



Development of Pericyclic Gearbox for Roving Application

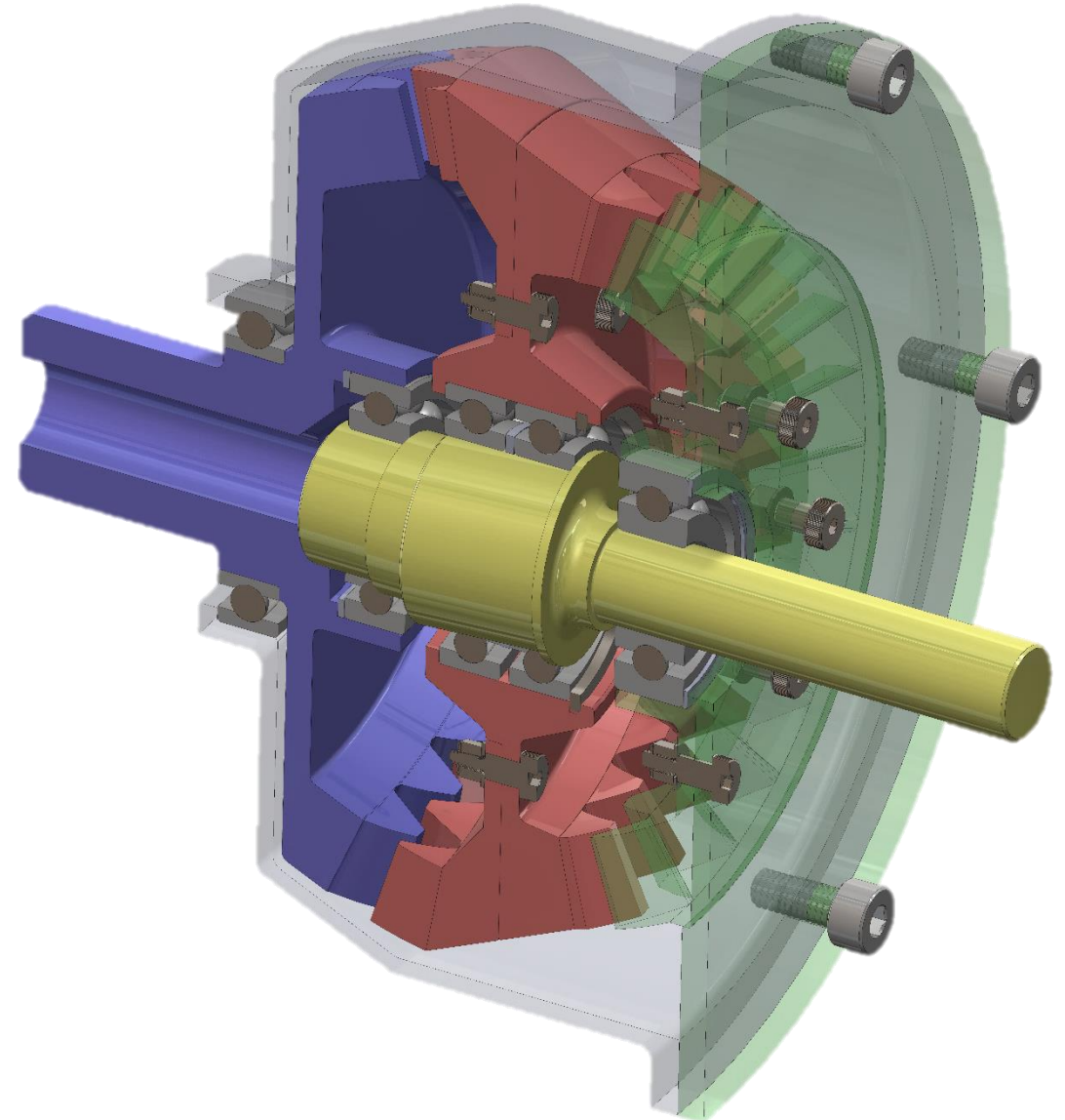
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Zachary Cameron

NASA Glenn Research Center
Materials and Structures Division
Rotating and Drive Systems Branch

Outline

- Background & Motivation
- Design Tool Development
- Prototype Fabrication
- Conclusions
- Future Work

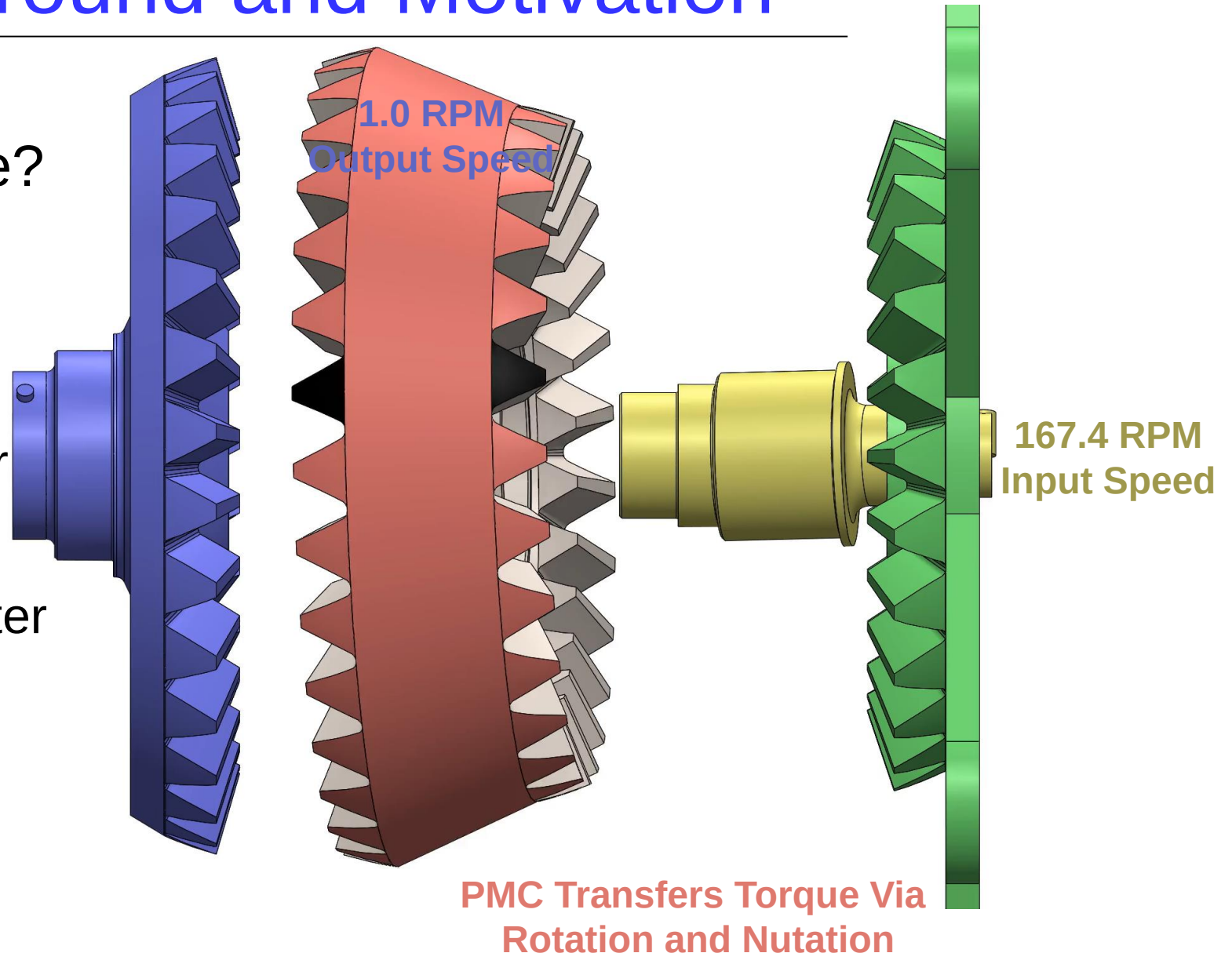


Background and Motivation

What is a Pericyclic Drive?

Four Main Components:

1. Input Shaft - Yellow
2. Reaction Control Member (RCM) Gear - Green
3. Pericyclic Motion Converter (PMC) Gear - Red
4. Output Gear - Blue

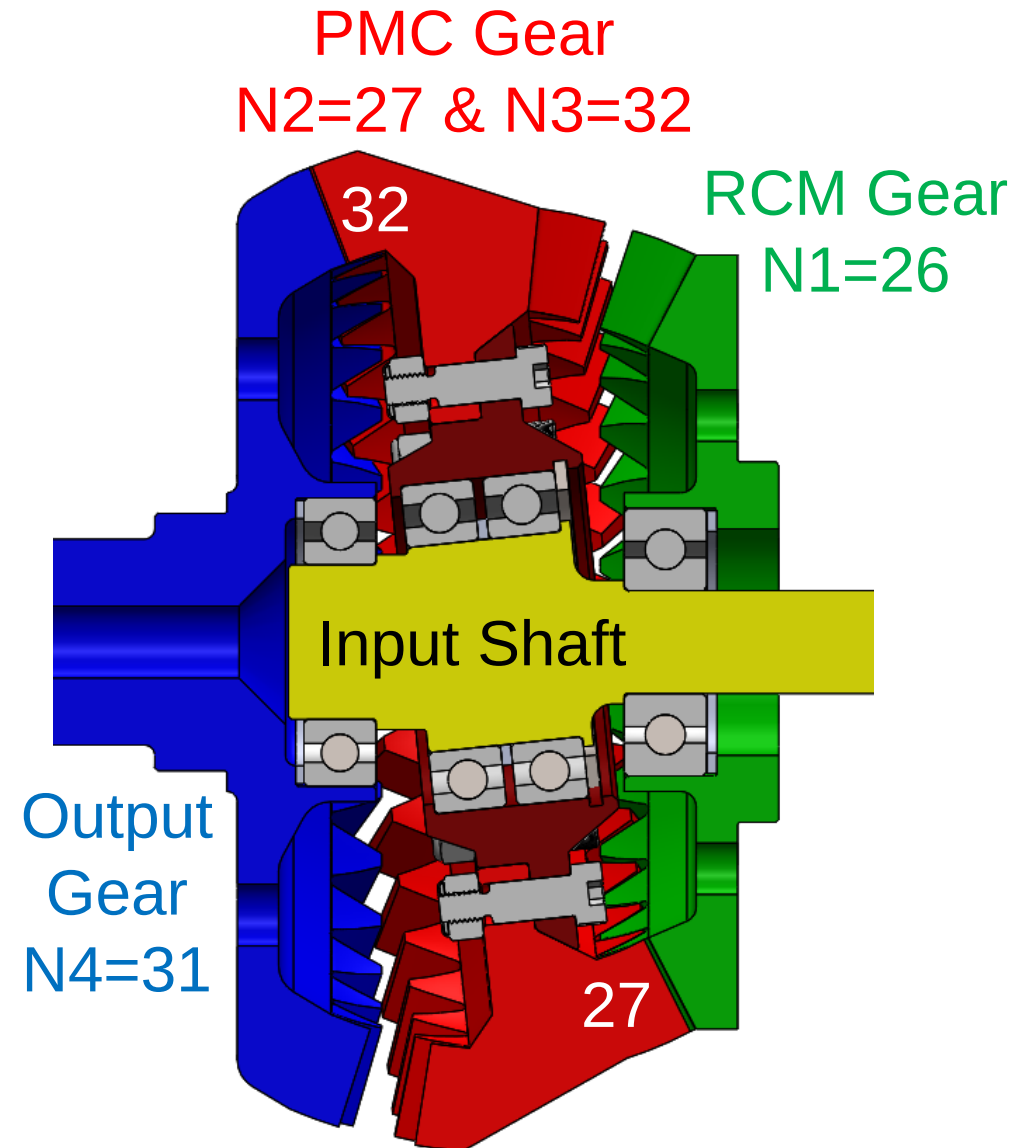


Background and Motivation

The pericyclic drive's kinematics enables high reduction ratios with low tooth number differences

$$\frac{\omega_{in}}{\omega_{out}} = \frac{1}{\left(1 - \frac{N1}{N2} * \frac{N3}{N4}\right)}$$

Few gear drives can offer very high ratios with as compact form and as low total part count

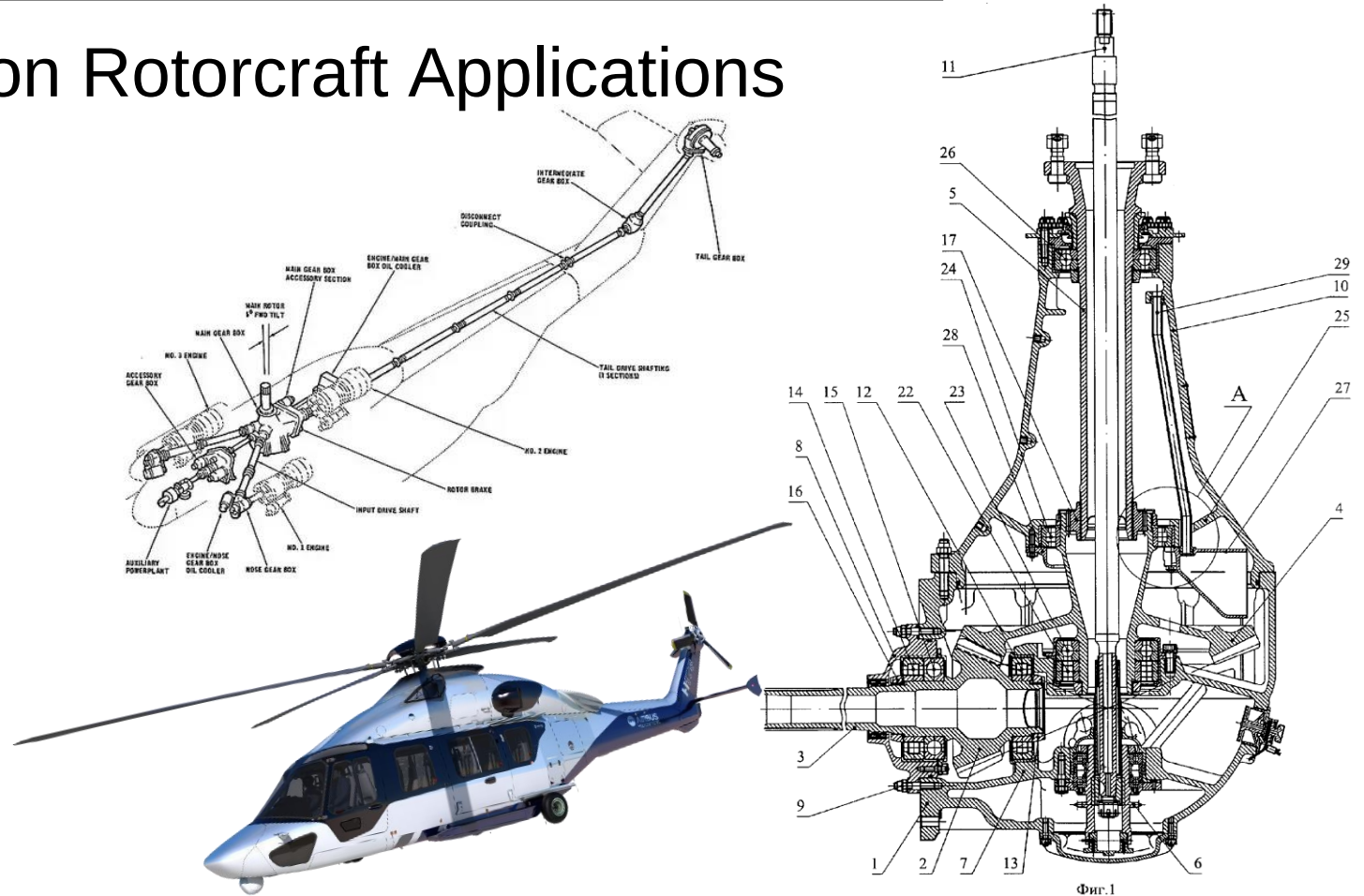


Background and Motivation

Previous Work Focused on Rotorcraft Applications

Benefits:

- Reduce total gear stages
- Reduce weight
- Decrease gear noise
- Improve reliability

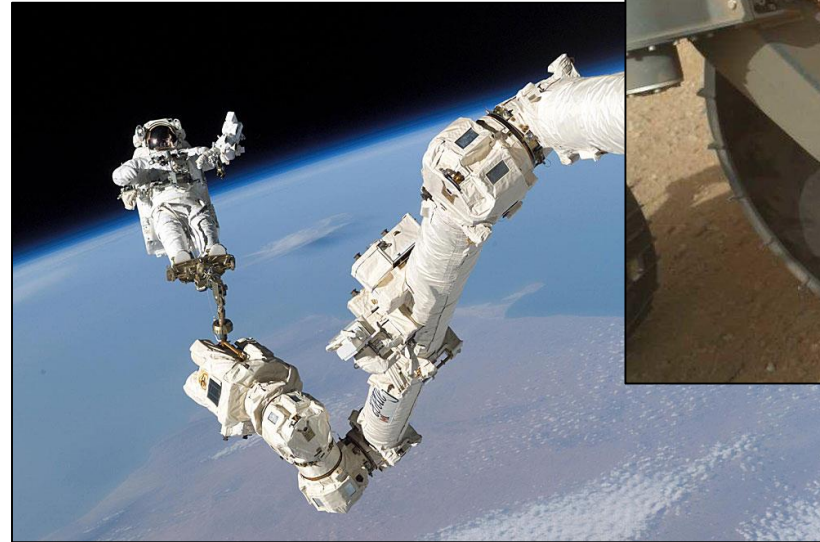


In this design space, **high speeds** and **high inertias** generate **high gyroscopic loads**, resulting in **excessive bearing loading**

Background and Motivation

Low Power, High Reduction Ratio Applications

- Rover Wheel Actuators
- Robotic Arms
- Antenna/Solar Gimbals
- Aerospace Actuators
- Winch Devices



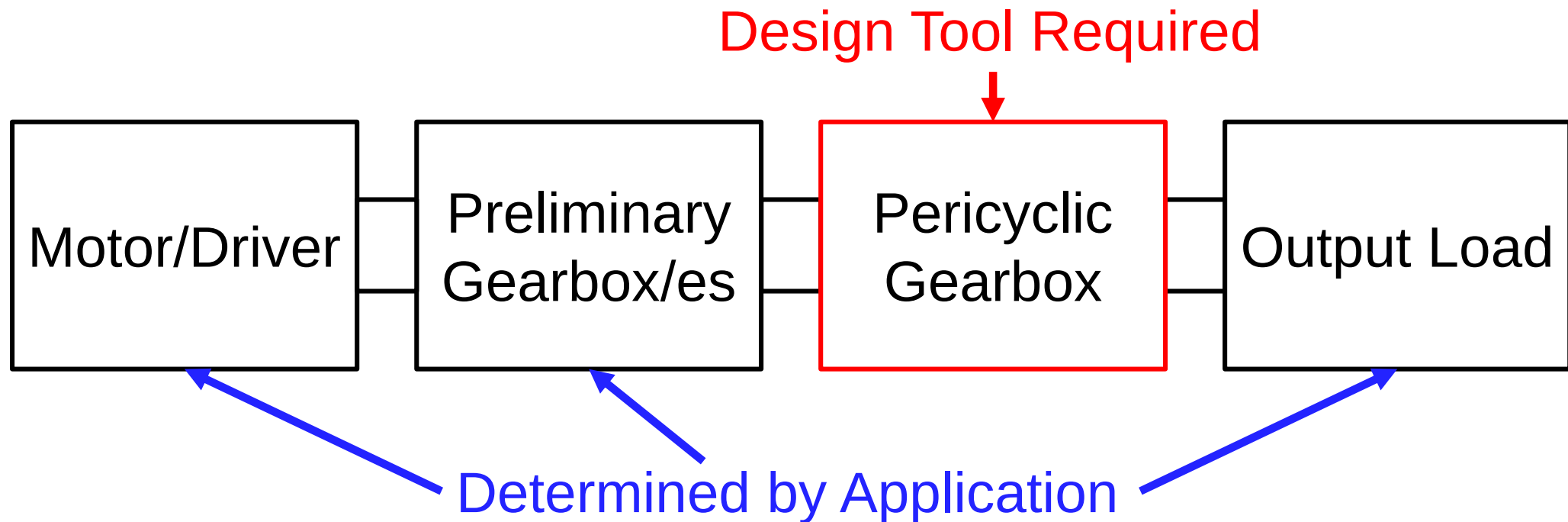
Allows for precision positioning and high output torque from lightweight motor

Lower speed and lower inertia means lower gyroscopic loads and reasonable bearing loads



Design Tool Development

Develop a tool where output torque, radial/thrust loads, and output speed are inputs, and pericyclic gearbox mass, volume, and efficiencies are outputs over a range of designs



Design Tool Development

Design Selection Parameters:

$N1_{\min} - N1_{\max} (N2 = N1 + 1)$
 $N3_{\min} - N3_{\max} (N4 = N3 - 1)$ } **Tooth Numbers Provide Reduction Ratio**

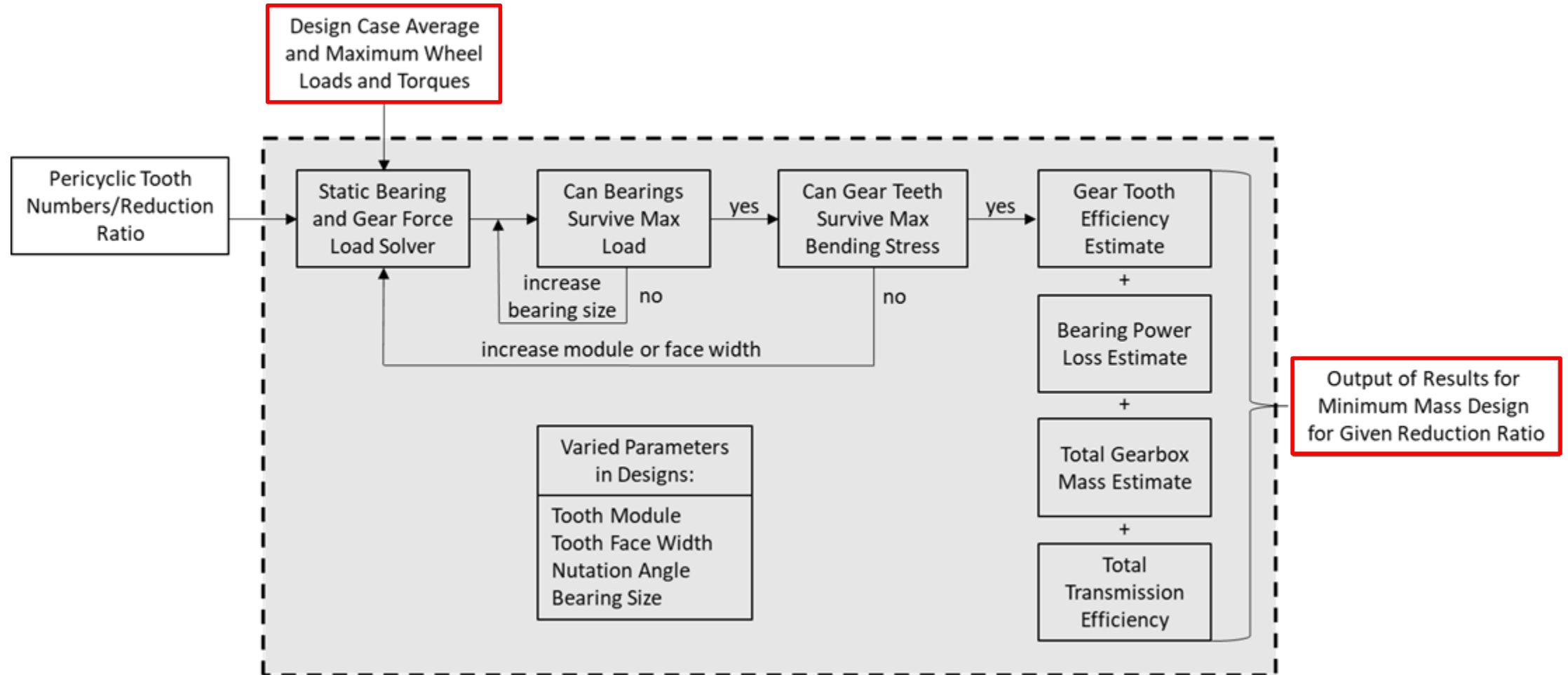
Gear Face Width Range (can be different for two meshes)
Gear Tooth Module Range (can be different for two meshes)
Nutation Angle Range
Bearing Selection Range

 } **Selected to minimize mass**

One combination of parameters generates one design solution

Design Tool Development

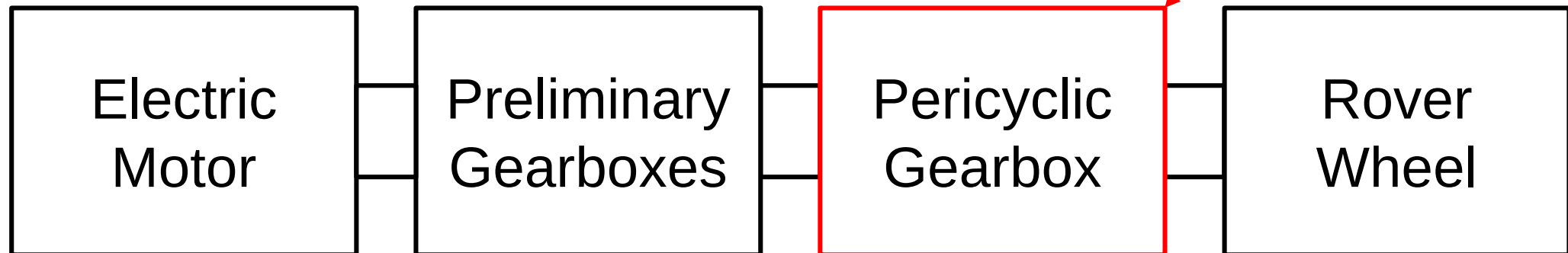
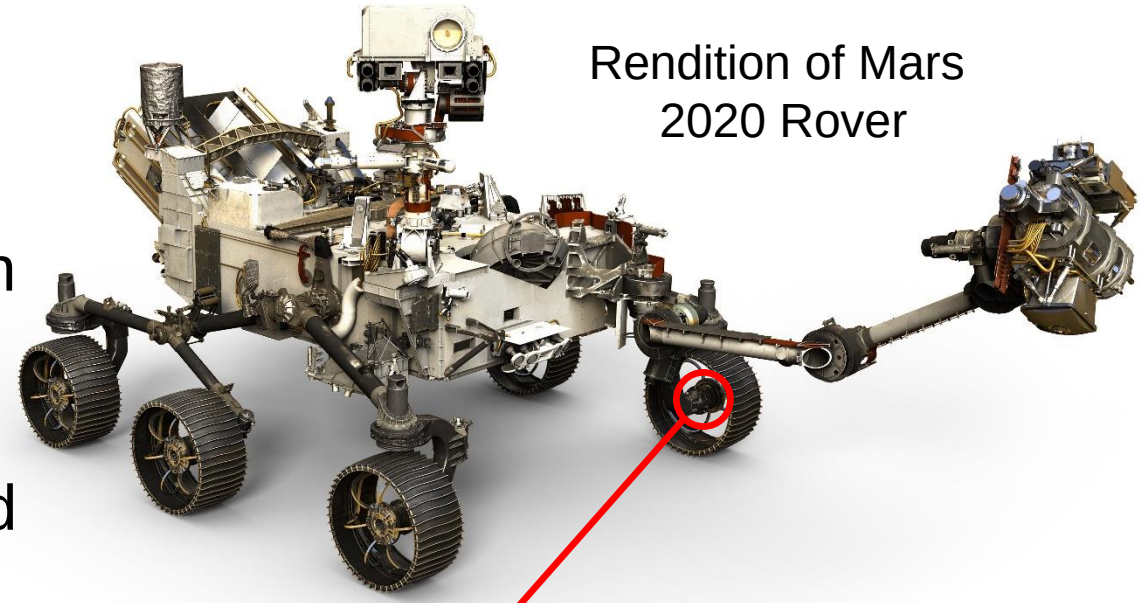
Visualization of Design Selection Parameters



Design Tool Development

Design Case: Mars 2020 Rover Wheel Steer Actuator

- Mean loads from continuous operation
- Maximum loads from touchdown
- Allowable volume and mass estimated from requirement documents

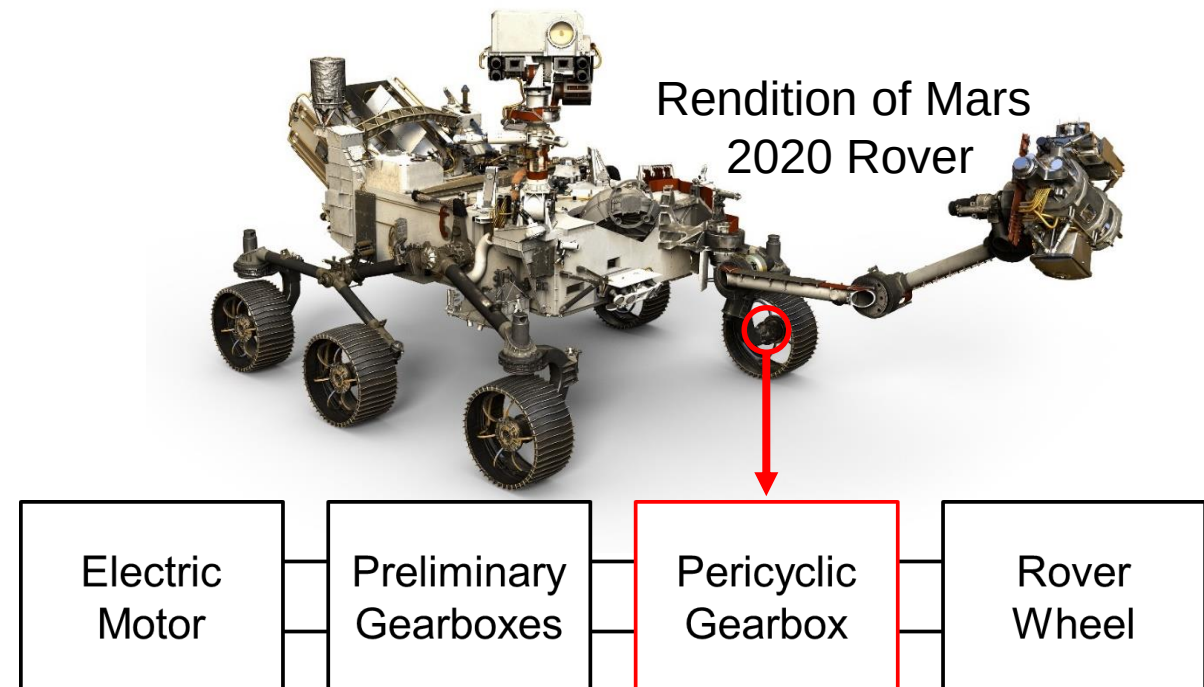


Design Tool Development

Design Case: Mars 2020 Rover Wheel Steer Actuator

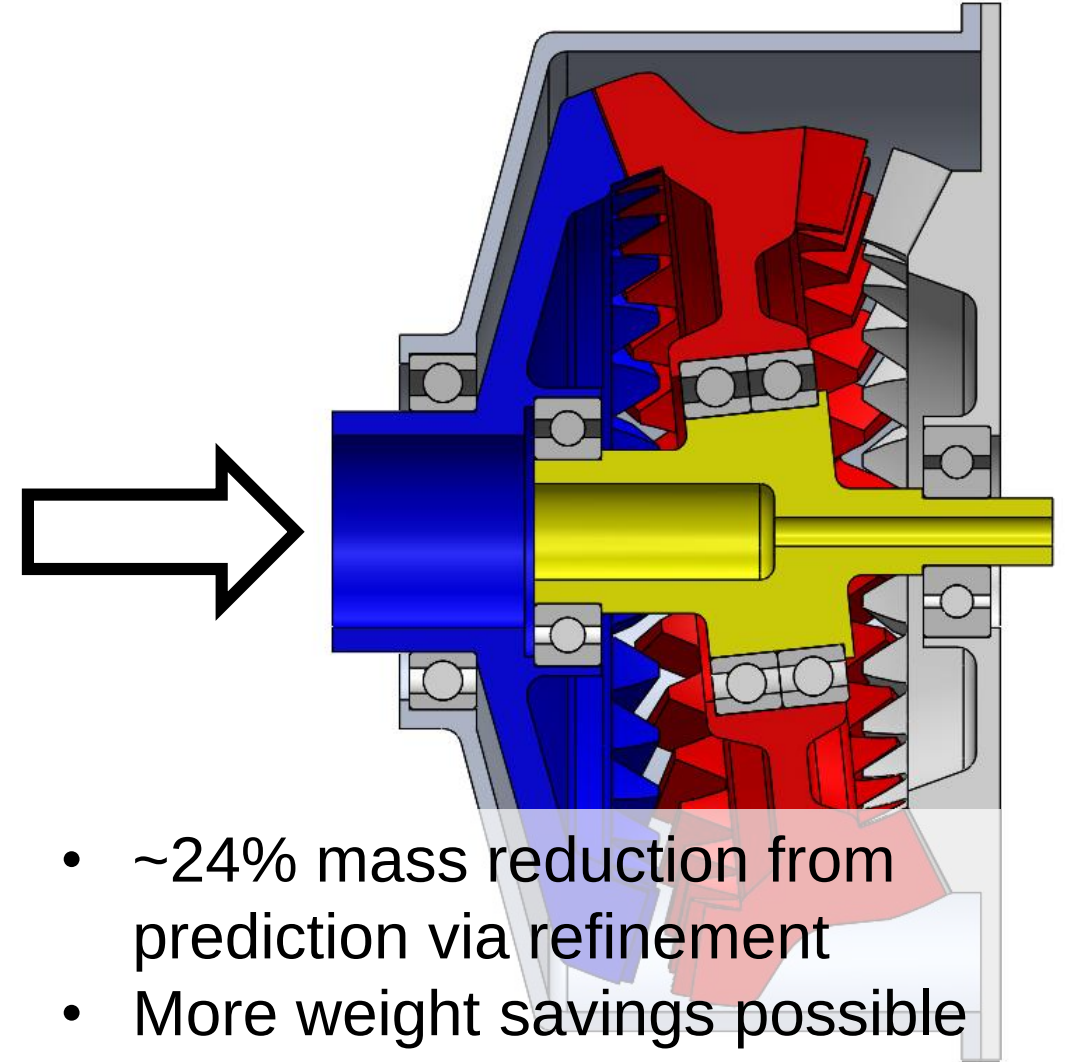
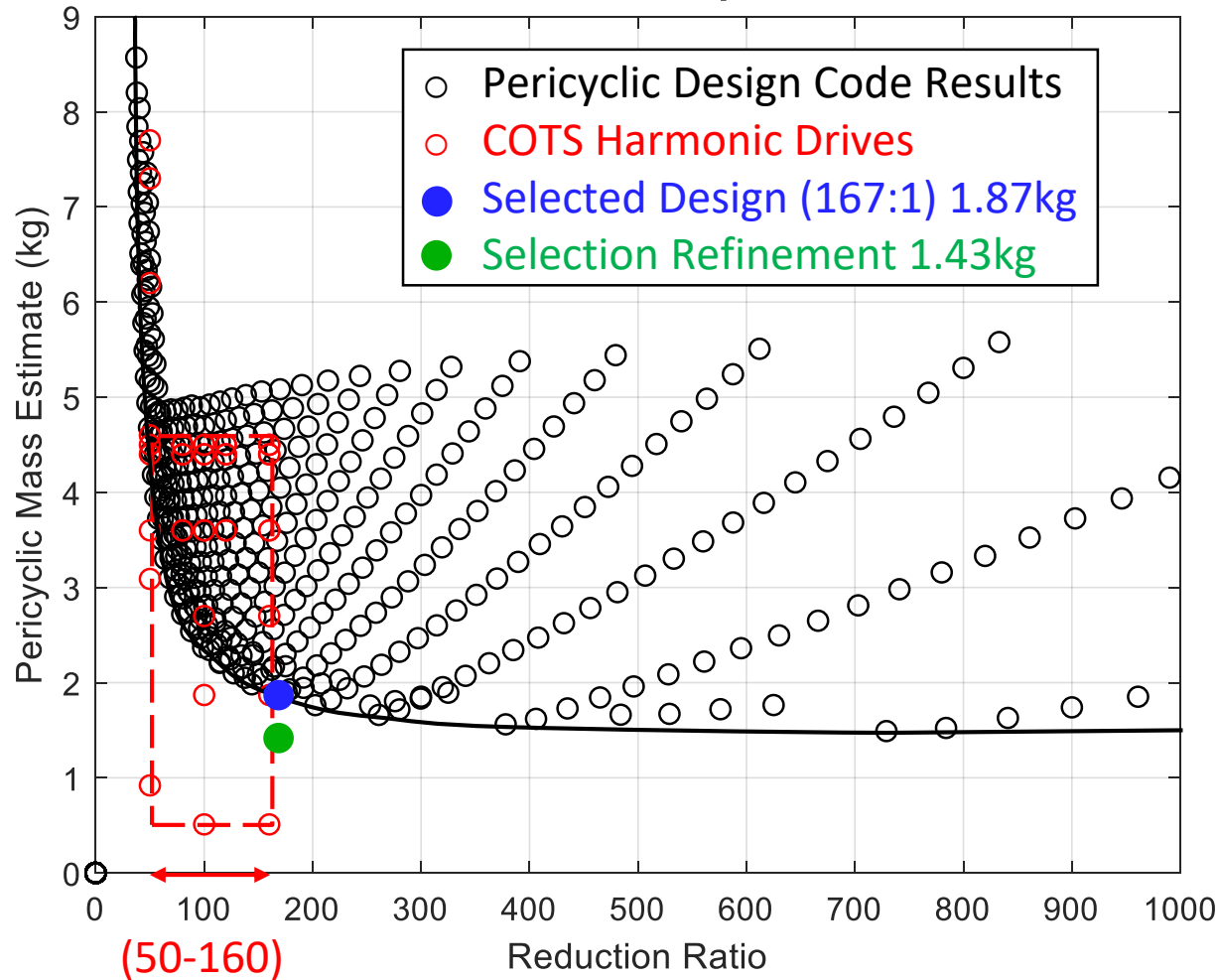
- Goal to generate **lightest pericyclic drives possible** for design requirements
- Compared results **with harmonic gears** of the same rated output torque

Design Aspect	Design Requirement
Total Gear Ratio of All Stages	> 1024:1
Total Mass (motor, brake, gears, encoder)	5.8 kg
Outer Diameter	< 105 mm
Length	< 85 mm
Continuous Output Speed	1.53 RPM
Continuous Output Torque	98 N*m



Design Tool Development

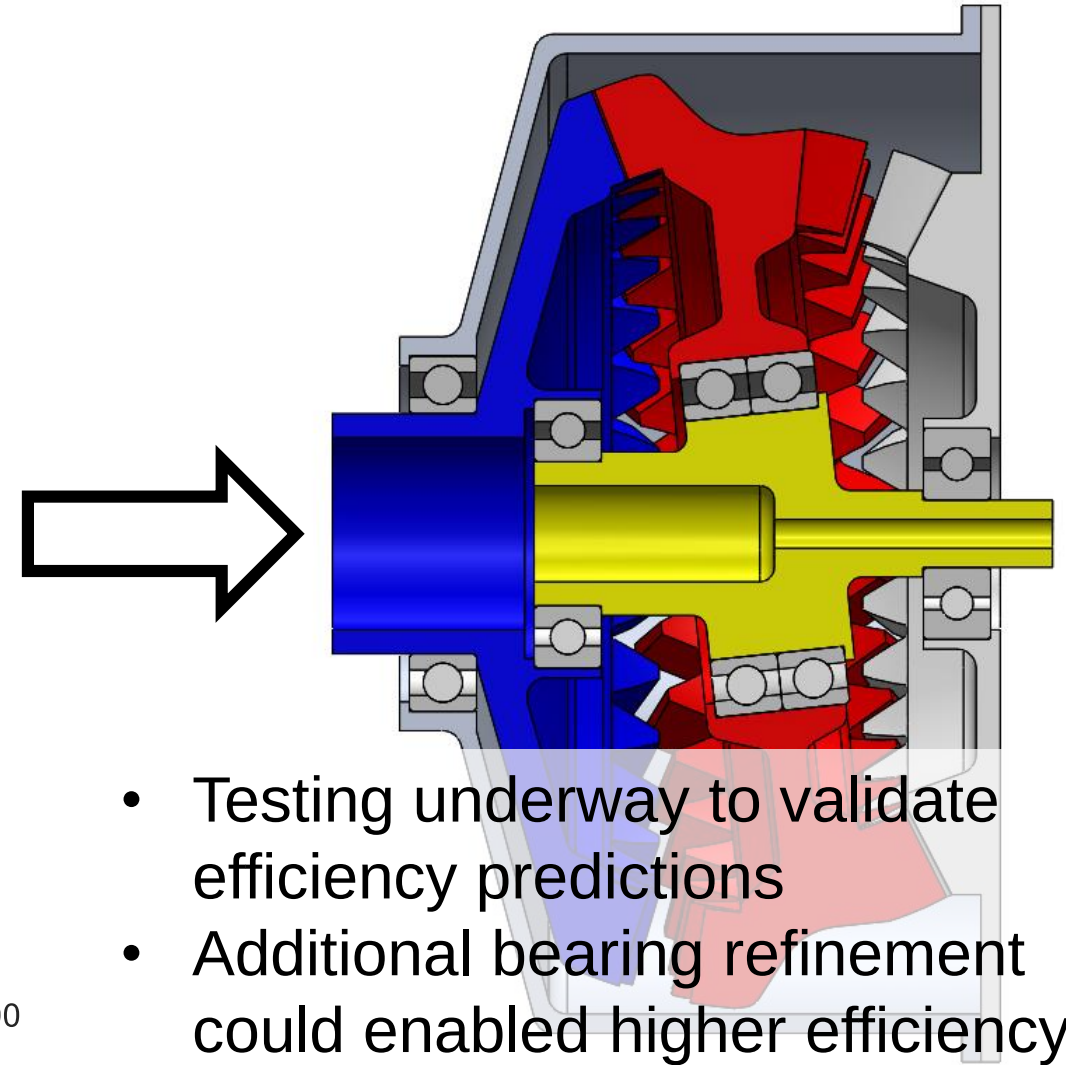
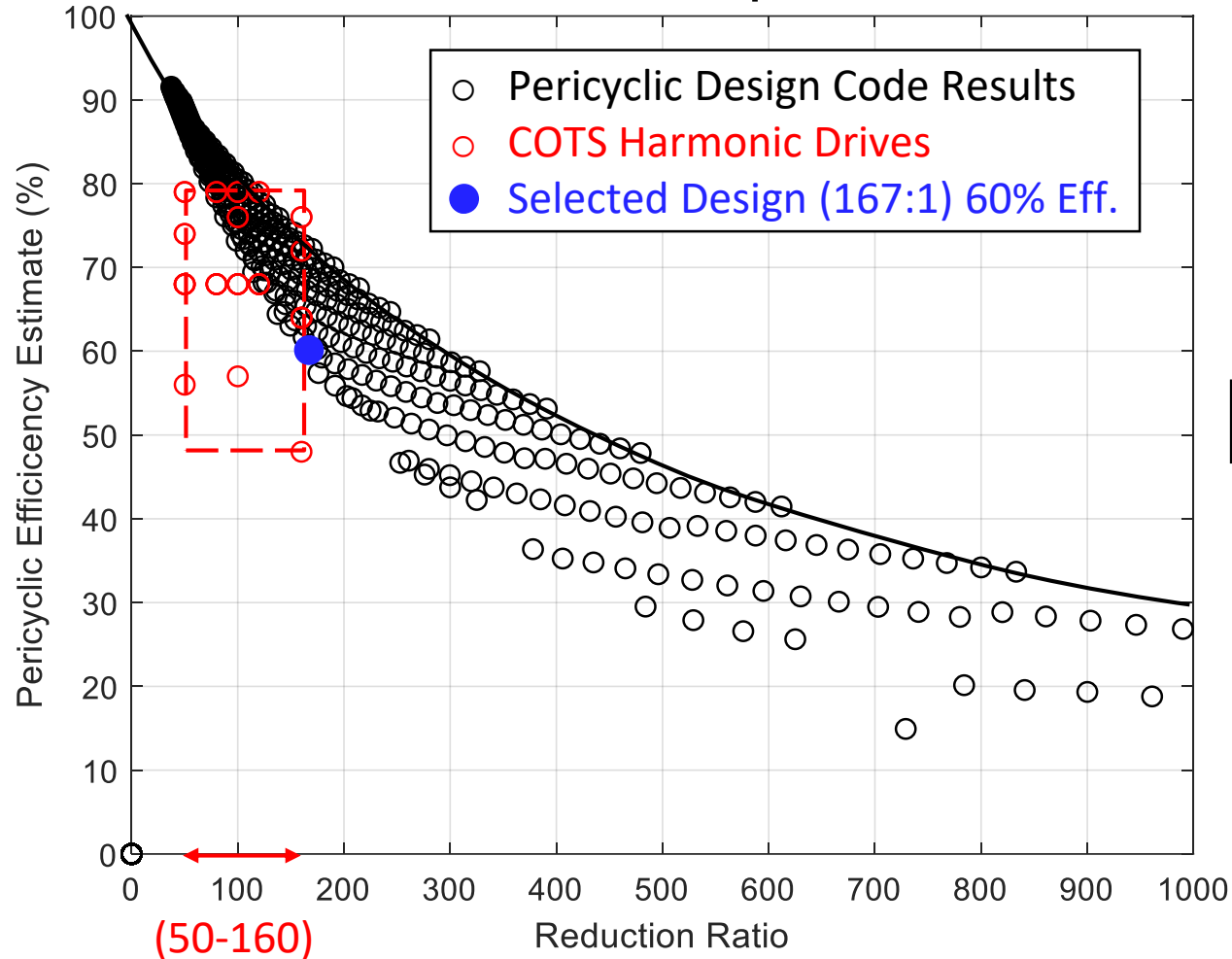
Pericyclic Mass for Mars 2020 WSA Output Gear



- ~24% mass reduction from prediction via refinement
- More weight savings possible

Design Tool Development

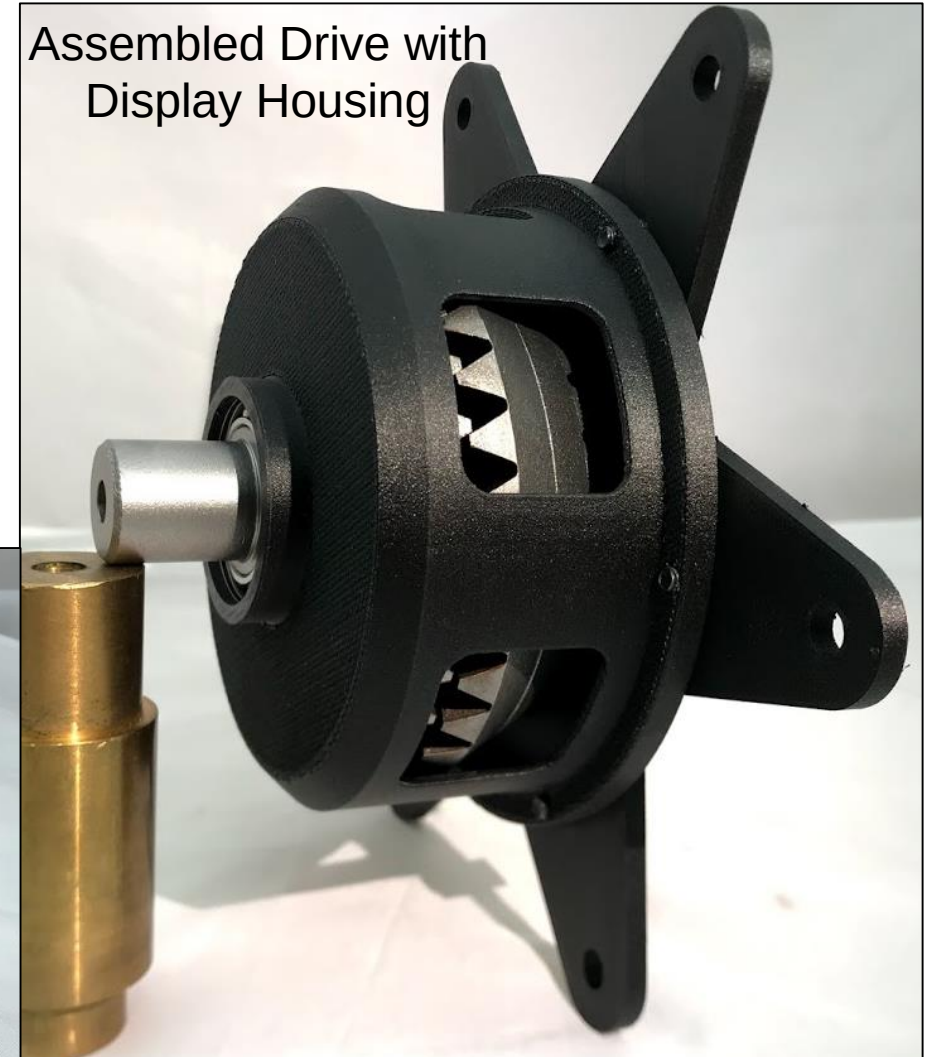
Pericyclic Efficiency for Mars 2020 WSA Output Gear



Prototype Fabrication

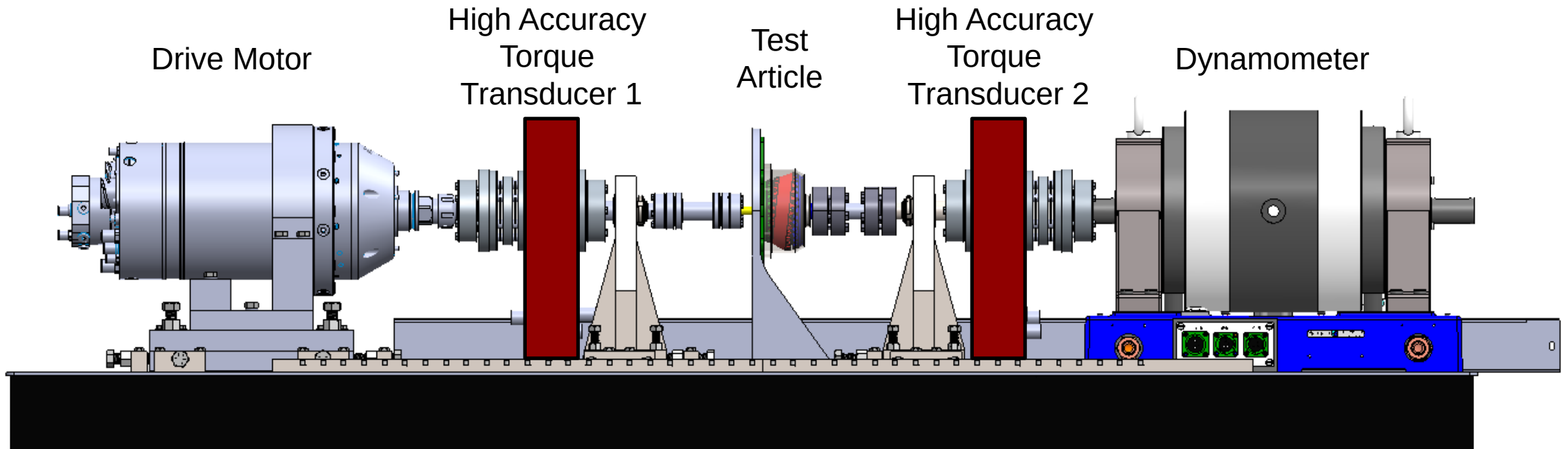
Components modified to allow for manufacturing/assembly and test stand compatibility

- Additively manufactured from 17-4 PH Stainless Steel
- Structures verified in FEA



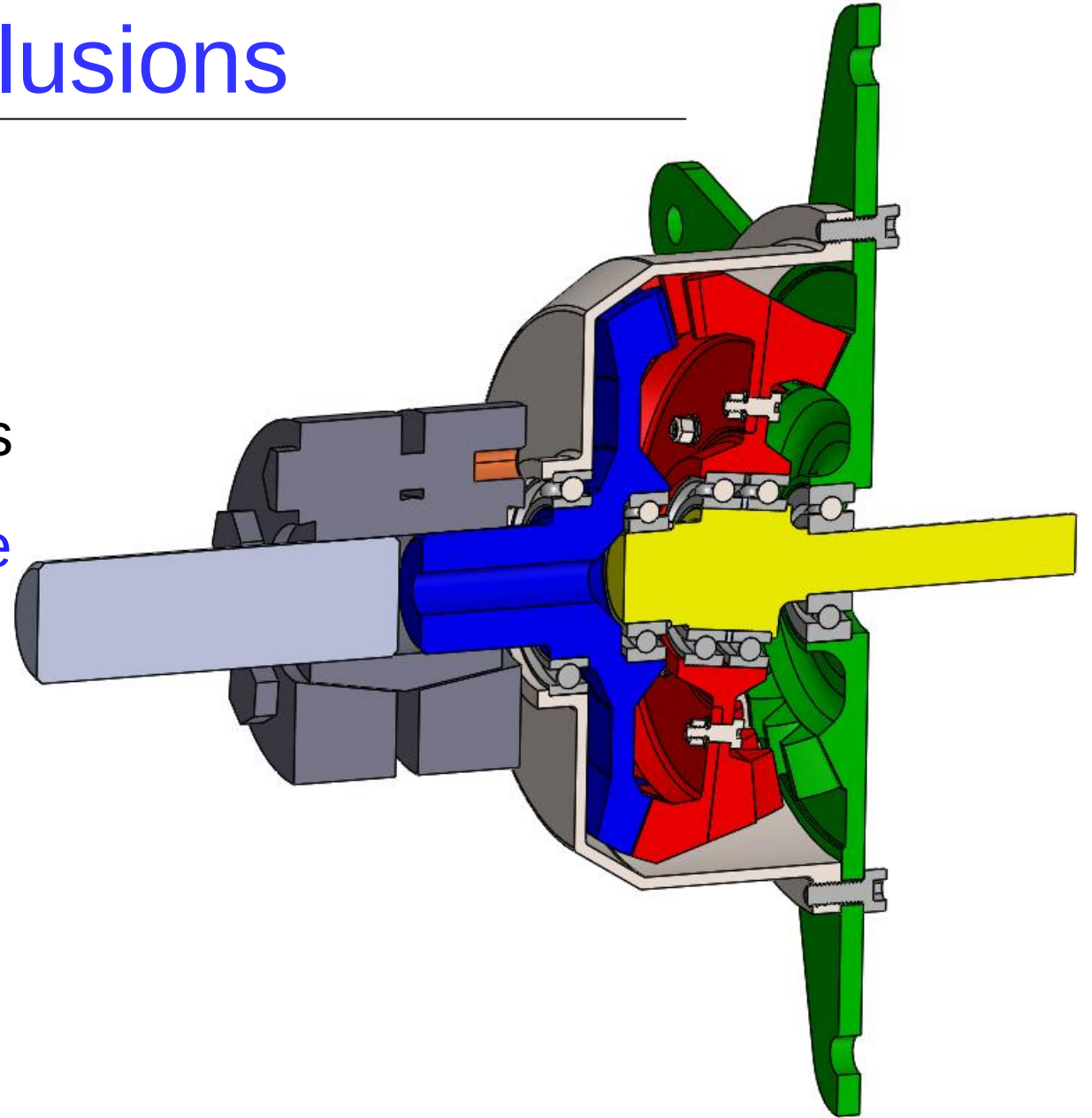
Prototype Fabrication

“E-Drives” Test Rig, Meant for Magnetic Gears and Electric Motors, Capable of Supporting Pericyclic Test



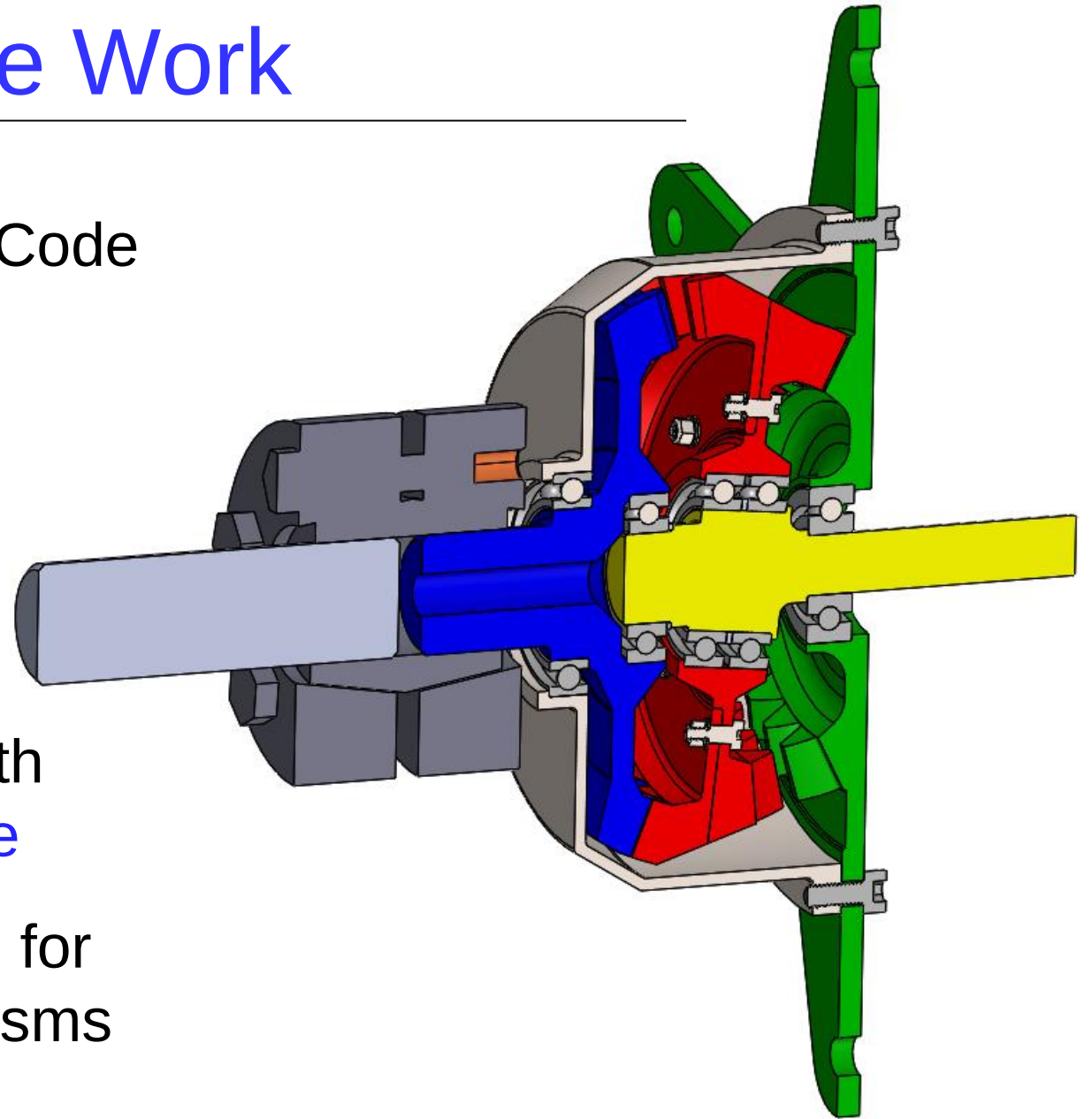
Conclusions

- Developed Pericyclic Gearbox Sizing Tool for Small Power Scales to Show Design Trends
- Pericyclic Designs Competitive With Harmonic Gears for Mars 2020 Application Investigated
- Prototype Designed and Fabricated to Verify Capability



Future Work

- Further **Refinement** of Design Code to Improve Bearing Selection, Decrease Power Loss
- Further **Improve and Advance Fabrication** Techniques
- Continue **Testing** Current Prototypes to Provide Data With Which to **Validate Design Code**
- **Implementation** of Design Tool for Additional Aerospace Mechanisms



Acknowledgements

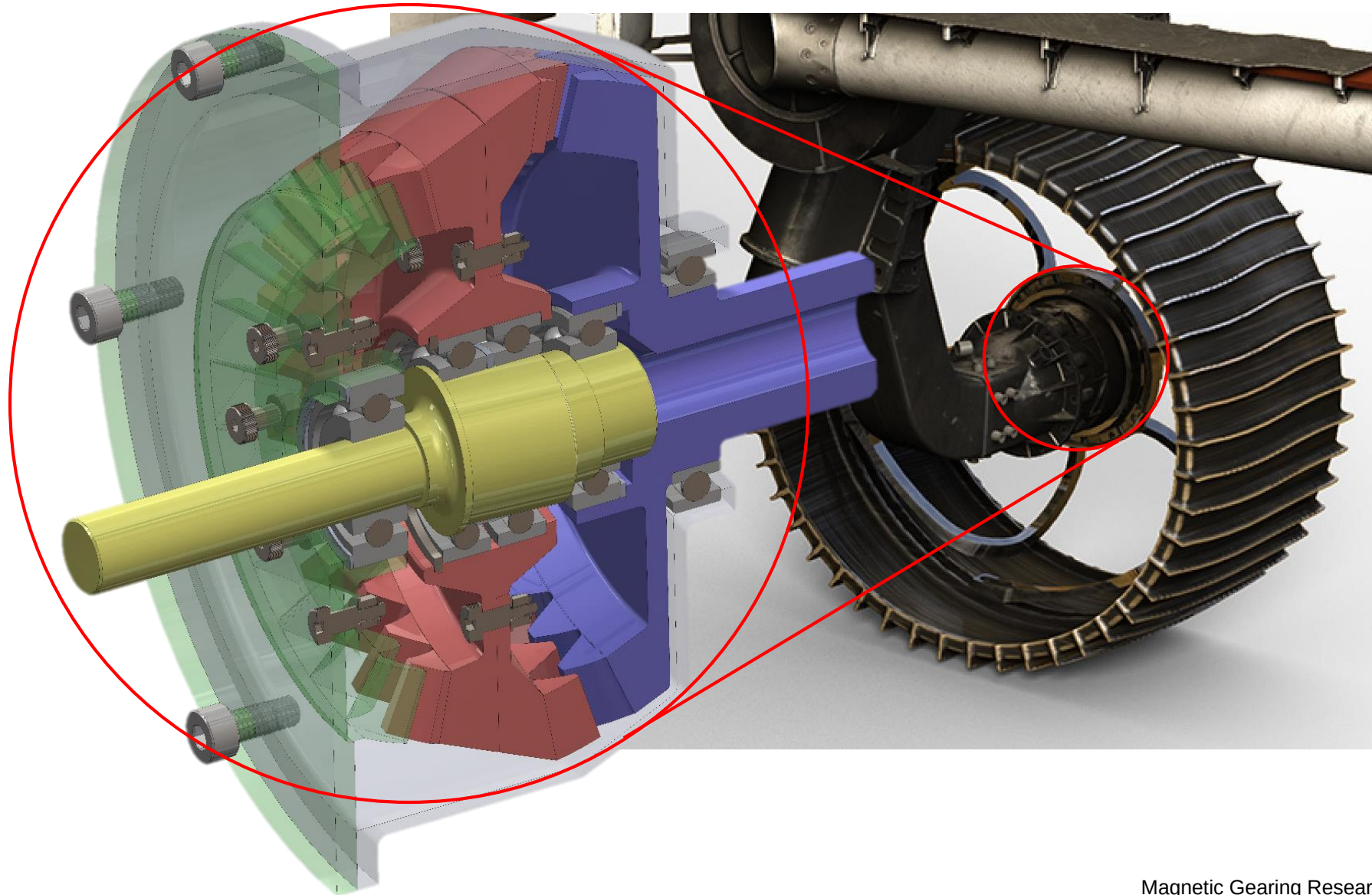
The project would like to acknowledge the support of the NASA Center Innovation Fund (CIF) for supporting this work along with:

- Scott Moreland, Patrick DeGrosse, and Mark Balzer of JPL for Design Information on the Mars 2020 WSA

QUESTIONS ?



APPENDIX



Magnetic Gearing Research at NASA

BMG for Harmonic Drives in Low T Space Environments

- Harmonic drives rely on flexible bodies
- Pericyclic uses rigid bodies to transmit torque



Low temperature harmonic gear testing

<https://phys.org/news/2016-11-metallic-glass-gears-graceful-robots.html>

https://gameon.nasa.gov/gcd/files/2016/08/FS_BMGG_FS_160808.pdf

Gears In Rovers Typically AGMA 13

<https://www.forestcitygear.com/industries/outer-space/>

<https://www.machinedesign.com/news/gear-maker-s-components-take-ride-martian-rover>

Additional Gearbox Locations

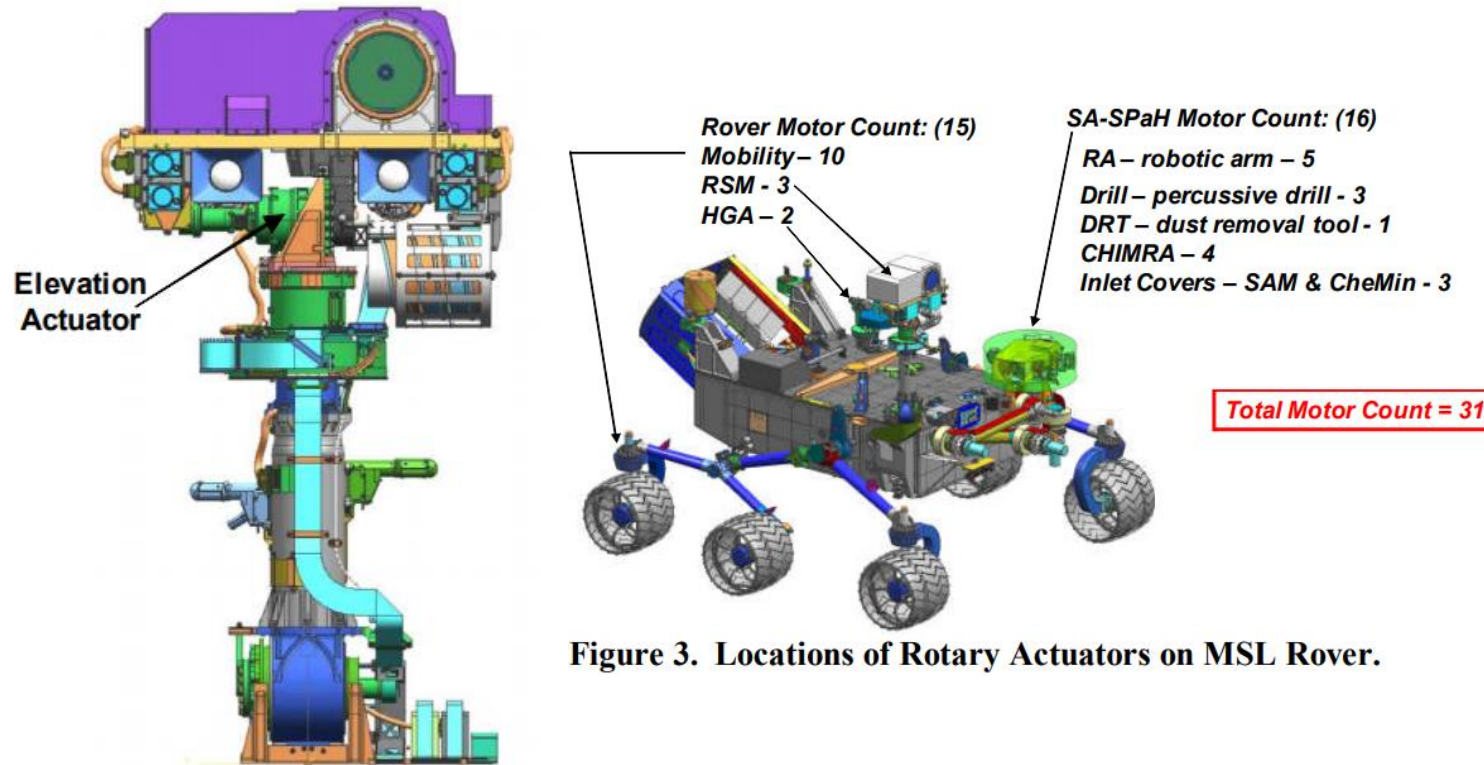


Figure 3. Locations of Rotary Actuators on MSL Rover.

Figure 8. Location of Elevation Actuator on RSM

<https://pdfs.semanticscholar.org/8899/e08595523634618d8c65306d83a95d9e9e8f.pdf>

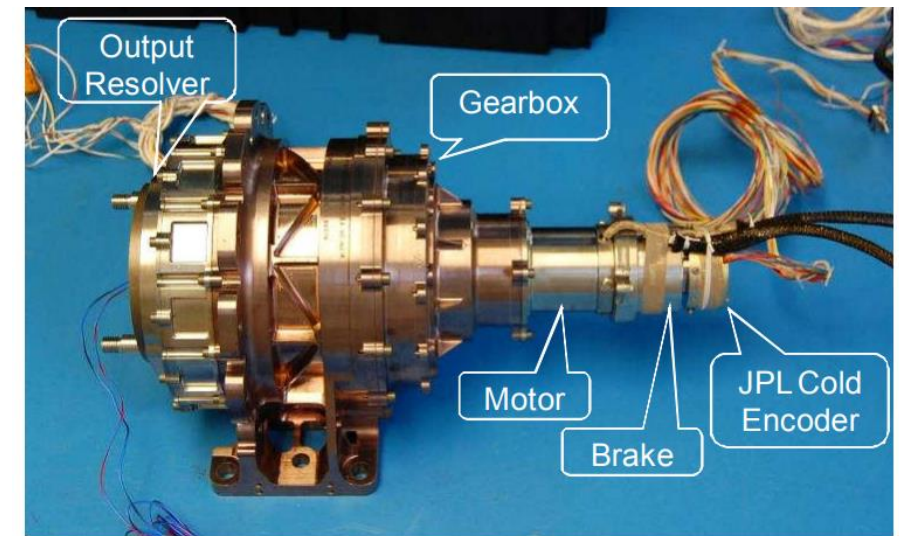


Figure 2. Typical MSL Actuator.

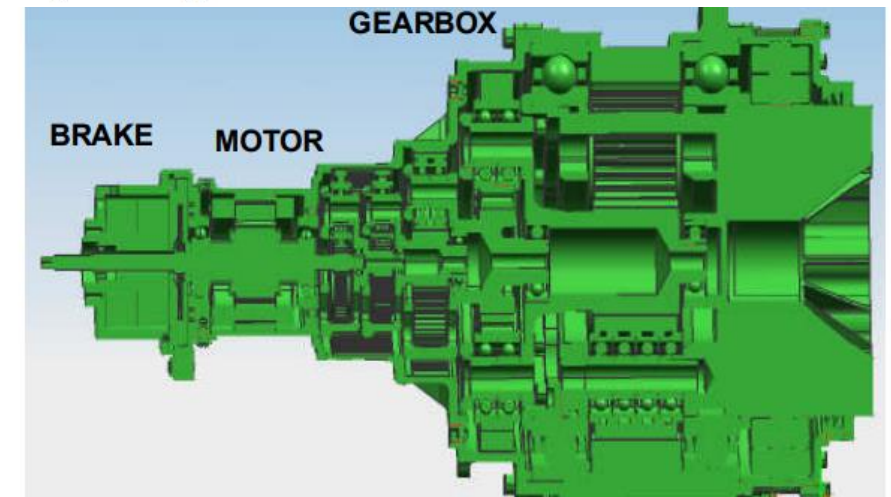


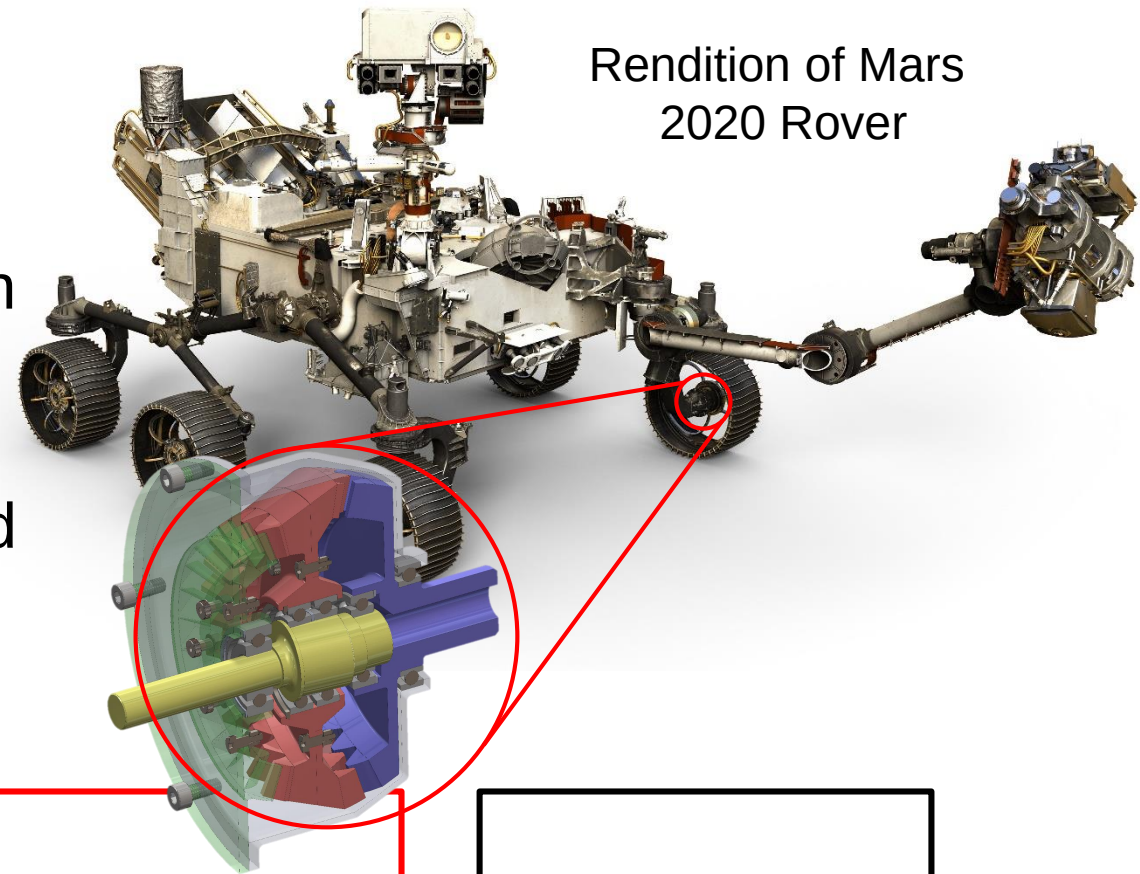
Figure 6. LPHTA Cross-Section

Magnetic Gearing Research at NASA

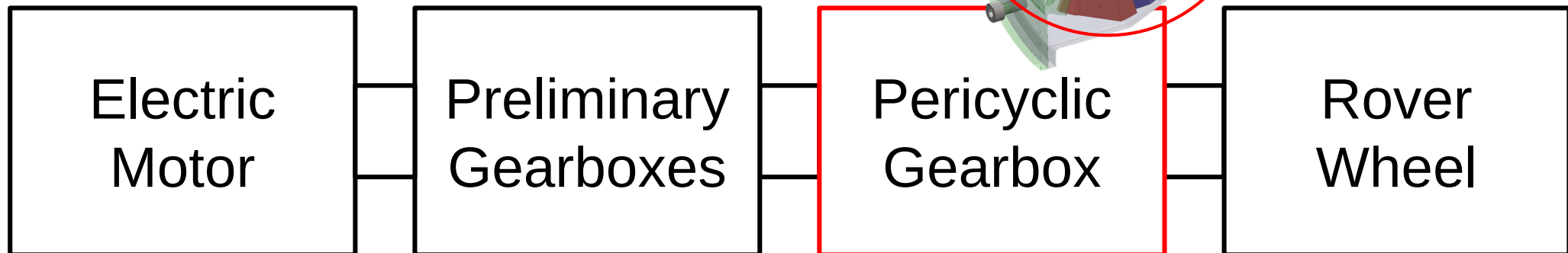
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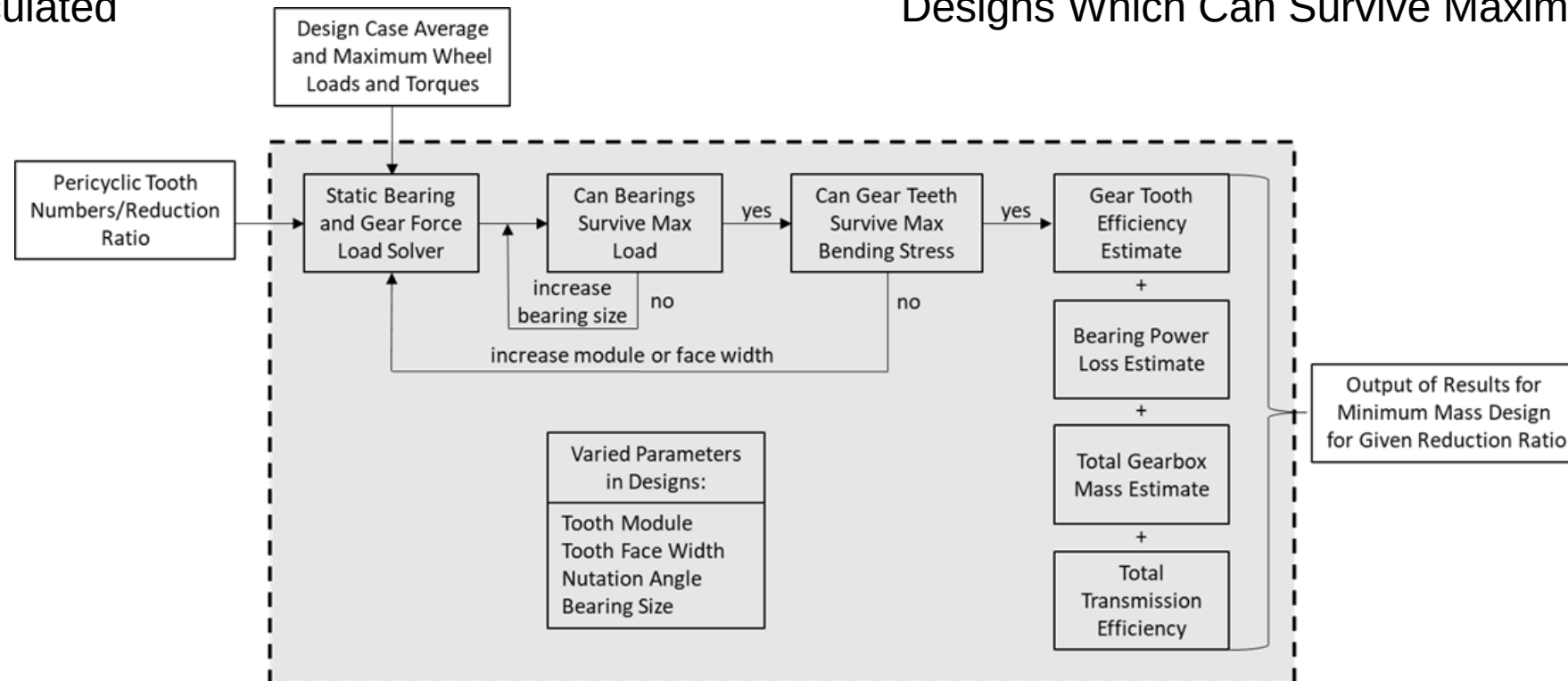


Rendition of Mars
2020 Rover



Design Tool Development

1. Design Defined by Tooth Numbers, Face Widths, Modules, and Nutation Angle
2. Maximum Load for Gear Teeth and Bearings Calculated
3. Mean Load for Gear Teeth and Bearings Calculated
4. Bearings Selected With Minimum Weight That Can Withstand Maximum Load
5. Bearing and Gear efficiency estimated with mean loads
6. Mass, Efficiency, and Dimensions Output for Designs Which Can Survive Maximum Loads

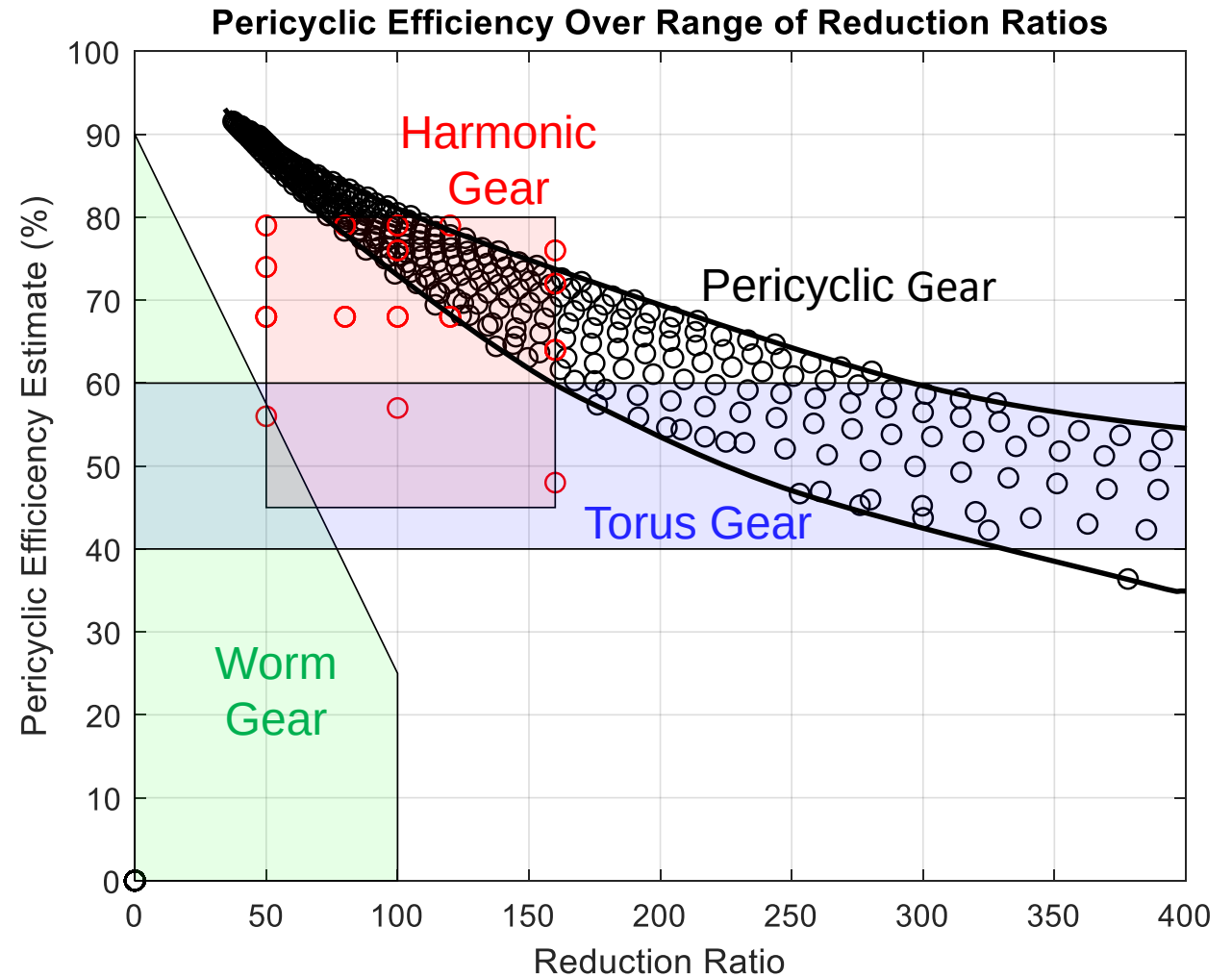


Worm, Strain Wave, Torus and Pericyclic

Harmonic gears taken from catalog, rated for 98Nm of torque continuous

Torus and worm gear data taken from Graessner website, torque unknown

Pericyclic data generated by code but not yet validated



<https://www.graessner.de/en/produkte-english/torusgear-planar-spiral-gearbox.html>