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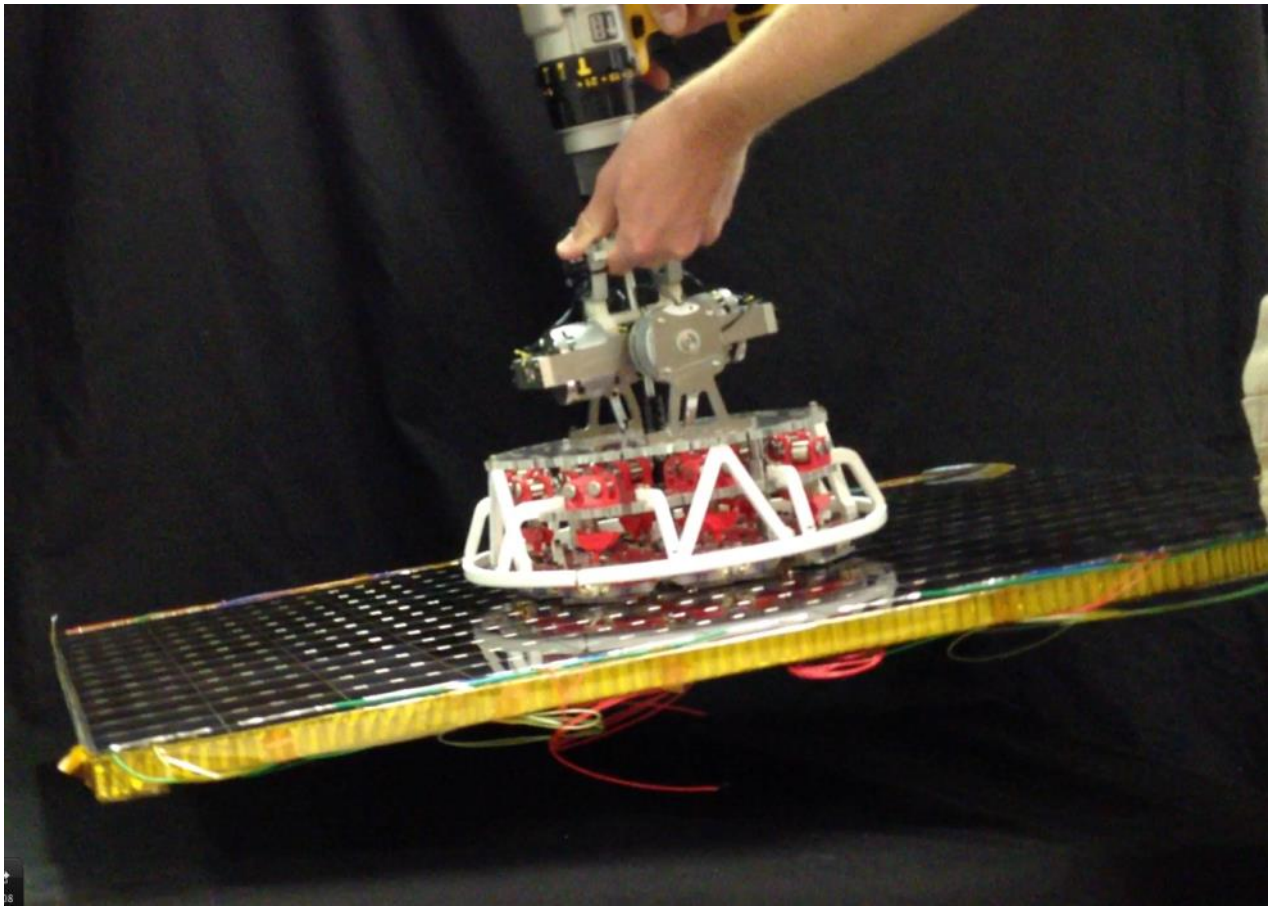
ON-OFF Adhesive Grippers for Earth Orbit



Dr. Aaron Parness, JPL/Caltech,

Aaron.Parness@jpl.nasa.gov

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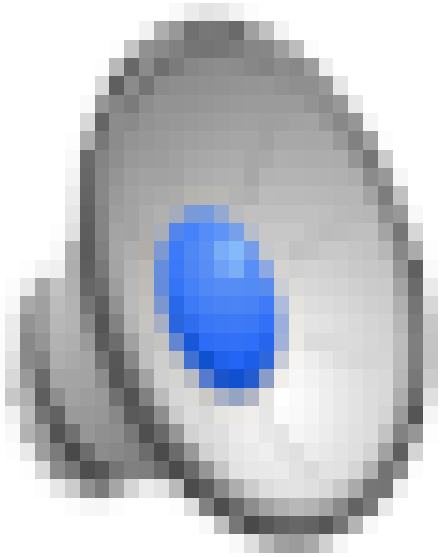

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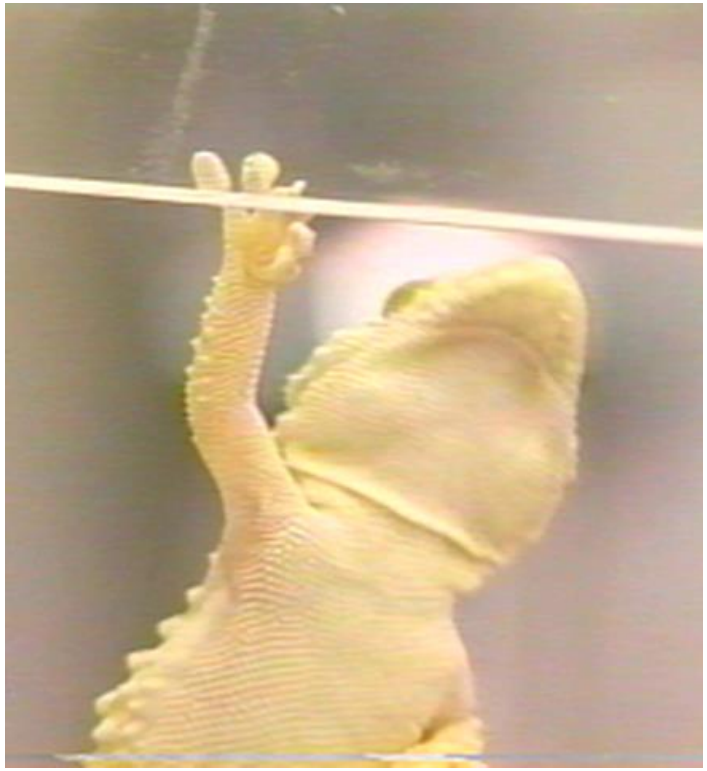
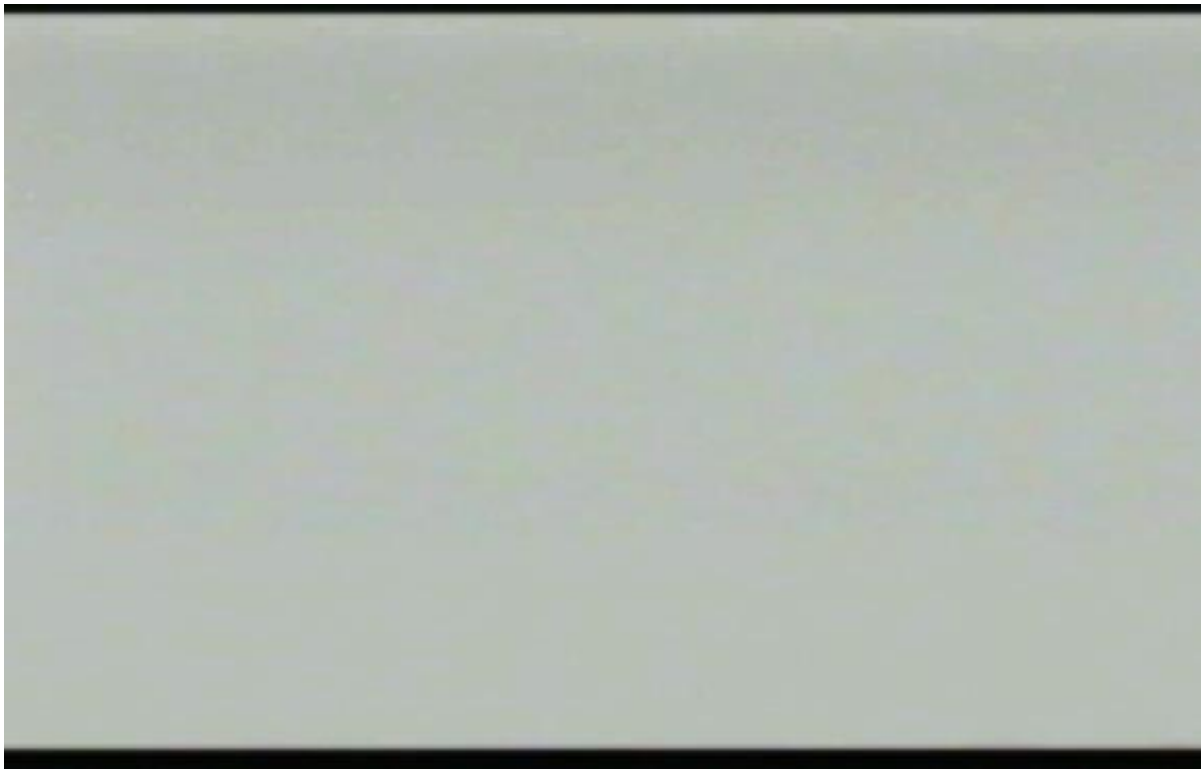
Intro to Gecko Adhesion

- Reusable
- Controllable (ON-OFF)
- Stick using van der Waals forces

The Amazing Gecko





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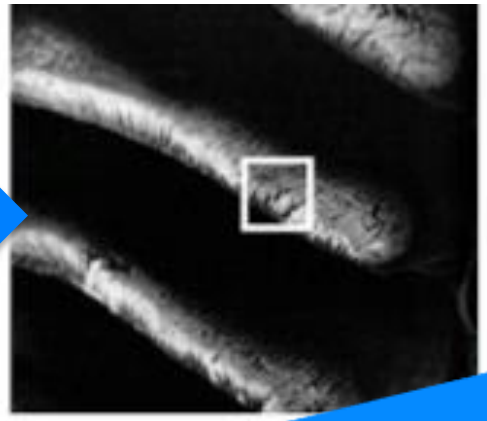
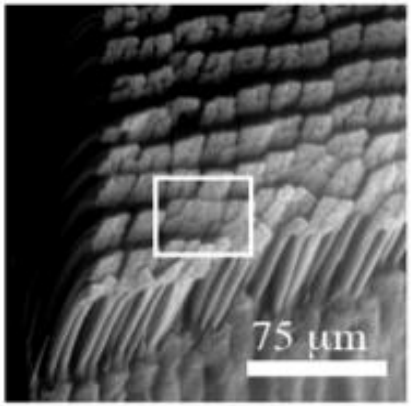
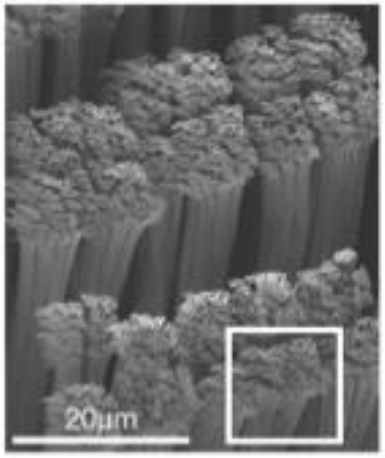
The Gecko Adhesive System

Lamellae—mm scale

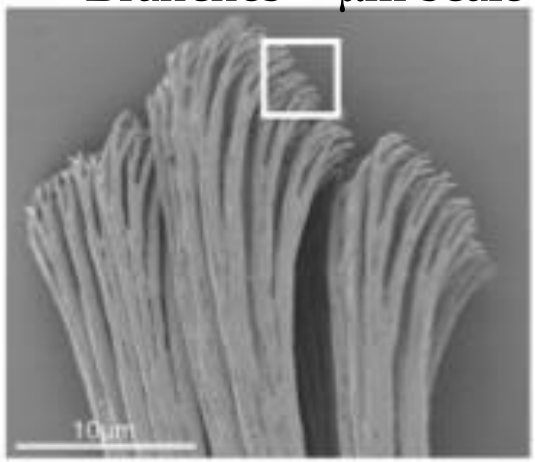


Setae—10s of µms

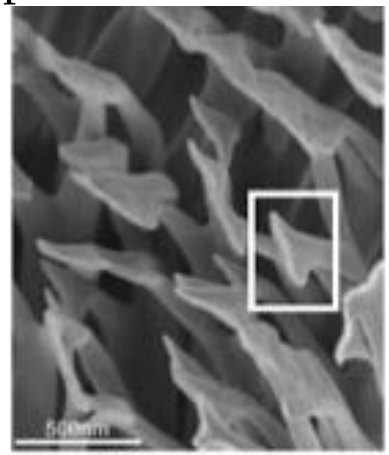




Branches—µm scale



Spatulae—10s of nms



Contact features use vdW forces

Autumn, Nature, 2002

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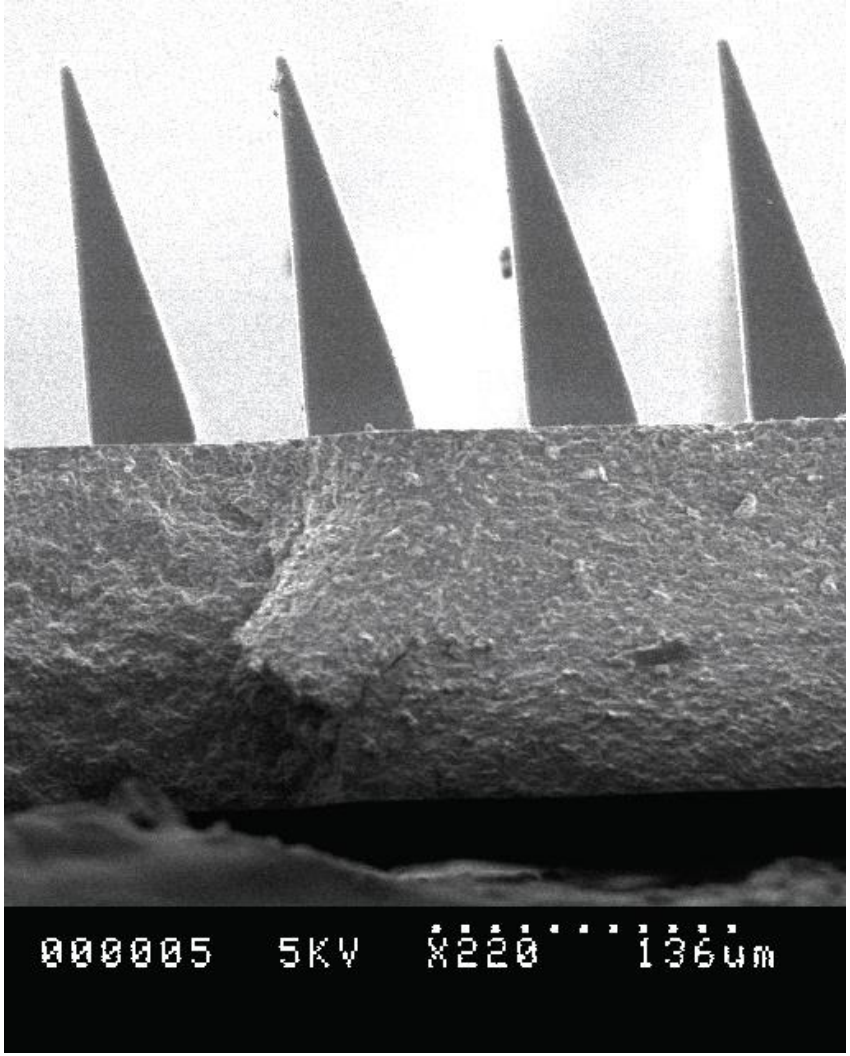
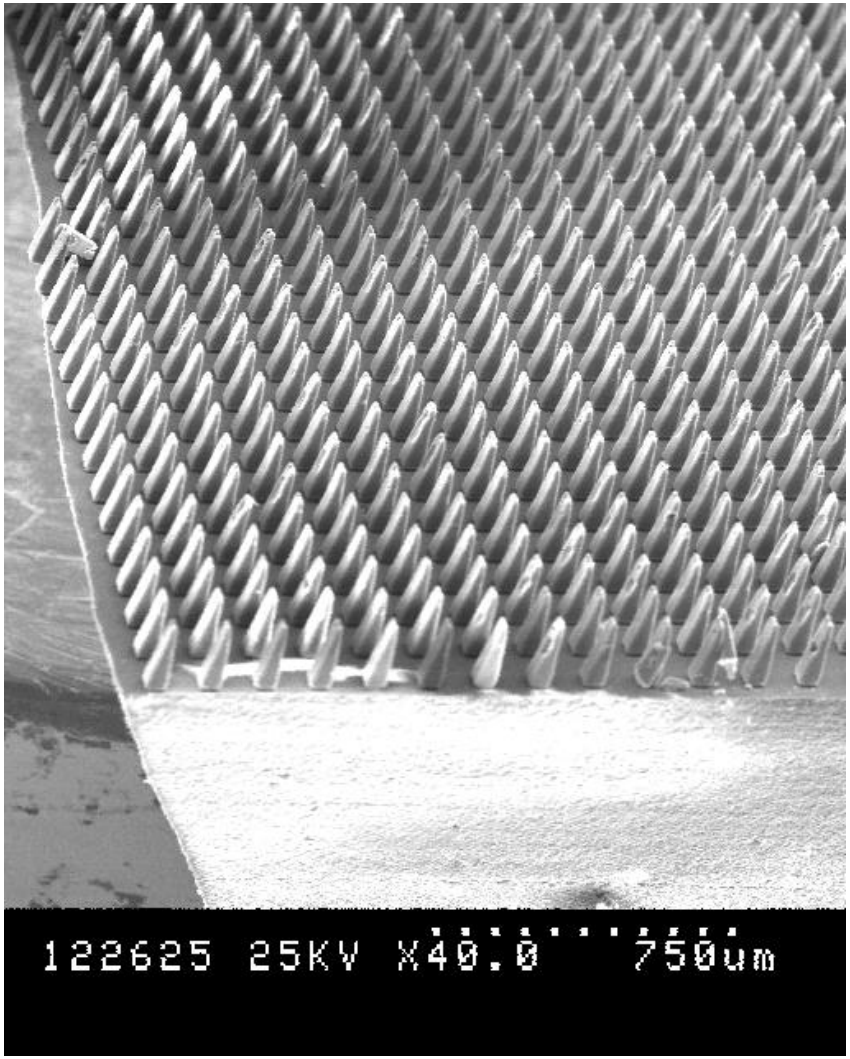
Synthetic Gecko Adhesive





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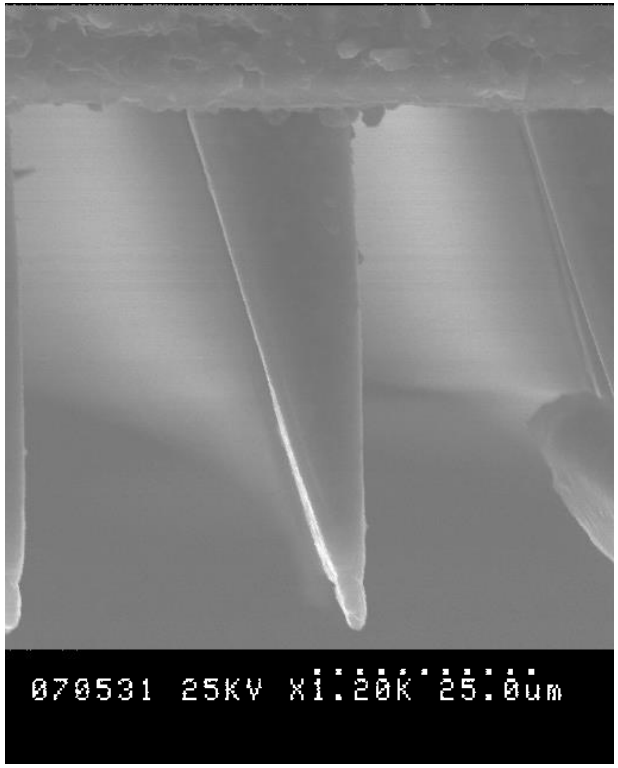
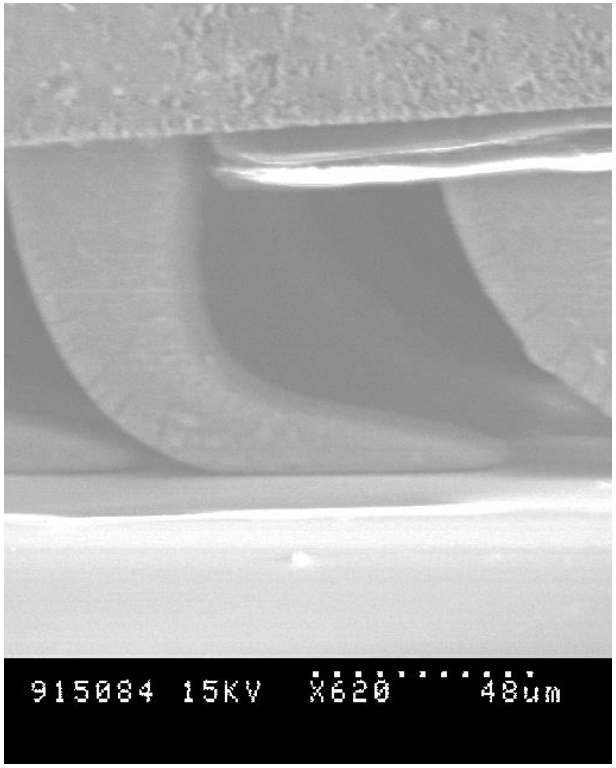
Loading the Wedges

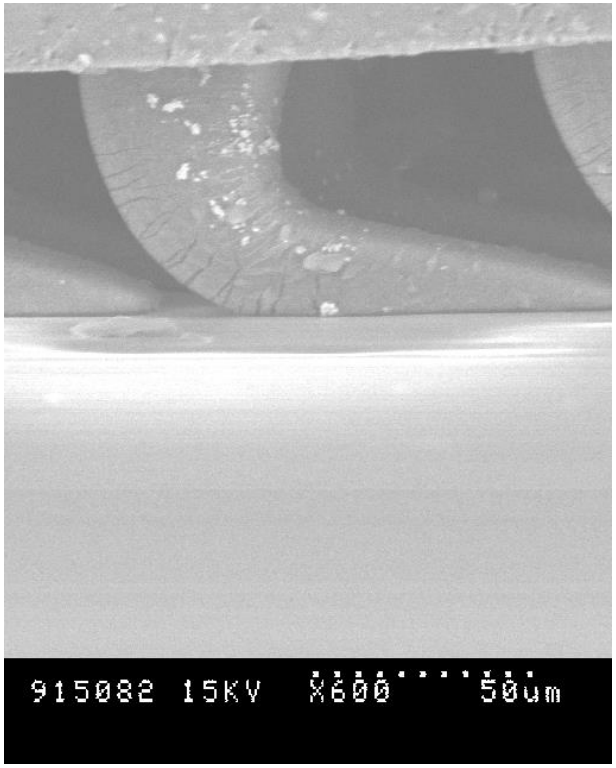
Load Direction



Unloaded
Adhesion OFF



Moderately Loaded
Adhesion ON



Heavily Loaded
HIGH Adhesion ON

Previous Work at Stanford

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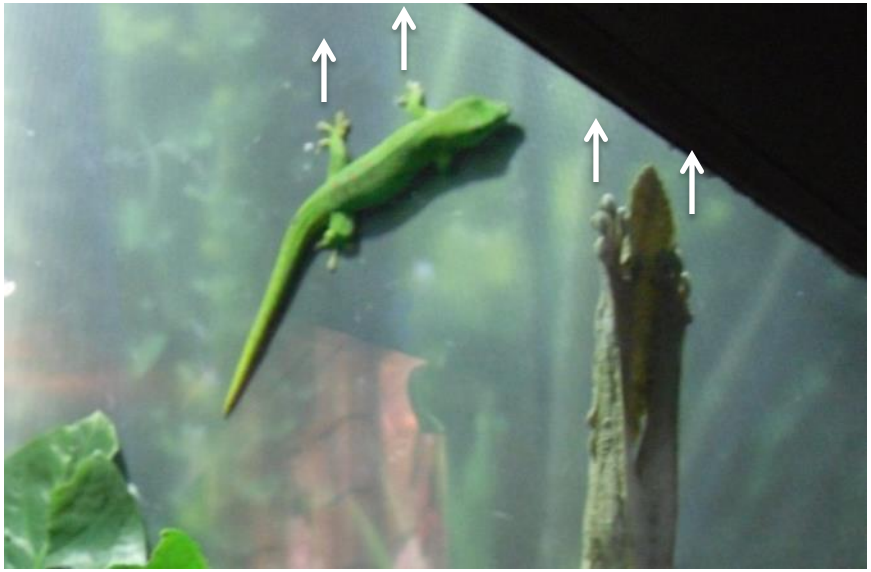
Directionality of the Adhesive

Sticky in one preferred direction

Enables excellent wall climbing performance, but uses gravity to engage the adhesive

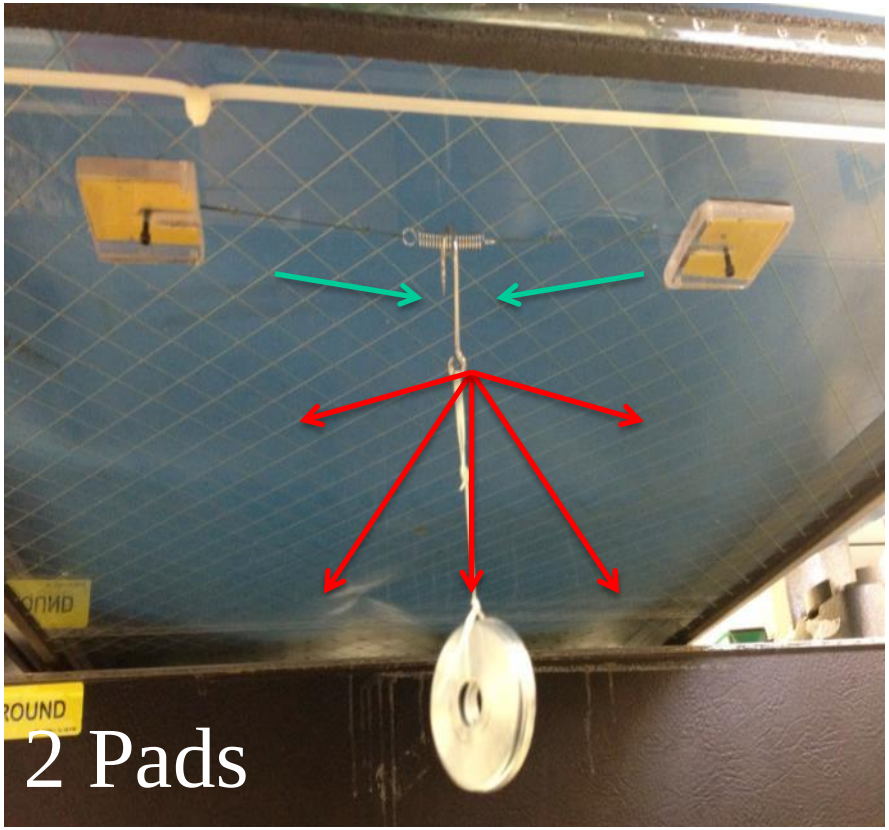
Will it work in zero gravity?

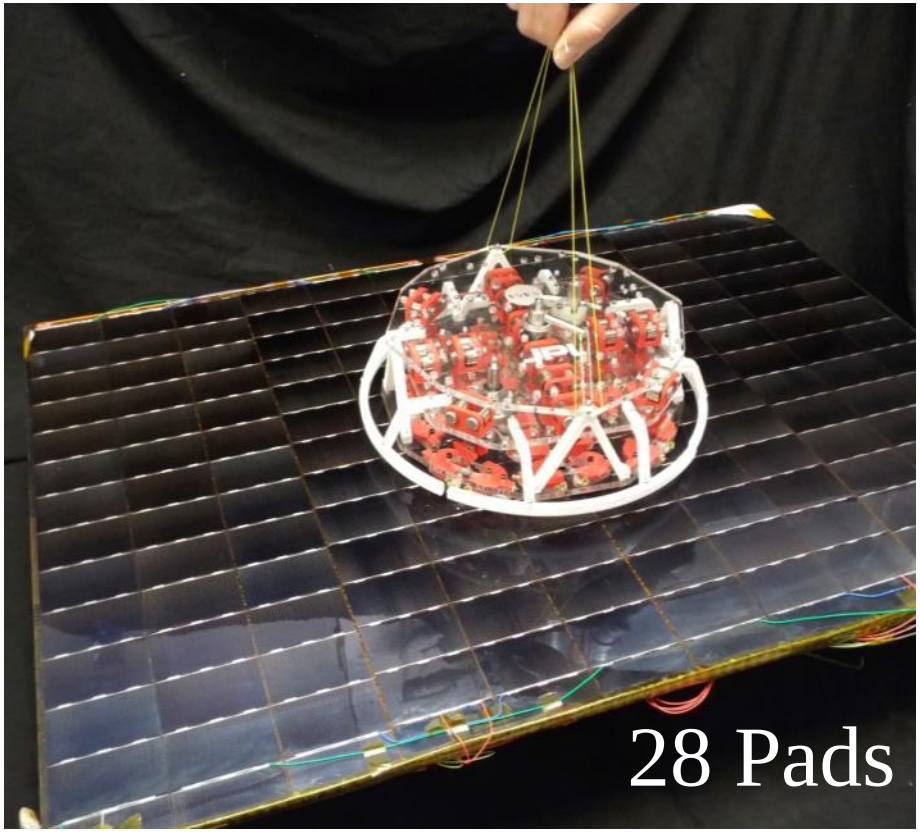


Using Gecko Pads in Opposition

Gecko adhesives are sticky in one preferred direction.

By placing multiple pads in opposition, we create omni-directional ON/OFF stickiness.





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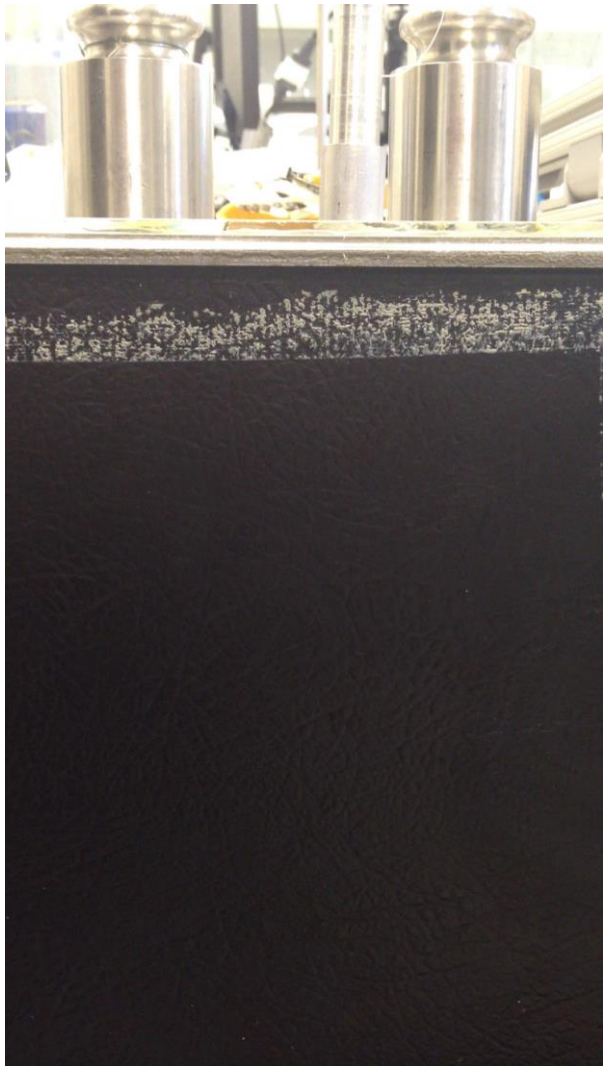
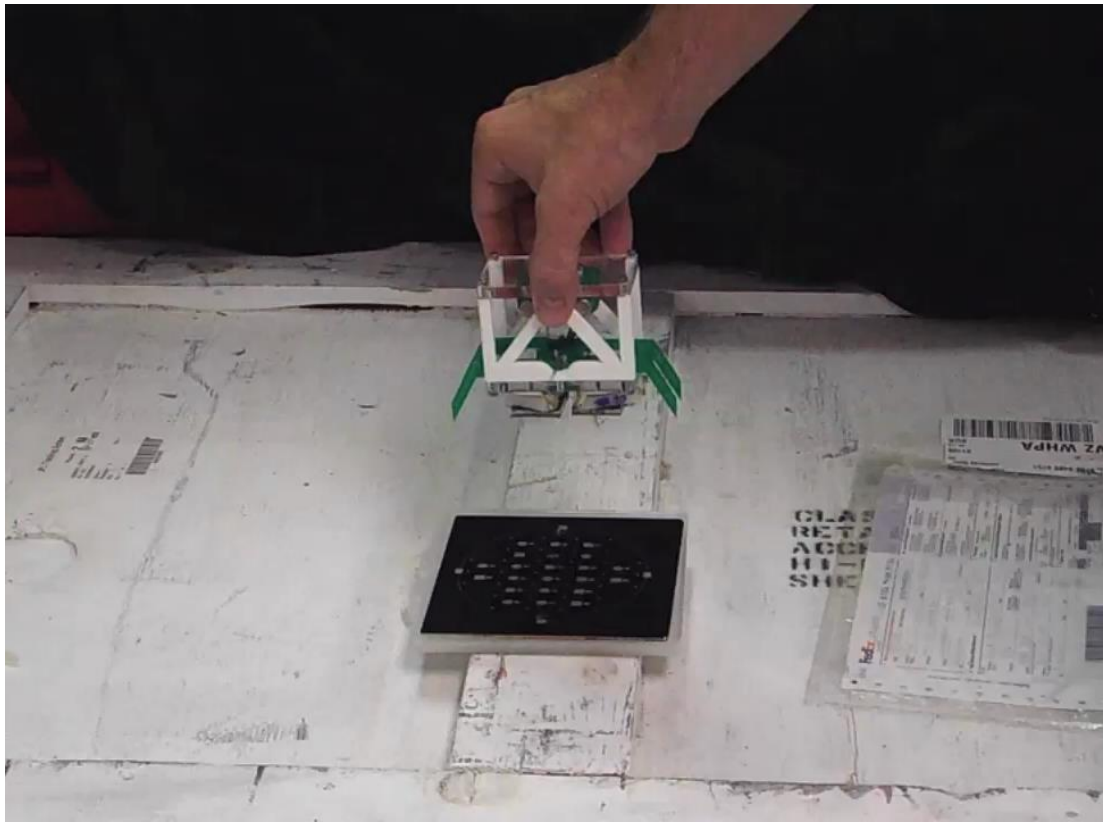
Two Pad Grippers

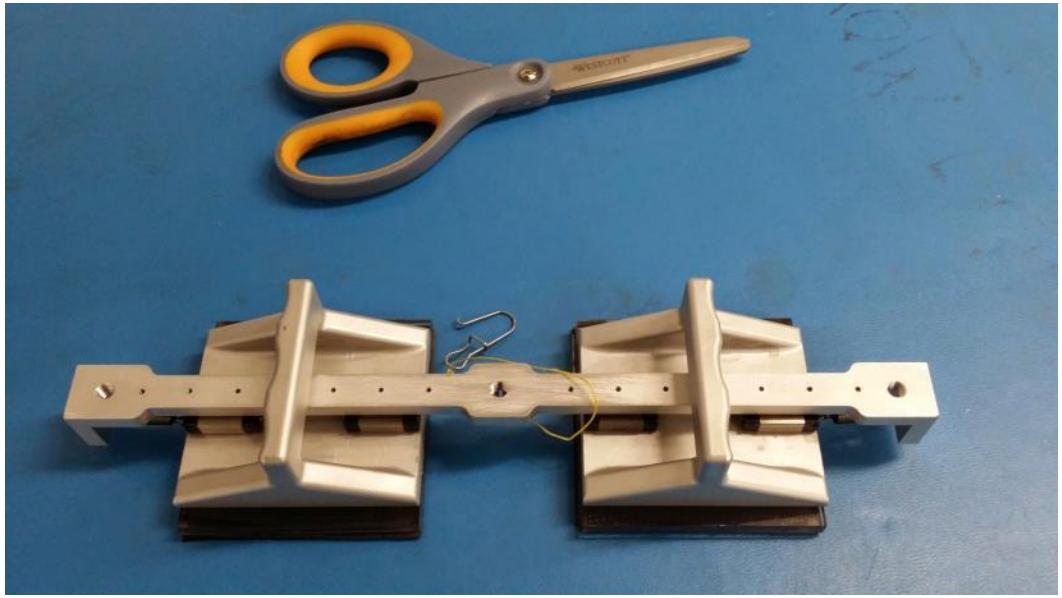


A pinch load between the pair of pads for ON, and released for OFF.



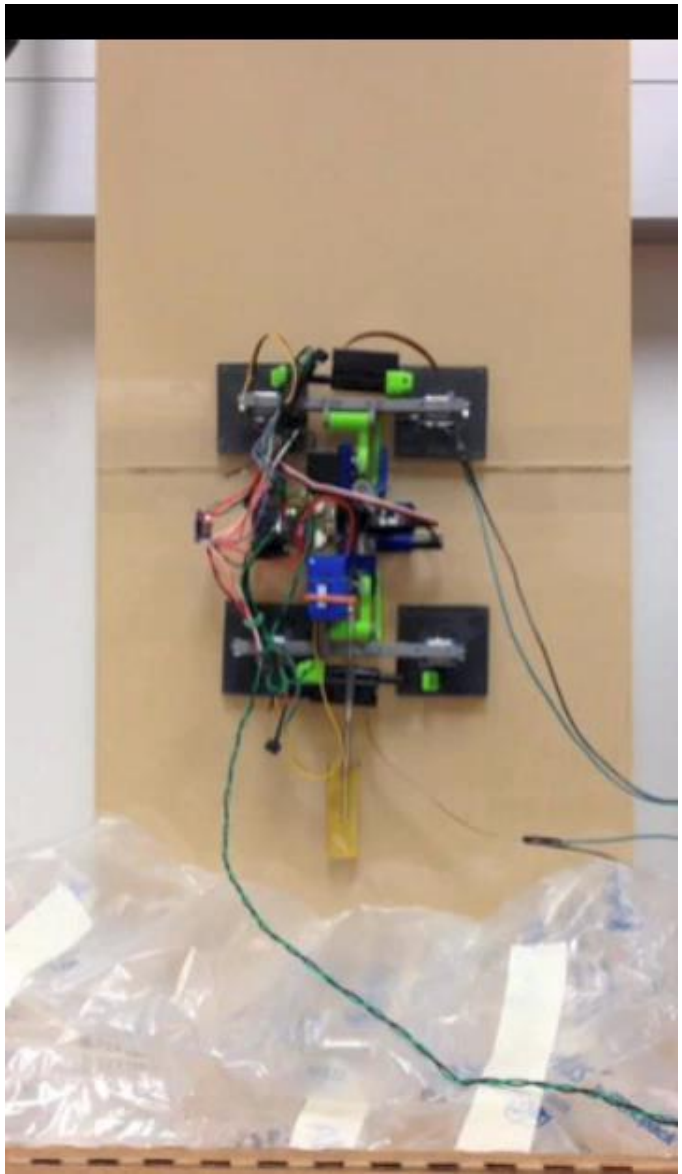
Astronaut Anchors

Astronaut Anchors

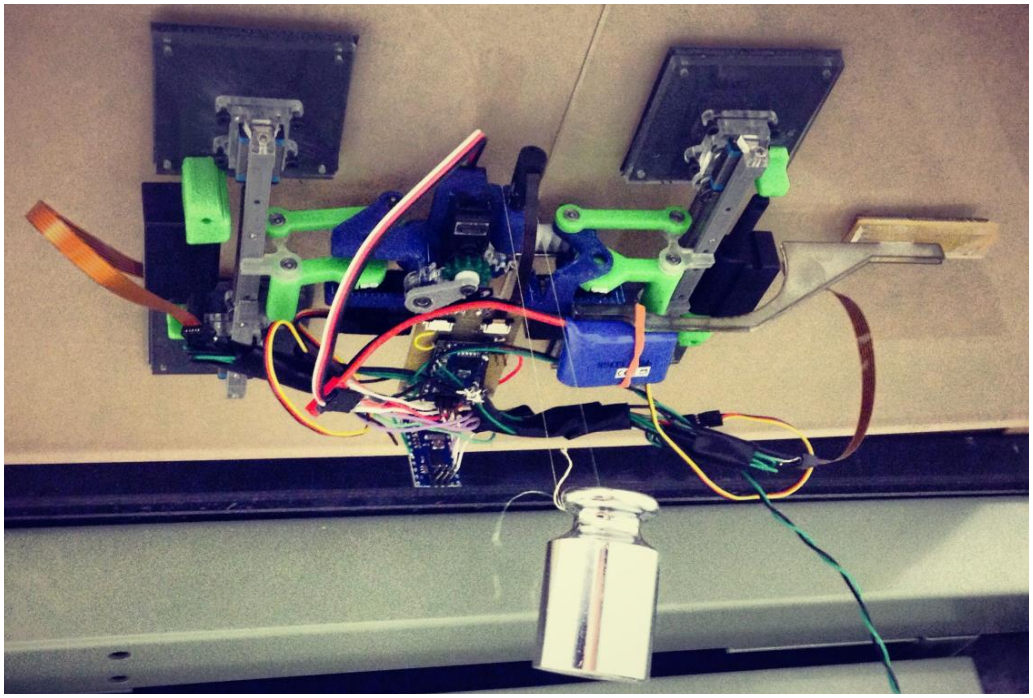


- One hand operation
- Provide mount points for cameras, sensors, work lights, clipboards, tablets, or other tools
- Unpowered
- Long life (> 1year)

Hard to Access Areas: "ACROBOT"



- Climb in any direction
- Transition between planes
- Maneuver through < 1.5" gap
- Carry sensor payload



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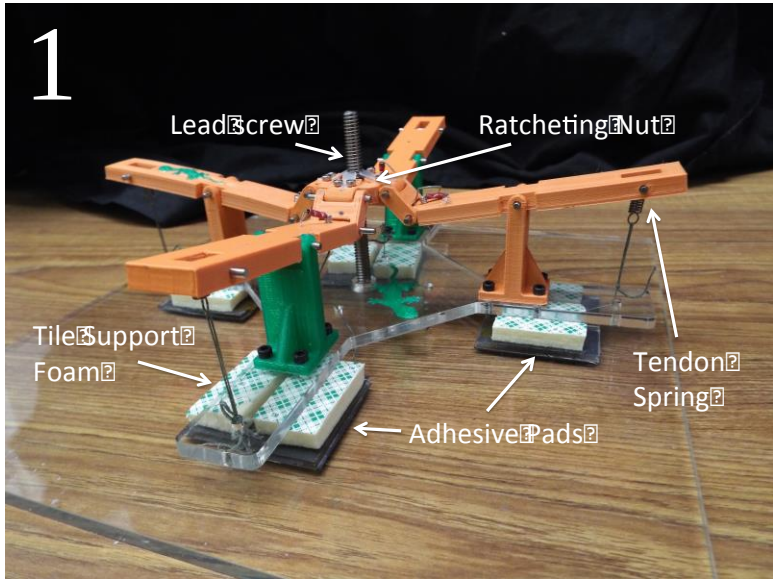
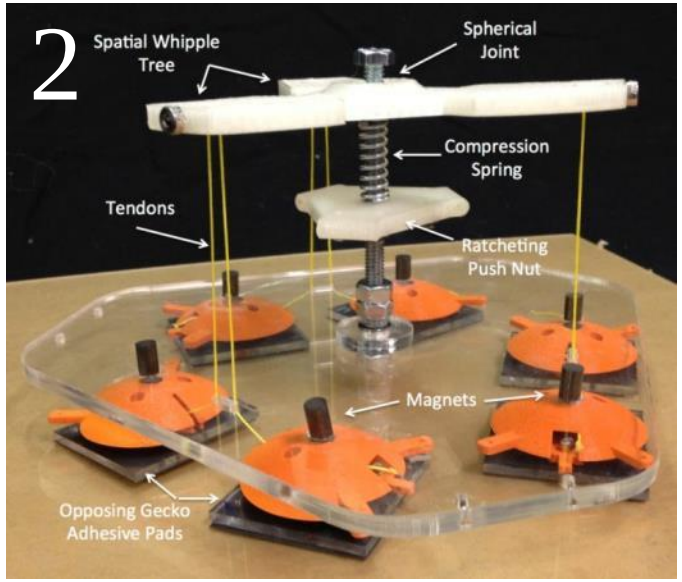
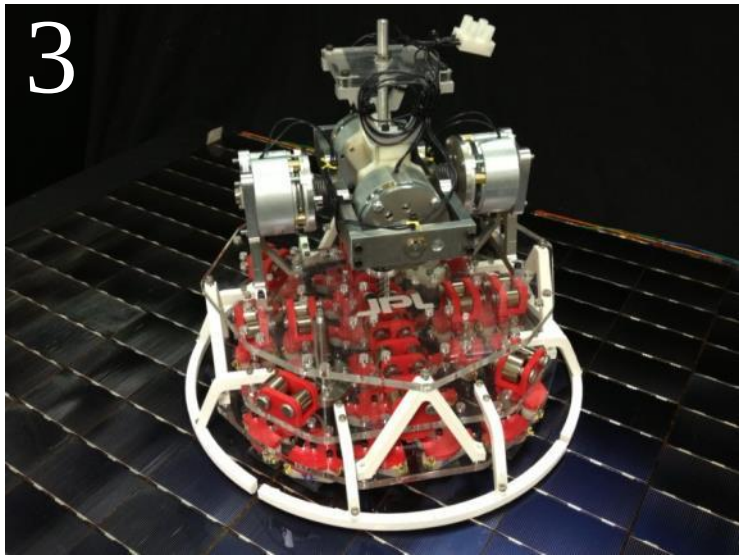
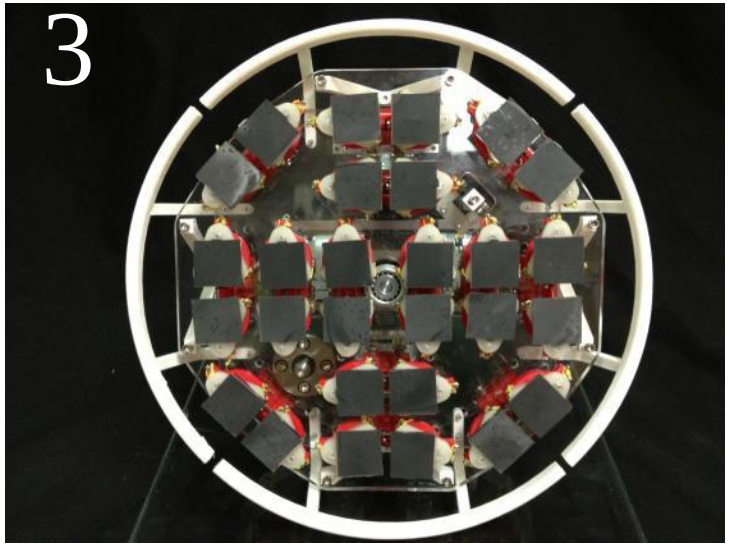
Improving Grippers Through Iterative Design and Testing

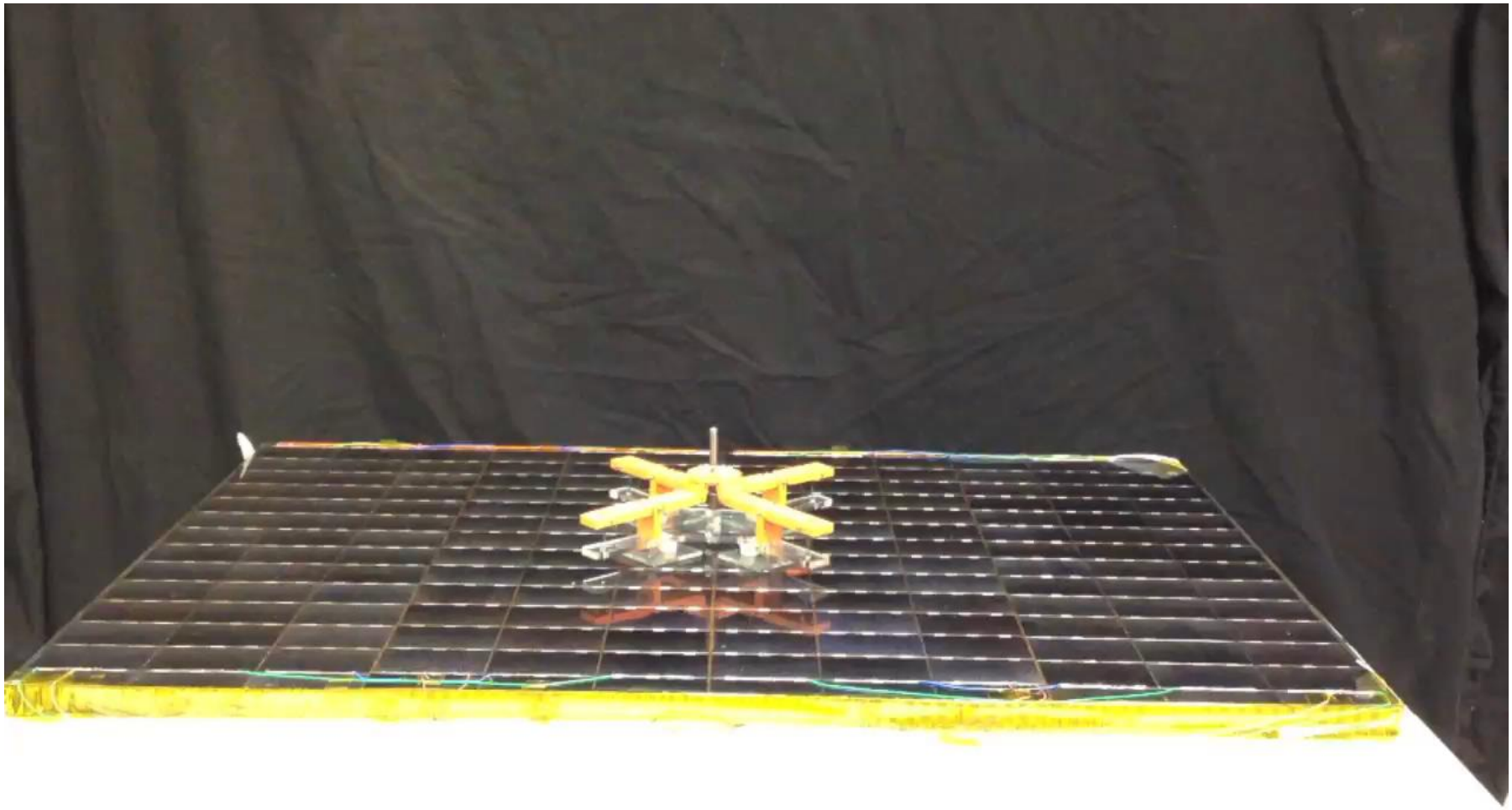








Design Style 1: Ratcheting Anchor



Design Style 1: Ratcheting Anchor

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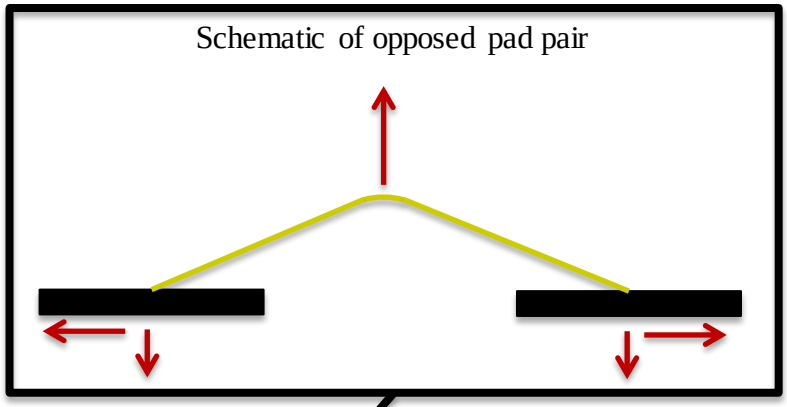
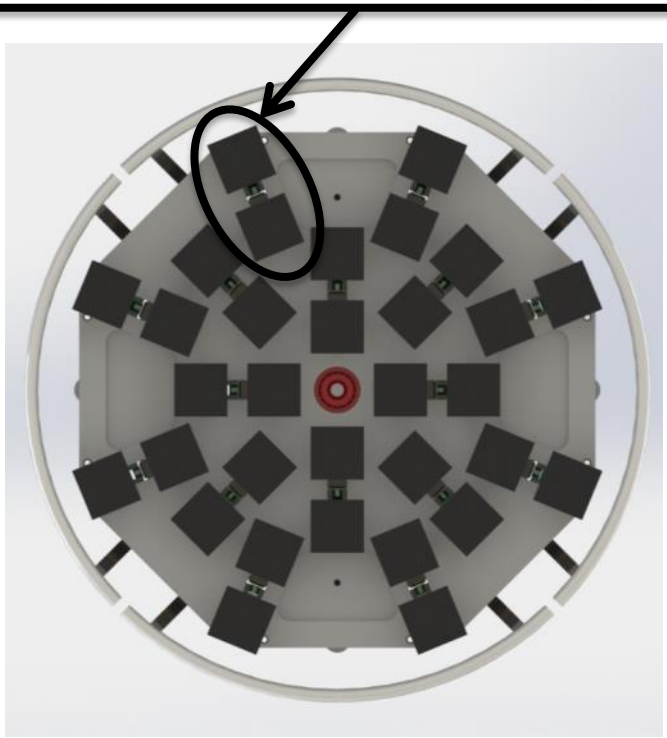
Design 3: Parallel Pairs Gripper

- Pairs of gecko adhesive pads loaded in opposition
- Pads loaded with tendons to always pull through the center of the pad without inducing moments
- Radial pattern of 16 pairs of opposing pads.
  - Each pad is 6.5 cm^2 (1 in^2)
- Adjacent pad pairs provide local tension in order to anchor to soft-goods
- Distribution of pad pairs provides robustness to anchoring
  - "rip-stop" feature in case of individual pad anchoring loss
  - Handles discontinuities and edges



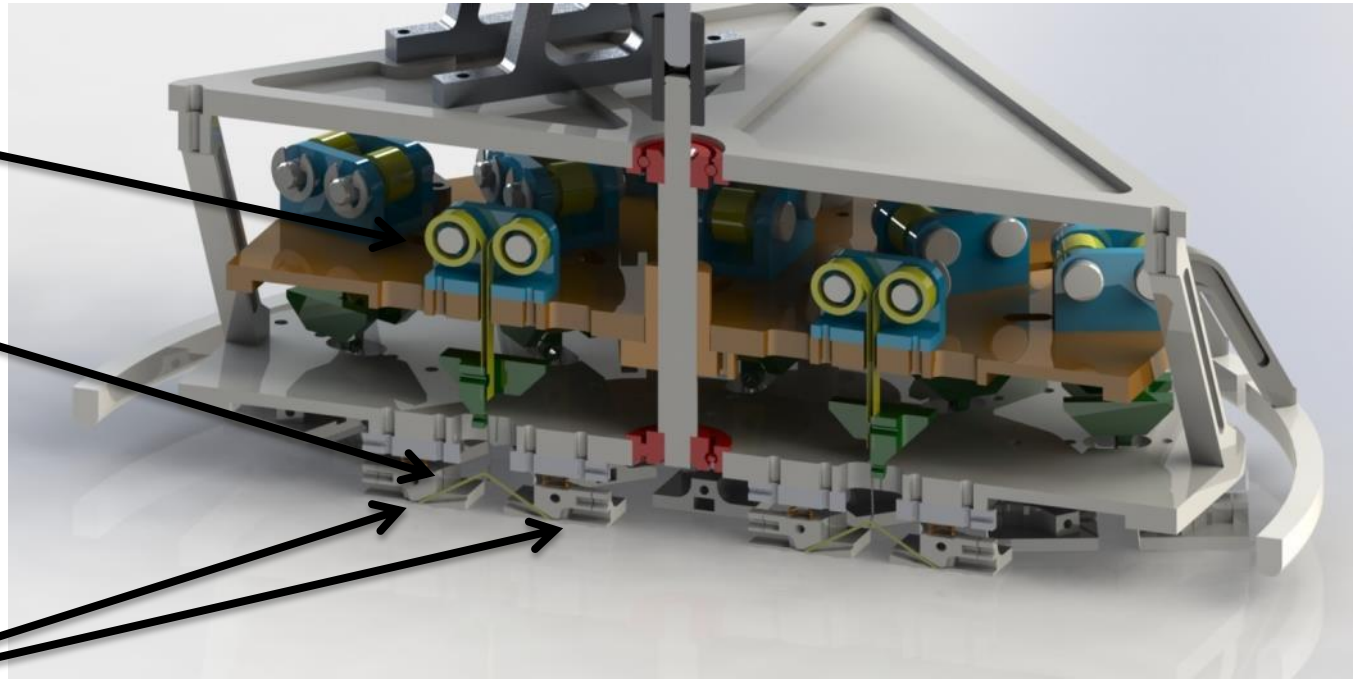


Cutaway View

Tendons loaded with constant force springs to decrease dependence on pad alignment and manufacturing tolerances

Constant force springs

Tendon



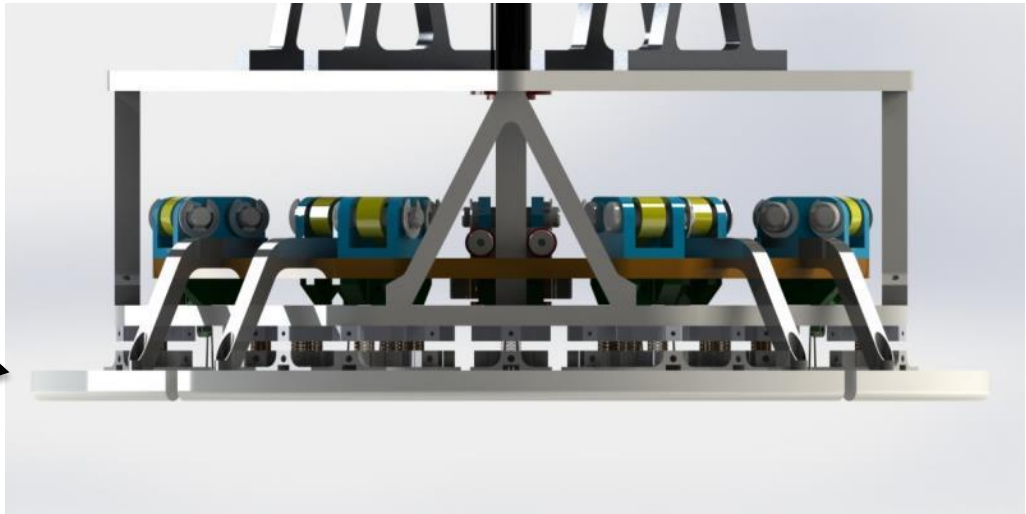
Cross section of mechanism in gripped state

Opposed pad pair

Actuation

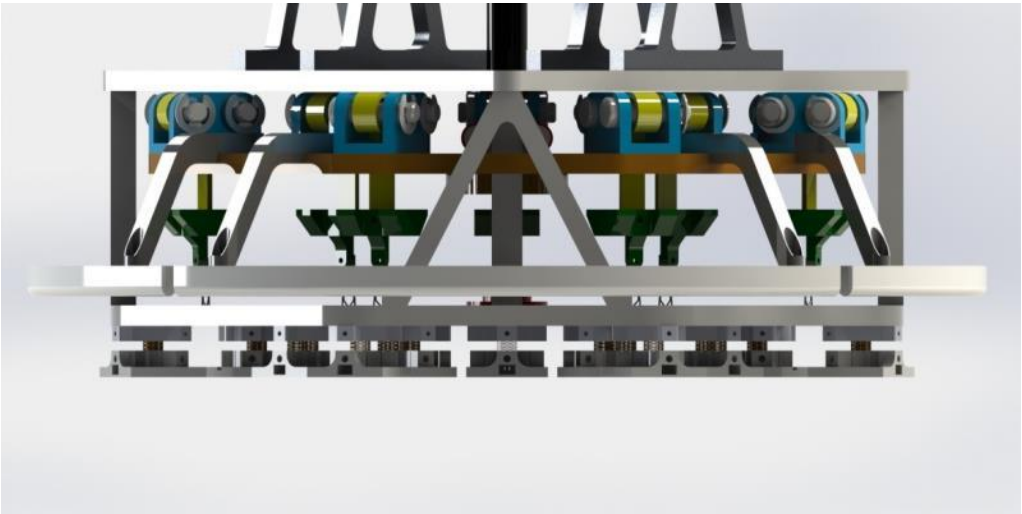
Released State

Outrigger ring in contact with object to be grappled

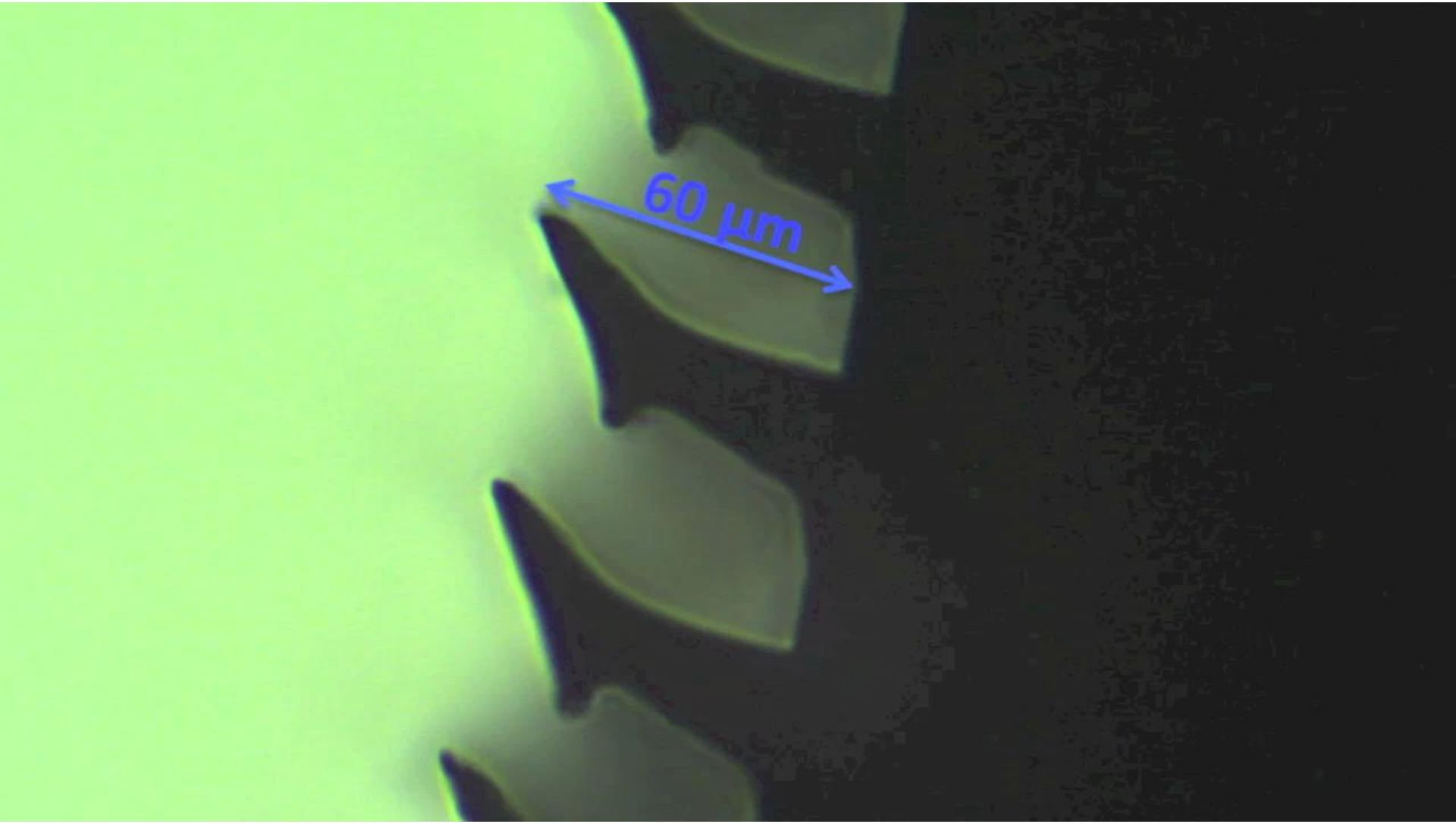


Gripped State

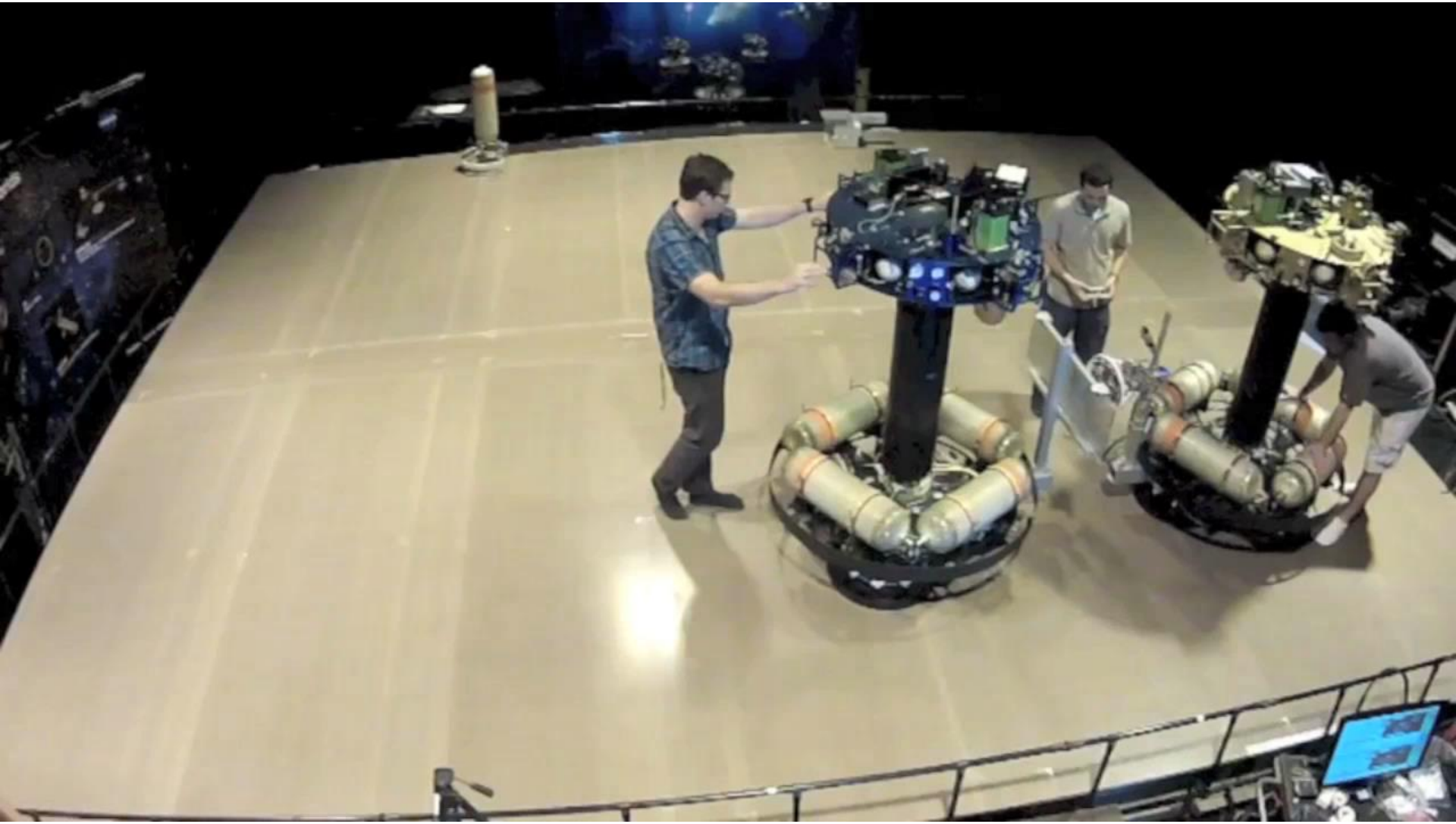
Loading plate and outrigger ring are retracted



Tool Performance Overview



Tool Testing in the JPL Formation Control Testbed



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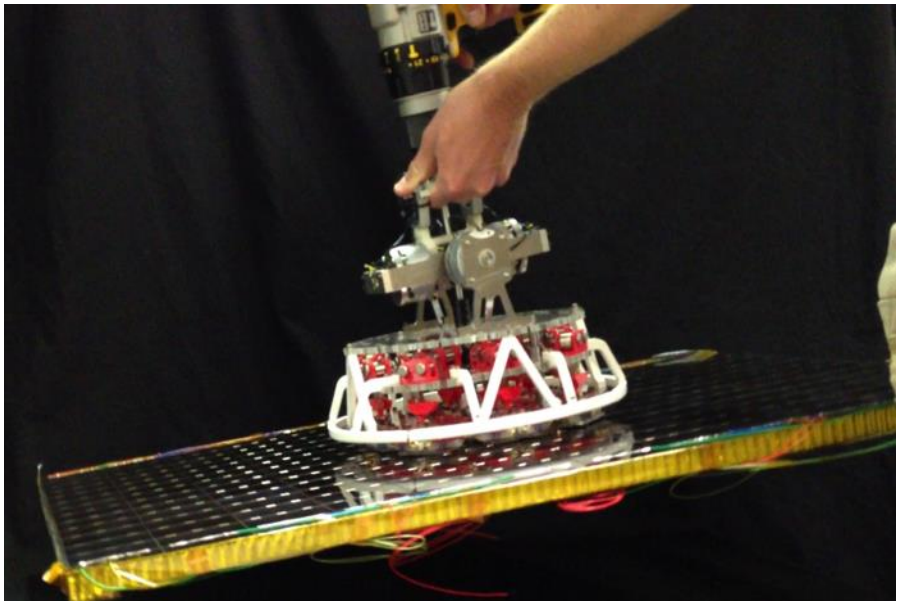
Testing Summary



Adhesive capture head lifting a spare GEO satellite solar panel.

<u>Key Data:</u>

- **Maximum adhesion was >80 N with this tool; maximum shear supported was >115 N**
- **Grips in <0.25 seconds**
- **Reusable 100s of times**
- **Lifetime test of >1 year sticking**

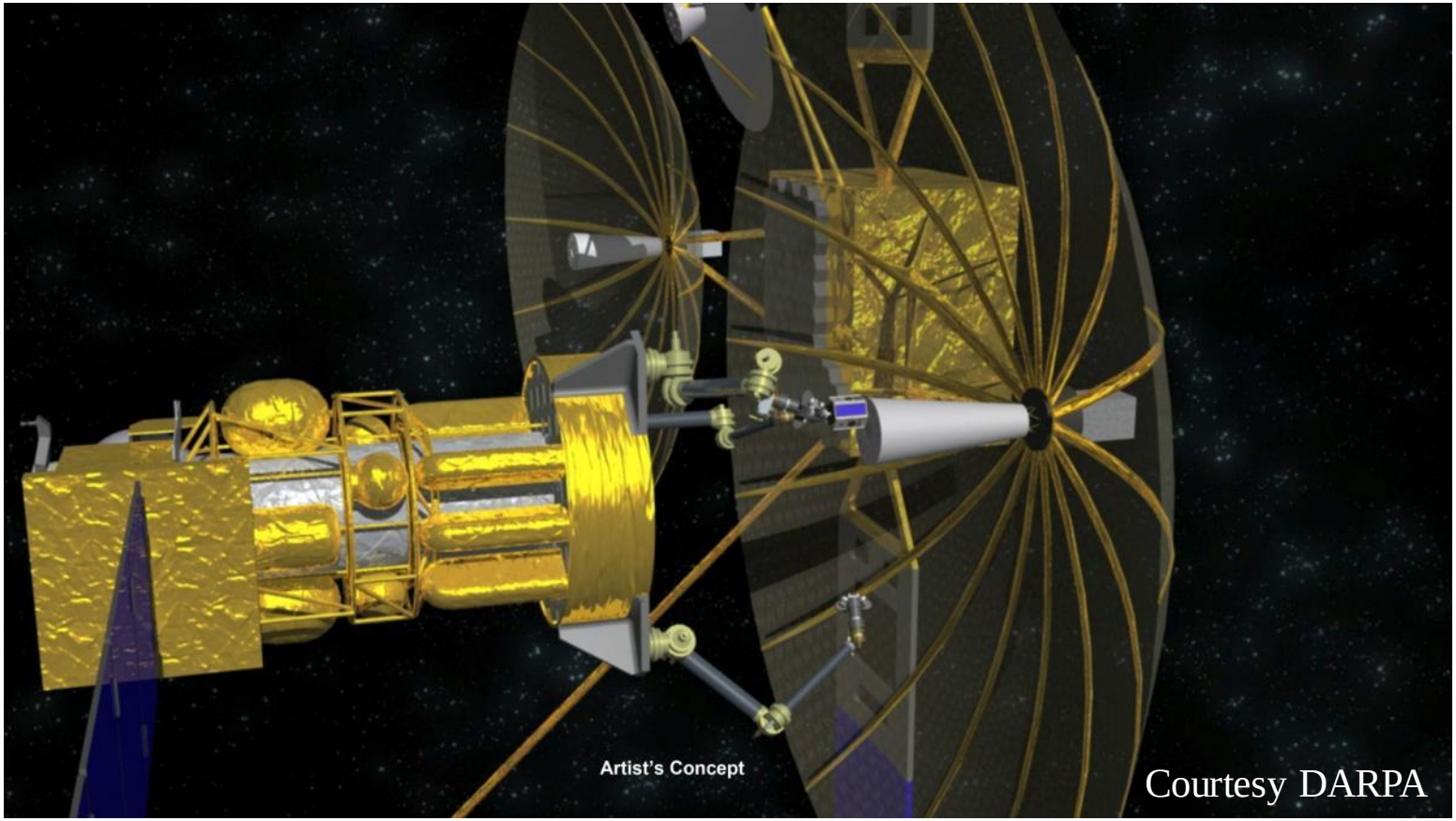
Material	Max Normal Adhesion (kPa)	Shear at Max Norm. (kPa)	Max Shear Adhesion (kPa)
Glass	13.0	44.4	76.3
Graphite M55J Composite from Juno	1.6	1.8	5.7
Gold Kapton from MER	5.8	16.9	31.5
MLI Blanket	1.1	2.4	24.7
Woven Astroquartz	7.3	23.3	43.2
Woven Astroquartz (armalon)	2.4	6.4	16.8
Al 6061 (bare)	3.5	12.0	27.5
Patch Antenna (copper clad)	1.1	1.1	3.4

Tested ON-OFF adhesive on over 30 common spacecraft surfaces to characterize performance

Chamber tested adhesive made from space-rated silicone at vacuum and -60C (193K)

Missions Applications

DARPA Phoenix, NASA RESTORE, RRM Experiment on ISS Hubble Telescope, …



Courtesy DARPA

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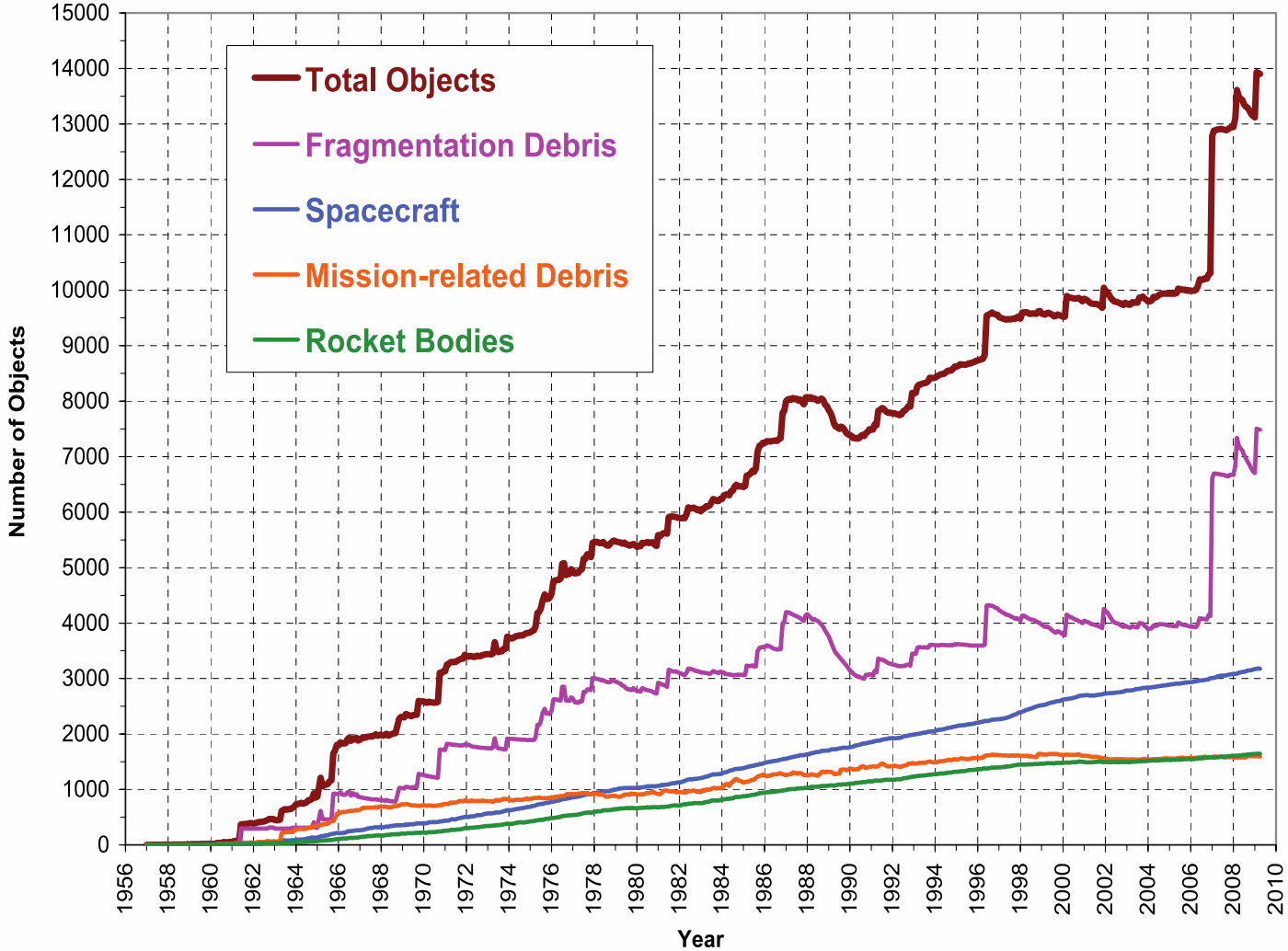
Orbital Debris Mitigation



J. Liou, Johnson Space Center "Orbital debris quarterly review," pp. 1-10, Apr 2009.

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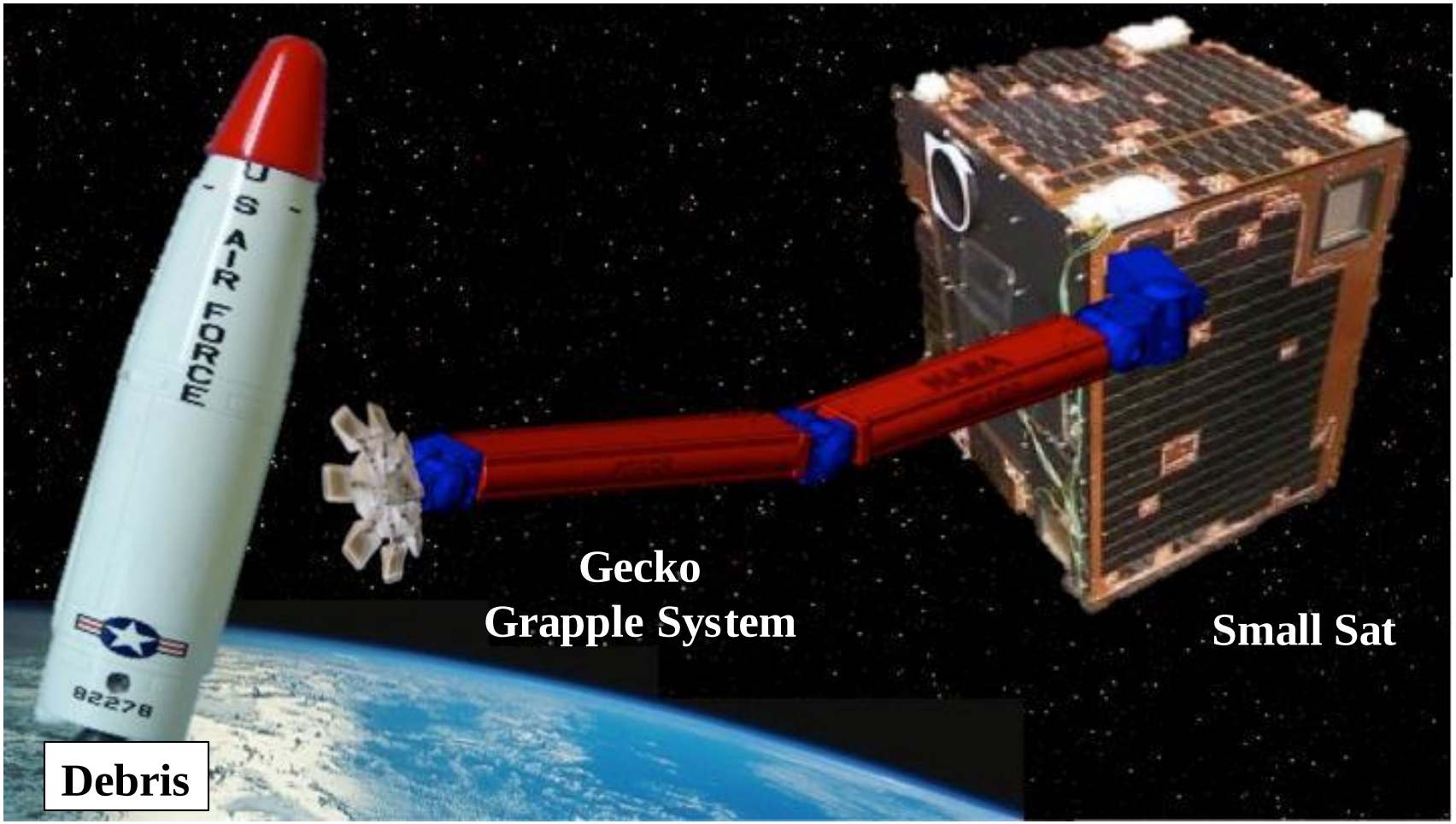
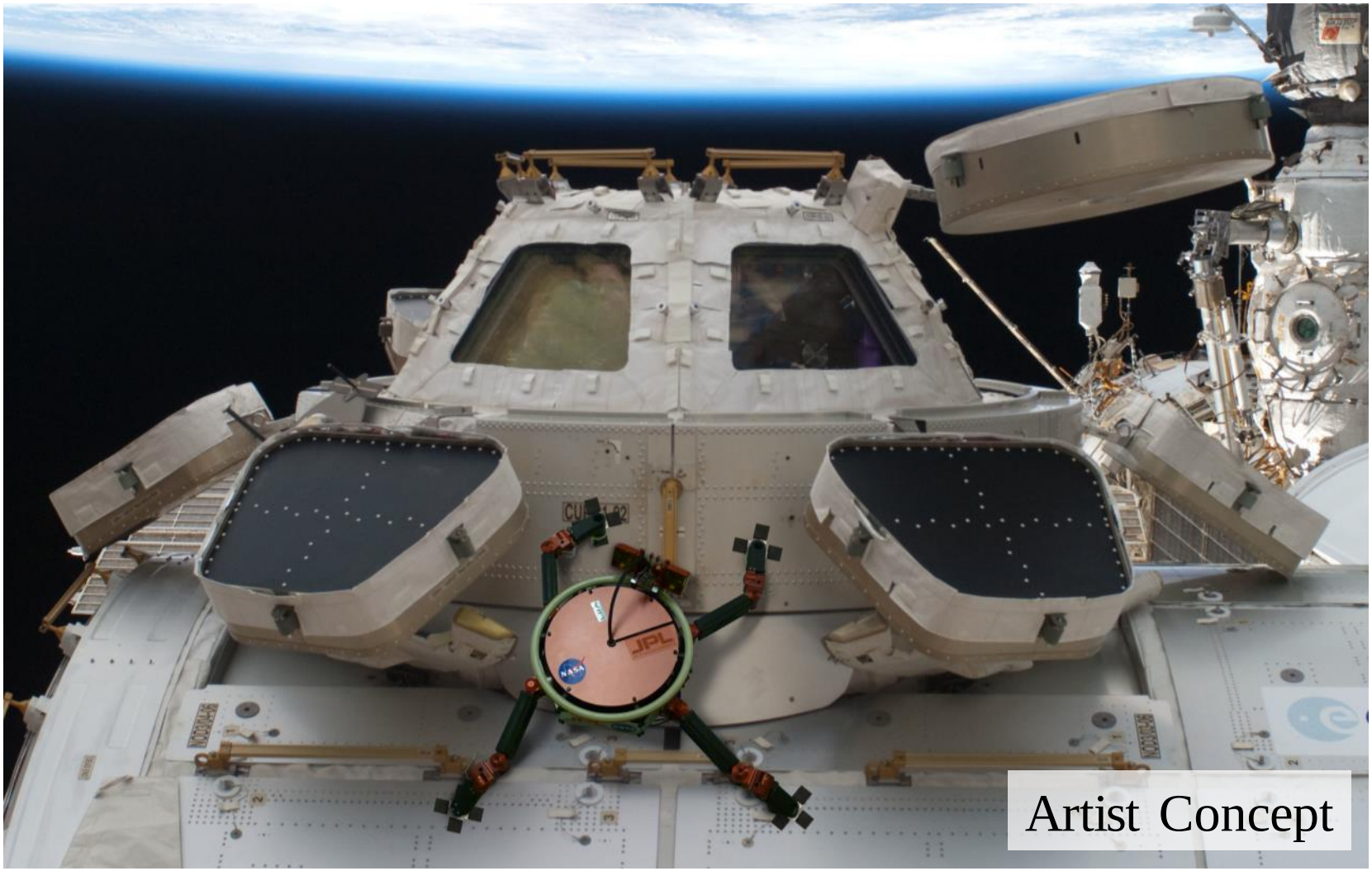
Grappling a Non-Cooperative Target By Virtually Any Surface



Implemented as an end-effector on a robotic arm

Inspection of Spacecraft and the ISS



Implemented as an end-effector on a robotic arm

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Co-Contributors:

Matt Heverly, Evan Hilgemann, Dan Copel, Nick Wettels, Tyler Hilgendorf, Victor White, Brett Kennedy

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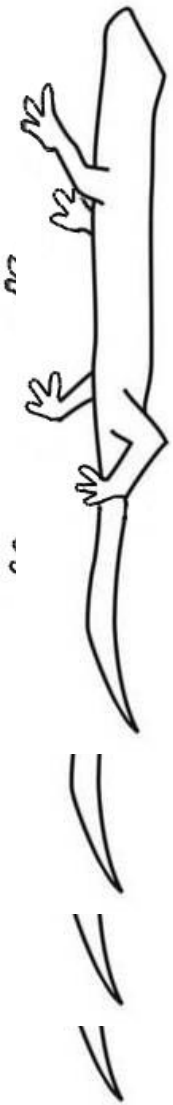

QUESTIONS

BACKUP

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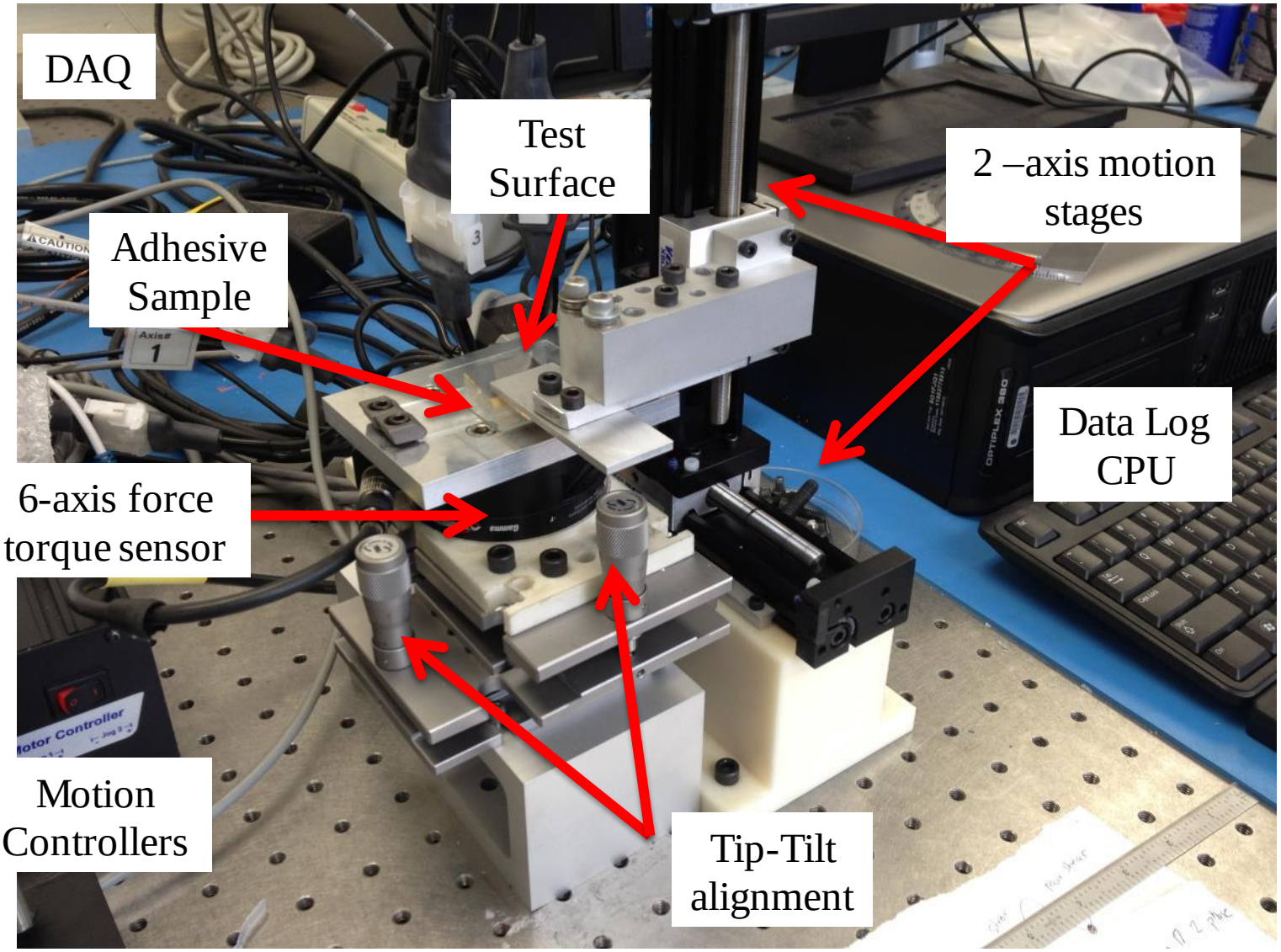
Test Setup



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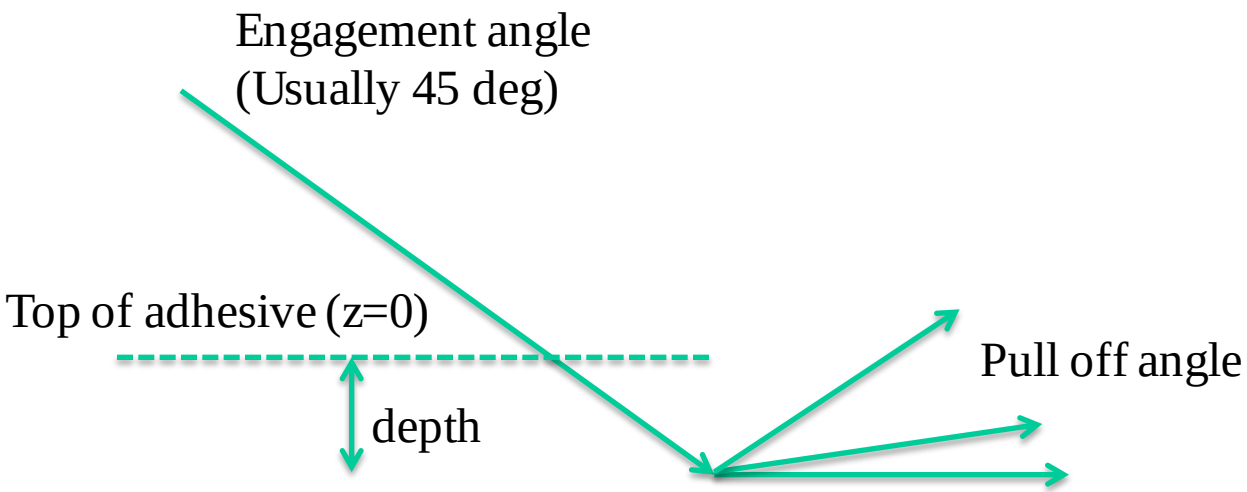
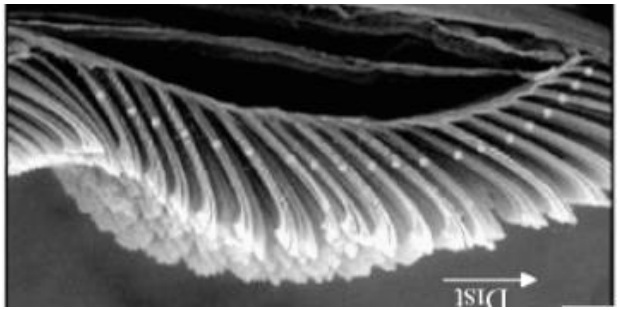
Example Trajectory



HIGH ADHESION &
SHEAR



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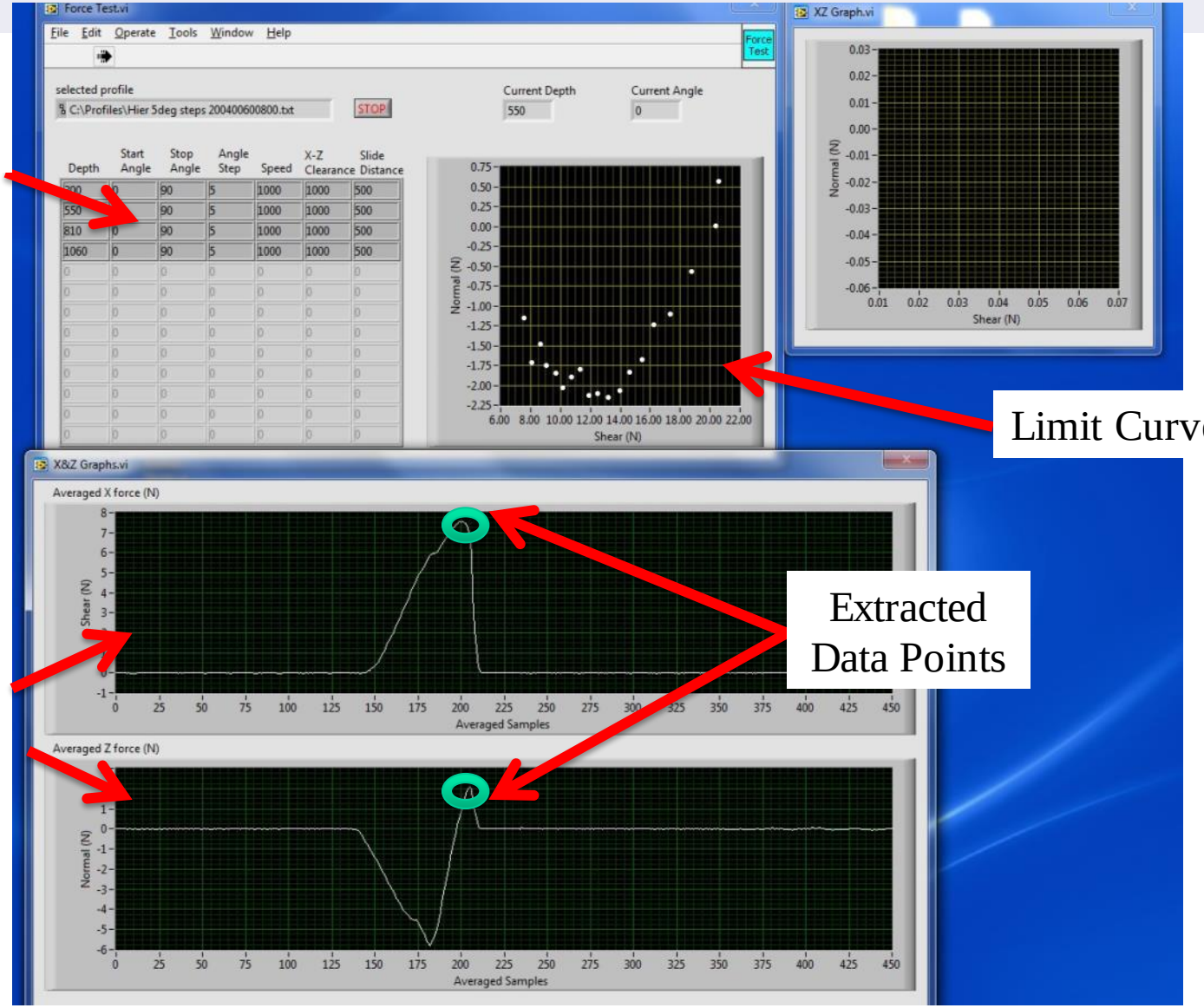
User Interface

Motion Trajectories



Limit Curve

Extracted Data Points

Force Time Traces

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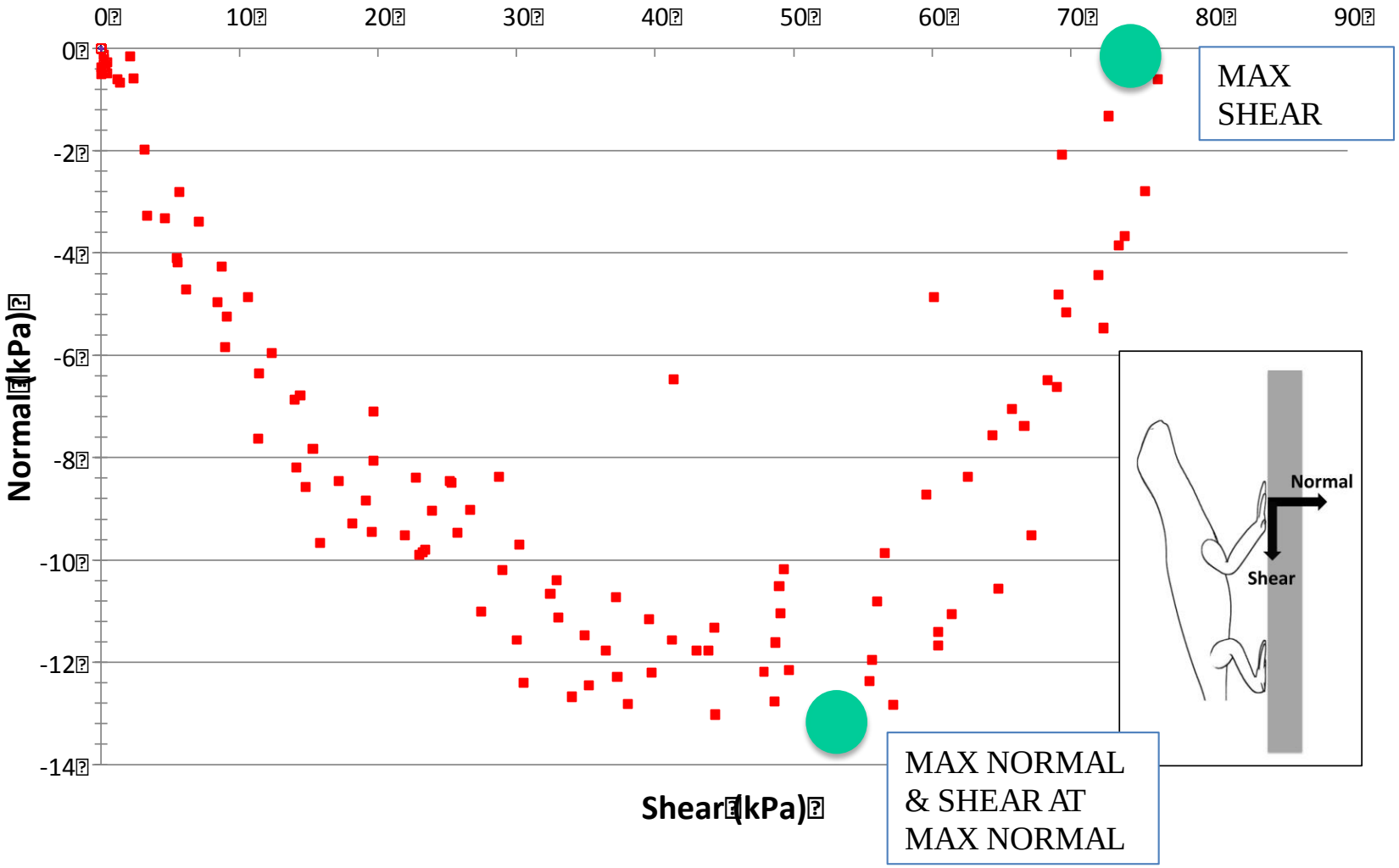
Synthetic Gecko
Adhesive Directional Behavior



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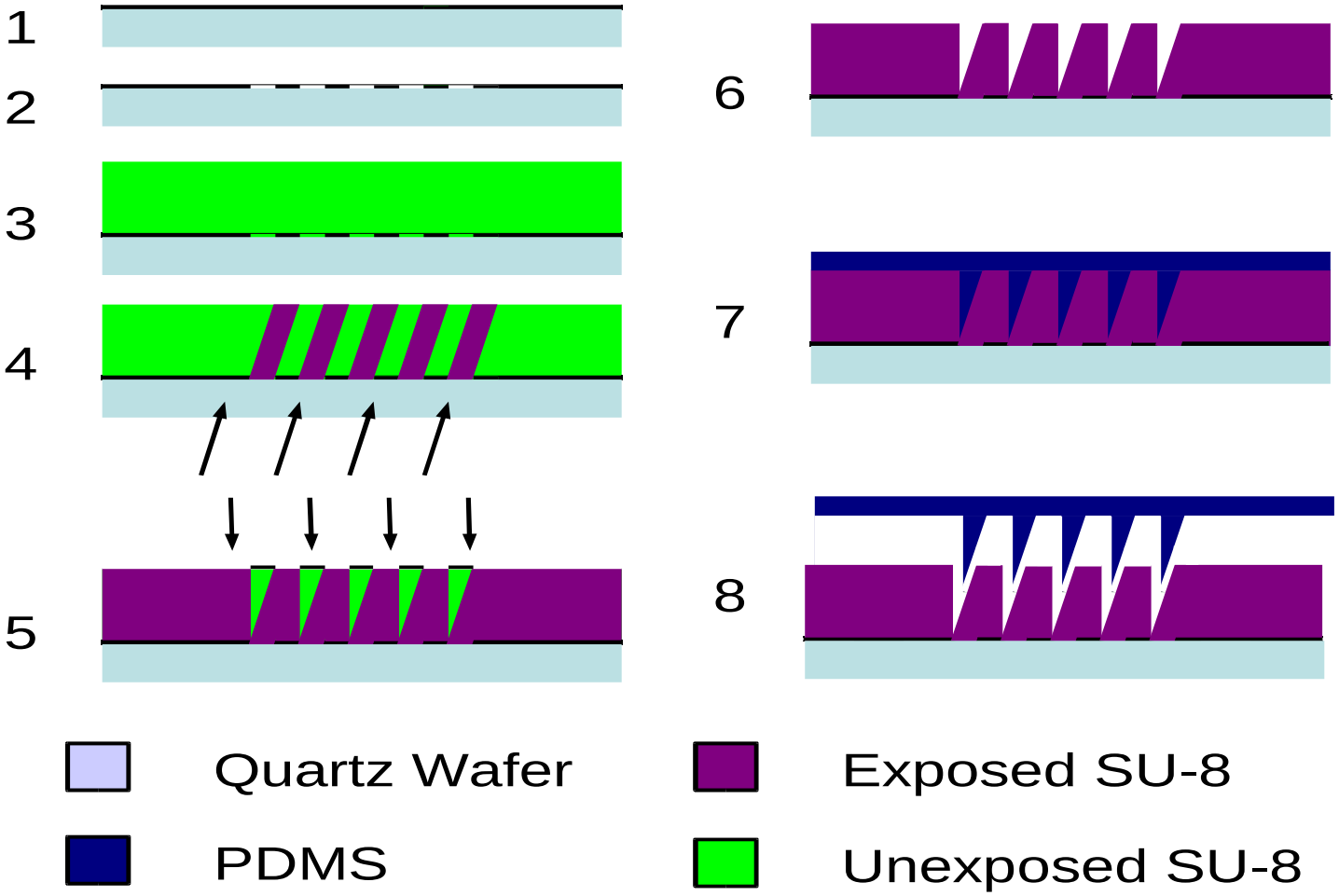
Fabrication of Microstructure



Curved Surfaces and Misalignment

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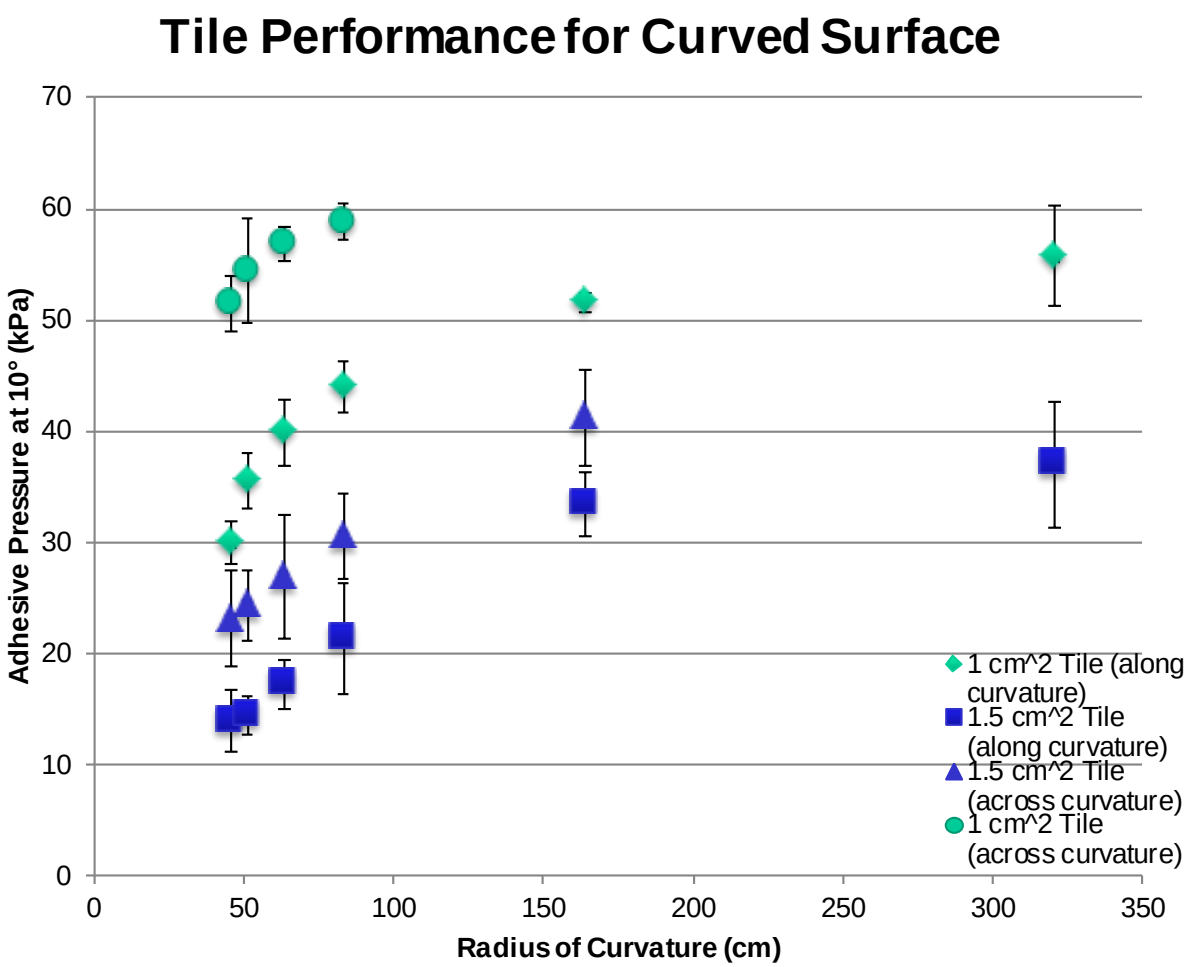
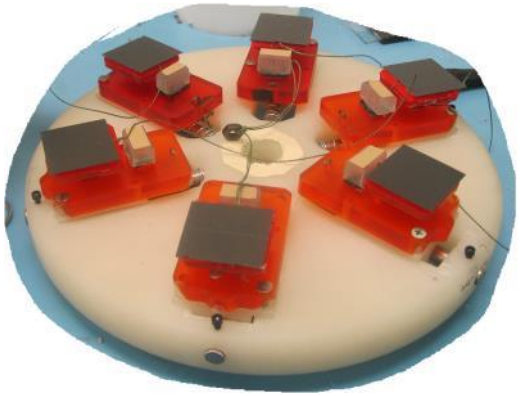


Gripping flat plates with misalignment



Gripping cylinders
1 m dia. – 3N
3 m dia. – 6N