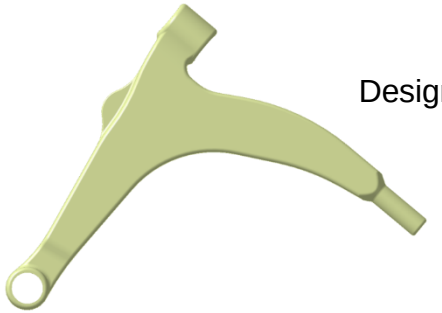


Hybrid Geometric Modeling Method for Large Scale Conformal Cellular Structures Hongqing Wang, Yong Chen, David W. Rosen, *ASME Journal of Computing and Information Science in Engineering, 2006, accepted (paper)*

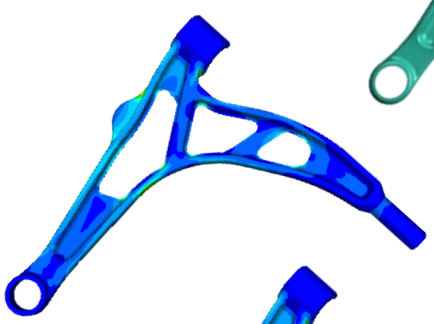
Topology & Shape Optimization: Process

New CAD design

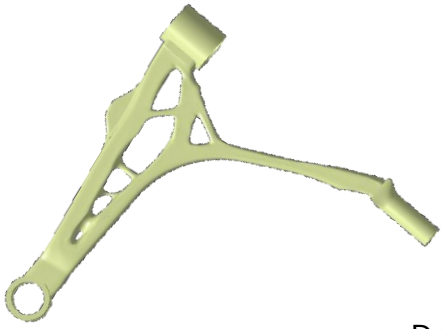
Design Space



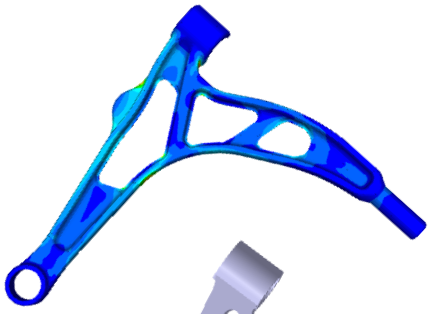
Shape optimization



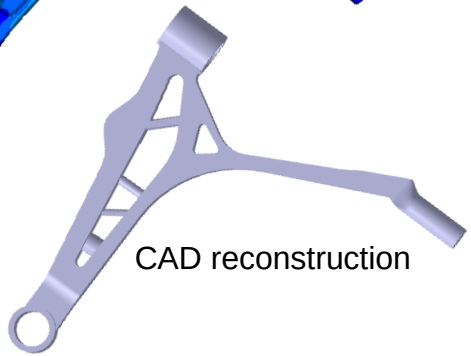
Topology Optimization Result



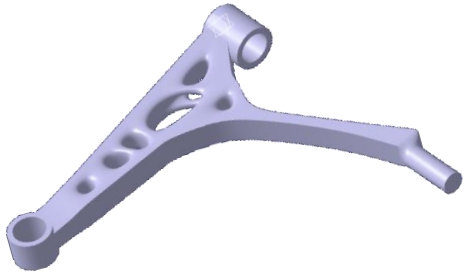
Validation Run



For conventional Manufacturing



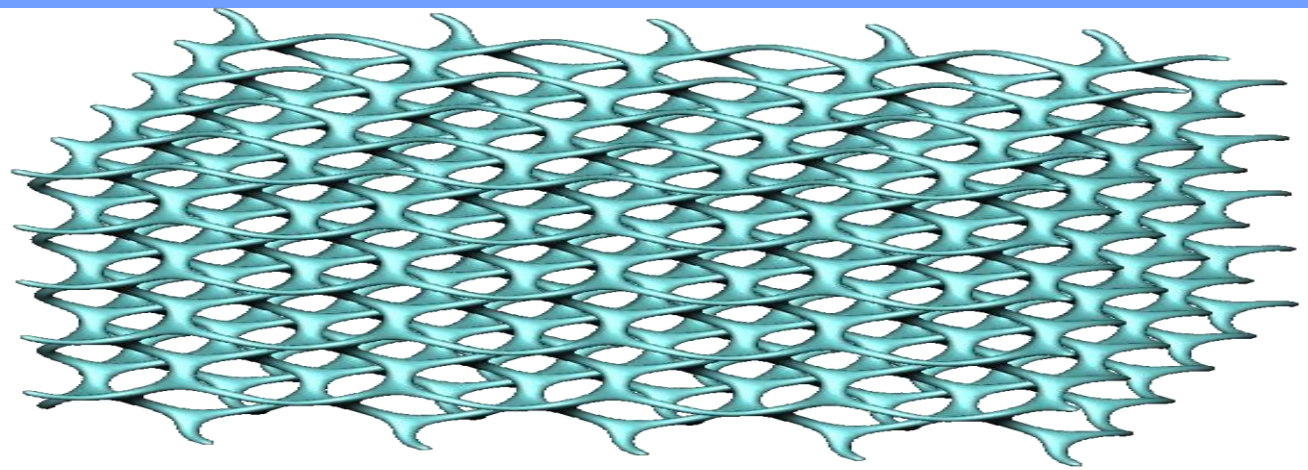
CAD reconstruction



For Additive Manufacturing

Daniel Pyzak,
Dassault Systèmes,
dpk@3ds.com

Six Stages of DeFAT



http://www.georgehart.com/rp/10-3.html

Stage Four

Stage Three

Stage Two

Stage One

Stage Zero

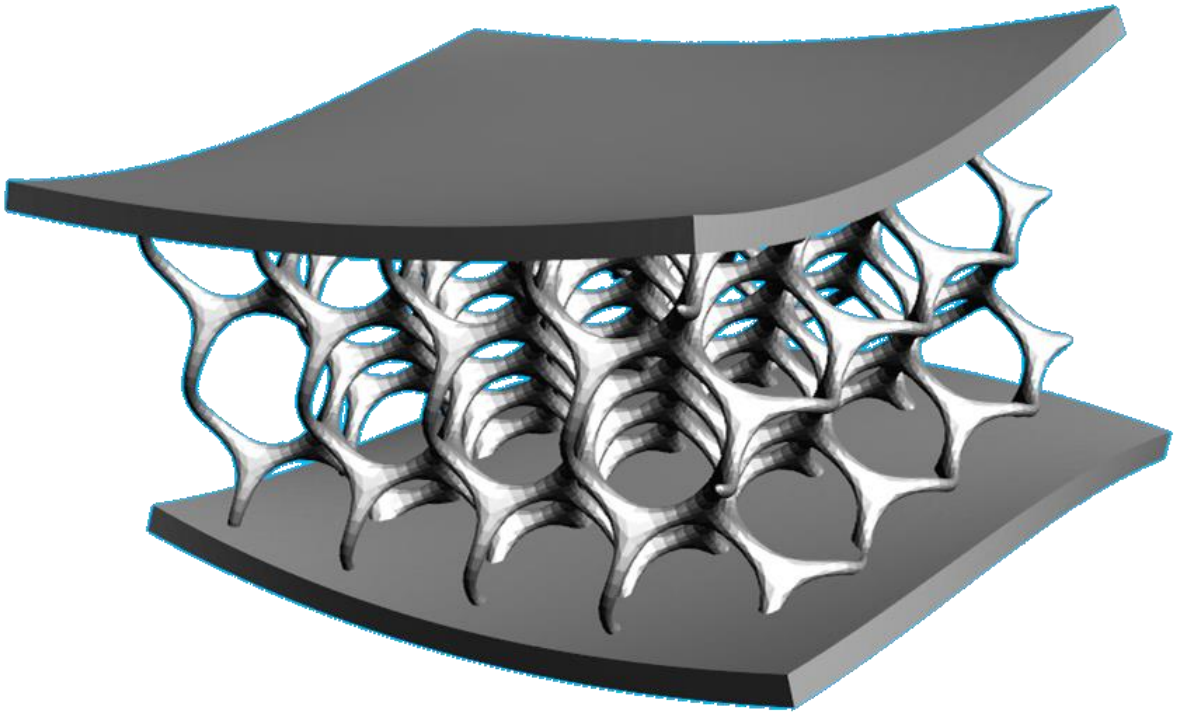
Thinking Inside the Box

- Mesostructure
- Tailored Structure
- Assemblies
- Internal Design Intent
- Graduated colors

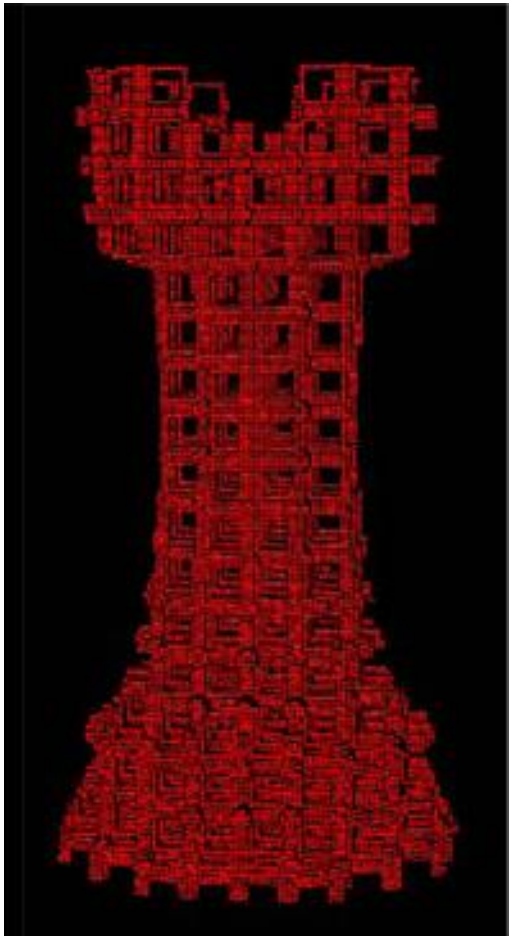
Varied Mesostructure Design

Disney Research Hub Presentation

Design Considerations - Lattice Structures



Hybrid Concept Model



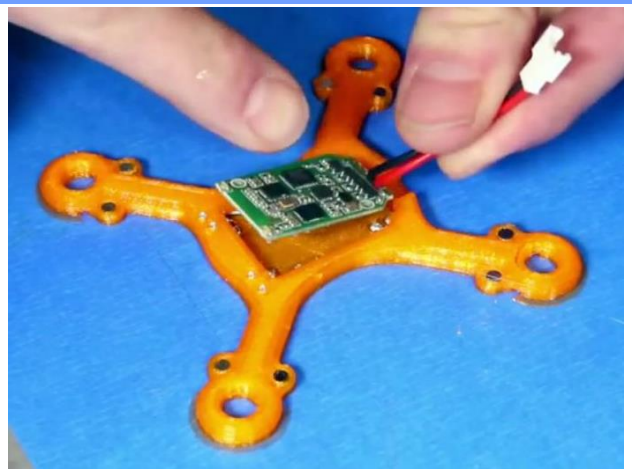
ASTM 42 – AMF Format

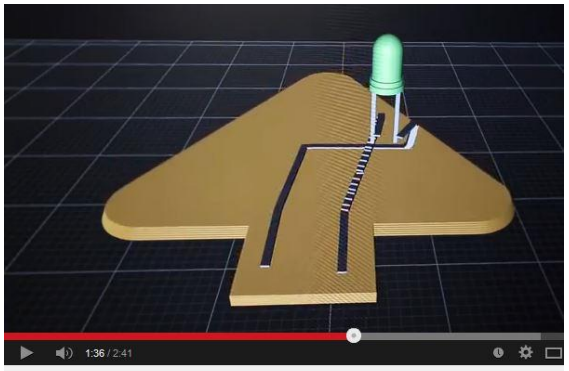
Design Considerations - Lattice Structures

European Space Agency

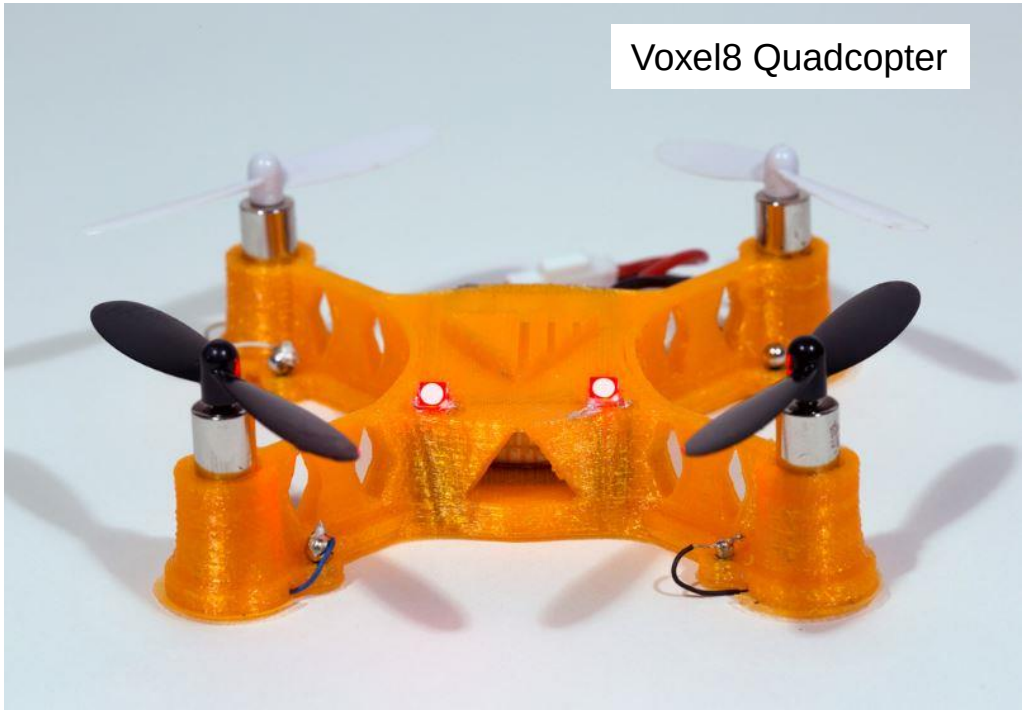
Source: Ryan Dehoff, Oak Ridge National Laboratory, Manufacturing Demonstration Facility

Multi-Functional Design





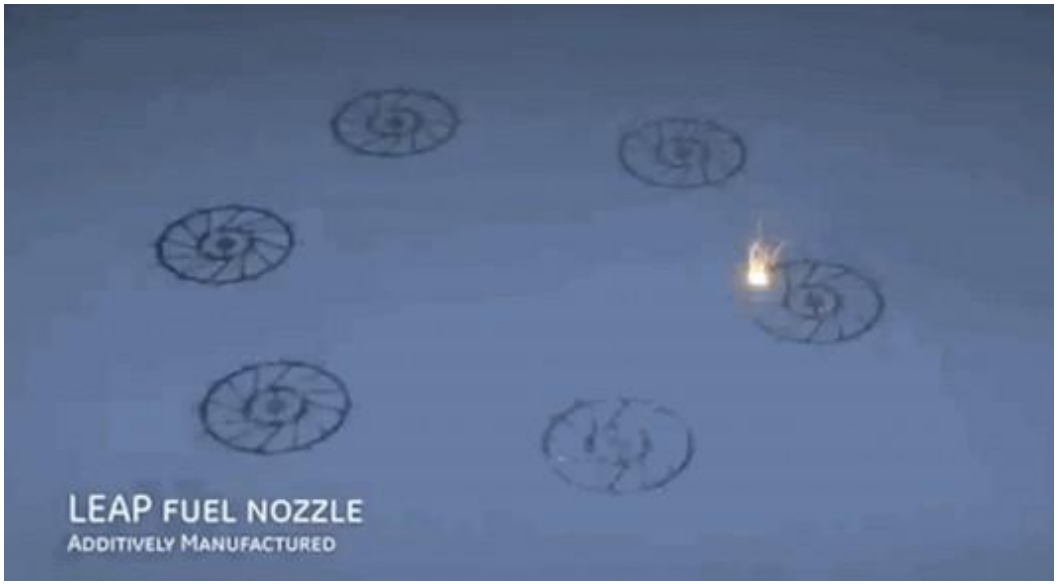
Voxel8: The World's First 3D Electronics Printer



Part Consolidation Example

Starting in 2015, GE Aviation will make 30,000+ fuel nozzles for LEAP engine.

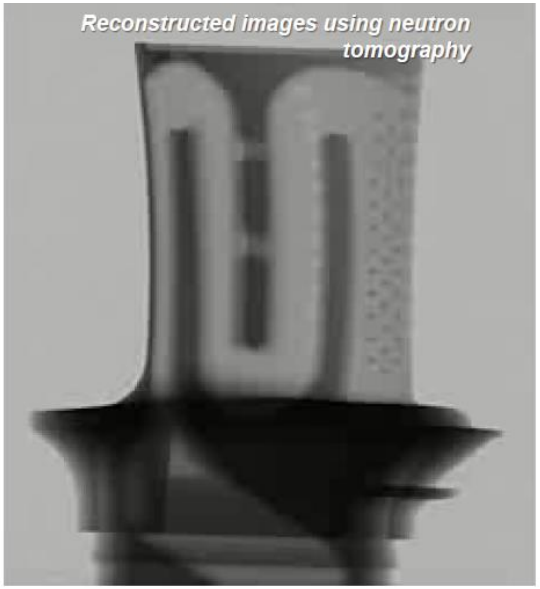
- **Consolidates 18 parts**
- **Eliminates brazing operation**
- **25% lighter**
- **5X more durable**
- **Design change to reduce carbon buildup -**

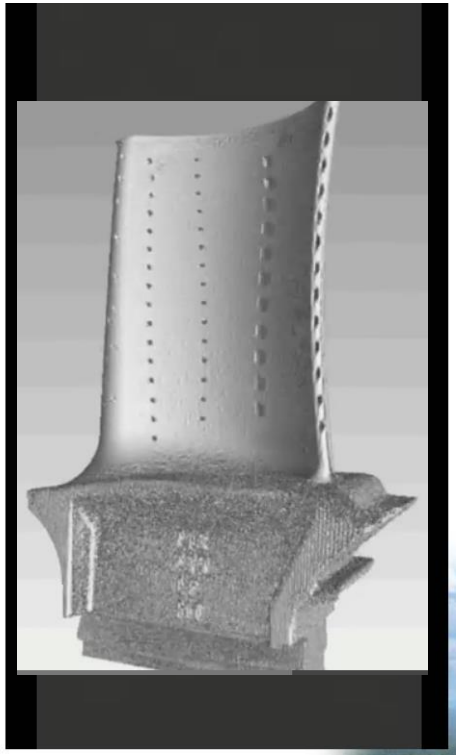


LEAP engine fuel nozzle, courtesy of GE Aviation

Internal Design Intent and Inspection

Application and Testing - ORNL





Reconstructed turbine blade using neutron imaging

- 210 Images around 180 degree rotational axis
- Currently 50-75 μm resolution at HFIR, VENUS is targeting 10 μm at SNS
- Developing methodology to perform stress mapping with tomography

U.S. DEPARTMENT OF ENERGY | Advanced Manufacturing

OAK RIDGE National Laboratory

3-D printing: the shape of things to come

By **Matthew Knight,** CNN
July 24, 2012 -- Updated 0957 GMT (1757 HKT) |

Engineers at EADS (the European Aeronautic Defense and Space Company) are researching ways of using the technology to build lighter, stronger parts for aeroplanes.

HIDE CAPTION

A new industrial revolution in 3-D?

WITHIN

HOME OVERVIEW BENEFITS SOFTWARE CASE STUDIES CONTACT & LINKS

"AN OPTIMISED LIGHTWEIGHT SUPPORT PART"

designed by WITHIN ENHANCE SOFTWARE

Six Stages of DeFAT

Stage Five Double Your Pleasure and Problems

Texture Maps

Graded Color/BMP maps

Hybrid structure/process

Multi-material configurations

Stage Four

Stage Three

Stage Two

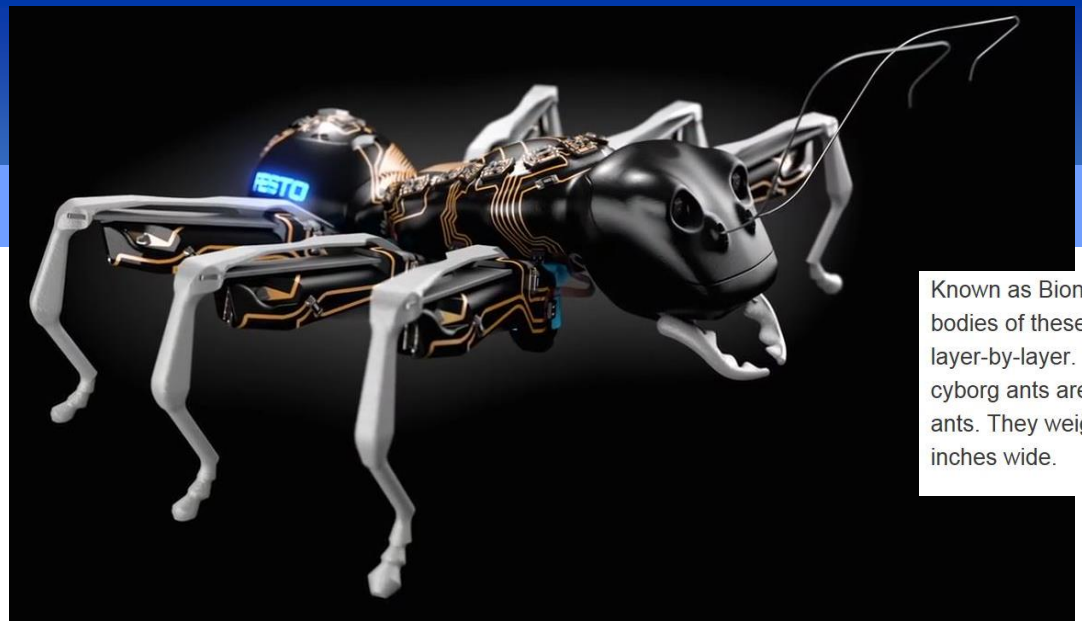
Stage One

Stage Zero

Graded Color and Multi-Material – Plus complex Geometry

Neri Oxman – MIT - Acoustical Chaise
44 different digital materials out of an "infinite palette"

Multi-Functional Design



Known as BionicANT's, (ANT standing for Autonomous Networking Technologies), the bodies of these robots are created by combining printed plastic powder, melted with a laser layer-by-layer. The electronic circuit on the top of the ANT's body is also 3D printed. These cyborg ants are about the size of a human hand, and have six articulated legs, like real ants. They weigh a quarter of a pound and are 1.5 inches high, 5.3 inches long and 6 inches wide.

3D Printing Bring High-Efficiency Solar Cells to Your Rooftop

The Engineer posted on February 16, 2015 | 1 Comment | 4532 views

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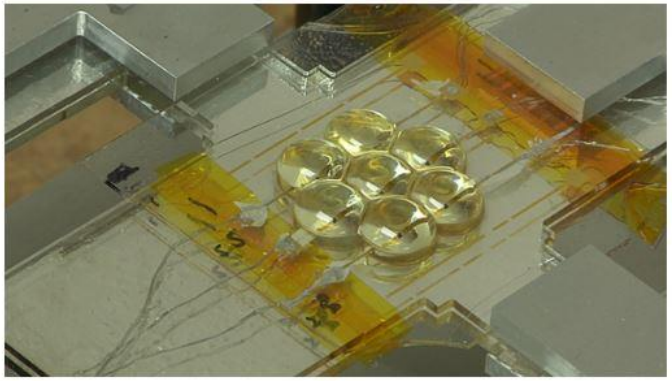
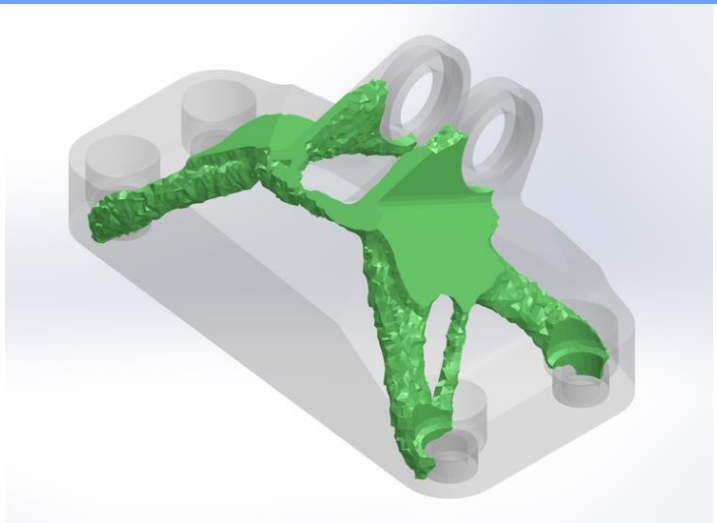
Ultra-high efficiency solar cells similar to those used in space may now be possible on your rooftop thanks to a new microscale solar concentration technology developed by an international team of researchers.



"Concentrating photovoltaic (CPV) systems leverage the cost of high efficiency multi-junction solar cells by using inexpensive optics to concentrate sunlight

Six Stages of DeFAT



Stage Five

Stage Four

Stage Three

Stage Two

Stage One

Stage Zero

Stage Six

Design Intent in the **REAL WORLD** ☹

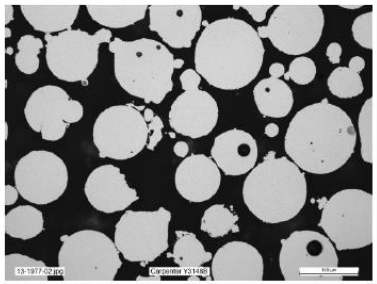
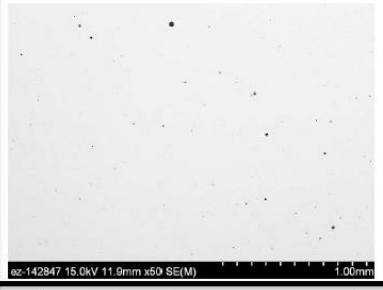
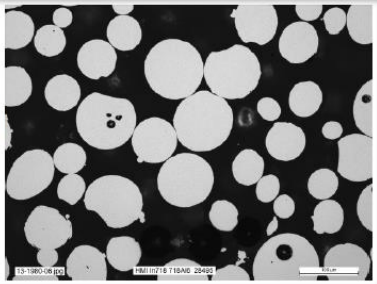
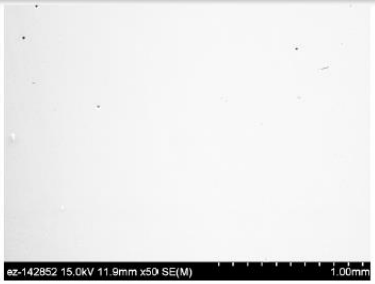
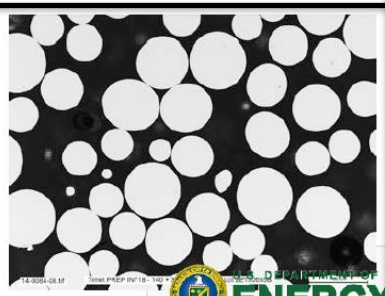
- Allowables/Analysis
- Dimensioning
- Anything but round
- Function rather than form
- Inspection
- Conveyance/Formats
- Data Size

NIST Research Program – contact Robert Lipman

- **Measurement Science for Additive Manufacturing**
  - Characterization of Additive Manufacturing Materials
  - Qualification for Additive Manufacturing Materials, Processes, and Parts
  - Real-Time Control of Additive Manufacturing Processes
  - Systems Integration for Additive Manufacturing
- **Some printers at NIST**
  - Metal powder bed fusion (EOS M270)
  - Metal binder-jetting (ExOne)
  - Makerbot, Z-Corp, Objet, Afinia, …

Application and Testing - ORNL

Porosity in Ni powders result in porosity in deposit

	Powder	As Deposited	
Gas Atomized			Porosity in Powder = 0.873% Porosity in Deposit = 0.117%
Rotary Atomized			Porosity in Powder = 0.491% Porosity in Deposit = 0.037%
Plasma Rotated Electrode			Porosity in Powder = 0.000% Porosity in Deposit = 0.000%

U.S. DEPARTMENT OF ENERGY | Manufacturing

OAK RIDGE National Laboratory

Allowables ? But, what if I vary them across a part?

- **Cobalt-Chrome (Co-Cr)**: Cobalt-Chrome alloy has fantastic resistance properties, high melting points, and is very durable at high temperatures. Fields where high wear-resistance is needed include aerospace, cutlery, bearings and blades, and recently has received more attention for medical applications.
- **Inconel Alloy 718**: This is generally used for components in aerospace, chemical, and energy markets. For example, it is used to build components like gas turbine blades, filtration and separation units, and in heat exchanger and molding processes. The alloy is is preferable for its oxidation and corrosion-resistant qualities, which allow it to function well in extreme conditions.
- **Iron-Chrome-Aluminum (FeCrAl)**: Iron-Chrome-Aluminum alloys are used to build electrical furnaces, electrical ovens, home appliances, electrical heaters, and infrared settings. They have high heat and corrosion resistance, even more so than the alloys I've mentioned so far.
- **17-4 Stainless Steel and 316 Stainless Steel**: In the automotive, medical, and general industry markets, these alloys are used to produce surgical tools, metallic filters, pumps, impellers, and structural automotive parts. These grades are known for being cost-effective, as well as having excellent mechanical and corrosion resistance properties.
- **Tungsten Carbide (WC):** With a melting point of 2770°C, Tungsten Carbide is used mainly in the manufacturing of high wear-resistant abrasives, carbide cutting tools (knives, drills and circular saws), and milling and turning tools used by metalworkers, woodworkers, miners, as well as the petroleum and construction industries.

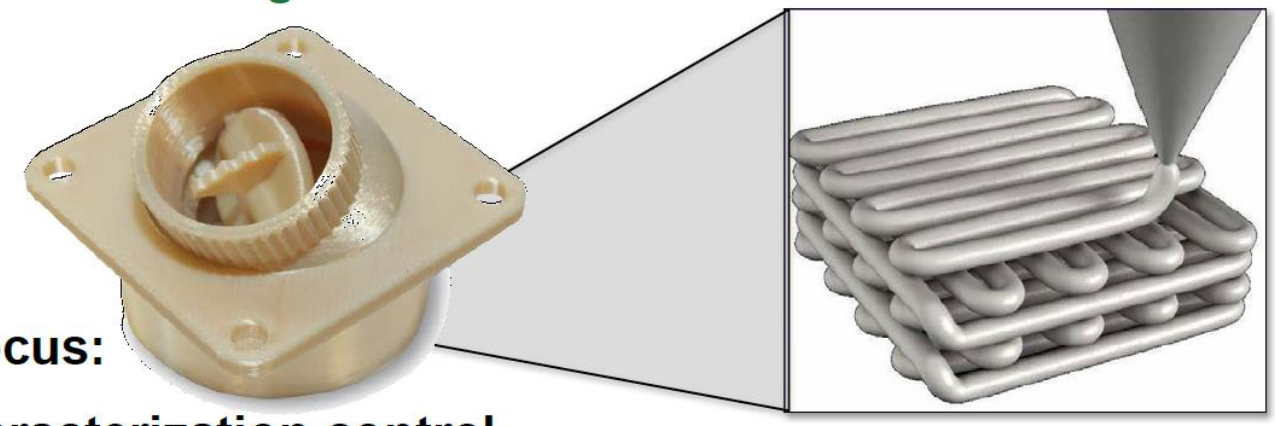
ExoOne New Materials

Application and Testing - ORNL

Globa

Polymer additive manufacturing

Fused Deposition Modeling



Research focus:

- In-situ characterization control
  - Thermography
  - Vision systems
- Materials development
  - Specific strength equivalent to heat treated Al alloys
  - High strength and fiber reinforced polymers
- Isotropic mechanical properties
  - Process modifications to improve build-direction strength

Application and Testing - ORNL

Working with Industry

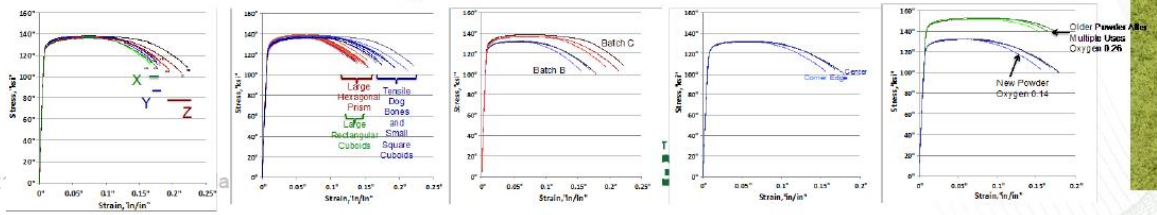
Creating data sets for qualification of parts

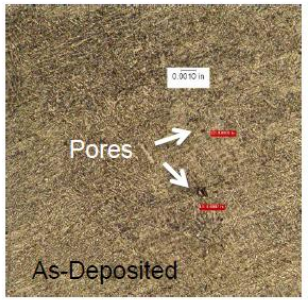
- Fabricated using Arcam EBM, followed by HIP, and machined
  - Met ASTM standards for tensile properties
  - Decrease *buy-to-fly* ratio from 33:1 to ~ 1.5:1
  - Decreased cost by over 50% using AM
- Bracket is currently being evaluated for JSF qualification

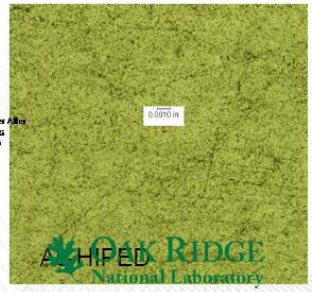
Property	Minimum Value		Maximum Value	
Ultimate Tensile Strength, (ksi, MPa)	132	910	152	1,048
Elongation, %	12		22	

Over 60 Tensile Specimens Tested Within a Matrix of Processing Conditions

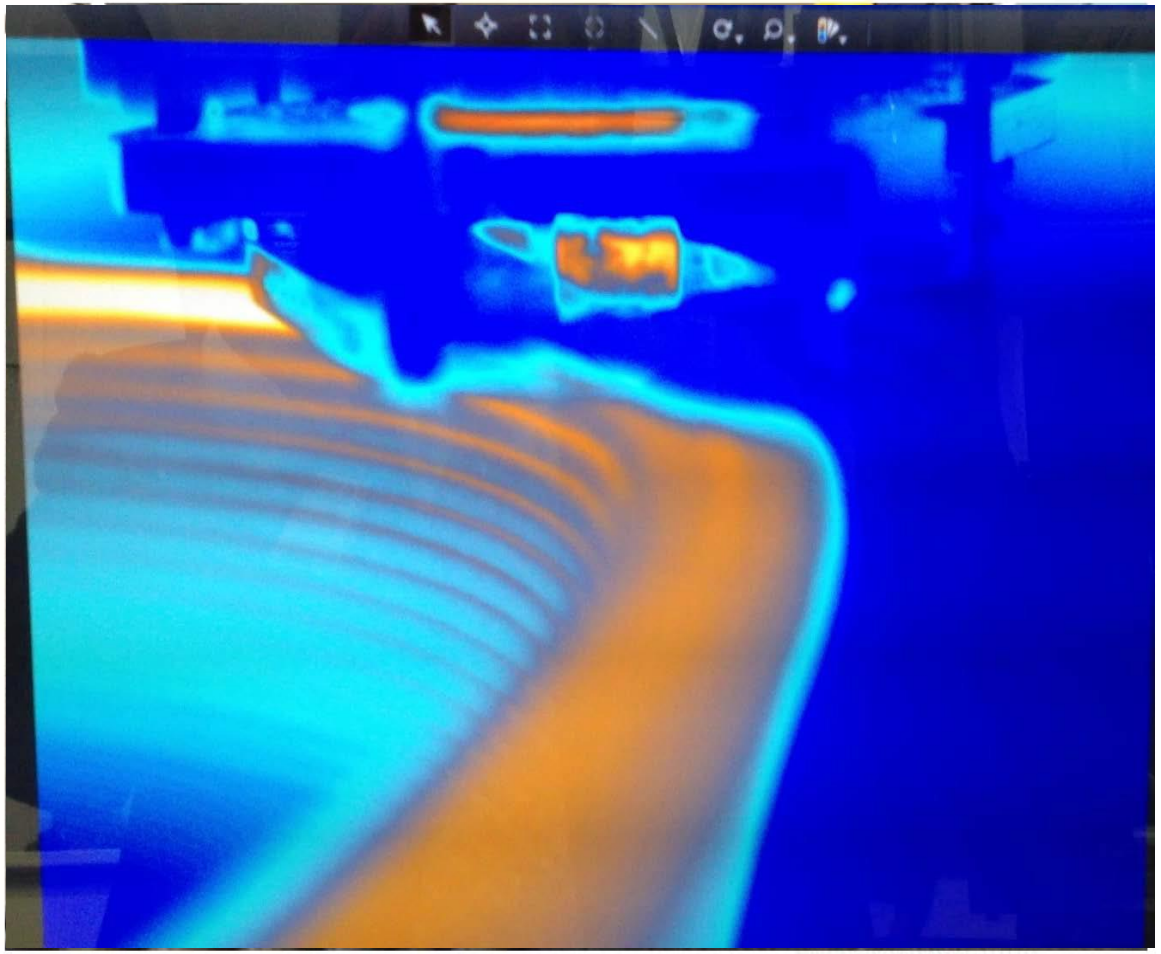
Orientation **Geometry** **Batch-to-Batch** **Location** **Interstitals**







Application and Testing - ORNL

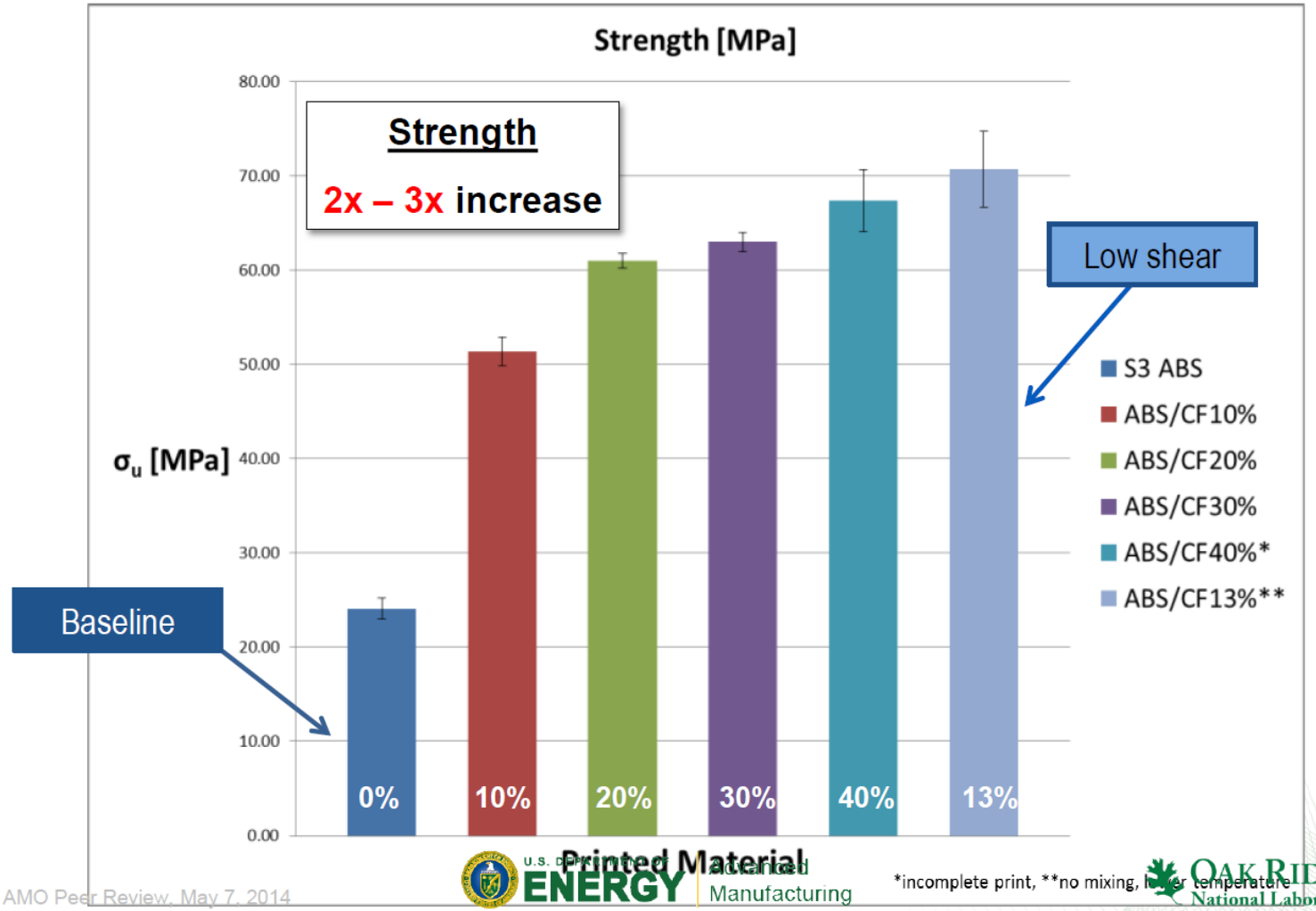


Application and Testing - ORNL

Global F

Reinforced-ABS printed parts

Mechanical Performance



ENERGY Advanced Manufacturing

OAK RIDGE National Laboratory

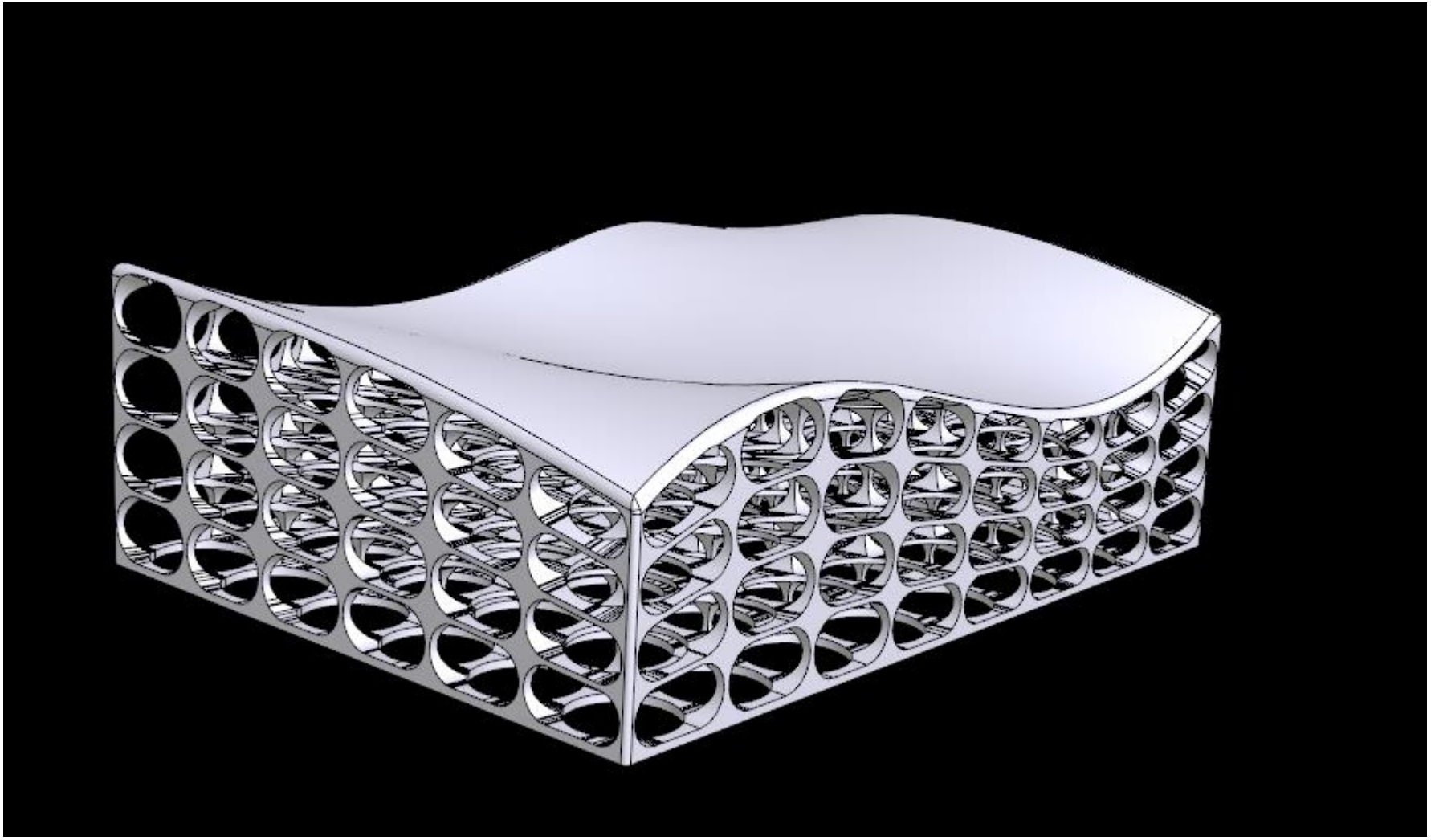
ELYSIUM

ULTEM Material Qualified for fire and smoke One of the few.

Air Duct for New Orbis Flying Eye Hospital
by Bridget Butler Millsaps · October 10, 2014

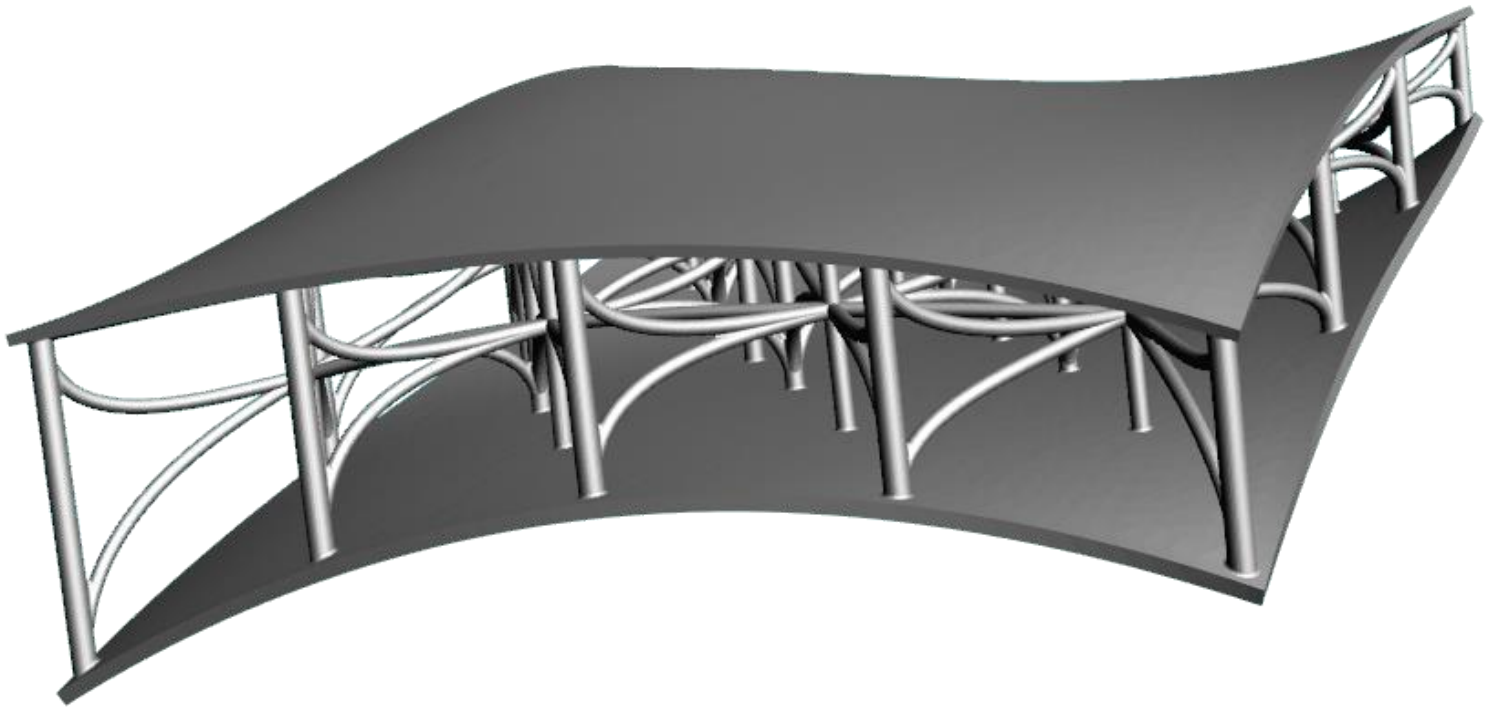
EOS's Aluminum AlSi10Mg alloy for a Rennteam Uni Stuttgart racing car

Dimension This?



Or maybe this?

Note – Every vertical support is different diameter based on its length

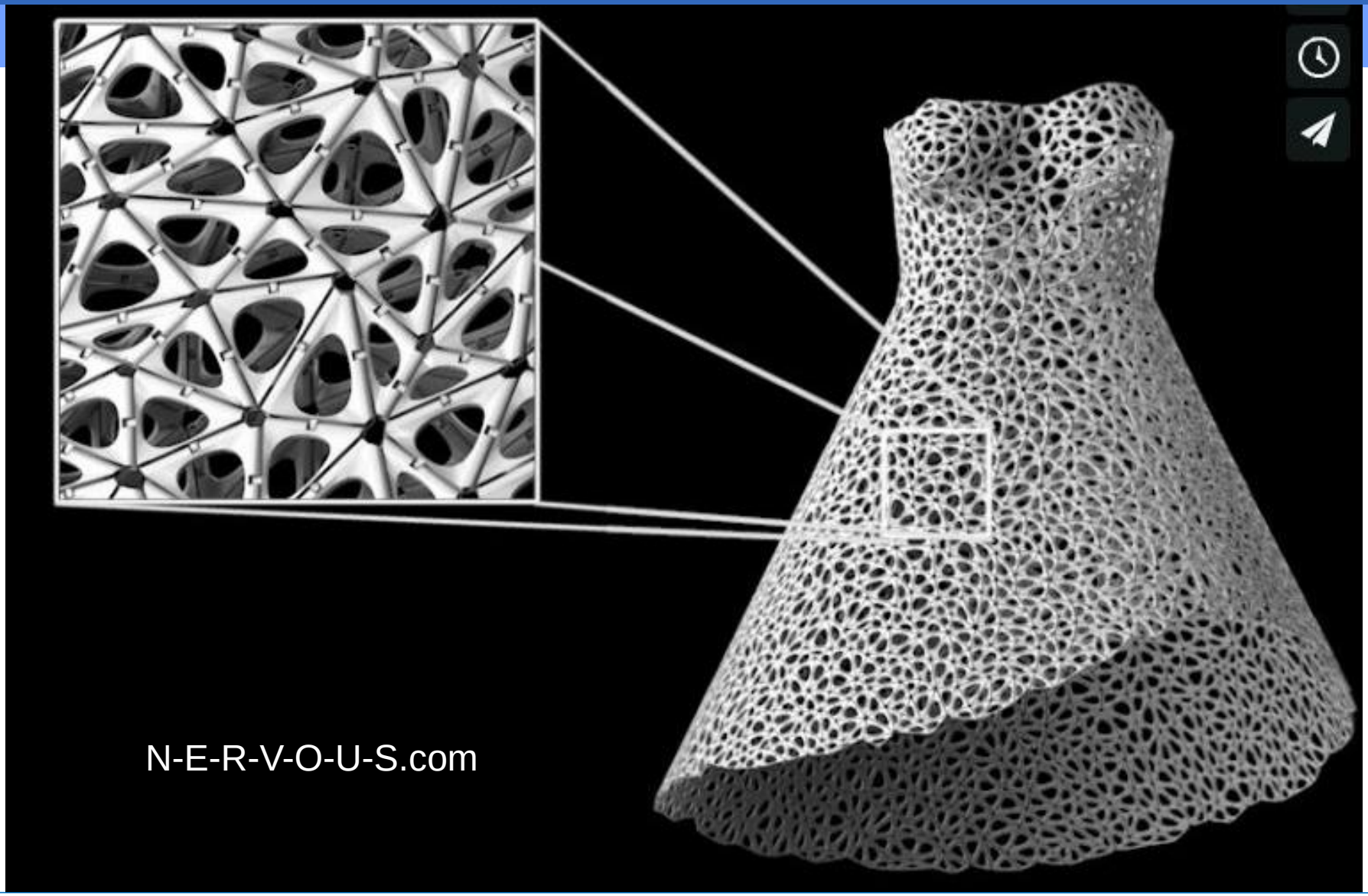


One commonplace element of part production that is decidedly not digital is the use of isolated linear feature dimensions as a proxy for the overall accuracy of the part. This practice, along with the awareness of **geometric dimensioning and tolerancing (GD&T)** that almost any machine shop takes for granted, **is a relic of 2D representations of parts onto paper**.

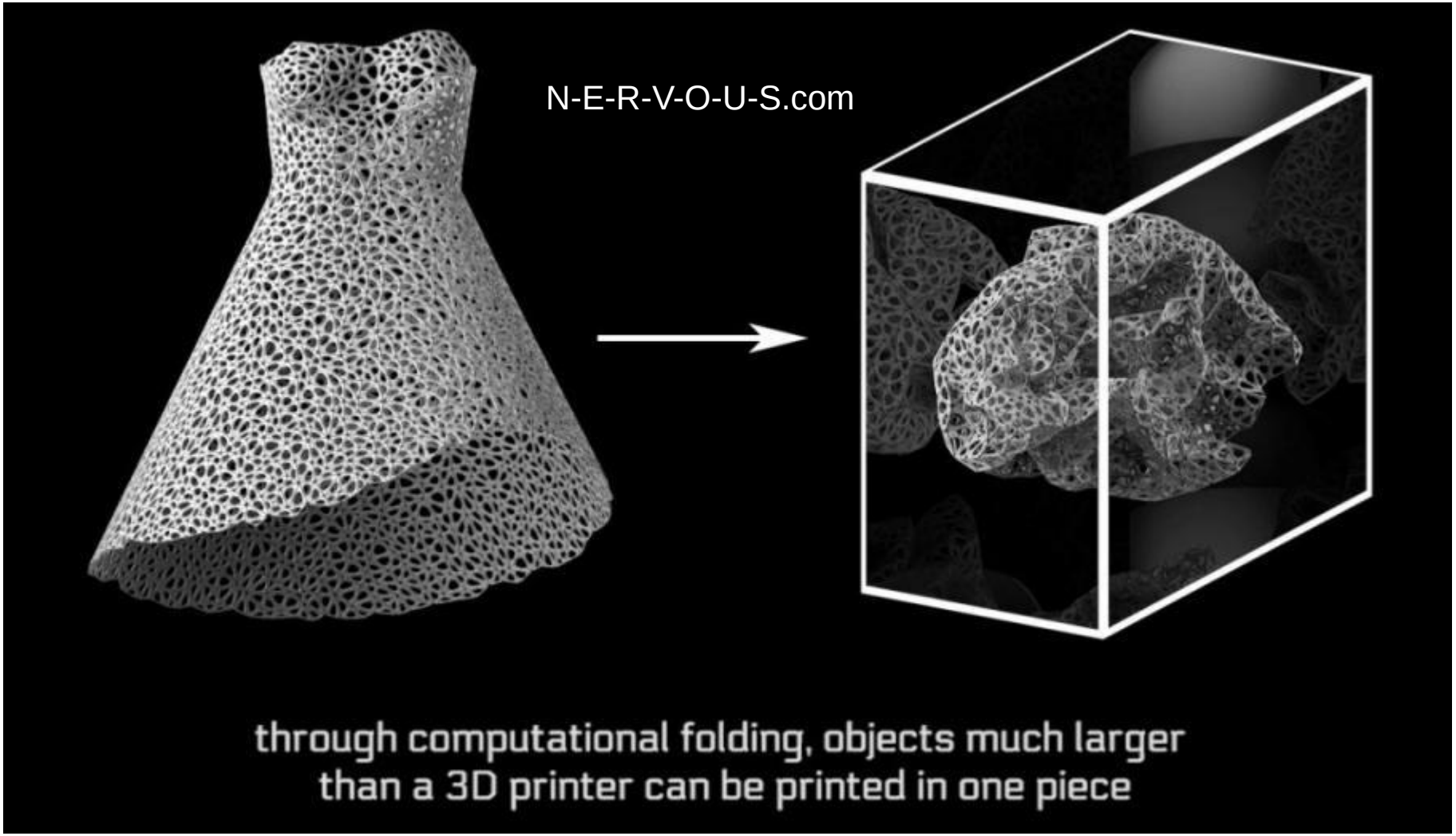
By contrast, Digital Tapestry manufacturing would instead be trusted to manifest the desired form of a part, whatever that form might be, within an **envelope of acceptable variation** all the way around the original design. In the Digital Tapestry, instead of enumerated feature tolerances indicating whether a part broke the envelope, direct digital comparison with the envelope itself would qualify the part.

The data for this **comparison might be obtained by scanning the part** and comparing the scan against the design model. However, Little says the more efficient way to accomplish this same goal would be to validate the part-making process in terms of its fidelity at producing a form to the precision needed. Either way, there would be **no dimensions and tolerances** that would be appropriate to anything like a shopfloor gage. That is, there would be **no numbers to describe the part** in anything like the way that a machinist might expect.

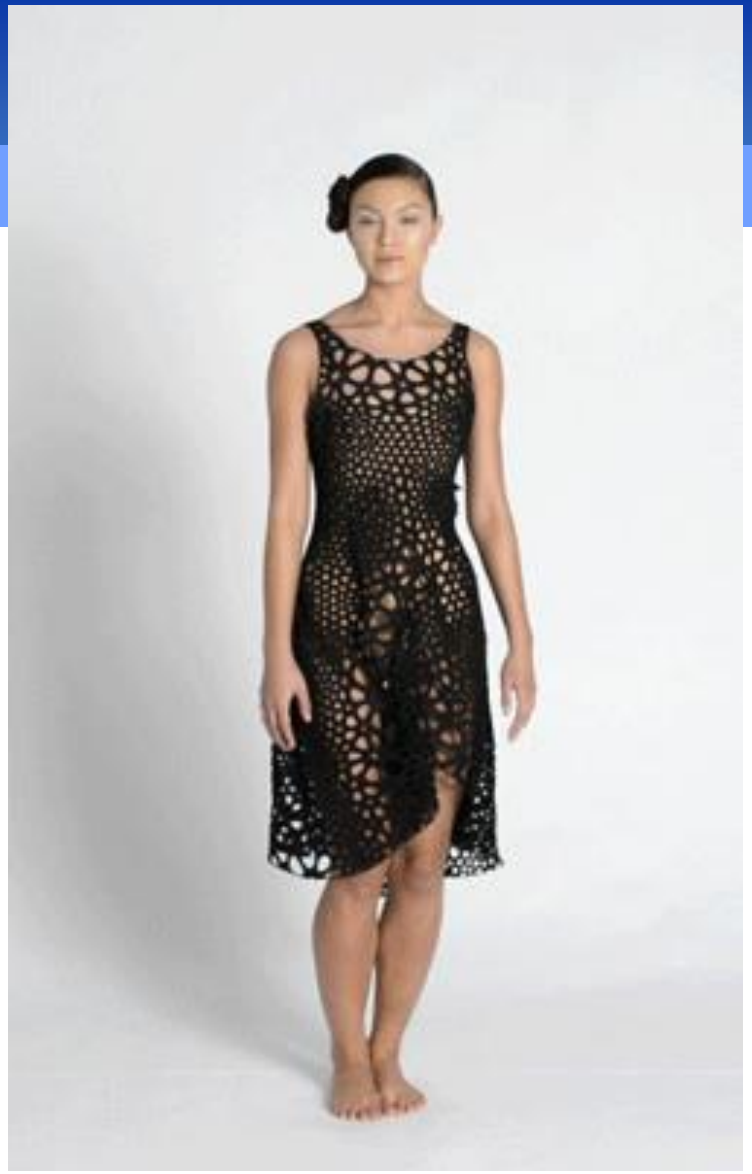
Data Size and Dimensioning Issues?



Very Functional Requirement – Build Volume



And wearability -



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Six Stages of DeFAT