National Aeronautics and Space Administration

Design and Manufacturing of Lightweight Excavating and Trenching Tools for Future Landers using Additive Manufacturing, Topology Optimization and Gradient Alloys

Principal Investigator: Douglas C. Hofmann (357H) CoI's: Phillipe Tosi (347C), Tent Bordeenithikasem (357H), Morgan Hendry (352M), Christopher Yahnker (347C), Cecily Sunday (347C), Samad Firdosy (357H), Andre Pate (357D), Mark Anderson (353E)

Program: Topic

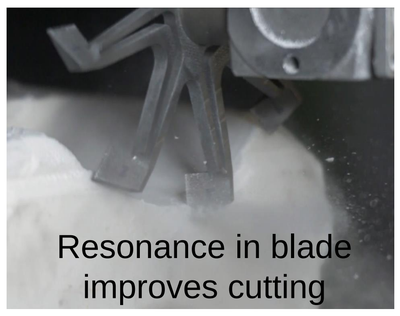
Project Background:

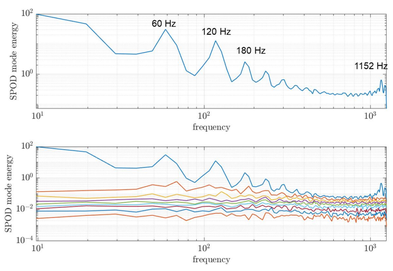
1. JPL wants to land spacecraft on ice (Enceladus, Europa and Comets)
2. Ice surface is uneven with unknown hardness and landers will be lightweight
3. What is the optimal material and design for excavating tools for that ice?
4. Can we make an excavating tool that's also a science instrument?

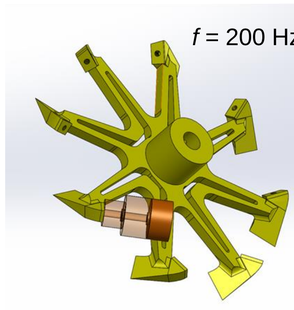
Robotic testbed

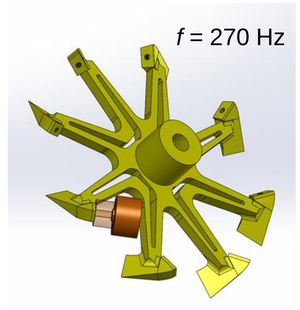
Powder-bed 3D printing of tools

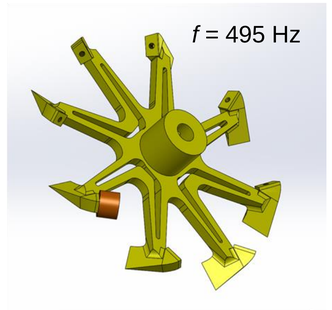
Titanium Compliant Cutting Tool

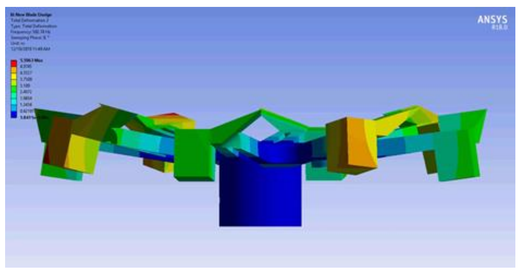






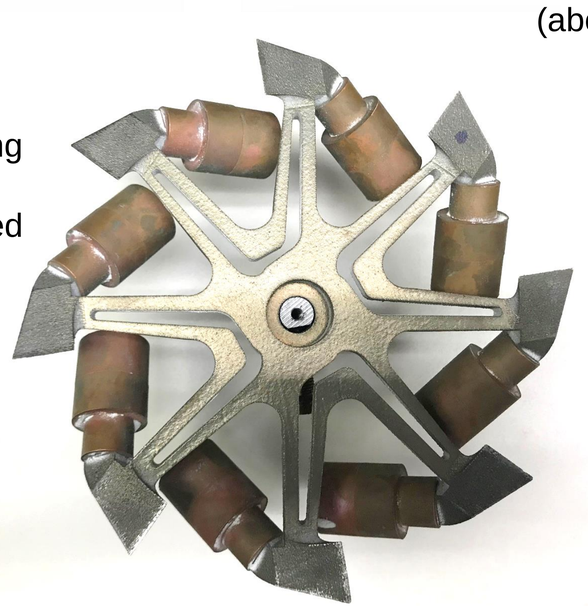


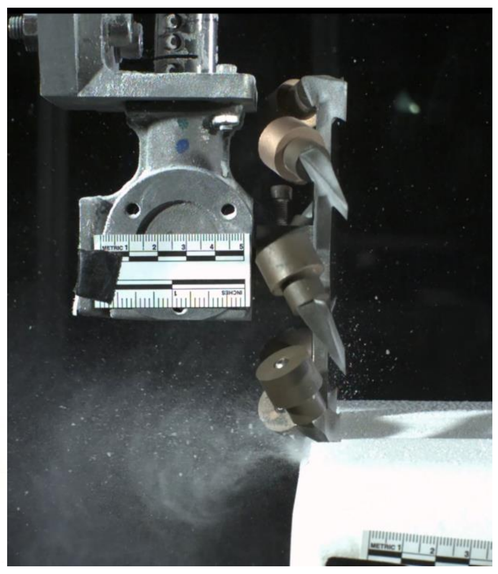


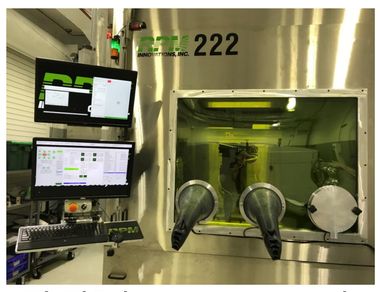


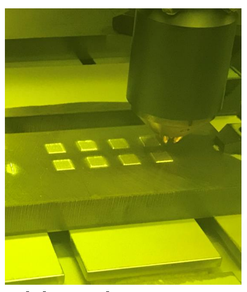
Model of the resonance modes (above) compared with video (below)

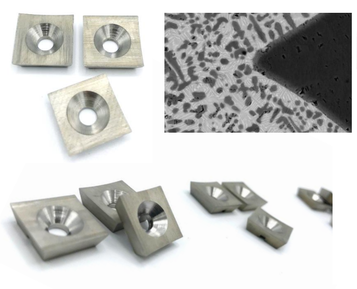
Resonance modes of the blade were changed to investigate the effect on cutting performance and compared back to the models. A weighted blade is shown at right.

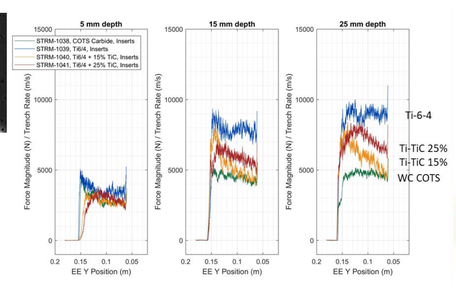










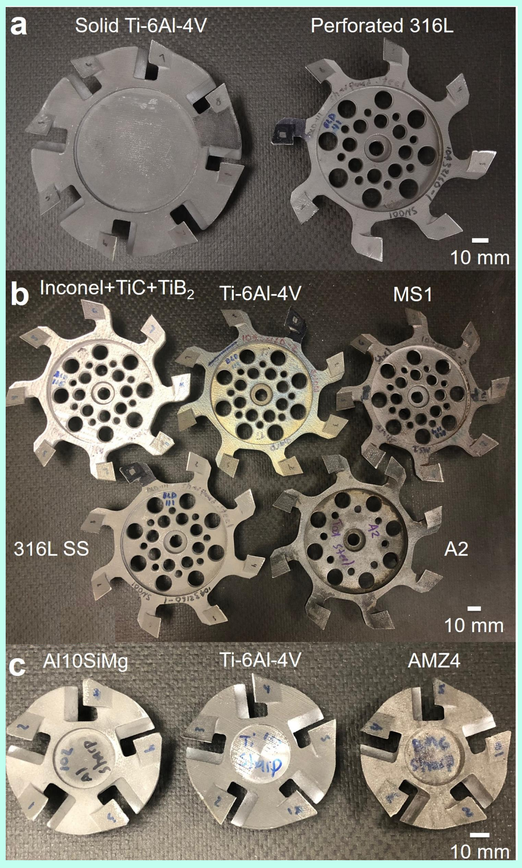


Ti-TiC inserts were printed into inserts to compare with COTS WC inserts

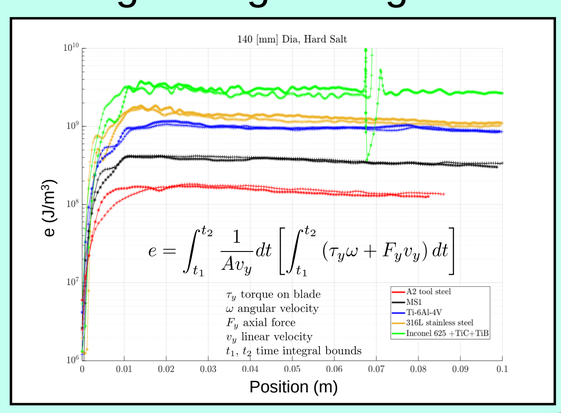
What have we learned?

- Tool steel and bulk metallic glasses have the best cutting performance in simulant
- Adding compliance to the blade increases cutting performance and blades can be designed at resonance to self-hammer
- Carbide-reinforced cutting teeth can be printed using additive manufacturing
- Porous tool bits can be used to perform compositional sensing during cutting

FY18/19 Results:

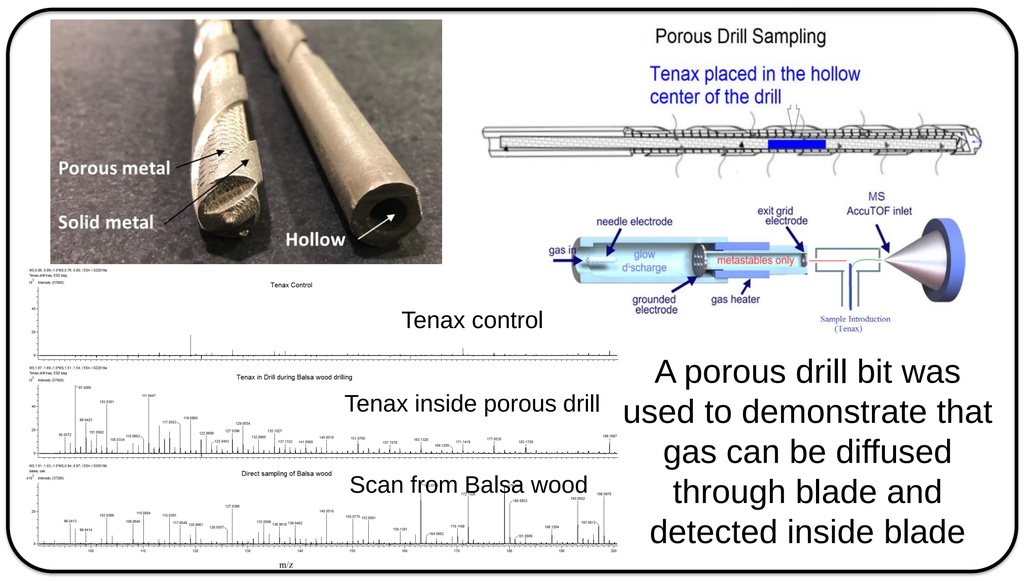


(Left) 3D printed metal cutting tools used in robotic testbed (Right) Plot showing the energy to cut through the simulant for each blade



Benefits to NASA and JPL:

- Ice cutting tools on landers should be compliant to provide self-hammering
- This work shows that 3D printing can be used to make excavating tools for cutting ice that are *also science instruments* on robotic end-effectors
- In-situ measurements of composition are possible while trenching in ice

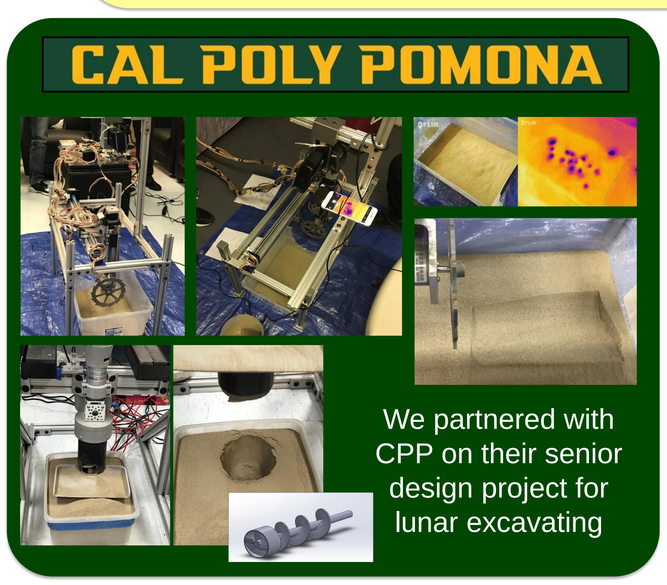


Tenax control

Tenax inside porous drill

Scan from Balsa wood

A porous drill bit was used to demonstrate that gas can be diffused through blade and detected inside blade



We partnered with CPP on their senior design project for lunar excavating

Publications:

1. Dynamic Cutting Performance of a Flexible Rotary Blade. Phillipe Tosi *et. al.* (2019) in preparation
2. Towards Additively Manufacturing Excavating Tools for Future Robotic Space Exploration. Douglas Hofmann *et. al.* (2019) in preparation

PI/Task Mgr. Contact Information:
Dr. Dougals C. Hofmann
dch@jpl.nasa.gov

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National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov