Geometry Characterization of Electroadhesion Samples for Spacecraft Docking Application

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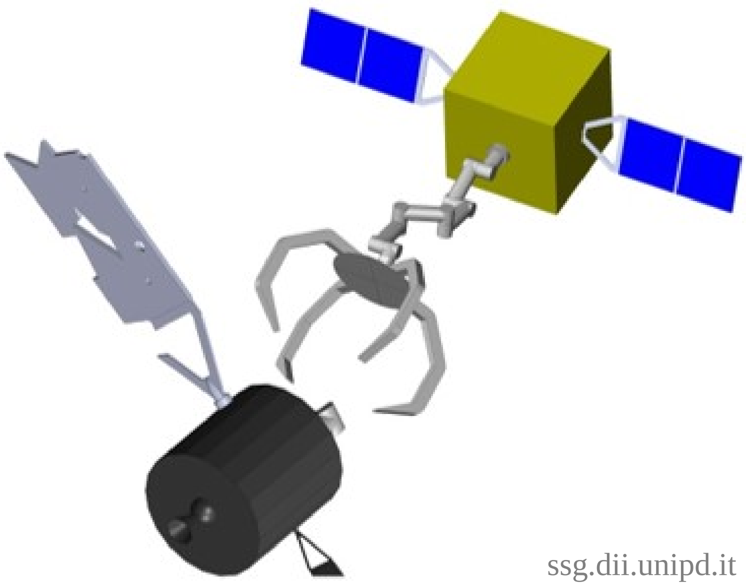
Motivation

Docking mechanisms are essential in space missions. Determining a low-risk, low-cost alternative to past docking techniques advances the frontier of space technology.



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Research Objective

Study maximum shear forces of Electroadhesion samples composed of space-rated materials on substrates, test geometries of samples with air-bearing platforms as docking mechanisms, and propose a metric for capturing.

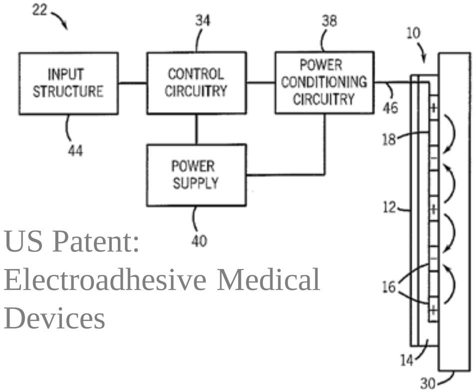
Introduction

Applications of Electroadhesion

Industrial

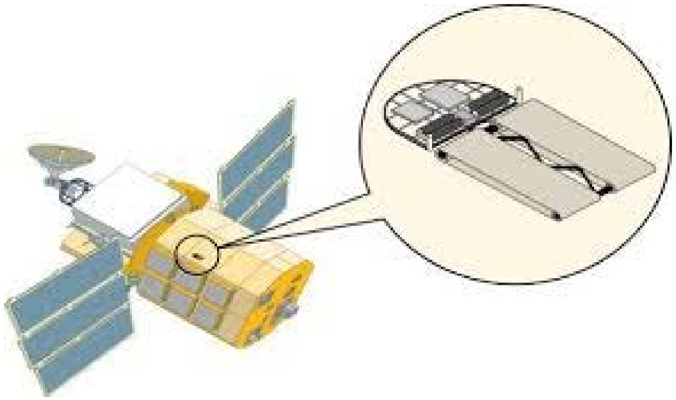
Military

Biomedical

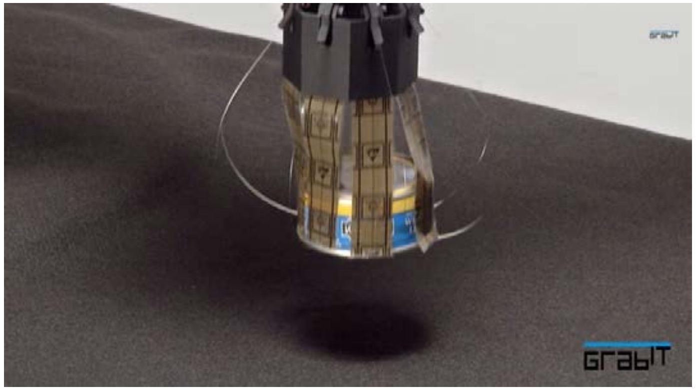


US Patent: Electroadhesive Medical Devices

Space



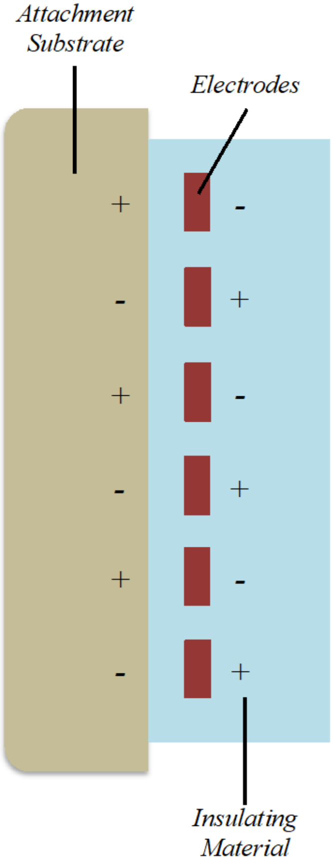
Consumer



Introduction

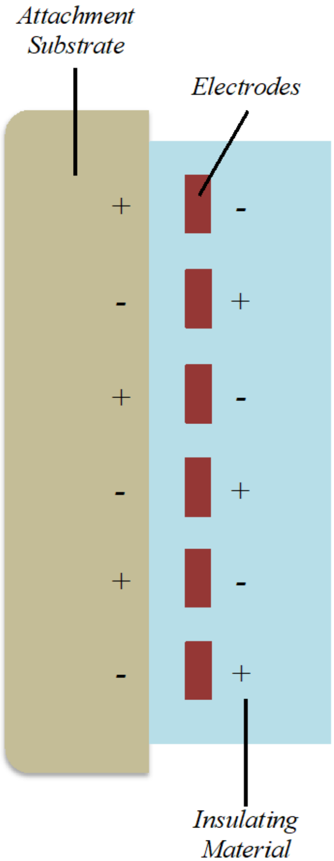
Electroadhesion Technology

Cross-Sectional View:

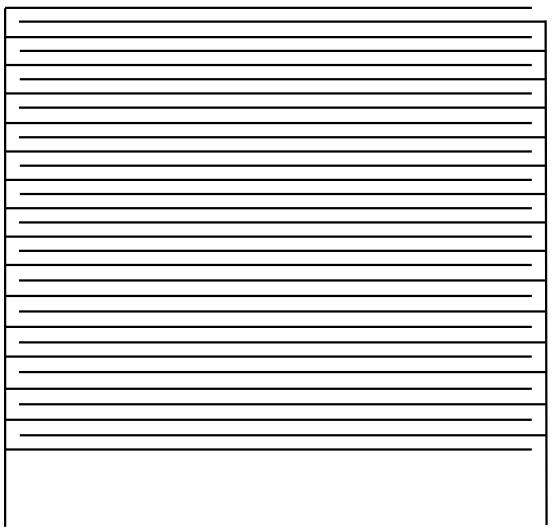


Electroadhesion Technology

Cross-Sectional View:

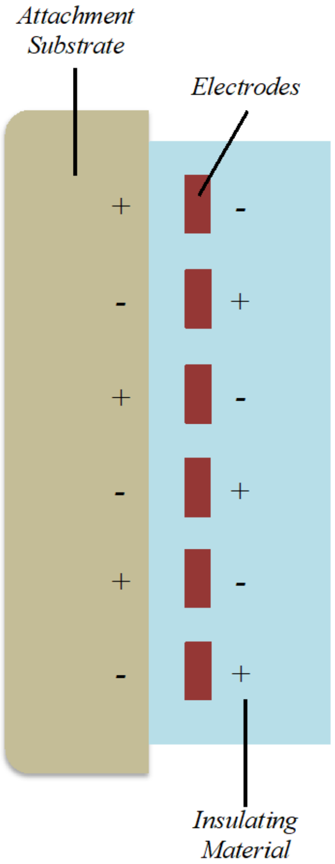


Top View:

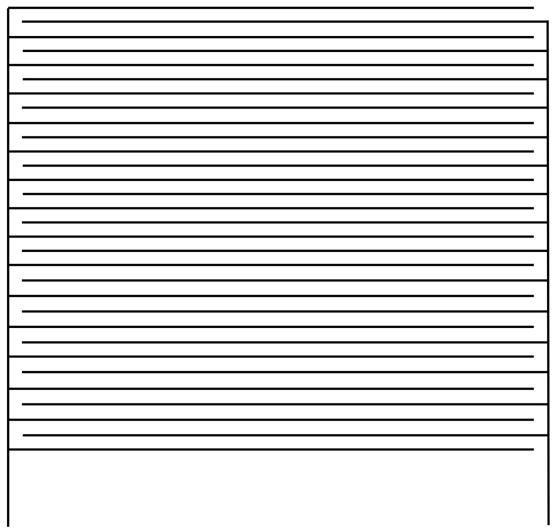


Electroadhesion Technology

Cross-Sectional View:



Top View:



Governing Equations:

$$P_N = \frac{\varepsilon_0 \varepsilon_C e^2}{2(2d)^2}$$

$$P_S = \mu_S P_N$$

ε_0	Dielectric Constant of Vacuum
ε_C	Dielectric Constant of Kapton
e	Applied Voltage
d	Kapton Thickness
μ_S	Coefficient of Static Friction

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Materials and Method

- Measure maximum shear forces of Electroadhesion samples at variable input voltages (1 kV – 5 kV)
- Configure samples into proposed geometries and test with air-bearing platforms
- Materials
  - Electrode Material
    - Heavy Duty Aluminum Foil
  - Substrate Materials
    - Anodized Aluminum
    - Bare Aluminum
    - Aluminized Mylar
  - Clamping (Insulating) Material
    - Kapton

Static Response

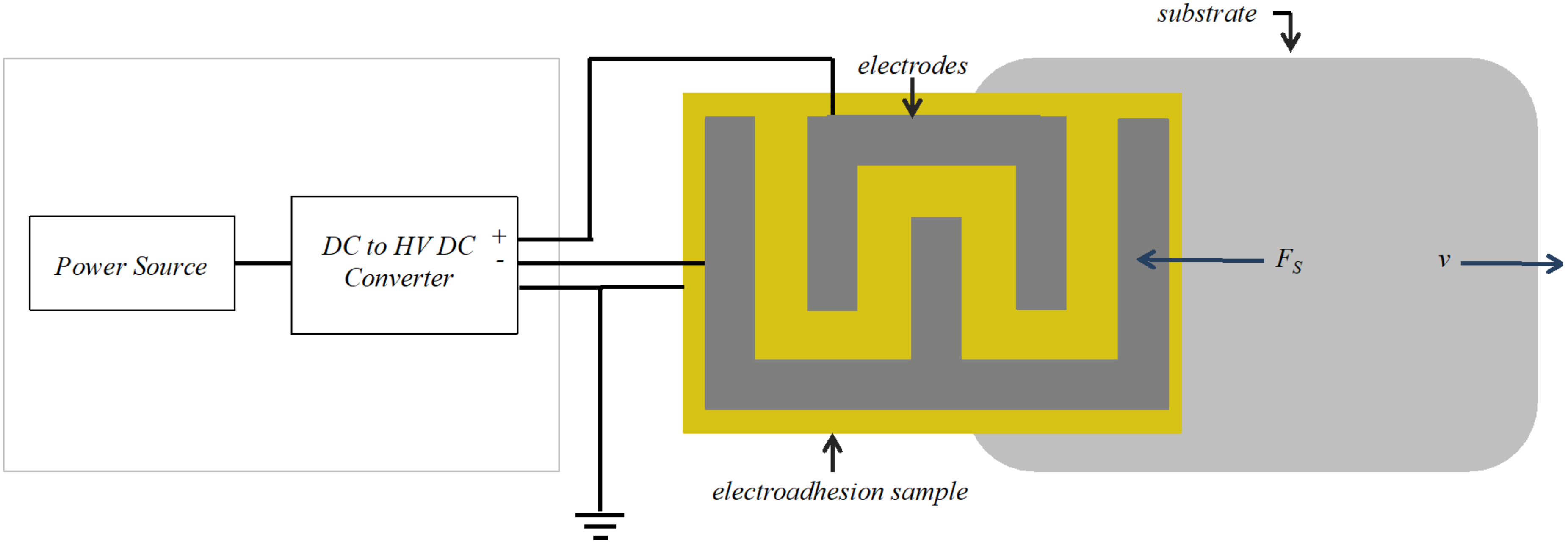

Figure 1: Experimental setup of electroadhesion sample attached to substrate with measured shear force.

Experiment

Dynamic Application

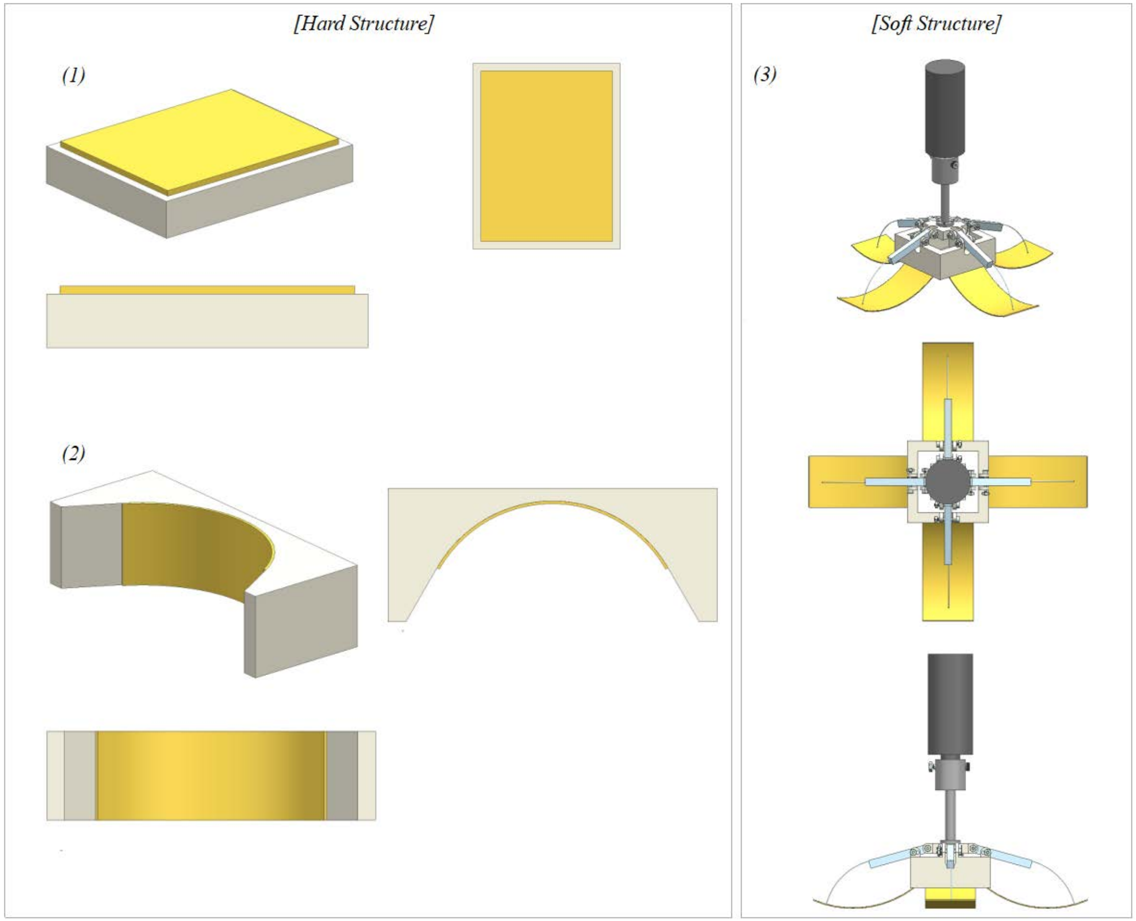

Figure 2: Geometry configurations of samples.

(1) Flat Plate
- Cubesat
- Flat Spacecraft Side

(2) Concave Cylinder
- Cylindrical Spacecraft
- Torque Mitigation

(3) 4-Arm Clamp
- Variety of shapes on Spacecraft
- Other small objects

Experiment

Dynamic Application

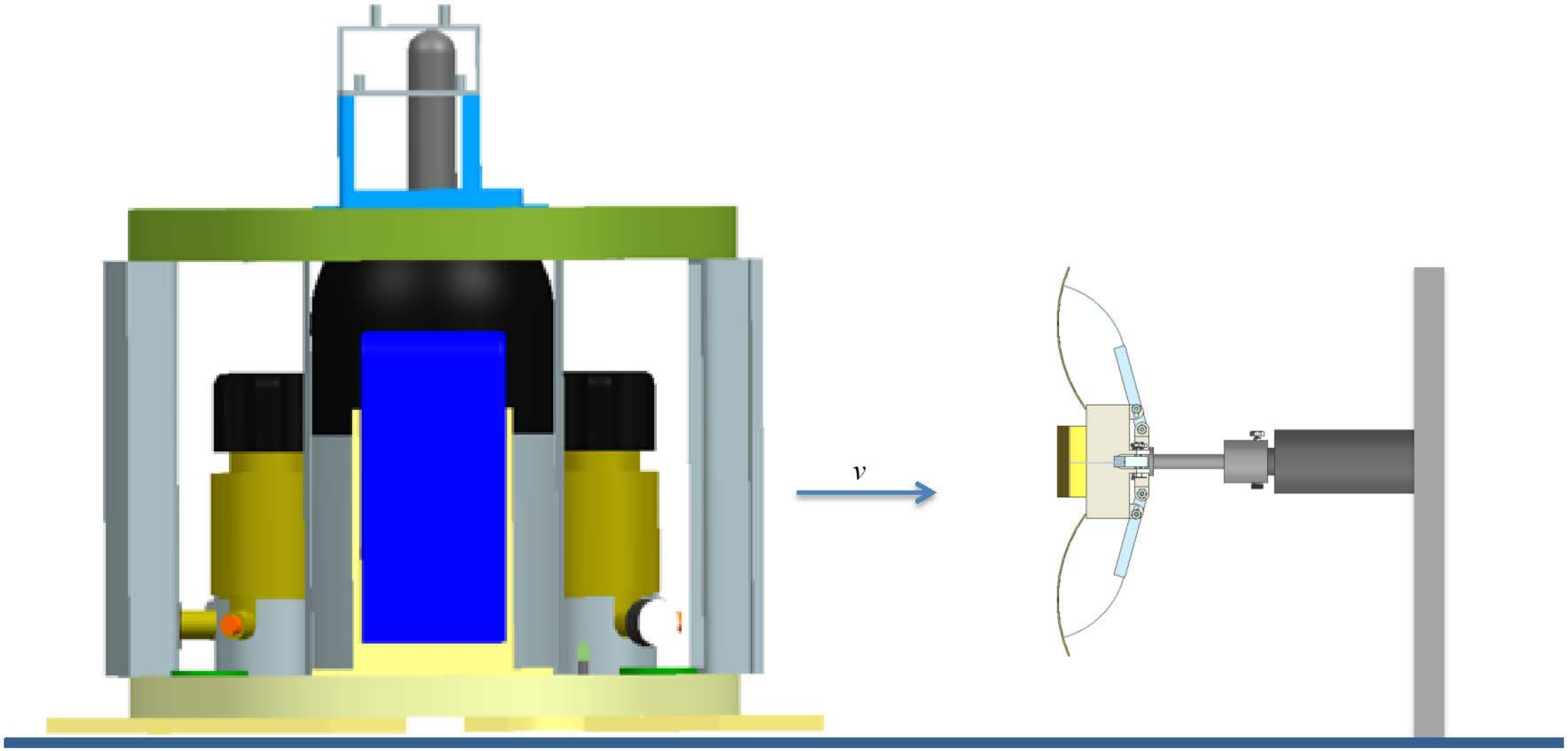

Figure 3: Experimental setup of air bearing platform with attached substrate and electroadhesion device of geometry (3).

Experiment

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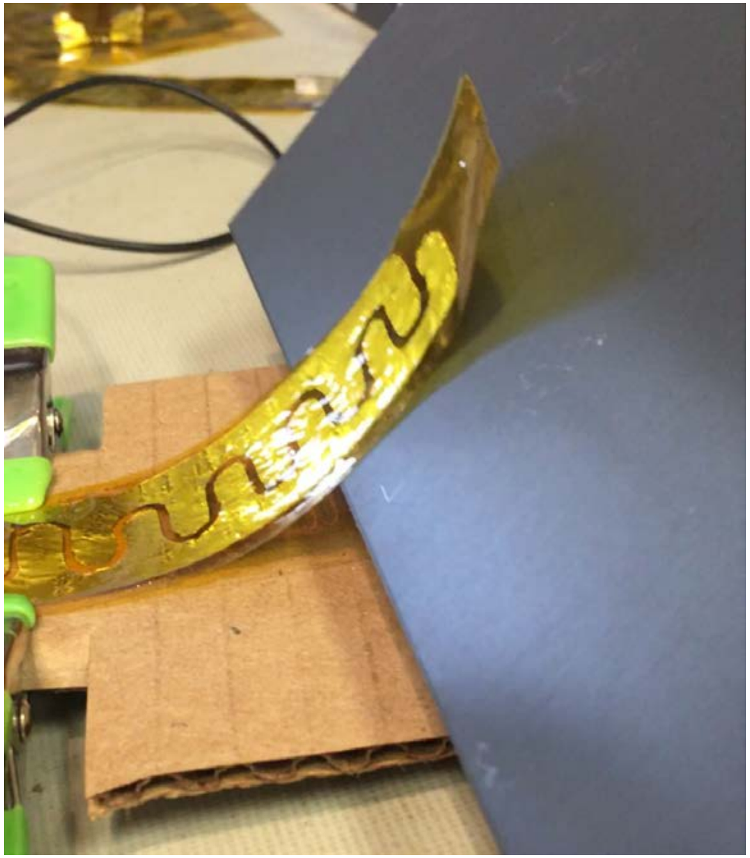
Static Response



Results and Discussion

Static Response

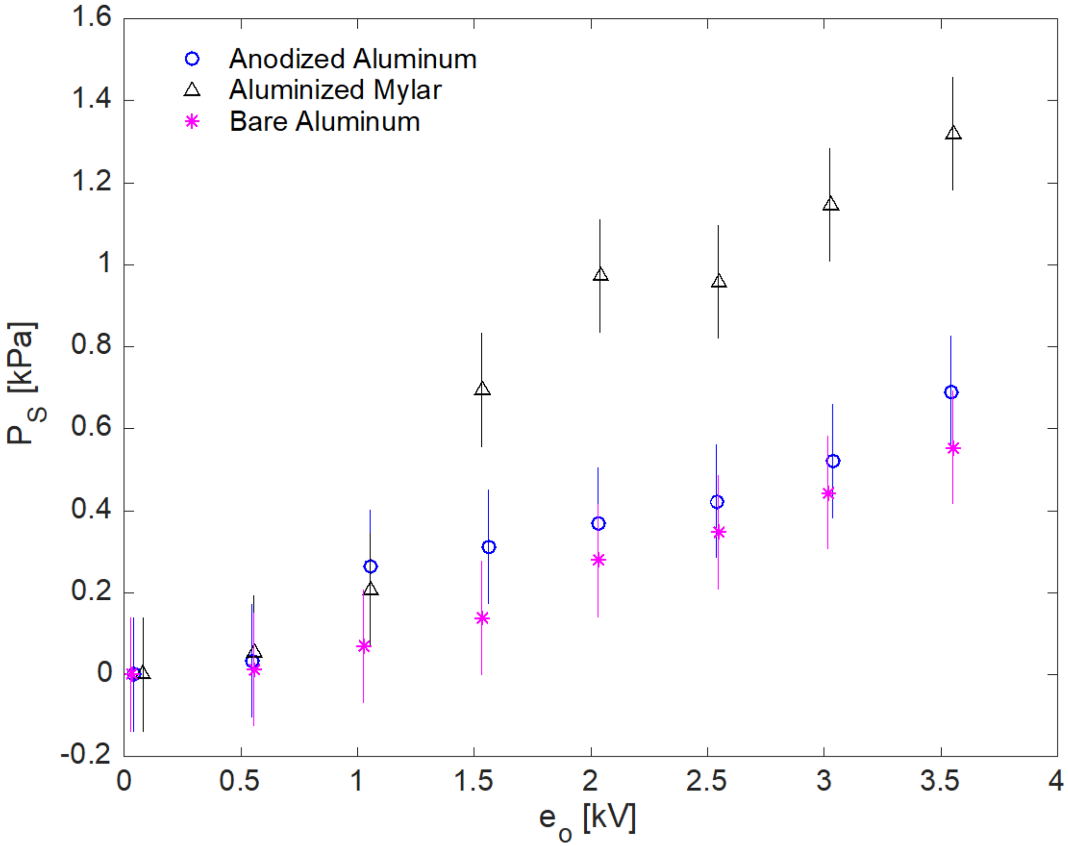


Figure 4: Static shear pressure.

Aluminized Mylar

- Efficiently conformed to electroadhesion sample
- Largest shear pressure

Aluminum (Bare and Anodized)

- Rigid substrates
- Air pockets between sample and substrate

Results and Discussion

Constructed Geometries

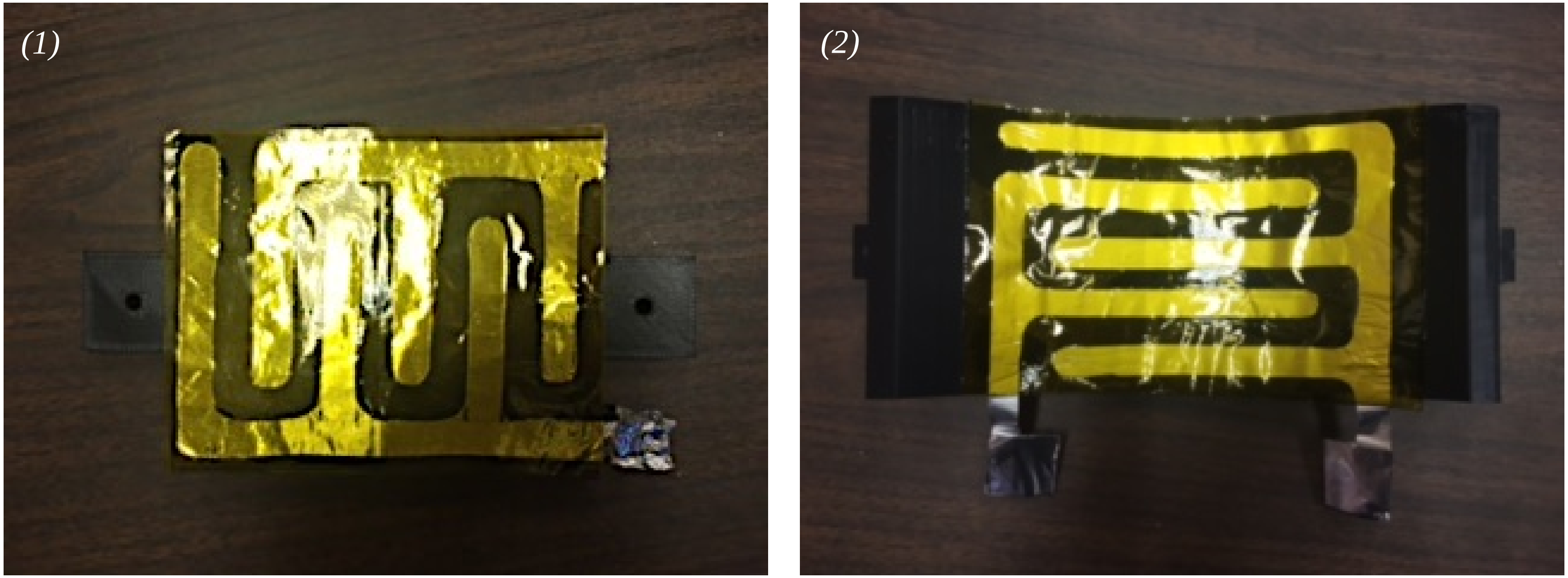


Figure 5: Clamp Geometry (1) (left) and Geometry (2) (right) of electroadhesion samples.

Constructed Geometries

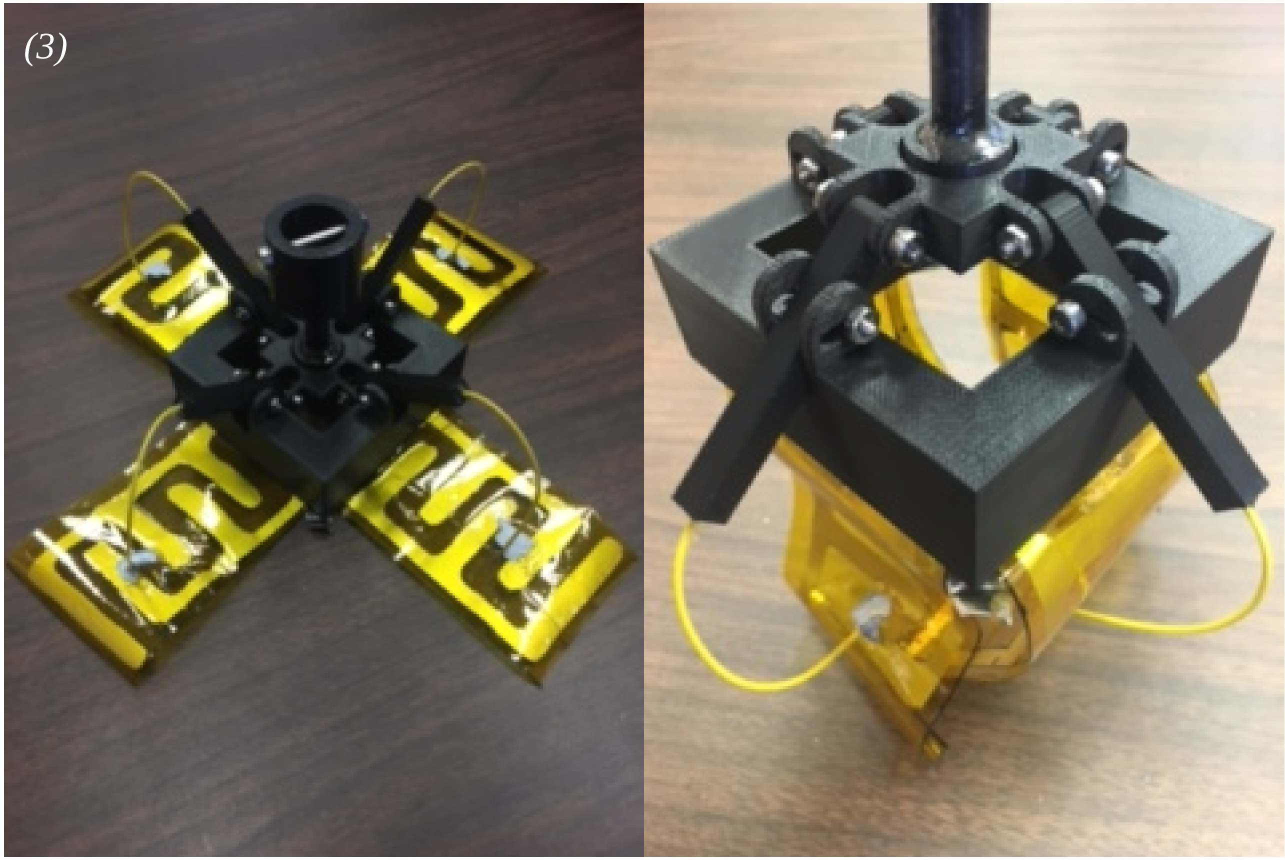
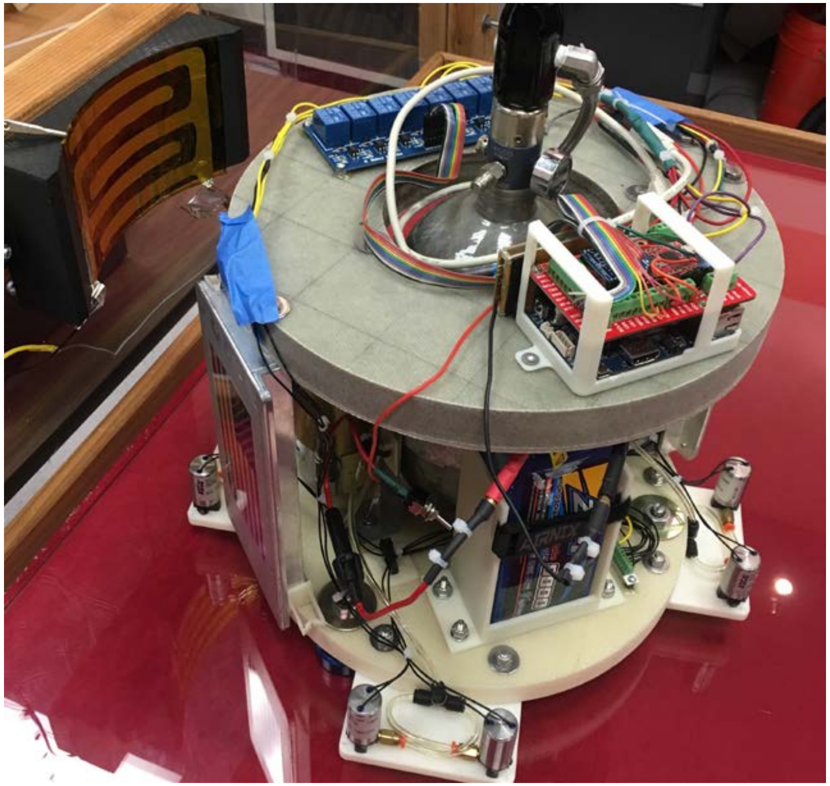


Figure 6: Clamp Geometry (3) of electroadhesion samples.

Dynamic Application



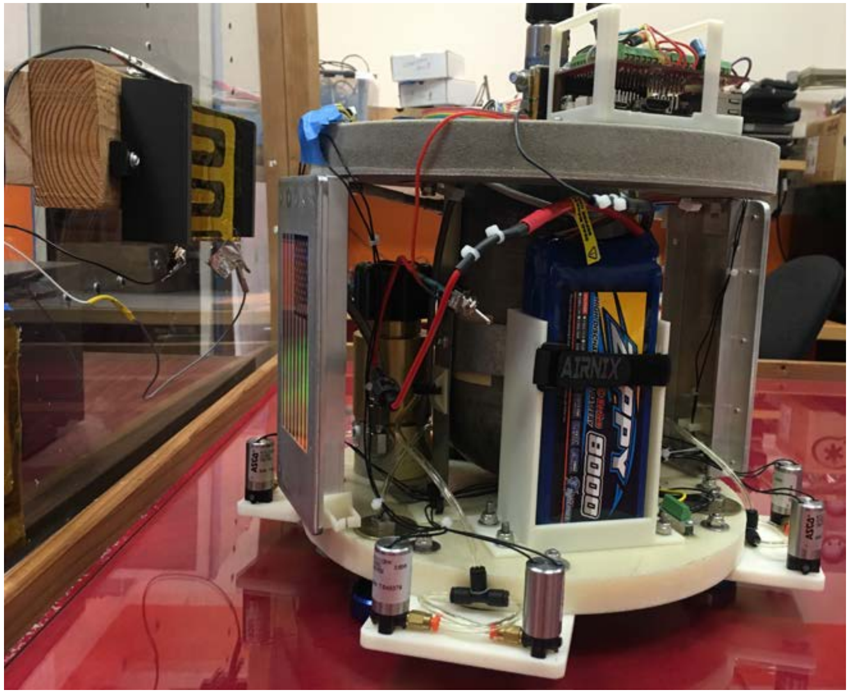


Figure 7: Air-bearing platform isometric and side views.

Results and Discussion

Dynamic Application

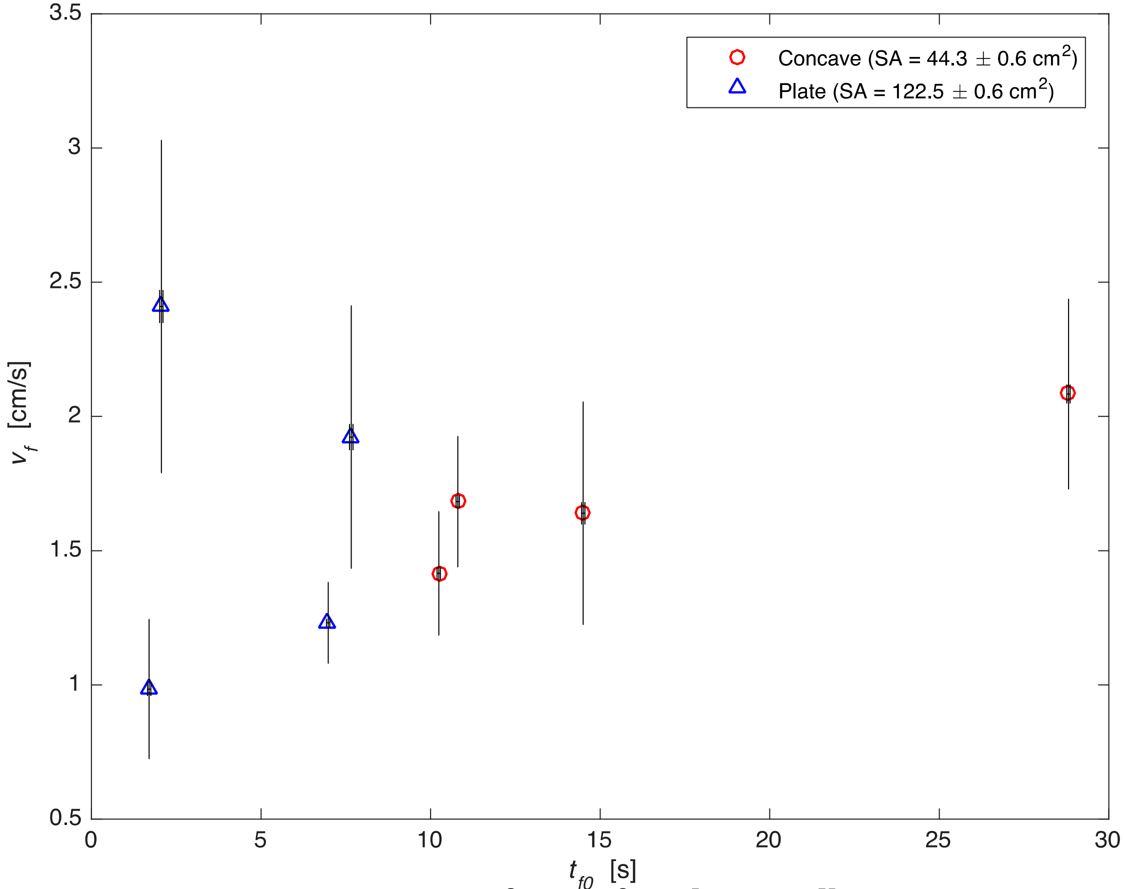
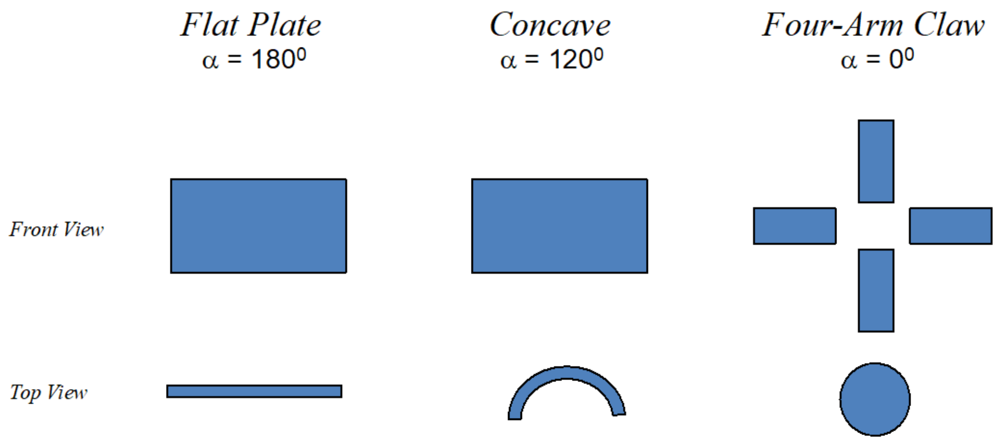


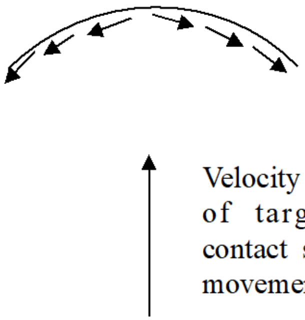
Figure 8: Comparison of time for electroadhesion geometry to stop movement.

Results and Discussion

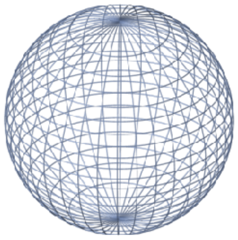
Proposed Metric for Capturing



Multiple number of shear forces that are opposed to each other across the surface, depending upon angle. For 2D surfaces max angle may be 180^0.



Velocity Vector of target to contact surface movement



For a 3D surface, number of shear forces that could oppose each other is greater than 180^0, and the third dimension allows for increased contact resistance to movement.

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Summary of Results

- Superior geometry is dependent on scenario
  - Lag of material from hard structure determined best docking scenarios
  - Implies soft structures are optimal
- Flexible aluminized Mylar material produced greatest shear pressure with electroadhesion sample
- Linear relationship between initial approach velocity, residual motion, and surface area of contact
- A metric is proposed to determine the stop time of initial and residual motion dependent on electroadhesion geometry and contact surface area

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Future Research

- Varying Insulating Material
- Manufactured electroadhesion samples to acquire greater shear forces (NASA-JPL)
- Additional sample geometries
- Control algorithms for docking with claw geometry

Further Investigation

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