



DIGITAL TRANSFORMS PHYSICAL

GENERATIVE DESIGN CORE COMPETENCIES AND INDUSTRIAL APPLICATIONS

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AGENDA

GENERATIVE DESIGN

CORE COMPETENCIES & INDUSTRIAL APPLICATIONS

AGENDA

- An Early Success Story
- Yesterday's Hands-On Experience
- Technical Underpinning
- Core Competencies
- (More) Industry Examples
- Questions & Answers

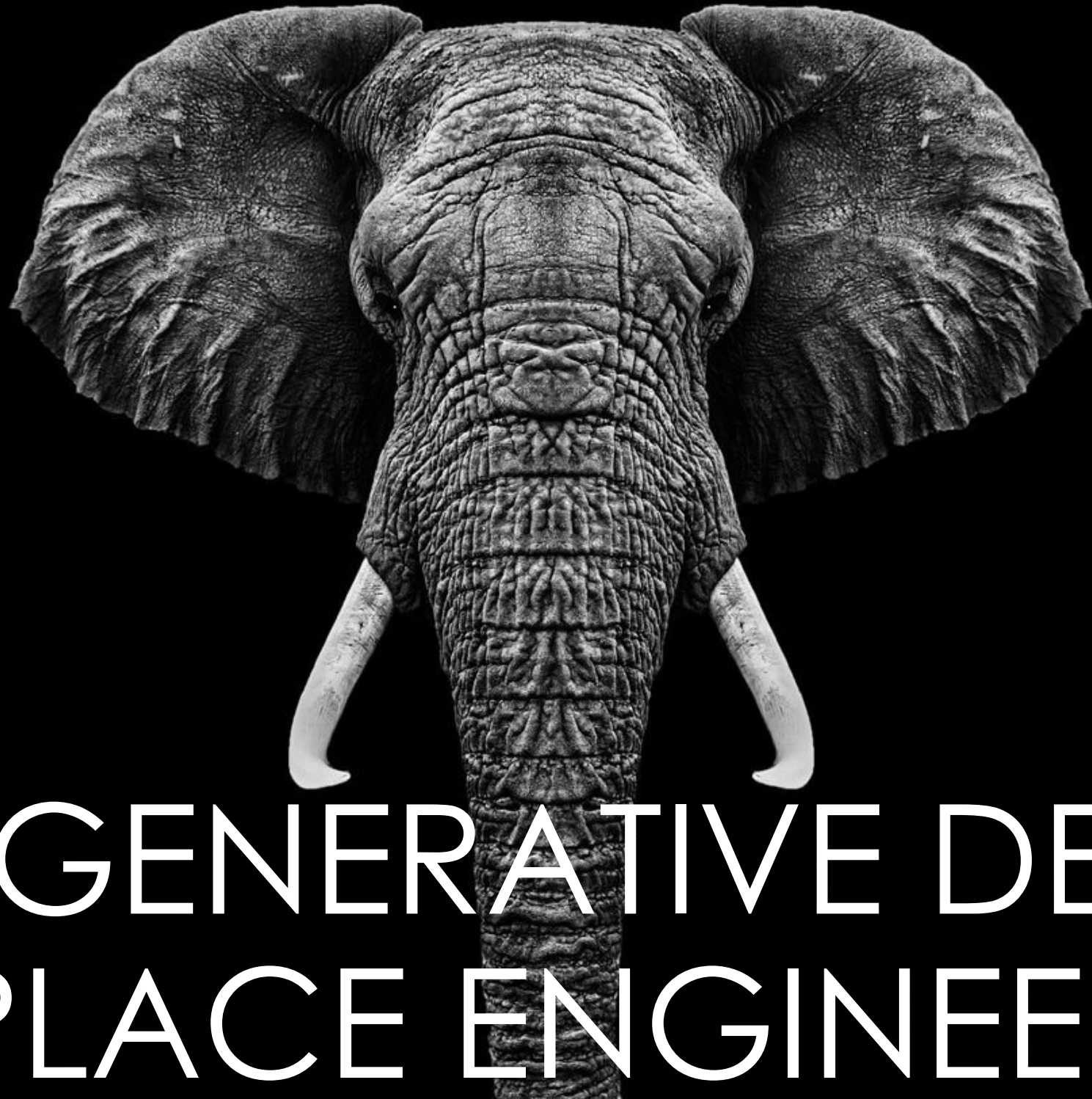
Kevin McClintock & Volvo
Educational Implications

Implicit Geometry

Nuts, Bolts, and Tripwires

Jesse Craft & Jacobs Engineering
PTC & Technion

Jeff Olsen & Hiller Measurements



WILL GENERATIVE DESIGN
REPLACE ENGINEERS?



VOLVO SUPERTRUCK 2

KEVIN M^cCLINCTOCK & VOLVO

UNBELIEVABLE PRODUCTIVITY

WHAT DID HE ACHIEVE ON HIS OWN?

- Redesigned the entire powertrain installation systems
- Generatively designed a cast engine mount (below), a machined fan motor mount, and an additively manufactured bridge bracket
- Convinced Volvo executives to upgrade his workstation and expand generative design to his entire group





YESTERDAY'S
HANDS-ON
EXPERIENCE

ONSHAPE GENERATIVE WORKSHOP

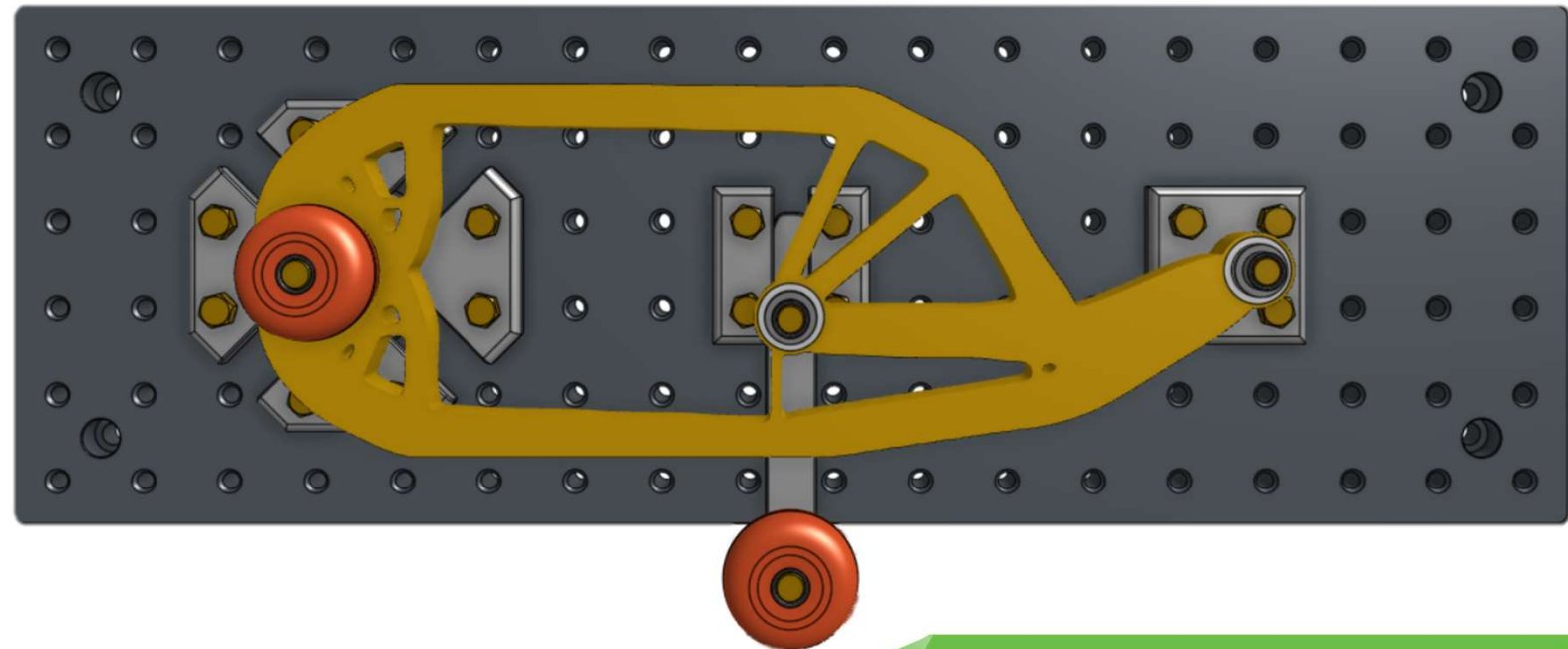
EDUCATIONAL IMPLICATIONS

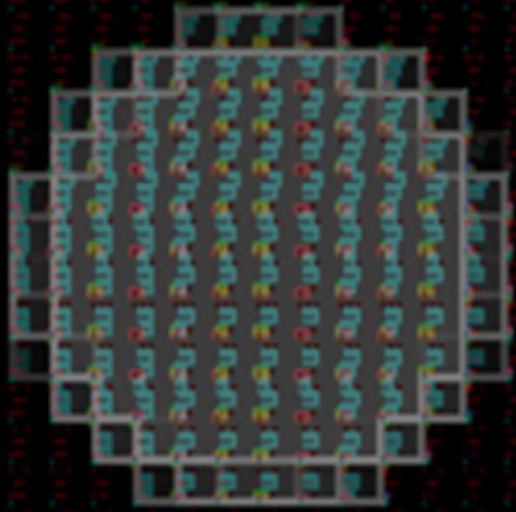
WHAT MAKES THIS “WORK”

- Generative Design enables exploration – so explore the space
- The results can be felt – find ways to involve physical test specimens
- Generative Design builds (and tests) your intuition – leverage it as such

SYSTEMS-LEVEL THINKING

- Establishing load cases is an exercise in itself
- Realize that every interface is a negotiation
- Measure the consequences of each decision
- Generate the pareto front of optimum designs





TECHNICAL UNDERPINNING

IMPLICIT GEOMETRY

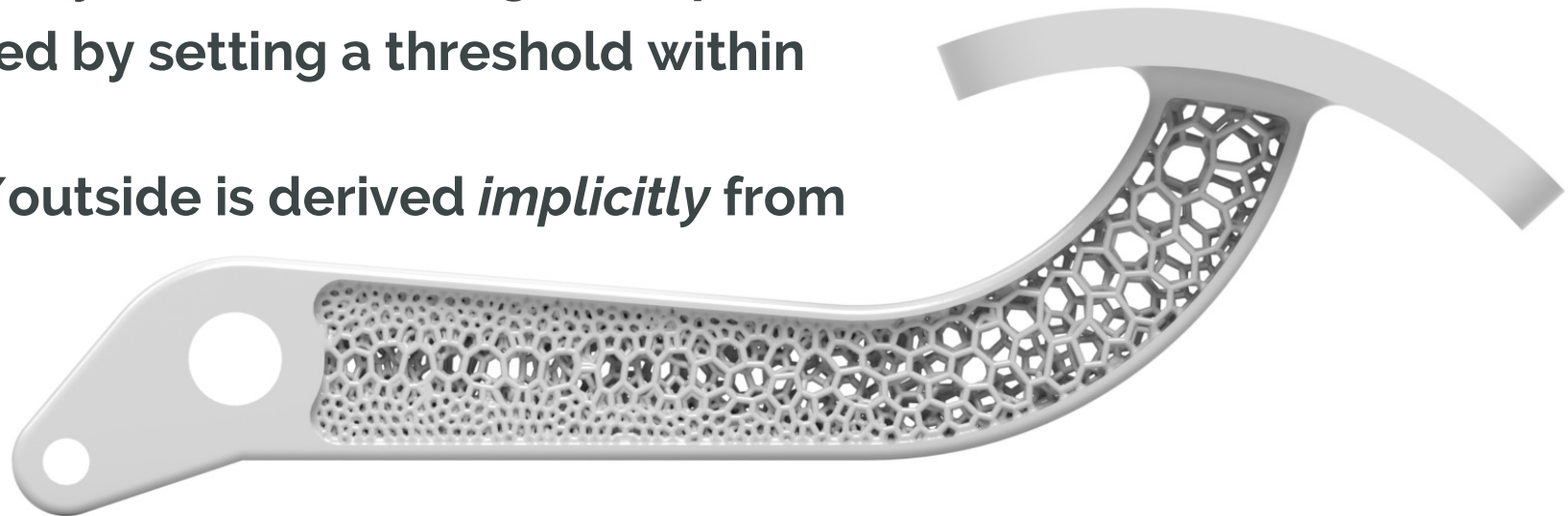
DEFINING GEOMETRY FROM THE INSIDE-OUT, NOT THE OUTSIDE-IN

WHAT IS “NORMAL” GEOMETRY?

- Conventionally, geometry is defined by a Boundary Representation (BREP)
- Solid parts are what lies within the explicitly defined surfaces.

WHAT IS IMPLICIT GEOMETRY?

- Each Part is defined volumetrically as a field throughout space
- Part envelope is only determined by setting a threshold within that field
- The boundary between inside/outside is derived *implicitly* from that threshold
- One can superimpose fields to great effect





CORE COMPETENCIES

EXPERTLY ARTICULATE REQUIREMENTS

SOMETIMES (NOT) EASIER SAID THAN DONE

WHAT YOU WANT

```
Factorial( int N) {  
    for ( i : N-1 to 1 )  
        N = N*i  
    return N  
}
```

WHAT WOULD BE REQUIRED

- One input N
- One output M
- N should be integral
- N should be greater than 0
- N will not be greater than 1,000,000
- Function should be $\leq O(N)$ complexity
- Function should return N multiplied by each smaller non-zero integer
- Function should compile without warnings

Students must learn to be precise and unambiguous even in the “simple” things.

THINK ABSTRACTLY

OR AT LEAST KEEP IT IN MIND

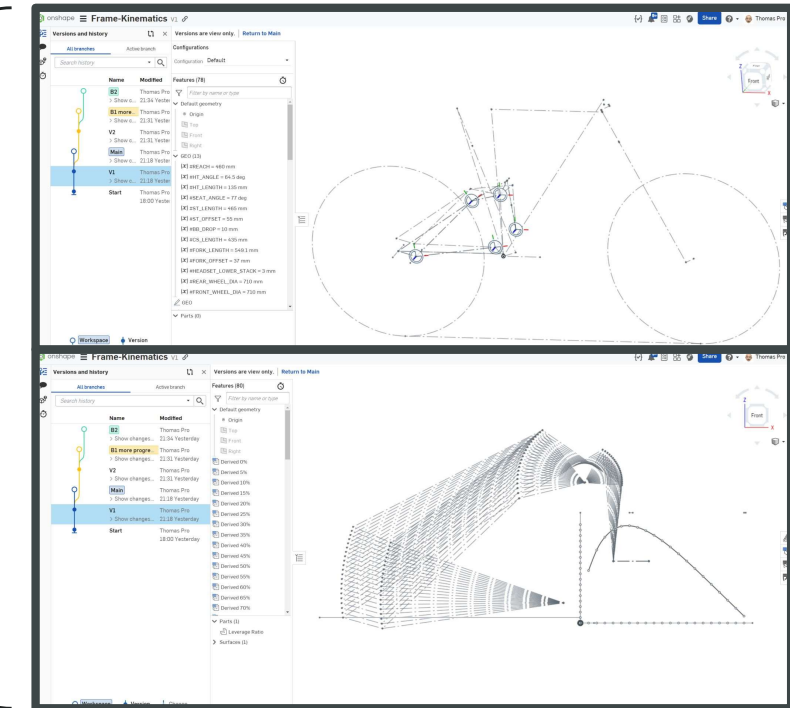
MOTIVATION

- Generative Design encodes design intent, not just design features
- Most problems are not entirely new
- Demonstrate complete understanding of the problem
- Parametrically extend your investigation to any portion of the system

FURTHER MOTIVATION

- Implicit geometry results are more robust if your generative model is properly abstracted

Abstracted Bicycle Frame Kinematics
Courtesy of Principia MBDS & OnCAD



BOUNDARY CONDITIONS, KEEP-INS, AND KEEP-OUTS

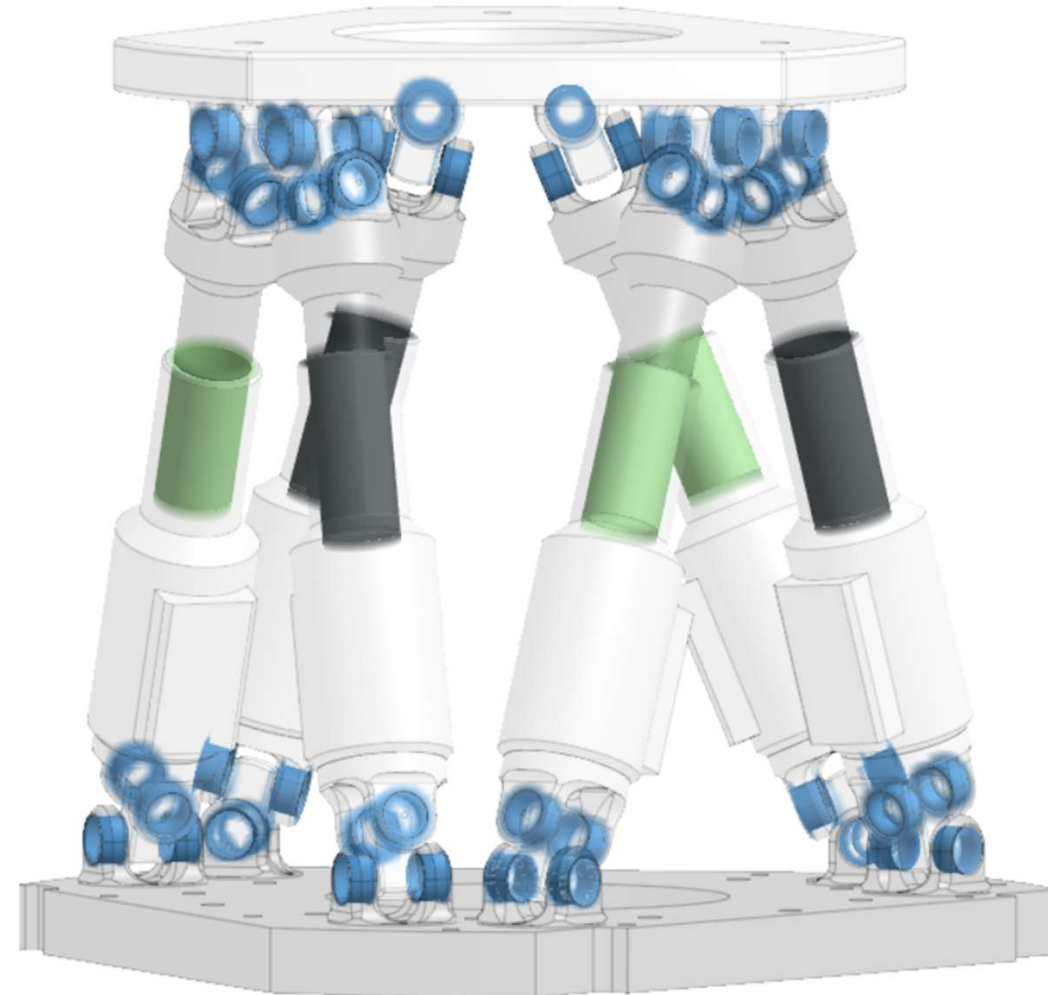
NOT DIFFICULT, BUT DETAILED

NECESSARY CONSIDERATIONS

- Simulation is not reality
Make intelligent approximations
- Mindfully consider each and every interaction
- Keep-ins are often best modeled by hand if you know what you want
- Keep-outs should consider assembly & installations requirements, not just obstacles and self-collision

TYPICAL PAIN POINTS

- Improperly identifying Ground
- Under-constrained (linear-static) assemblies
- Under-specification of implicit offsets



SIMULATION, LOADS, AND LOAD CASES

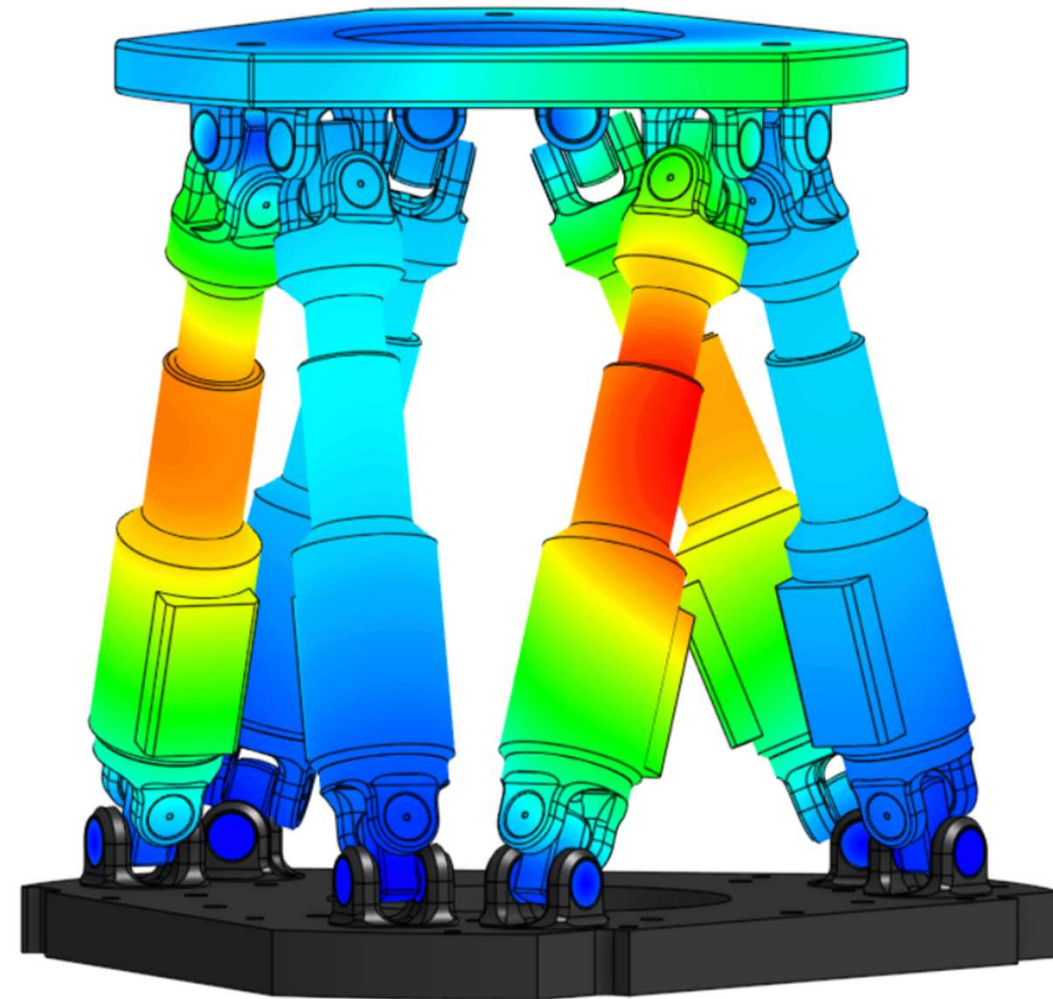
THE “ACTION” COMPONENT OF GENERATIVE DESIGN

NECESSARY CONSIDERATIONS

- Simulation is not reality
Make intelligent approximations
- Understand the simulation metrics you seek
- Construct load cases as close to your intended physical validation tests as possible
- Use multiple load cases
...unless one is truly enough

TYPICAL PAIN POINTS

- Not understanding simulation's limiting assumptions
- Not understanding intended operating conditions
- Improper element size



OBJECTIVES, CONSTRAINTS, AND WEIGHTS

KNOW YOUR LIMITS AND BE PREPARED TO HONOR THEM

BASIC

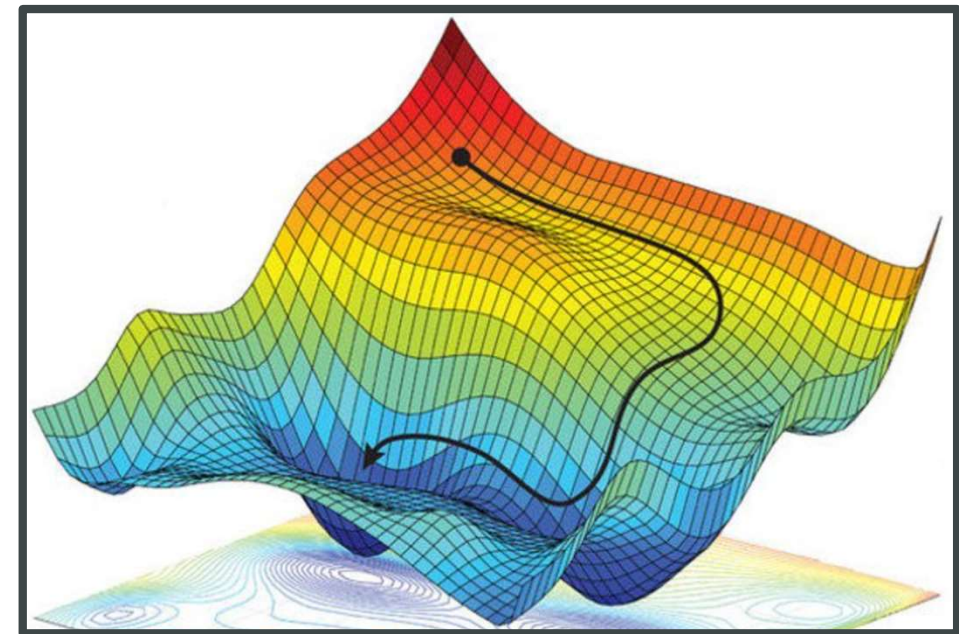
- Ceiling/Floor
- Minimize/Maximize
- Target... actually Minimize in disguise... actually Minimize(Maximize) in disguise

MODERATE

- Geometric Constraints and Objective Weights
- Constraint-less aka Competing Objectives
- Different goals for different load cases
- Layered implicit fields

ADVANCED

- Self-authored optimization functions



COMPUTER AIDED DESIGN


GEOMETRY IS THE LANGUAGE OF DESIGN



onshape™



creo®



INDUSTRY EXAMPLES

JESSE CRAFT & JACOBS ENGINEERING

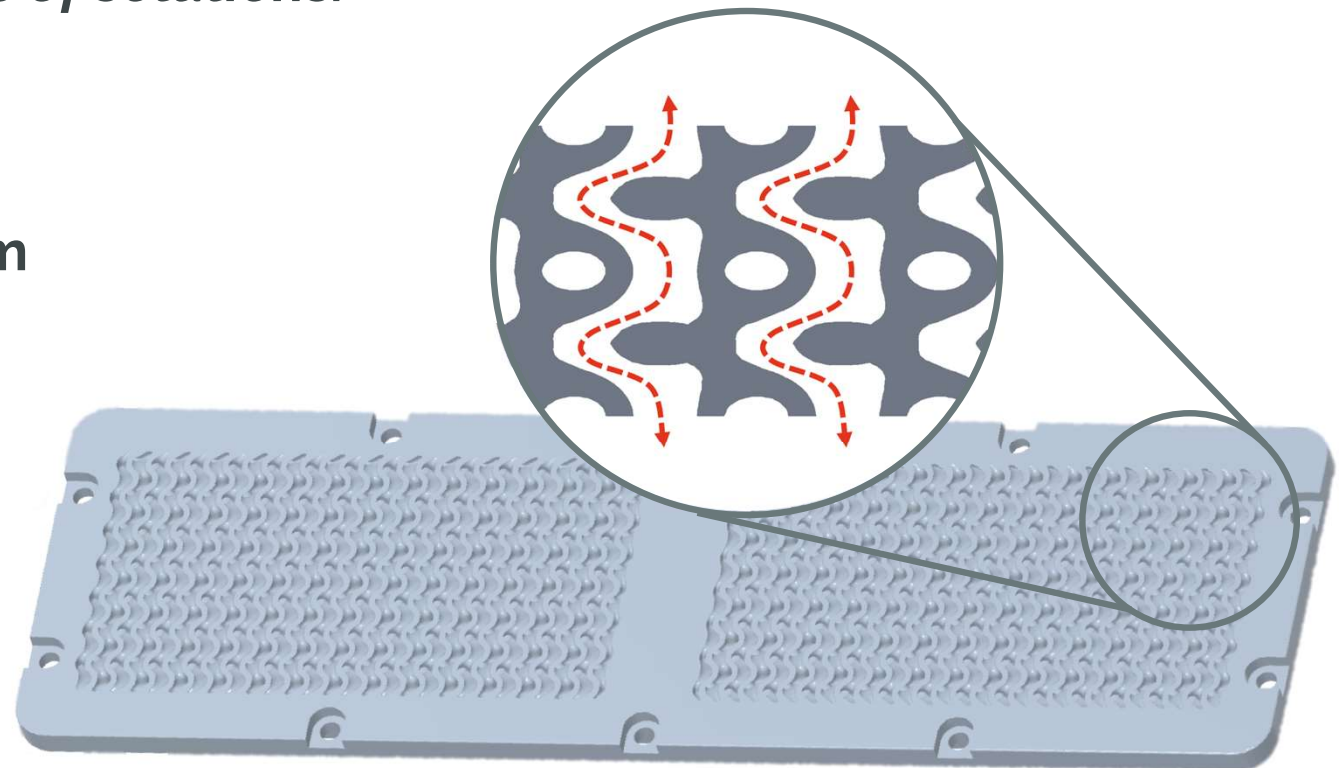
PORTABLE LIFE SUPPORT SYSTEM FOR LUNAR MISSIONS

IN HIS OWN WORDS

As an engineer, I like right angles, flat surfaces and round dimensions, and generative design says that may not be the best solution. And so, if I want to be the best possible engineer at my job, I look to generative design to find those kinds of solutions.

GENERATIVE APPROACH

- CO2 Exhaust Cover needed to shield from any direct micrometeoroid strike
- Periodic minimal surface structures provided guaranteed protection, ventilation, and additive manufacture
- Tortuous conventional geometry modeling becomes trivial with implicit geometry



PTC & TECHNION

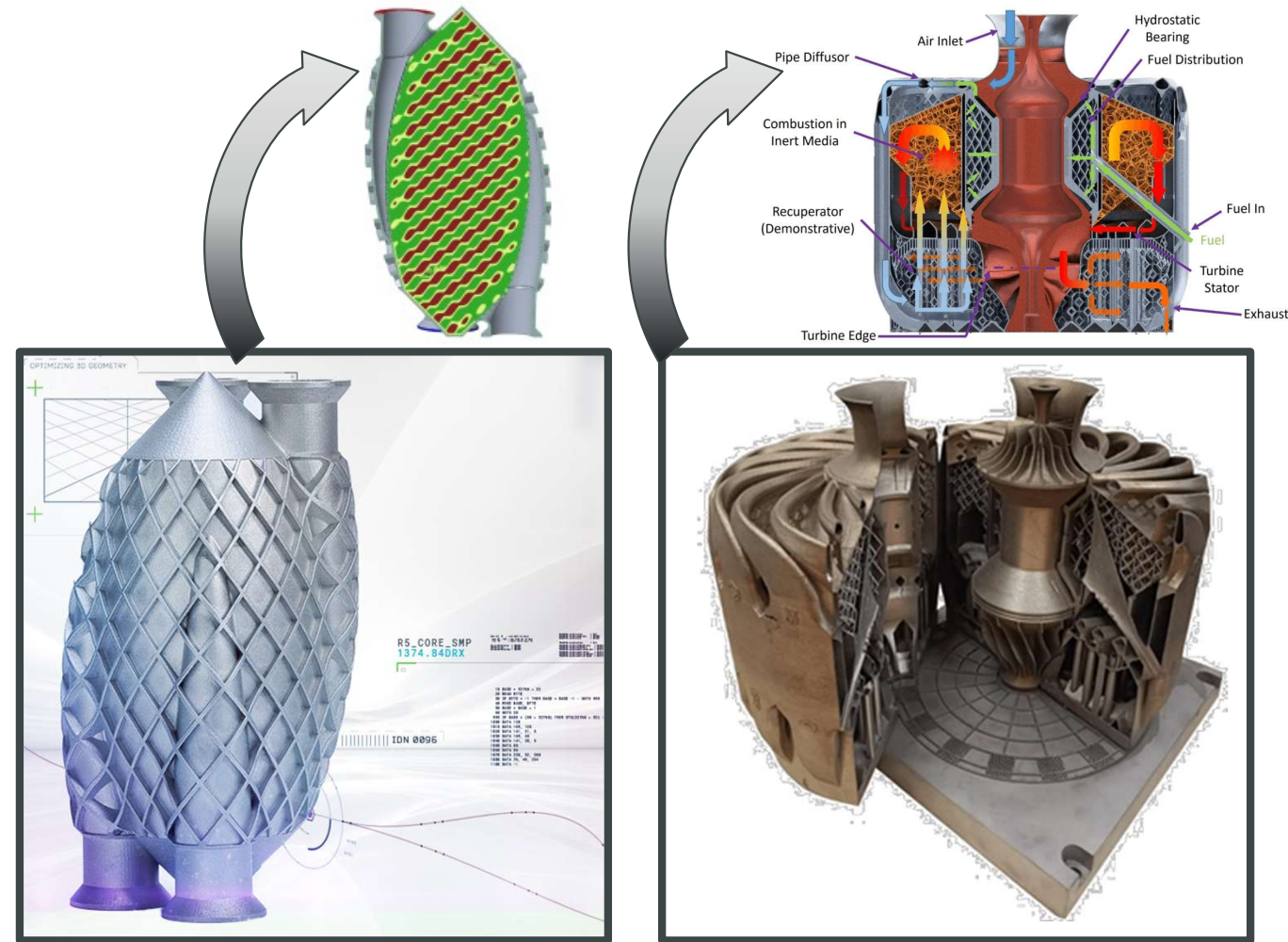
THERMAL AND AEROSPACE APPLICATIONS

GENERATIVE APPROACH

- Recognize that periodic minimal surface structures offer unprecedented heat transfer opportunity
- Recognize that lattice reinforcement could also serve as combustion chamber flame holder
- Leverage engineering insights and intuition with novel geometry

FURTHER ENHANCEMENTS

- Optimize using simulation-driven implicit field



JEFF OLSEN & HILLER MEASUREMENTS

HIGH VALUE CUSTOMIZATION – AT SCALE

IN HIS OWN WORDS

It's not your job to design the product anymore. Your job is to design the constraints and allow software to design.

Quite frankly, even though you may or may not like the generative design aesthetics, from a business perspective and engineer perspective, it makes more sense.

FURTHER ENHANCEMENTS

- Incorporate generative solutions in other areas of design, starting with component placement and wire routing
- Integrate directly to online customer sales funnel for near-instant





Q&A

THANK YOU!