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N-O-MAD Research Institute

NOMAD XIII FINAL PRESENTATION

Breaking Bats: Designing Dynamically Representative Baseball Bats Using Topology Optimization

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Rob Flicek (SNL), Nic Basore (KCSNC)

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

SAND2026-24726PE

OUR TEAM

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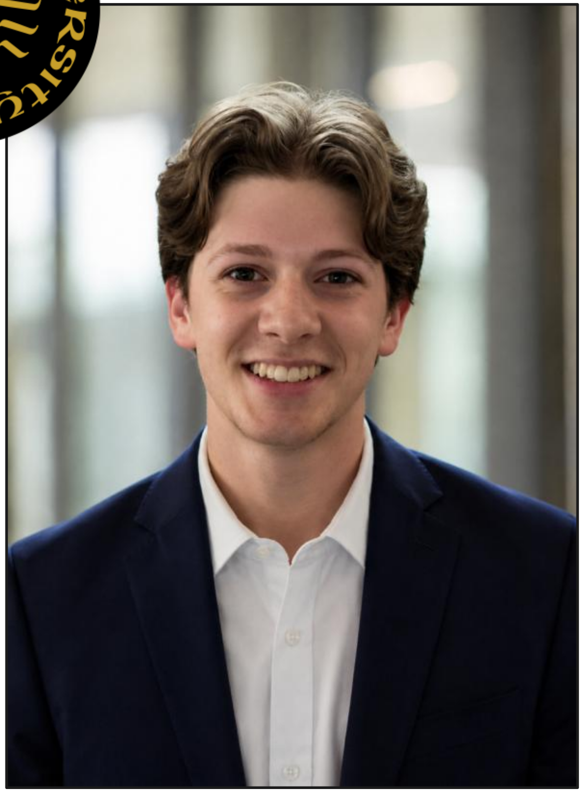
Mechanical Engineering Grad



Matthew Mueller

Purdue University

Mechanical Engineering Undergrad

AGENDA

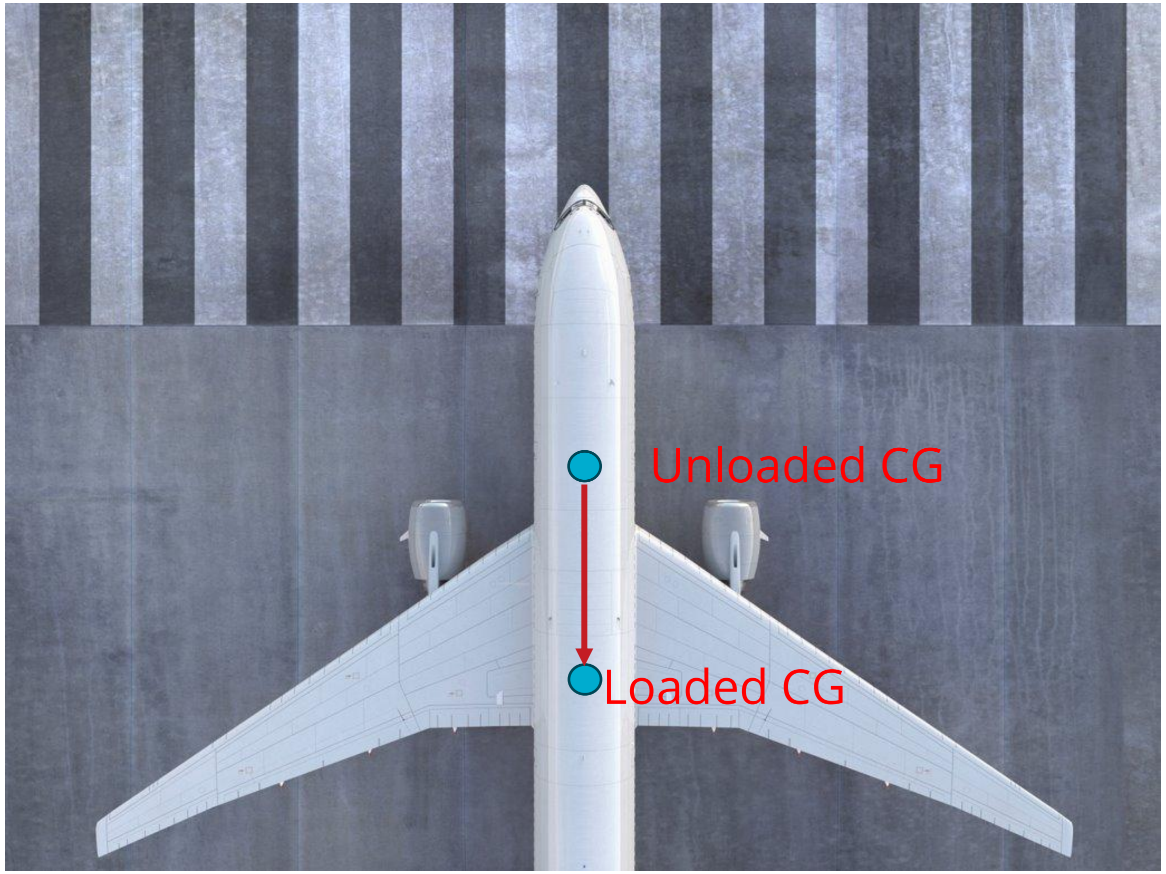
Background & Motivation

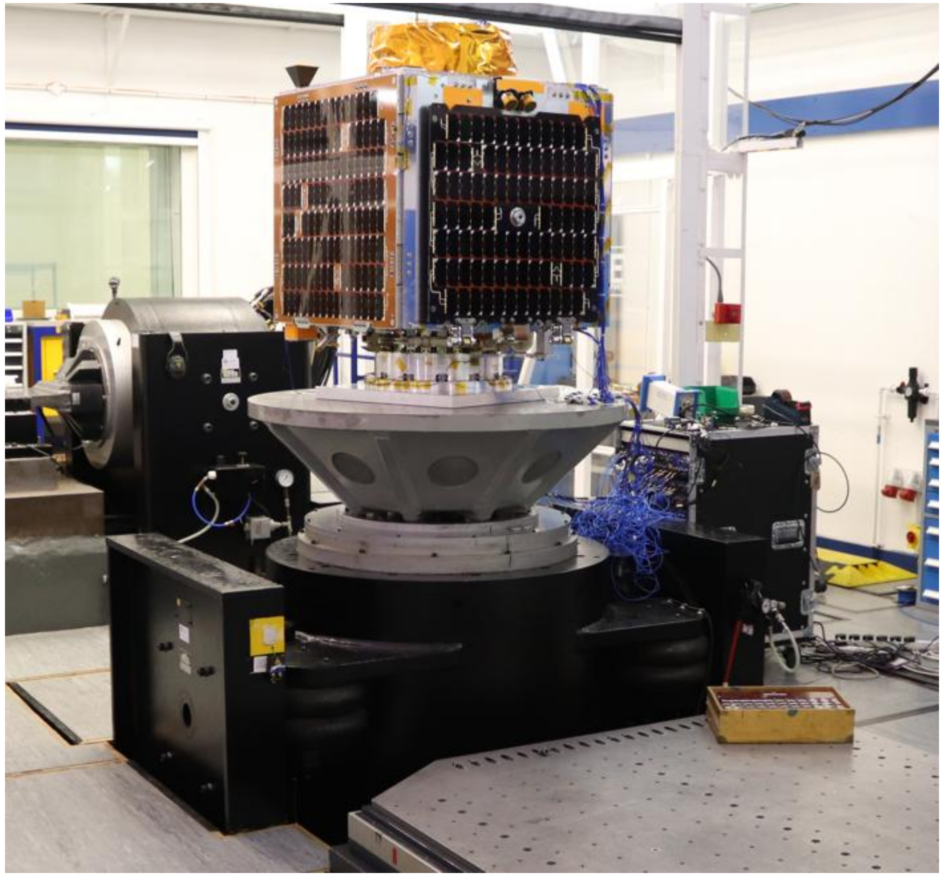
Evaluation of each bat design:

- Manufacturability
- Testing
- Modeling
- Optimization

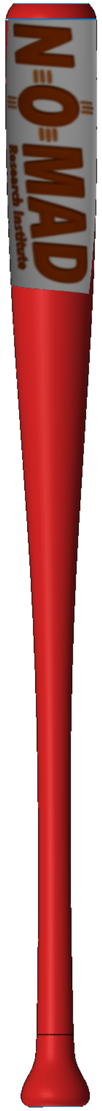
Conclusion

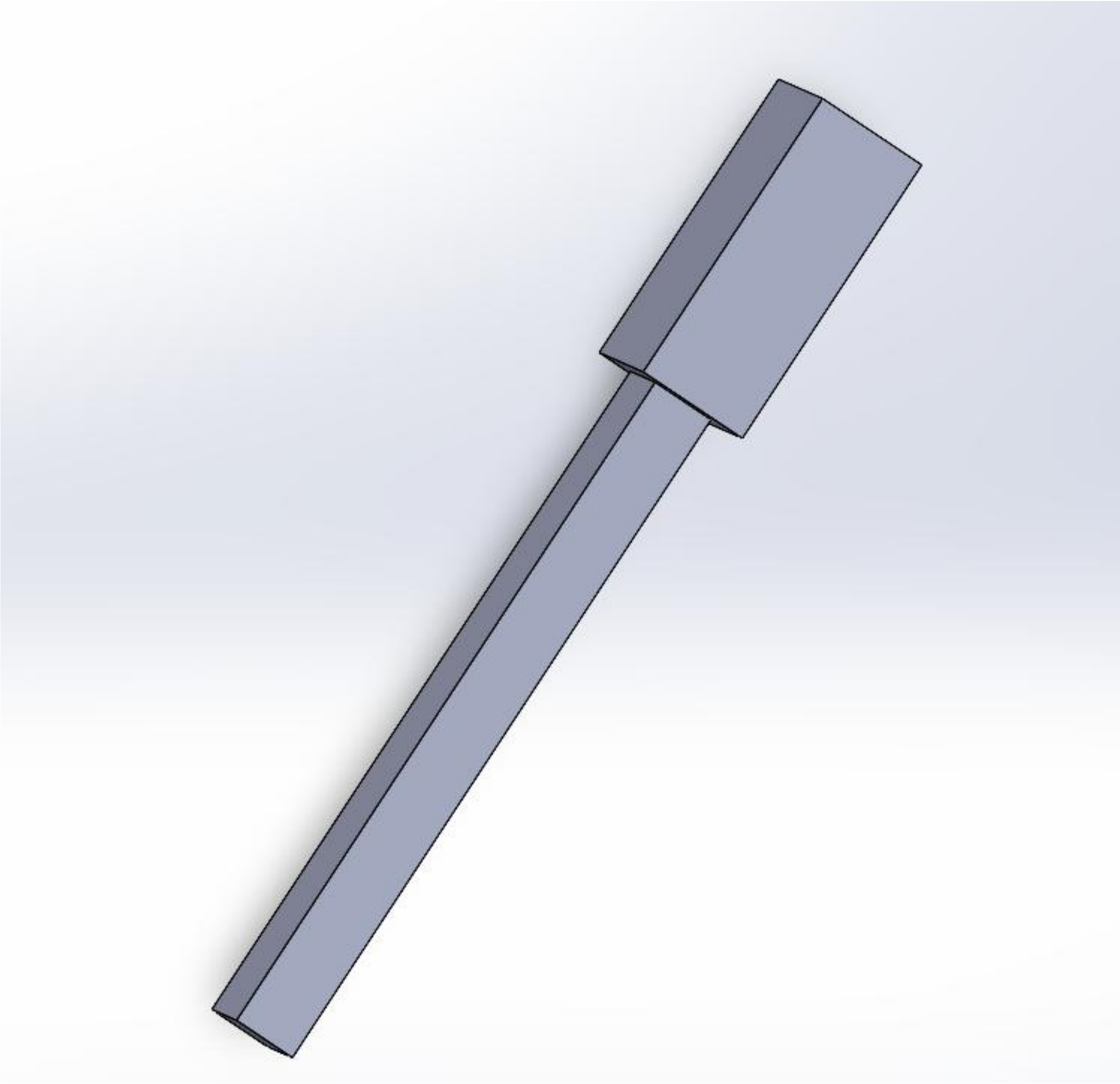
MOCK COMPONENTS ALLOW FOR REPRESENTATIVE DYNAMIC TESTING WHEN PARTS OF THE SYSTEM ARE UNAVAILABLE



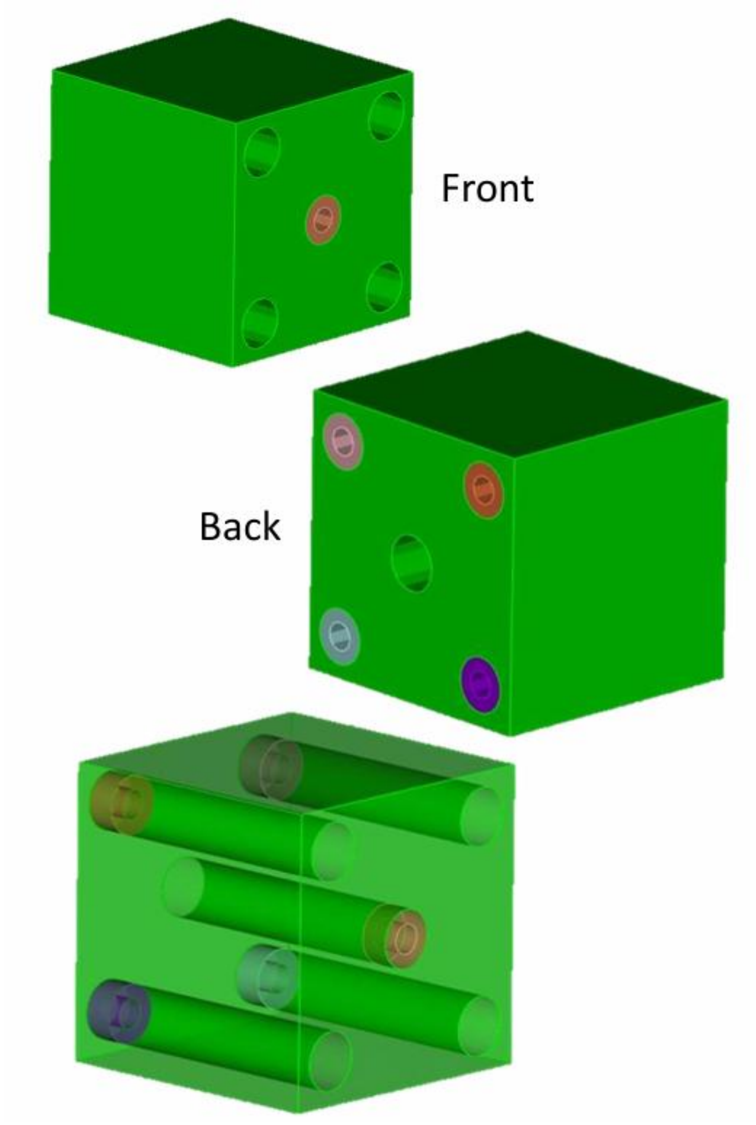


CURRENT STANDARD PRACTICE ONLY INCLUDES MATCHING THE CENTER OF GRAVITY AND MASS





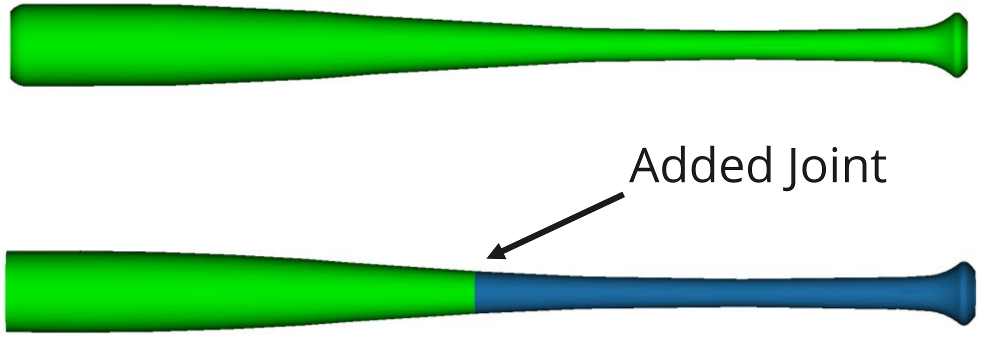
PLATO TOPOLOGY OPTIMIZATION SOFTWARE ENABLES THE DEVELOPMENT OF PROPERTY MATCHED MOCK COMPONENTS

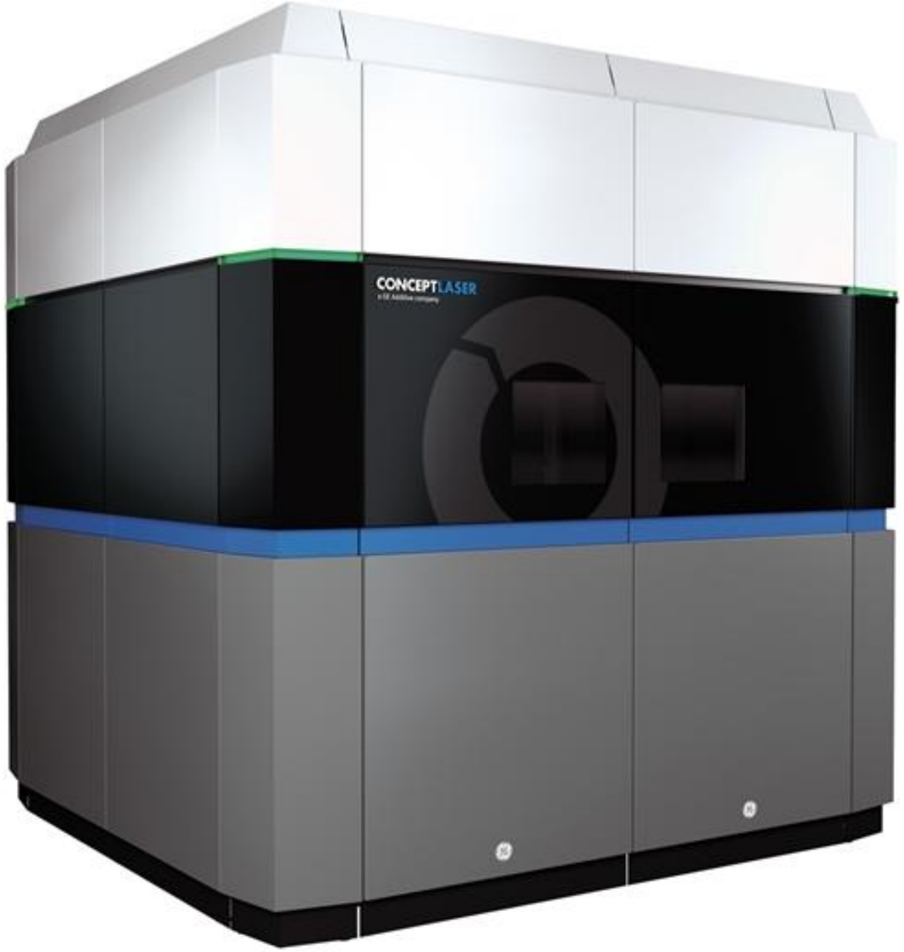


- Define **fixed** and **optimizable** regions
- Define **loads** and **boundary conditions**
- Define optimization **constraints** and **objective**(s)

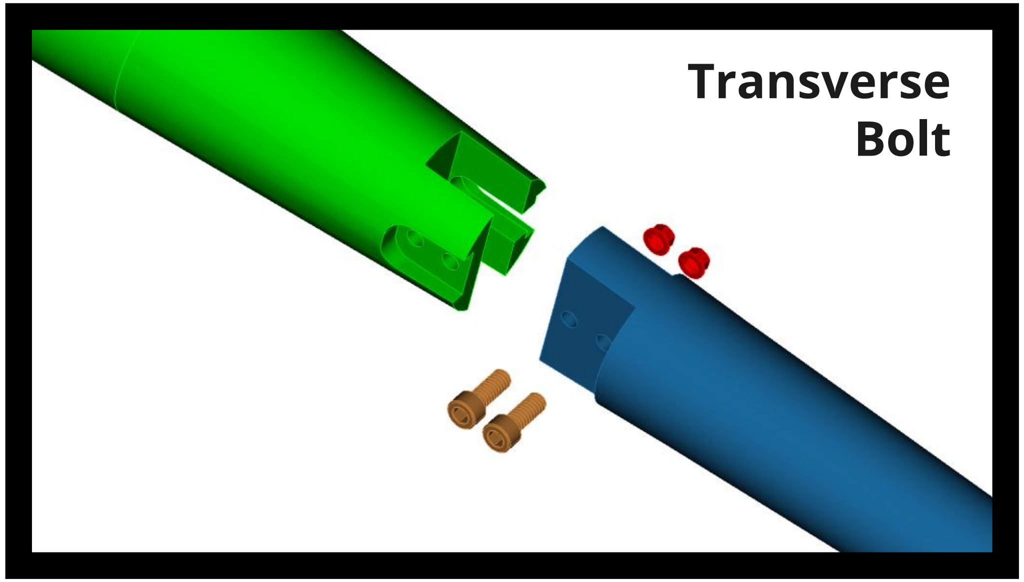
WHILE ADDITIVE MANUFACTURING IS THE STANDARD FOR TOPOLOGY OPTIMIZED PARTS, IT ALSO INTRODUCES LIMITATIONS

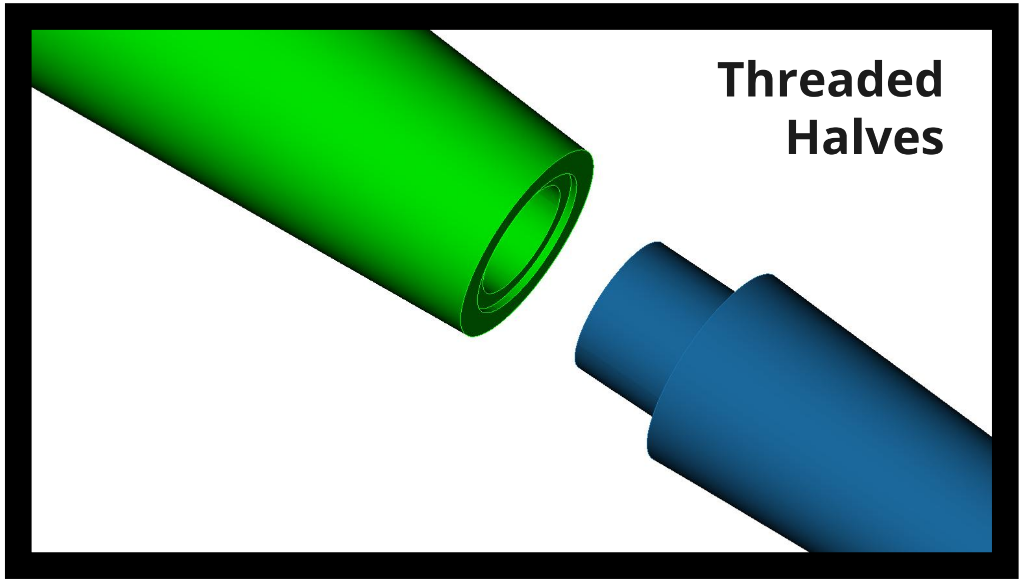
- Thin walls
- Surface finish
- Overhang Geometry
- Build Size

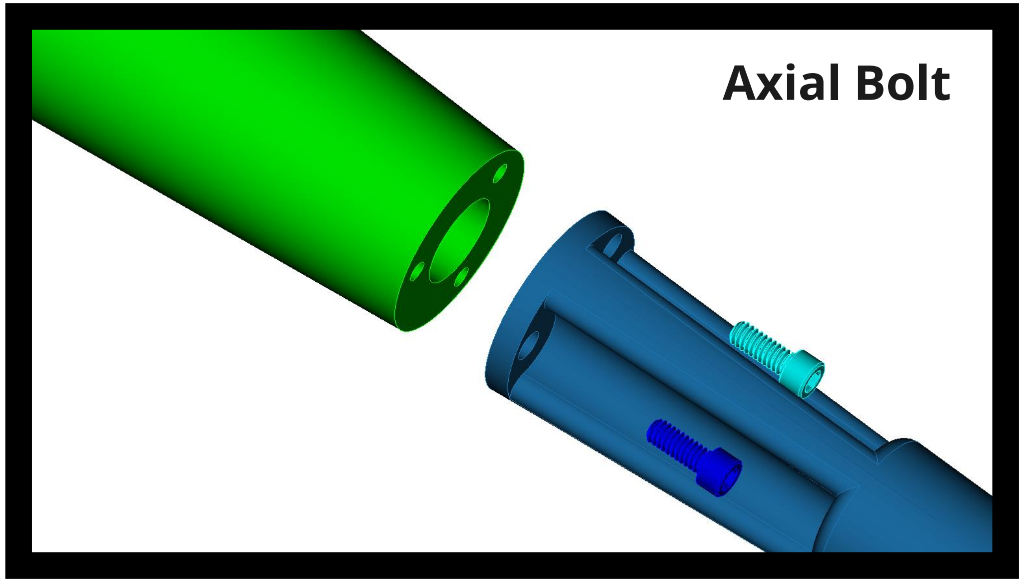


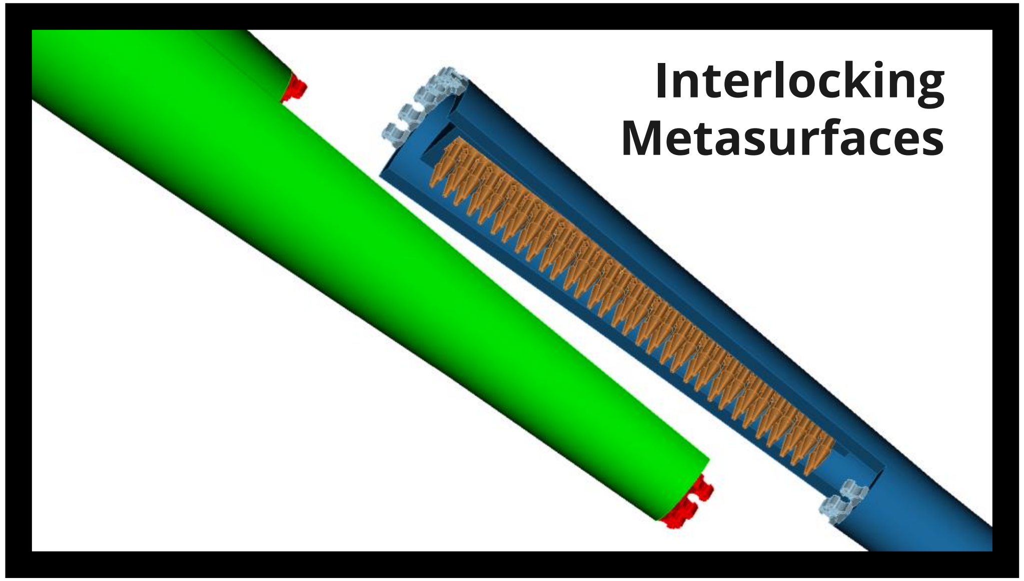


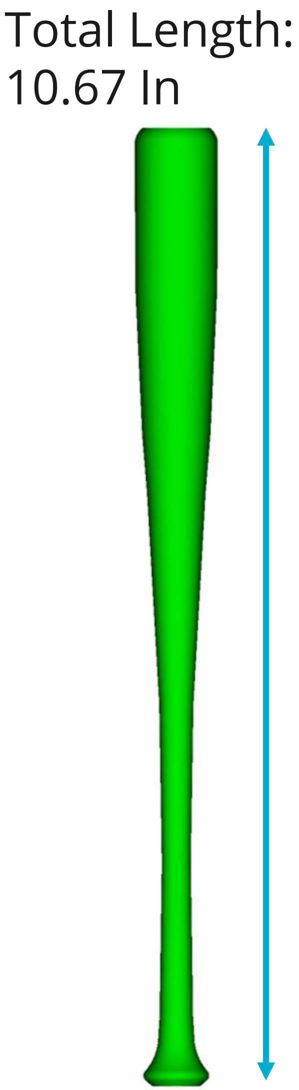
PROJECT GOAL: OPTIMIZE FOUR STYLES OF JOINTED BATS TO MATCH TARGET DATA FROM A MONOLITHIC BAT











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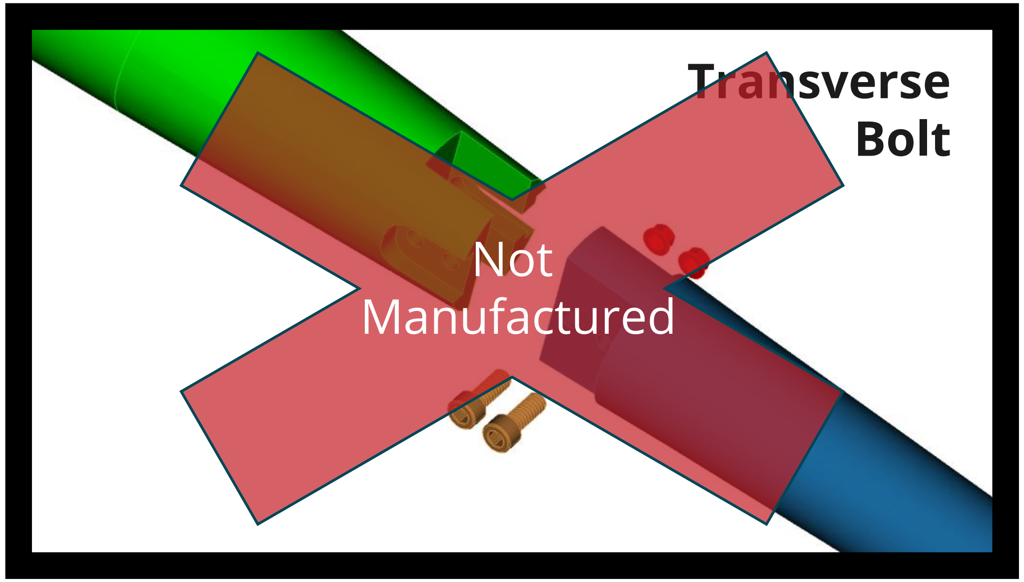
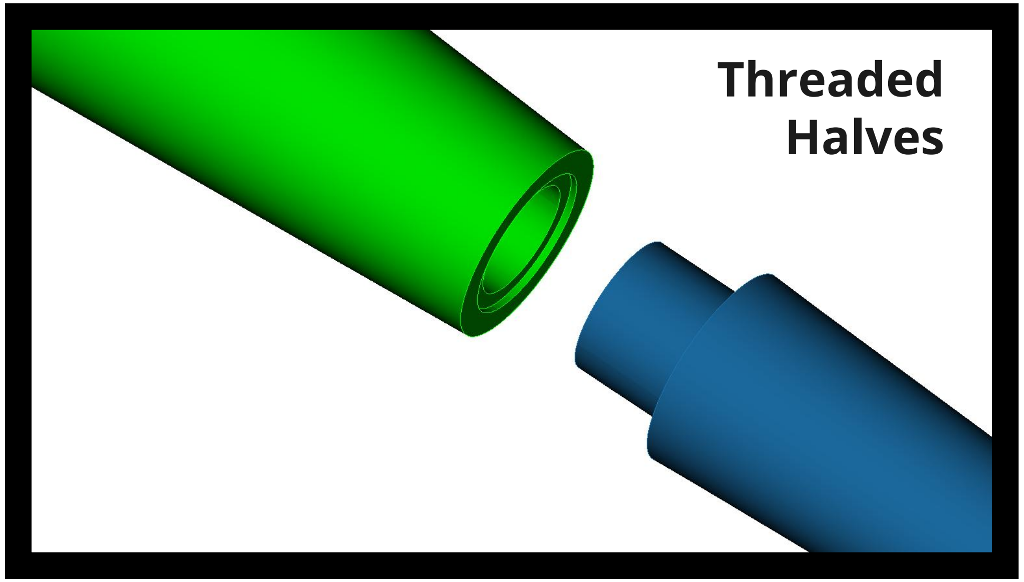
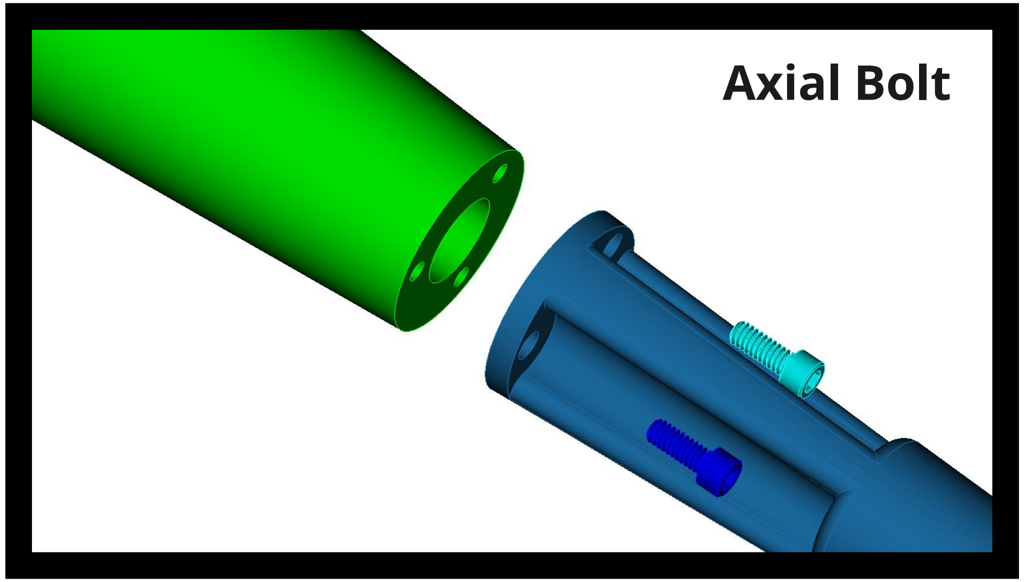
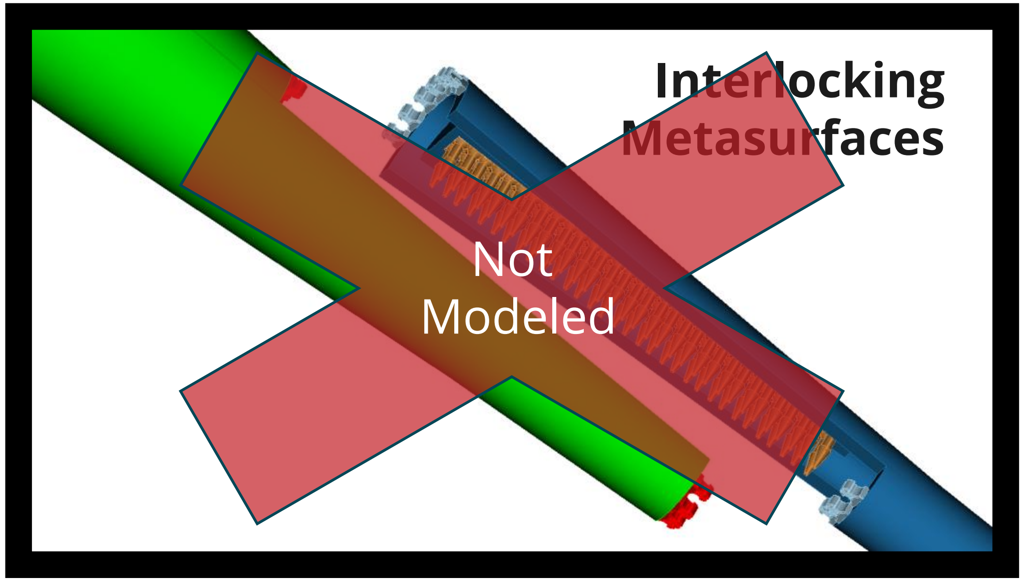
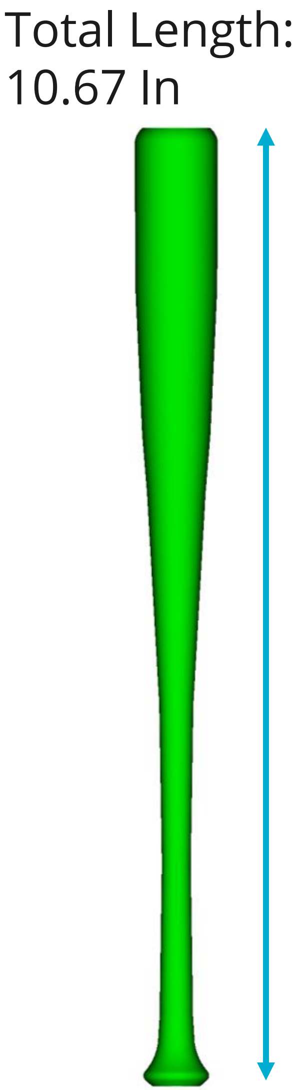










AGENDA

Background & Motivation

Evaluation of each bat design:

- Manufacturability **<<<<**
- Testing
- Modeling
- Optimization

Conclusion

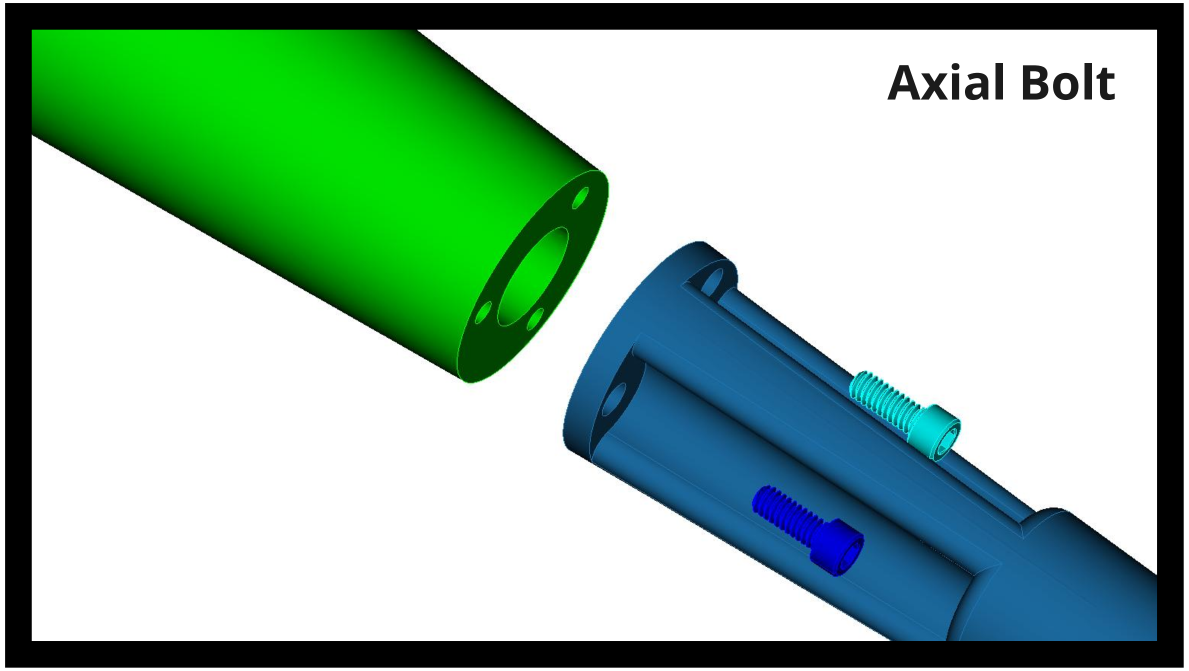
IDEAL MOCK COMPONENT REQUIRES MINIMAL POST-PROCESSING

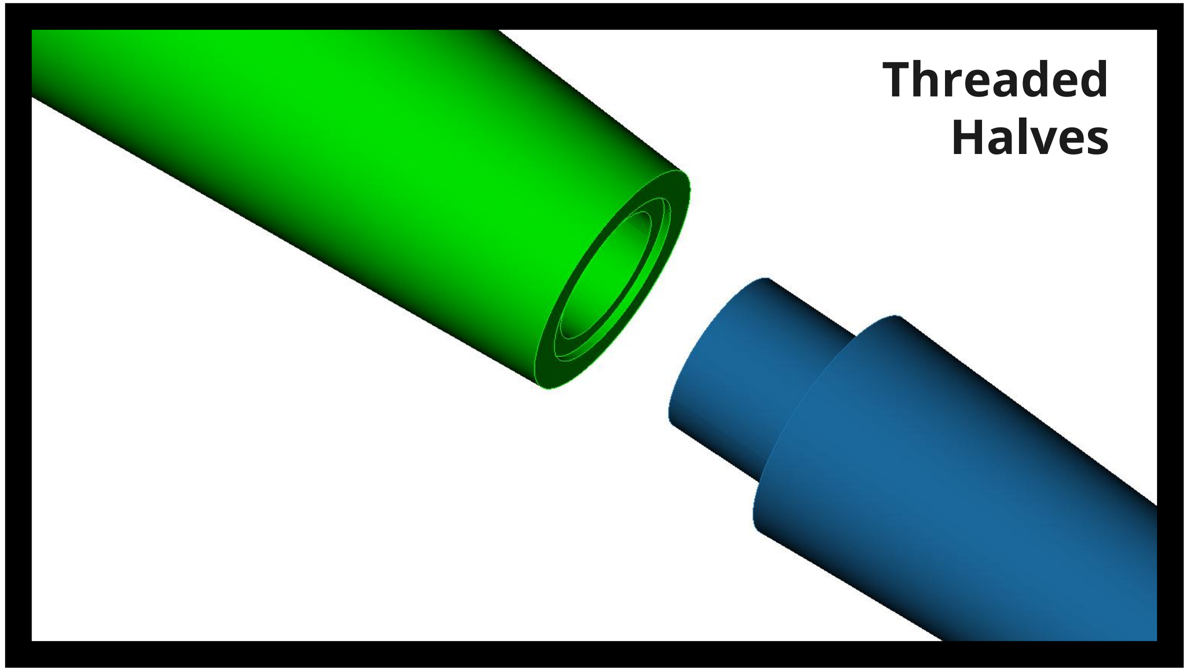
Axial Bolted Joint

- Required tapping of the 3 screw holes
- Machining the contact surface preferred
- Tiny bolts/threads created an issue
- Tapping could be avoided by including insets for nuts on the other side

Threaded Halves

- Both halves need to be threaded/tapped
- Machining the contact surface preferred
- Clocking becomes an issue for non-axisymmetric parts





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Evaluation of each bat design:

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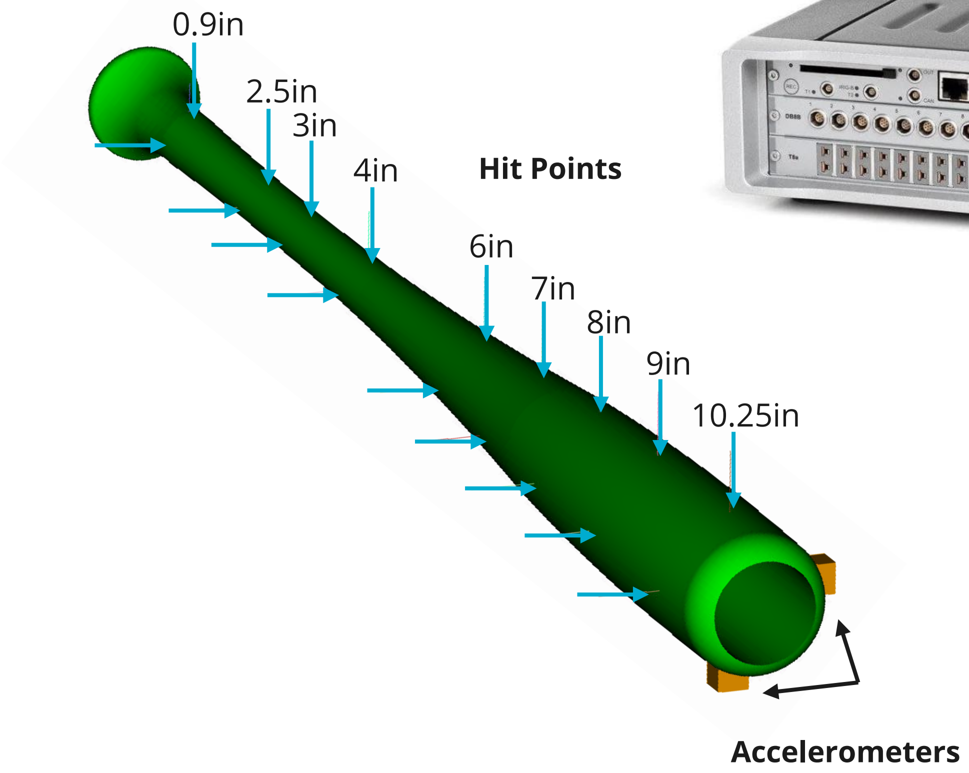
Conclusion

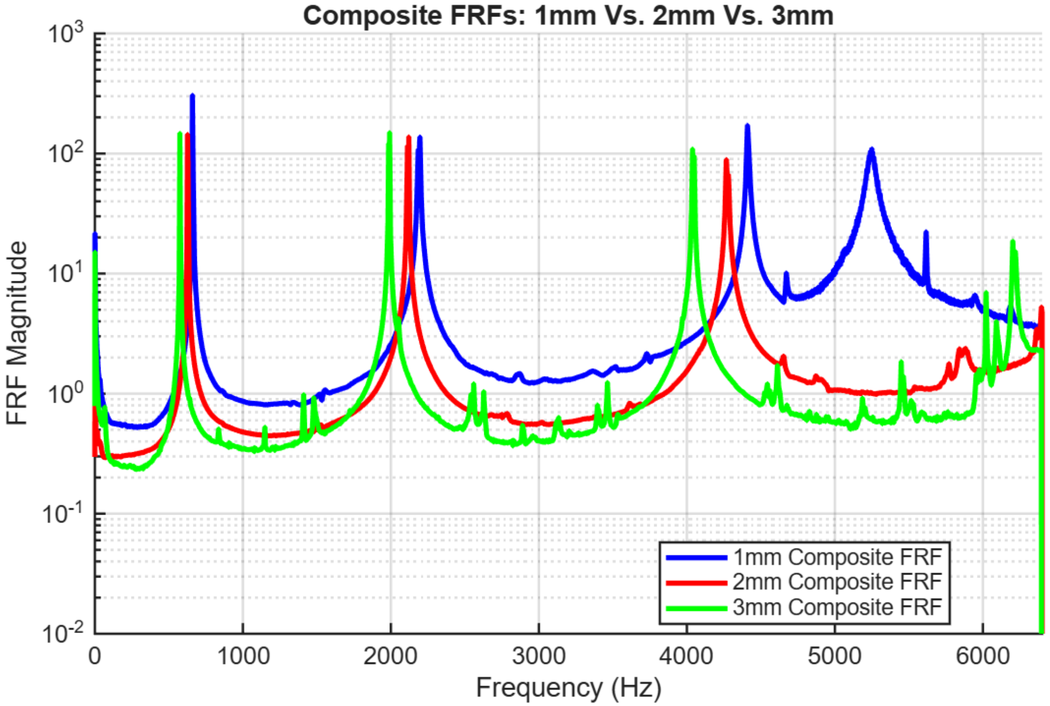
MODAL IMPACT HAMMER TESTING WAS USED TO CHARACTERIZE THE BEHAVIOR OF EACH BAT

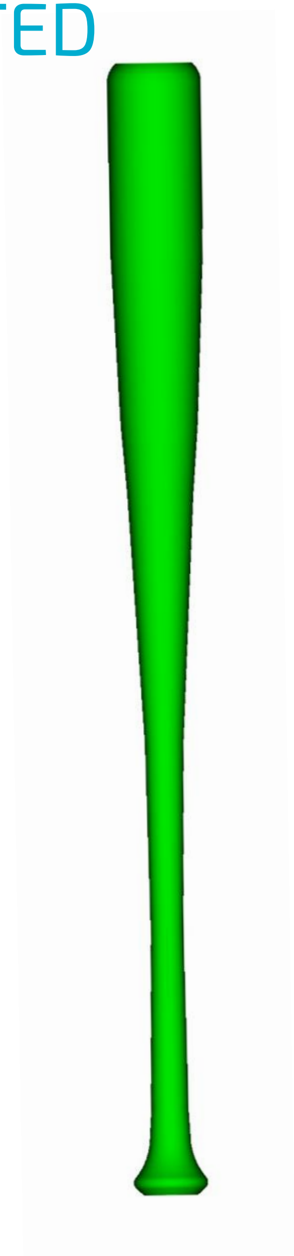
- Siemens Impact Testing Software
- Two Accelerometers 90° from each other
- 18 Hit Points, two rows 90° apart
- Modal Hammer, Metal tip



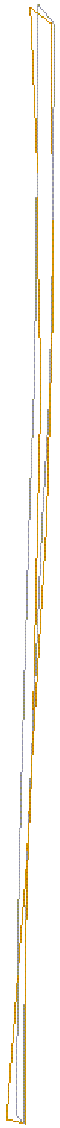
MONOLITHIC BAT DATA WAS COLLECTED

Bat Thickness	1st Bending Modes
2mm	625, 629
3mm	574, 576

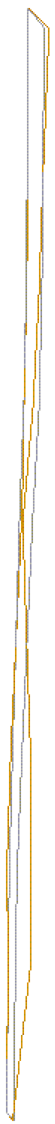




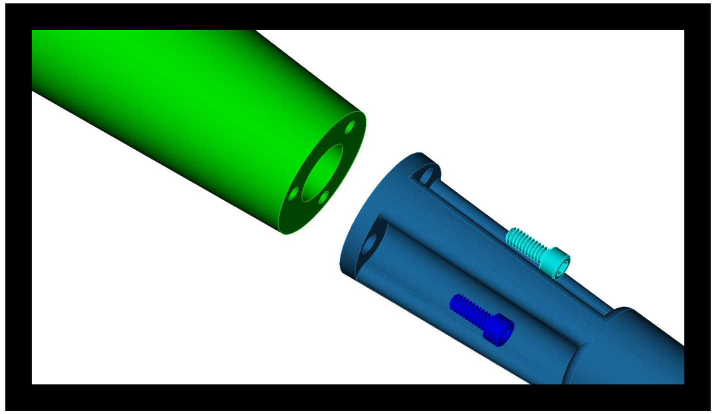
1st Bending Mode

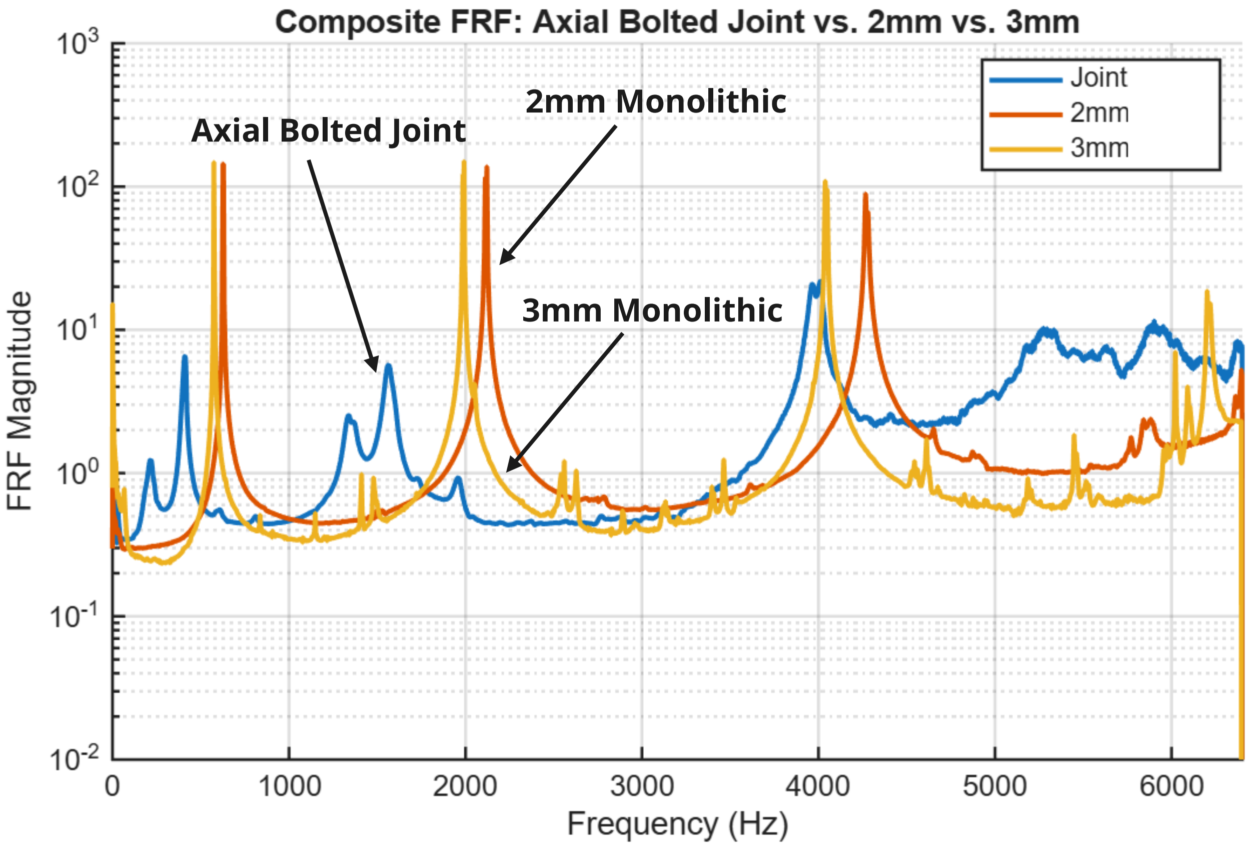


2nd Bending Mode



STRIPPED THREADS COMPLICATED TESTING OF AXIAL BOLT BAT

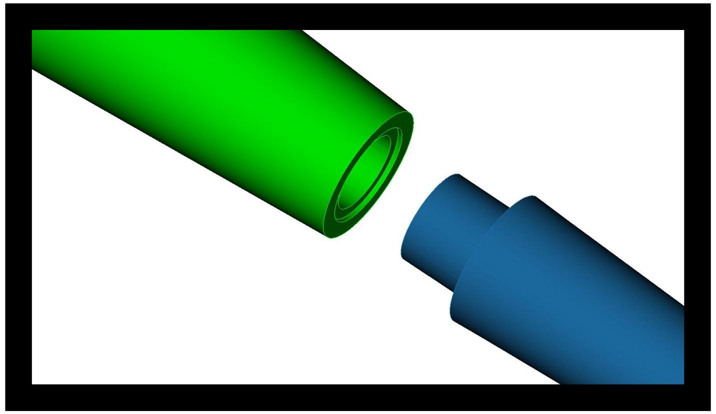


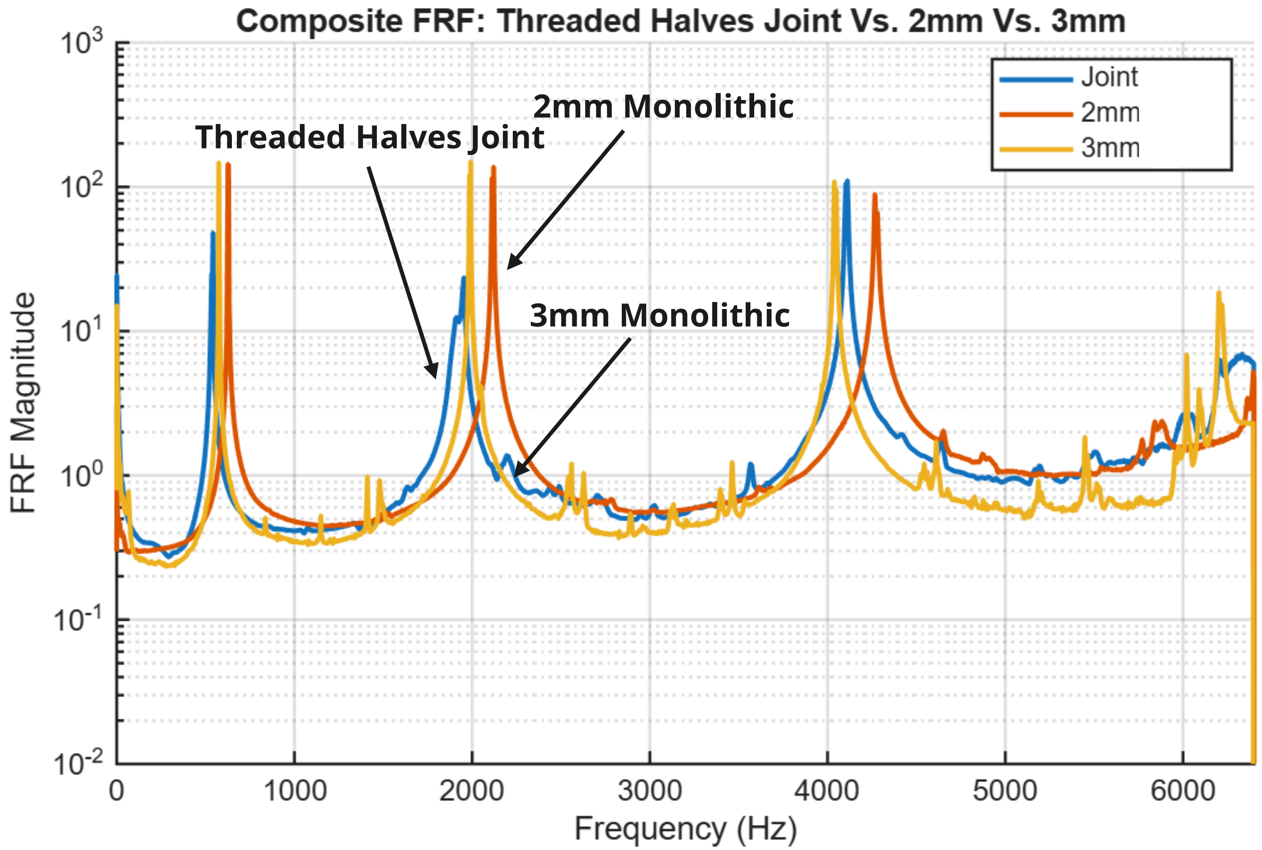


1st Bending Mode

Bat	1st Bending Modes
2mm Monolithic	625, 629
3mm Monolithic	574, 576
Axial Bolted Joint	212, 407

THREADED HALVES BAT HAD SIMILAR FREQUENCIES TO MONOLITHIC BATS





1st Bending Mode

Bat	1st Bending Modes
2mm Monolithic	625, 629
3mm Monolithic	574, 576
Threaded Halves Joint	532, 541

AGENDA

Background & Motivation

Evaluation of each bat design:

- Manufacturability
- Testing
- Modeling **<<<<**
- Optimization

Conclusion

MONOLITHIC BAT MODELED WITH TET ELEMENTS AND STOCK STEEL PROPERTIES

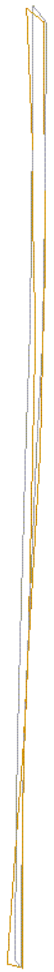
Stock Steel Properties:

$E = 2.97e7$ psi

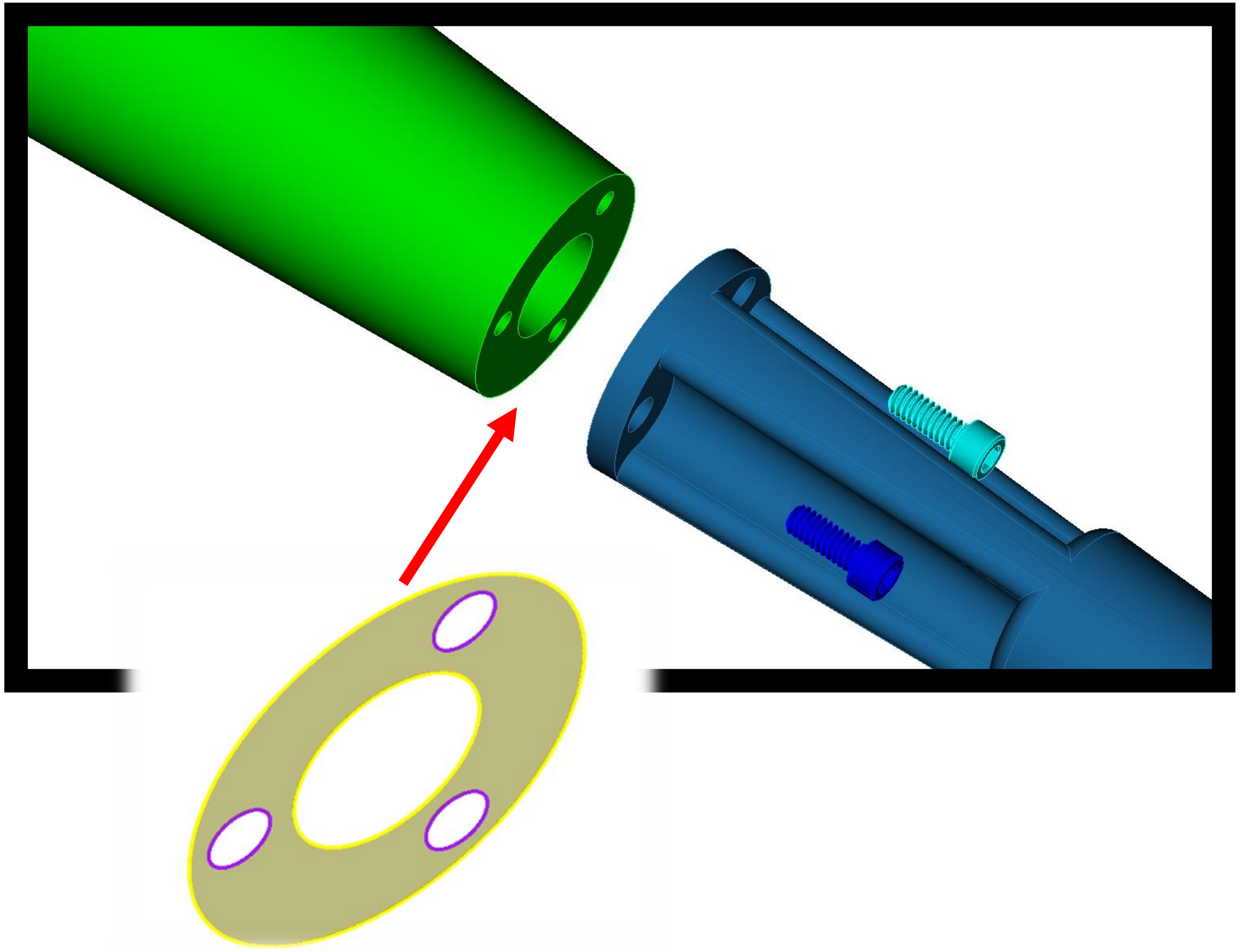
$\nu = 0.3$

$\rho = .284\ lb/in^3$

	1st Bending Modes	
Bat Thickness	**Finite Element**	**Experiment**
2mm	624, 624	626, 630
3mm	560, 560	574, 577



THE AXIAL BOLT MODEL WITH A RING OF CONTACT FOR EACH BOLT WAS SELECTED



Soft Vs. Stiff

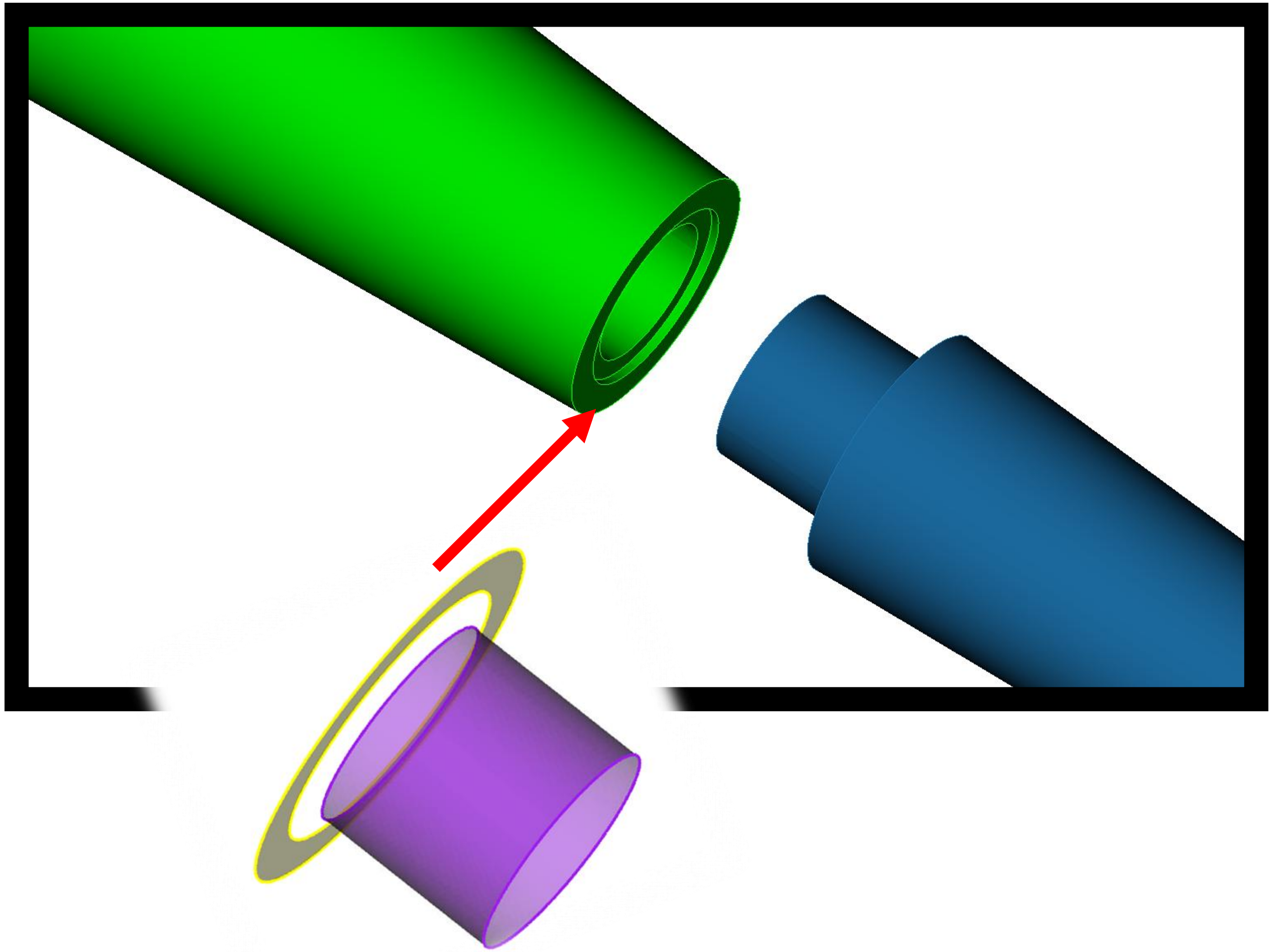
- Removed bolts
- Compared contact at just purple rings vs. entire yellow surface

Model	1st Bending (Hz)
Soft (rings)	469
Stiff (surface)	528

Two Bolt Model – two rings of contact

Model	Mode 1 (Hz)
Finite Element	233, 459
Test	212, 407

THE THREADED HALVES MODEL WITH ONLY CONTACT AT THE THREADS WAS SELECTED



Soft Vs. Stiff

- Threads were defeatured
- Compared contact at just purple surface vs. purple and yellow surface

Model	1st Bending (Hz)
Soft	541
Stiff	573
Test	536, 543

AGENDA

Background & Motivation

Evaluation of each bat design:

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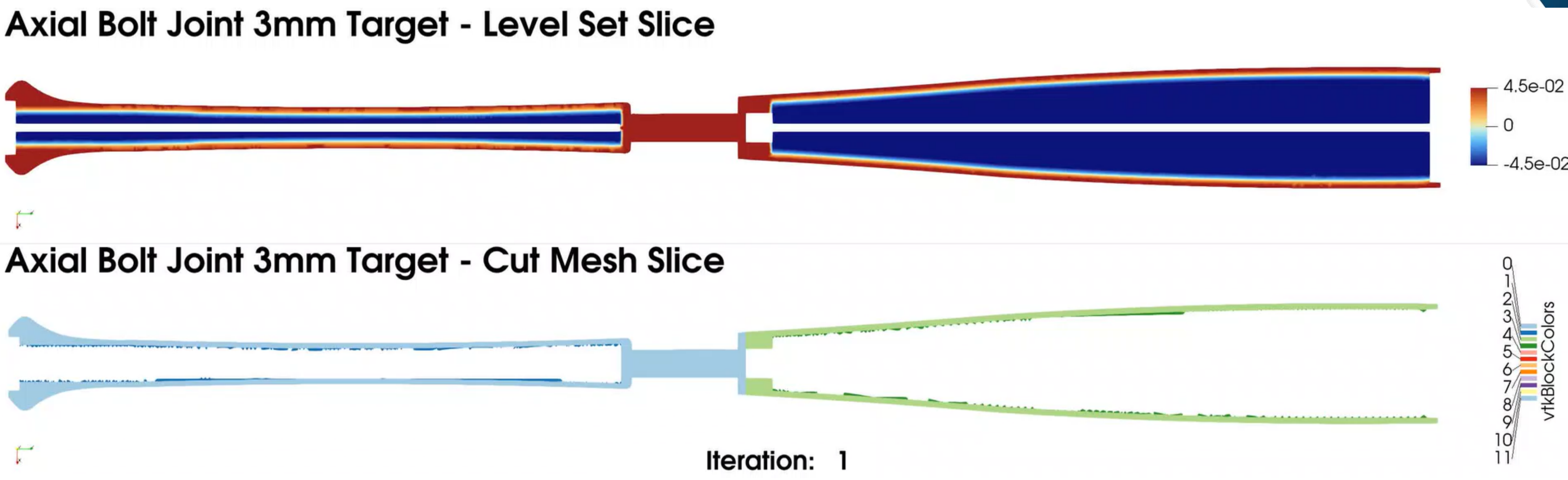
Conclusion

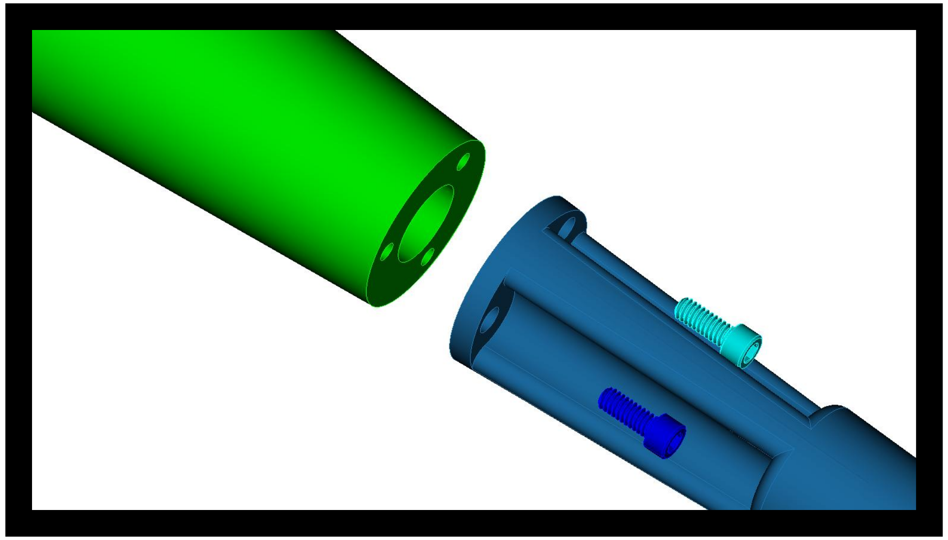
PLATO EDITS THE OPTIMIZABLE REGION TO MATCH MASS, CENTER OF GRAVITY, AND MODAL OBJECTIVES



- Handle – Fixed Region
- Handle – Optimizable Region
- Barrel – Fixed Region
- Barrel – Optimizable Region

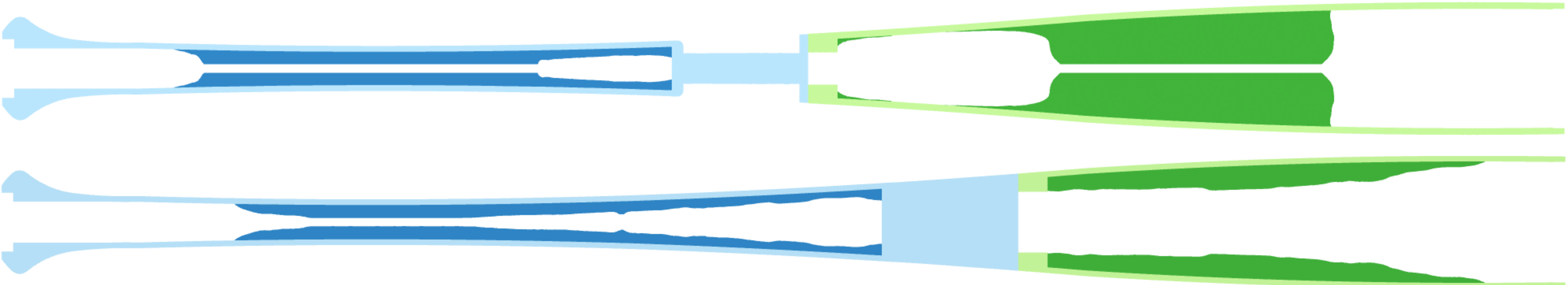
THE AXIAL BOLT MODEL COULD NOT STIFFEN ENOUGH TO MATCH THE TARGET DATA

Bat	1st Bending Modes (Hz)
3mm Target	561
Original Axial Bolt	468
Optimized Axial Bolt	495



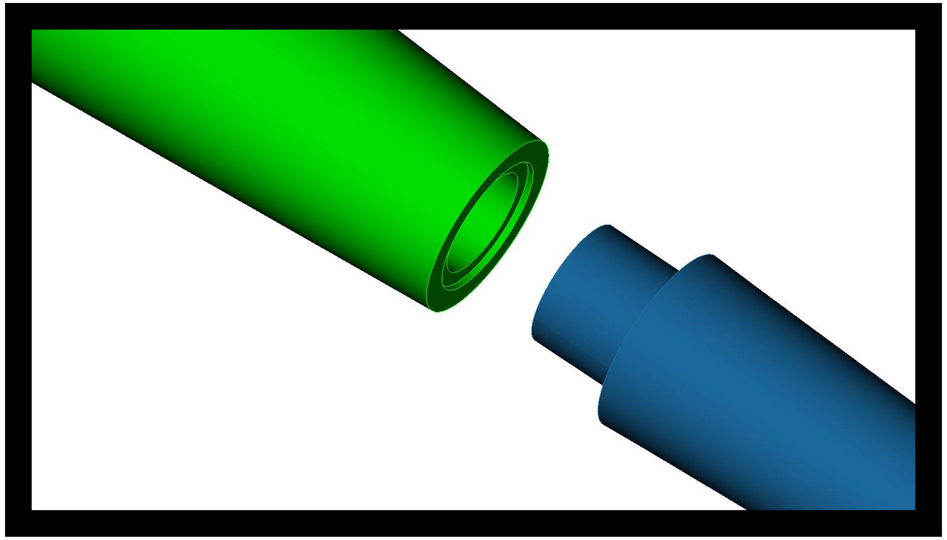
BY MOVING THE JOINT, THE OPTIMIZATION WAS ENABLED TO REACH ITS TARGETS

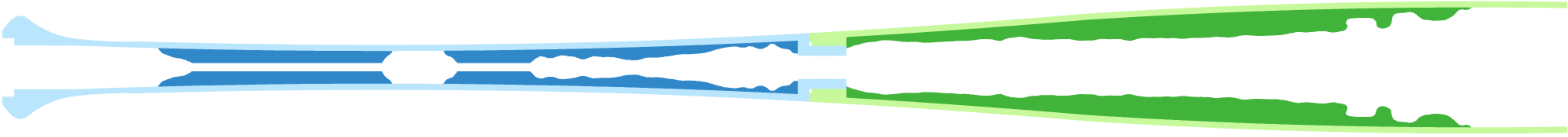
Bat	1^{st} Bending Modes (Hz)
3mm Target	561
Original Axial Bolt	468
Moved Axial Bolt	529
Optimized Moved Axial Bolt	561



THE THREADED HALVES JOINT OPTIMIZED WELL GIVEN ITS SMALL FOOTPRINT AND STIFFNESS

Bat	1st Bending Modes (Hz)
3mm Target	561
Original Threaded Halves	541
Optimized Threaded Halves	561

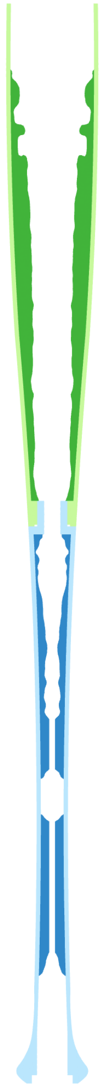




THE PRINTED TOPOLOGY OPTIMIZED BAT VALIDATED OUR DESIGN APPROACH

- Big thanks to CAMINO for getting this to us so quickly!
- Some asymmetry in the print split the 1st bending modes
- The average frequency is 559.6 Hz!

	1st Bending Mode (Hz)
Target Data	561, 561
Optimized Bat Test	545, 573



AGENDA

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Evaluation of each bat design:

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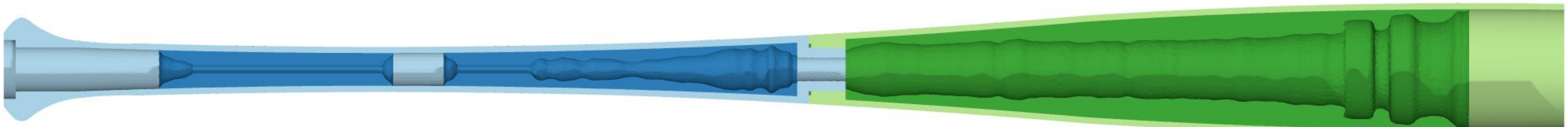
Conclusion

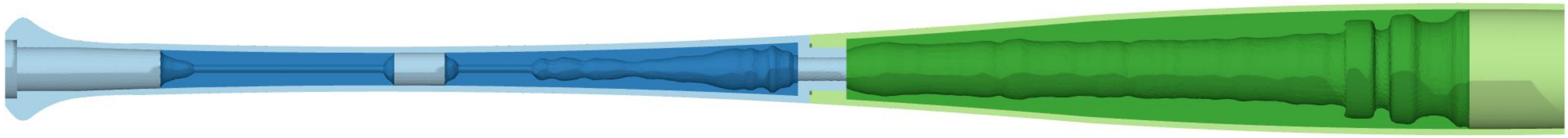
SUMMARY

1. Assessed two jointed bats: Threaded Halves and Axial Bolt
2. Noted challenges with additively manufacturing the jointed bats
3. Experimentally measured vibration modes
4. Calibrated structural dynamic models to match testing data.
5. Generated improved bat designs that matched the dynamic behavior of the 3mm monolithic bat using plato for topology optimization.
6. Printed and experimentally validated an optimized baseball bat design



FUTURE WORK

- Fix scaling issue on the axial bolts model to improve manufacturability
- Print the transverse bolt concept
- Find a better model for the interlocking metasurfaces style joint
- Attempt to optimize the bat to additional modal frequencies
- Attempt to optimize the bat to mode shapes as well



ACKNOWLEDGEMENTS

- This research was conducted at the 2026 Nonlinear Mechanics and Dynamics Research Institute hosted by Sandia National Laboratories and the University of New Mexico.
- We would like to acknowledge the support from Chris Sensor at Siemens for providing software licenses and support for the NOMAD laboratories.
- Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.
- Huge thank you to our mentors that helped us throughout NOMAD to successfully reach positive results!
- Thank you to CAMINO for their responsiveness in printing our jointed bats!