
FINAL REVIEW (FR) MEETING

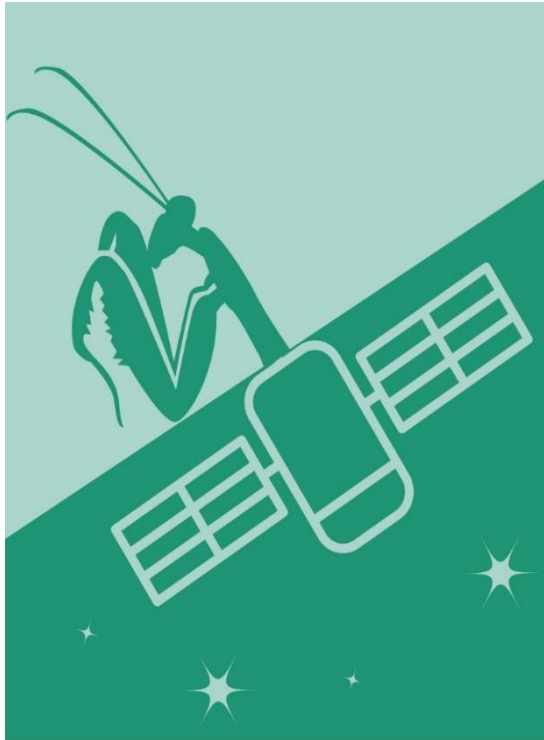
Fraunhofer CML, TU Braunschweig, ESA

28.02.2022



BIOINSPACED

Agenda



1

Project Introduction

2

Final Concepts Presentation

Subsystem 1: Grasshopper Catapult for Deorbiting Kit

Subsystem 2: Drag Augmenting Sail

Subsystem 3: Wood Wasp Reciprocating Drill

3

Test and Validation

4

Live Demonstration

Agenda



1 Project Introduction

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Subsystem 3: Wood Wasp Reciprocating Drill

3 Test and Validation

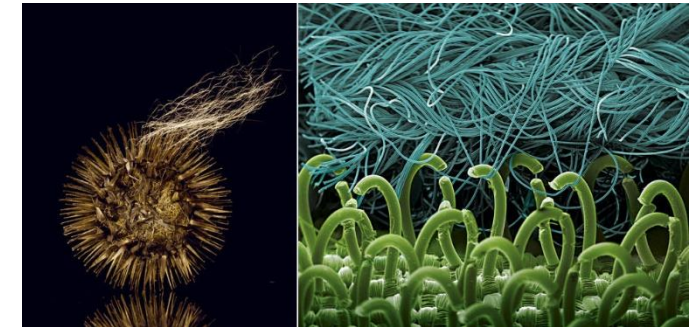
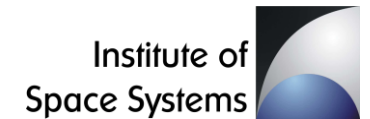
4 Live Demonstration

BIOINSPACED Project

Bioinspired Solutions for Space Debris Removal

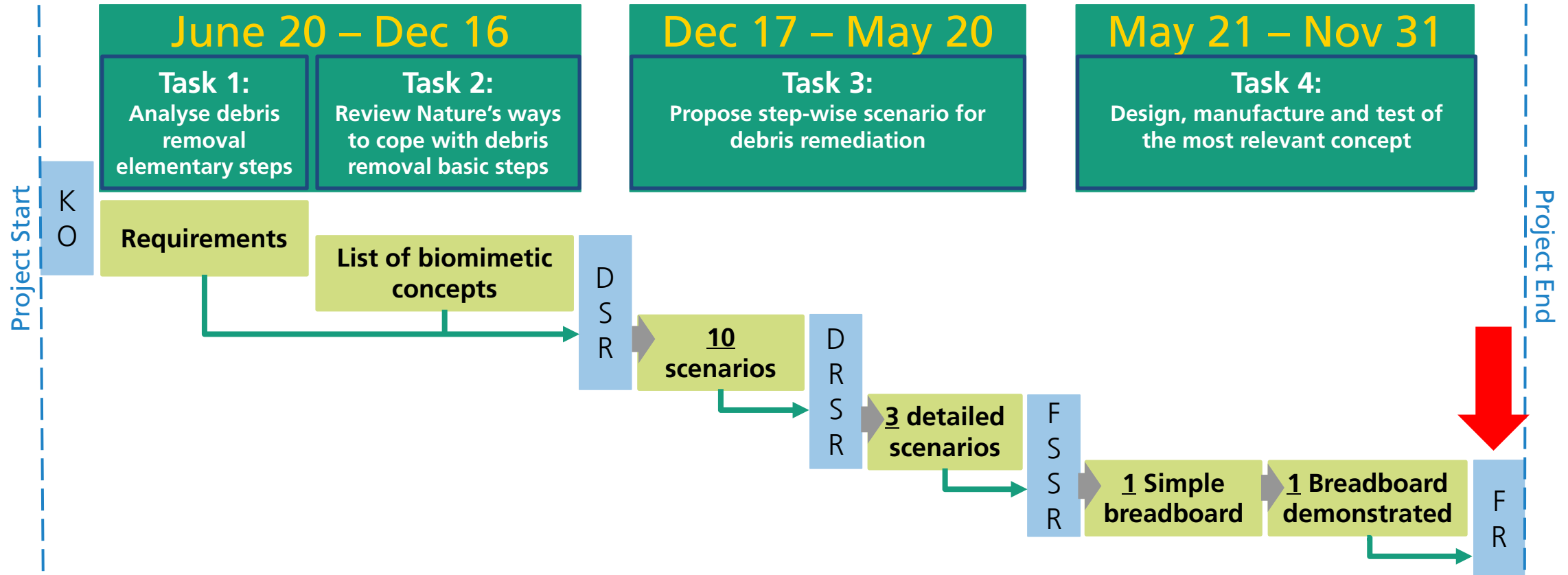


- Find biomimetic solutions for new technologies that can contribute to ESA's Clean space initiative
 - ESA-funded project
 - Project duration: 01. June 2020 – 28. February 2022
 - CML & TUBS (Subcontractor)
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- Biomimetics: transfer of biological models to technical applications by mimicking working principles of nature
 - Why Biology? Great diversity, evolution (optimization) over Millions of years = variety of features available with essential characteristics for space systems



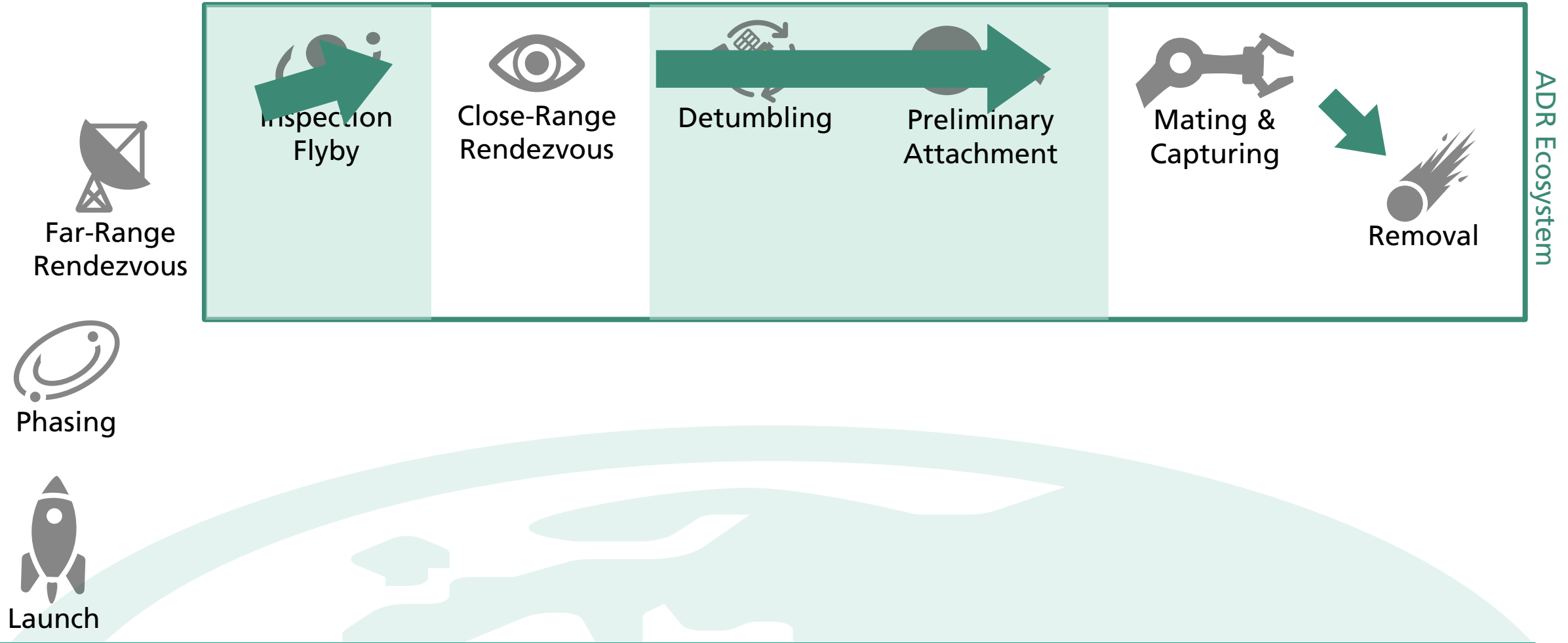
BIOINSPACED Project

The project at a glance



Task 1 - 6 Phases of ADR Missions

Elementary steps for debris removal



Task 2 – BIOINSPACED Catalogue

A Universal and Customizable Database

- Comprehensive and informative catalogue with rated information on several types of biological and biomimetic systems
- Documentation, classification and presentation of concepts and ideas by specifying:

GENERAL

BIOLOGY

SPACE

TECHNOLOGY

BIOMIMETICS

LITERATURE

➔ Interactive and customizable tool for using available information according to user needs
Summarizes biology's potential for space engineering applications

Task 2 - BIOINSPACED Catalogue

Biomimetic Concepts

130 Biomimetic Concepts

Task 2 – BIOINSPACED Catalogue

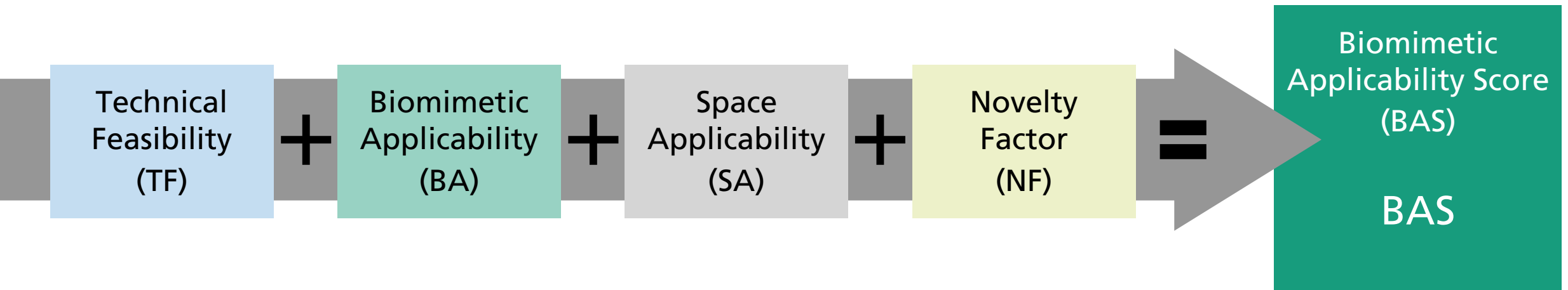
Deriving overarching principles

- Concepts analysed by CML and TUB, total number of assessors: $n = 8$
- 4 Parameters: Technical feasibility, Biomimetic applicability, Novelty factor & Space applicability
- Ranking from 1 (best) to 6 (worst)



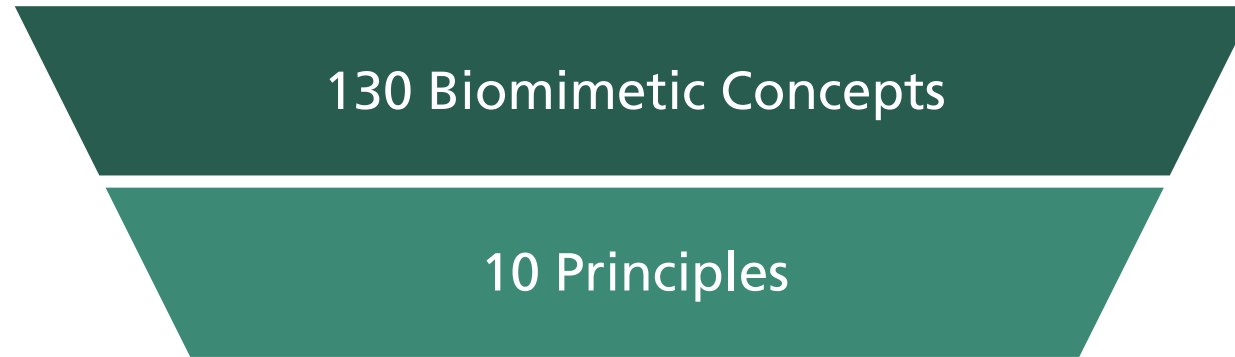
Task 2 – Feasibility Analysis

Determining Concepts with great Potential



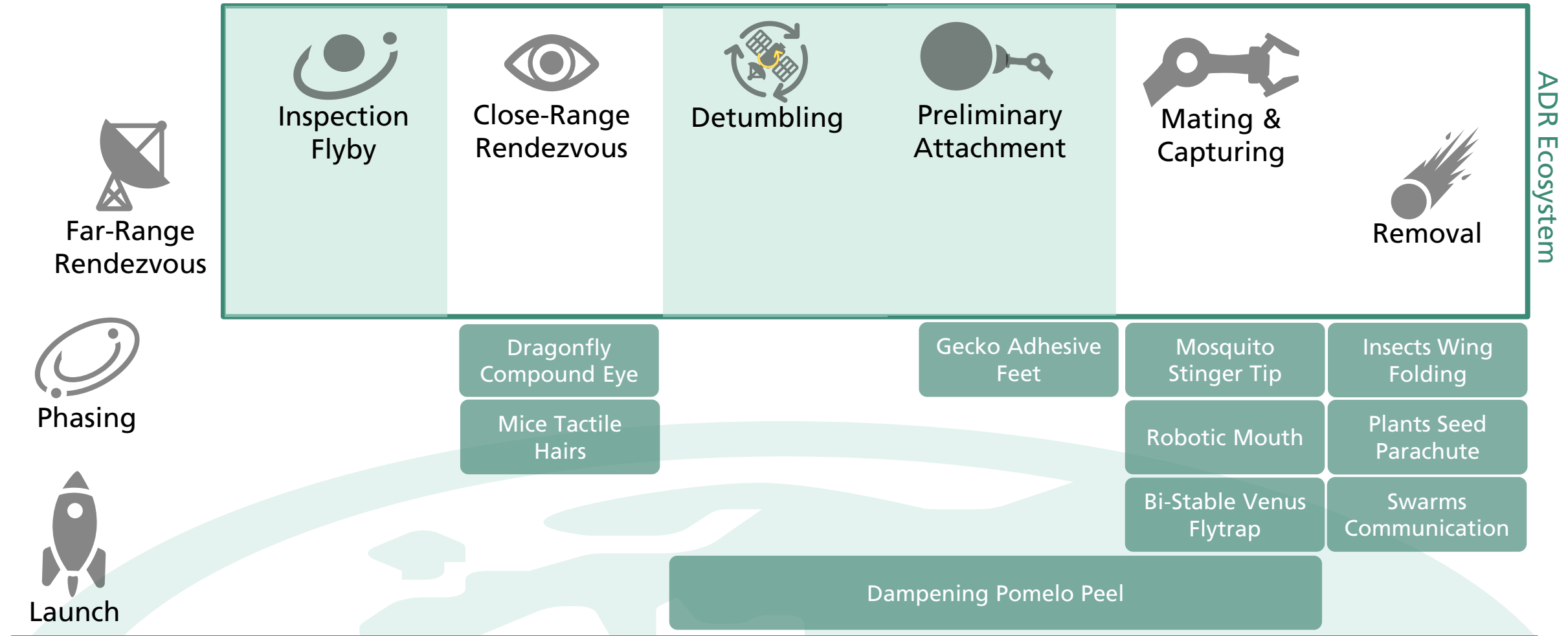
Task 2 – Top 10 Principles

Most Promising Biomimetic Principles



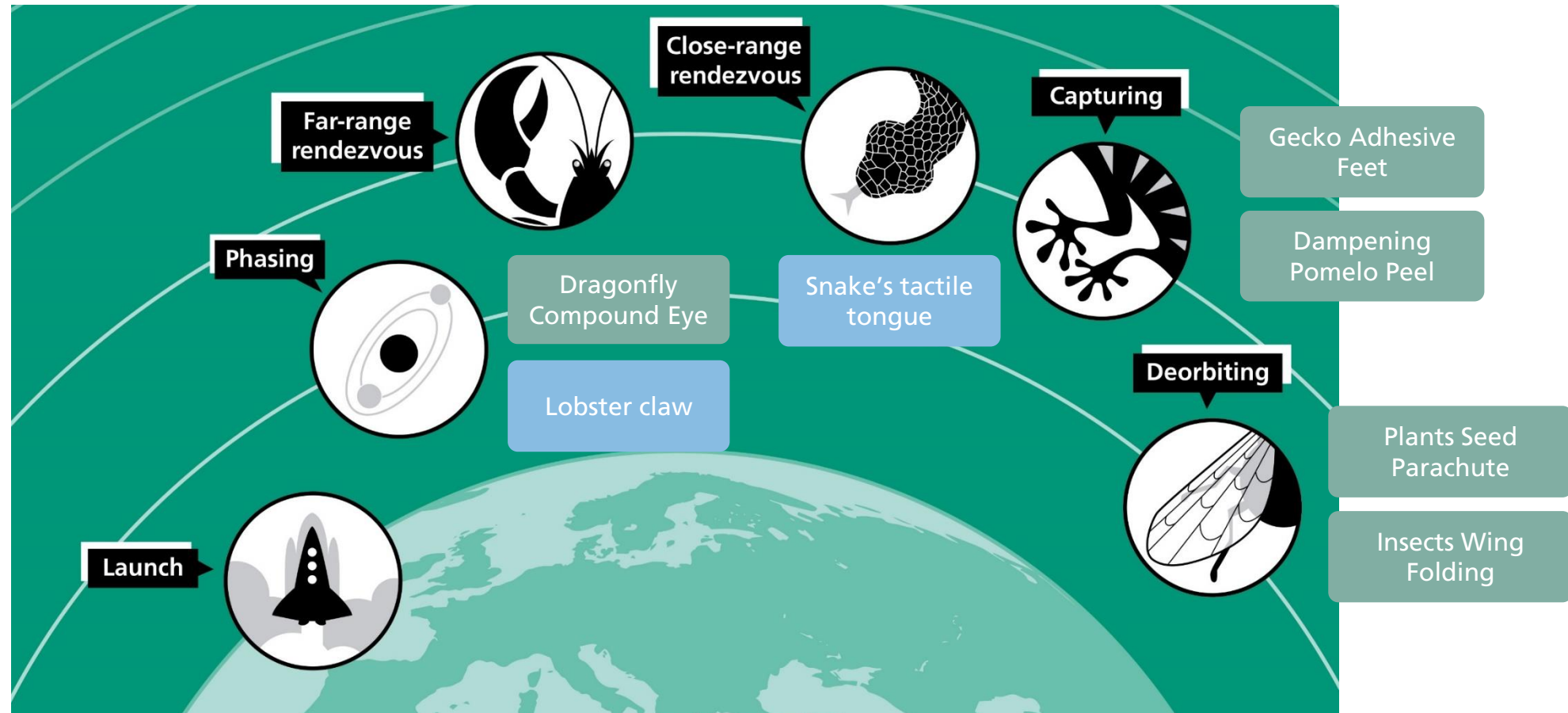
Task 2 – Top 10 Principles

Most Promising Biomimetic Principles



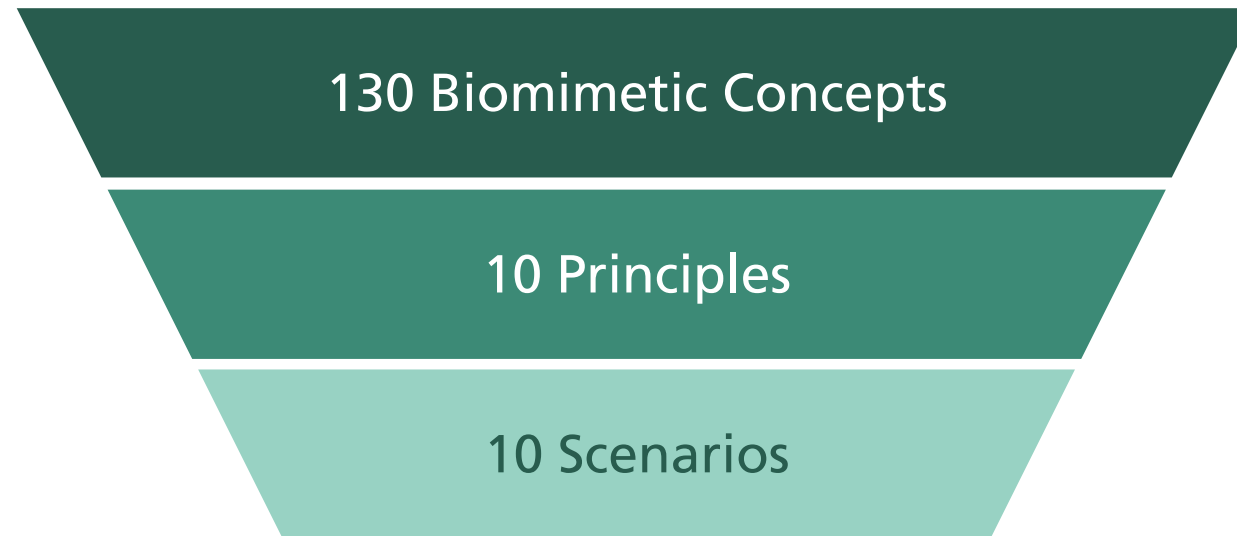
Task 3 – Top 10 Scenarios

Propose step-wise scenarios for debris remediation



Task 3 – Top 10 Scenarios

Propose step-wise scenario for debris remediation



Task 3 – Top 10 Scenarios

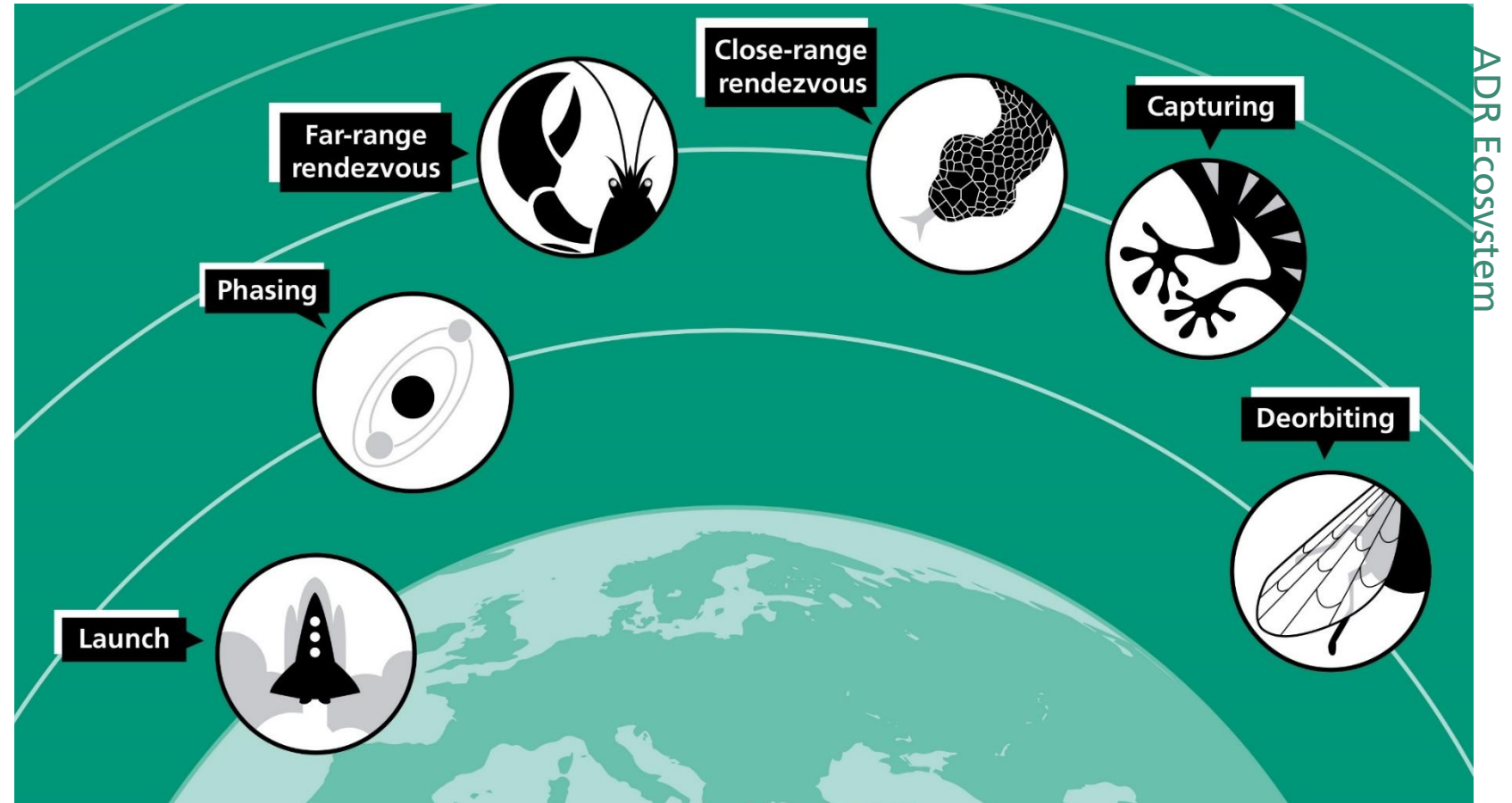
Propose step-wise scenario for debris remediation

Concepts

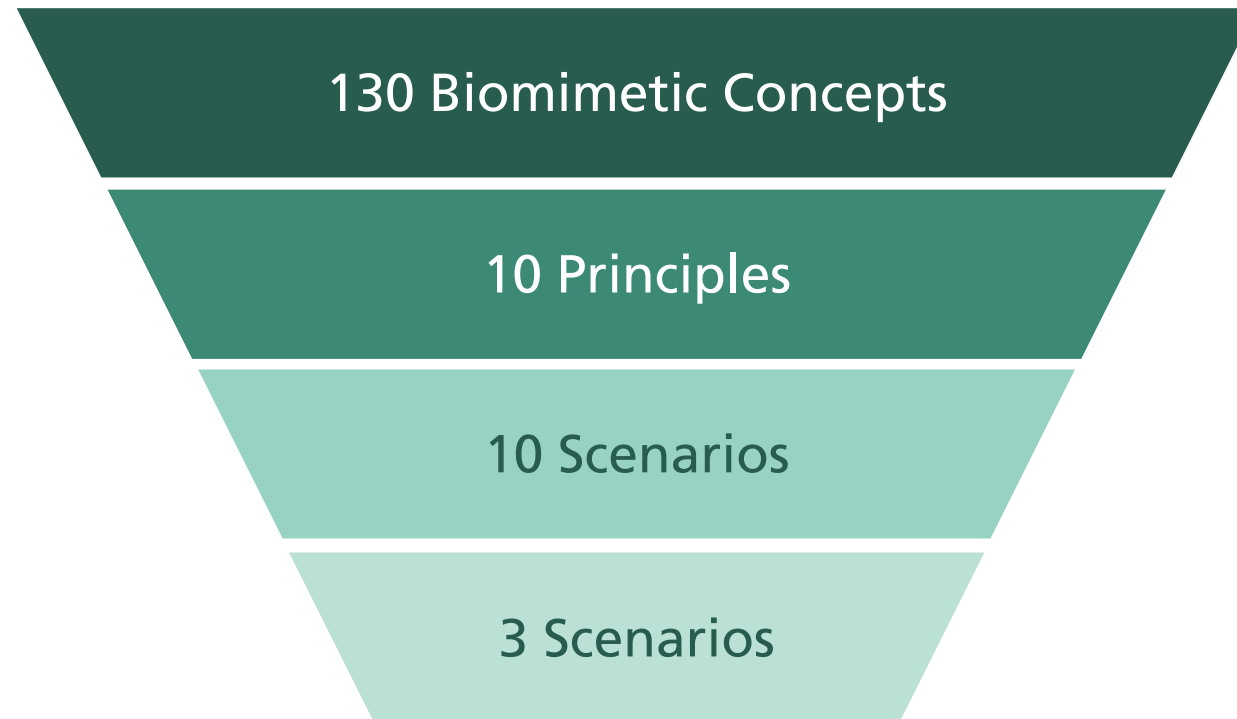
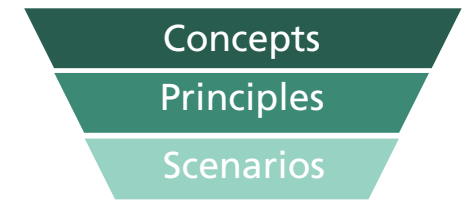
Principles

Scenarios

- Gecko Kit Canon
- Swallowing the Target Hole
- Gecko + Bee Harpoon
- Gecko + Wood Wasp Drill
- Plant Parachute
- Venus Flytrap
- Chaser ,Queen' & ,Worker' Swarm
- Passive Jellyfish Tentacles
- Tactile Sensing with Elephant Trunks
- Growing Octopus Arms



Task 3 – Top 10 Scenarios



Agenda

Concepts

Principles

Scenarios

Top 3



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Task 4 – Final Concepts Presentation

3 Subsystems from Top 3 Scenarios

Concepts

Principles

Scenarios

Top 3

Grasshopper Catapult
for Deorbiting Kit



Drag Augmenting
Sail after a Leaf



Wood Wasp
Reciprocating Drill



Task 4 – Final Concepts Presentation

Additional Concepts

Concepts

Principles

Scenarios

Top 3

Elephant Compliant Arm



Gecko Dry Adhesion



Pomelo Energy Dissipating Foam



Elephant Compliant Arm

compliant contact with low push back

Concepts

Principles

Scenarios

Top 3

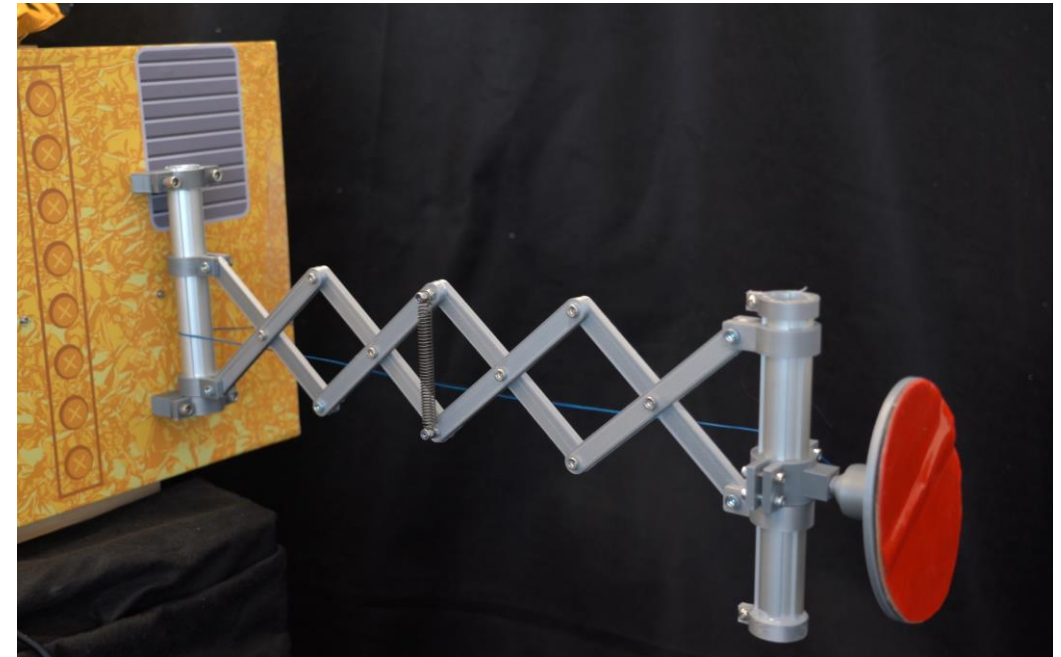
Biology – Elephant Trunk

- Multiple degrees of freedom²²
- High maneuverability and adjustability to complex debris motions and shapes



Technology Compliant Arm

- Simple robotic arm with reduced No. of joints
- If necessary kinematically redundant arm



Gecko Dry Adhesion

dry adhesion using van der Waals Forces

Concepts

Principles

Scenarios

Top 3

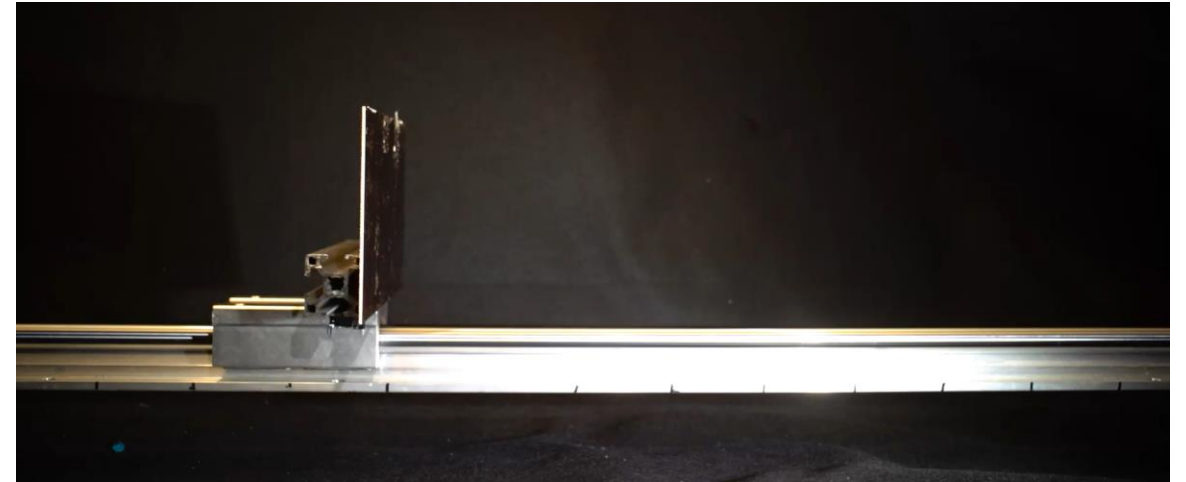
Biology – Gecko Feet

- Using van der Waals forces and small hairs on feet to adhere to a variety of surfaces
- Reversible
- Successfully tested in space environment^{15,16,17}



Technology – Gecko Tape®

- Micro-structured tape made from silicon with ca. ~29.000 adhesive units per cm²
- Strong adhesive force without leaving residue
- Application very similar to regular tape



Pomelo Foam

Efficient energy dissipation

Biology – Pomelo Fruit Peel

- open cell foam structure of varying pore size ¹⁹
- protect the fruit inside when falling from tree of up to 10 meters



Technology – Foam Stimulants

- Use memory foam as substitute to determine if dampening foam is favorable
- Conventional sponge material chosen for trials



Task 4 – Final Concepts Presentation

3 Subsystems from Top 3 Scenarios

Concepts

Principles

Scenarios

Top 3

Grasshopper Catapult
for Deorbiting Kit



Drag Augmenting
Sail after a Leaf



Wood Wasp
Reciprocating Drill



Subsystem 1

Grasshopper Catapult for Deorbiting Kit

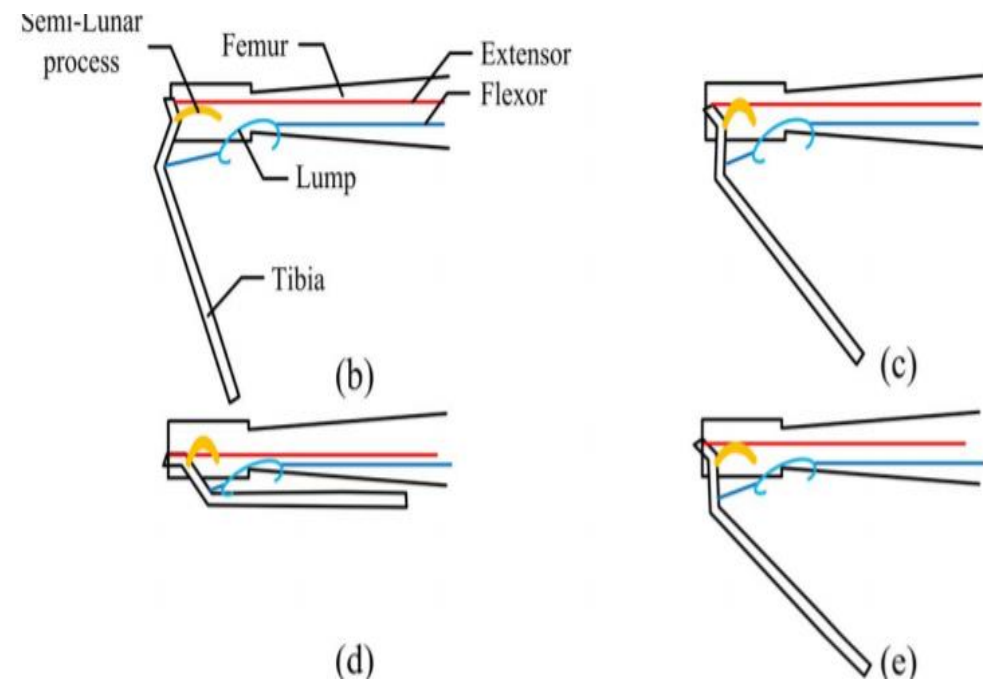
Concepts

Principles

Scenarios

Top 3

achieves high catapult forces by slowly contracting flexor muscle (spending only little energy)¹³
release triggered by the relaxation of another muscle causes fast and strong resulting action¹⁴



Subsystem 1

Grasshopper Catapult for Deorbiting Kit

Concepts

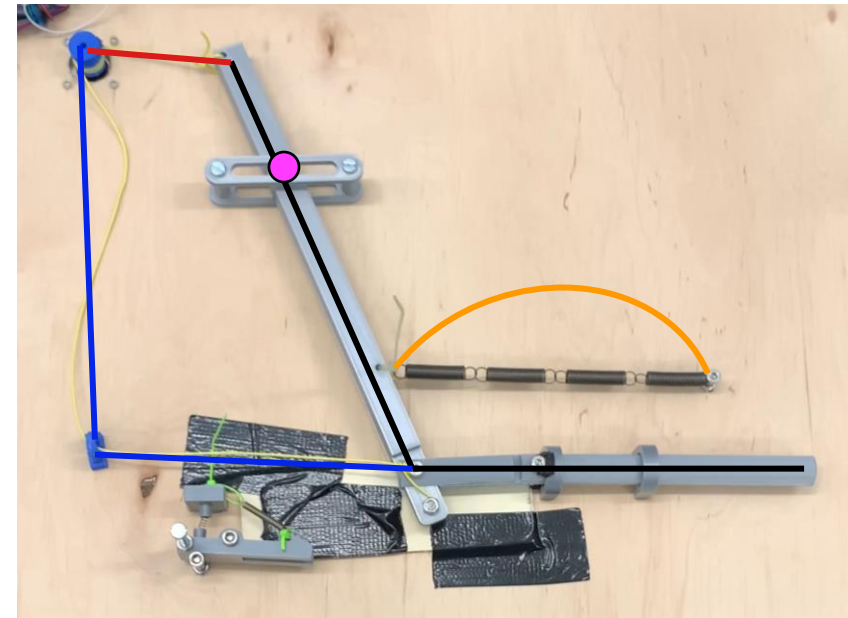
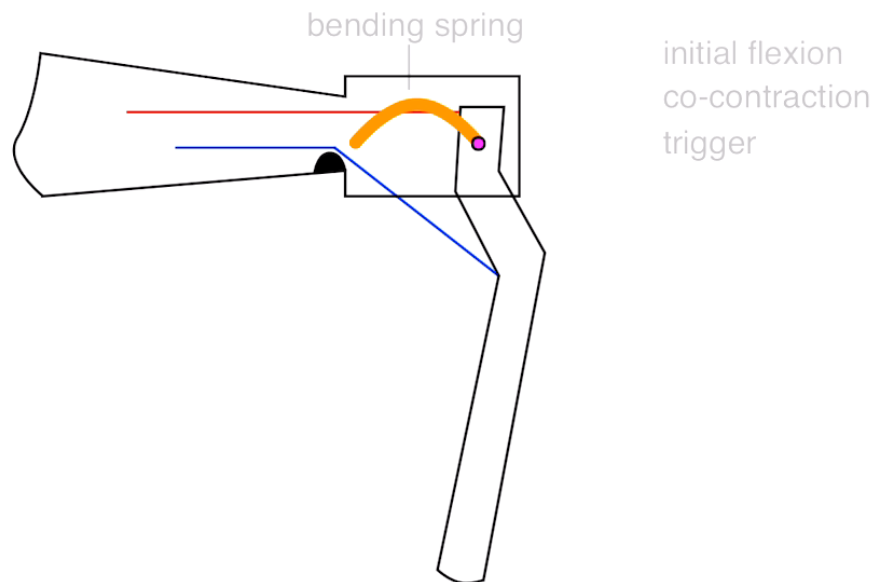
Principles

Scenarios

Top 3

Abstraction of locust dual-muscle tensioning system

Adapted to shoot payload away rather than pushing itself away



Subsystem 1

Deorbiting Kit – using gecko adhesion and pomelo foam

Concepts

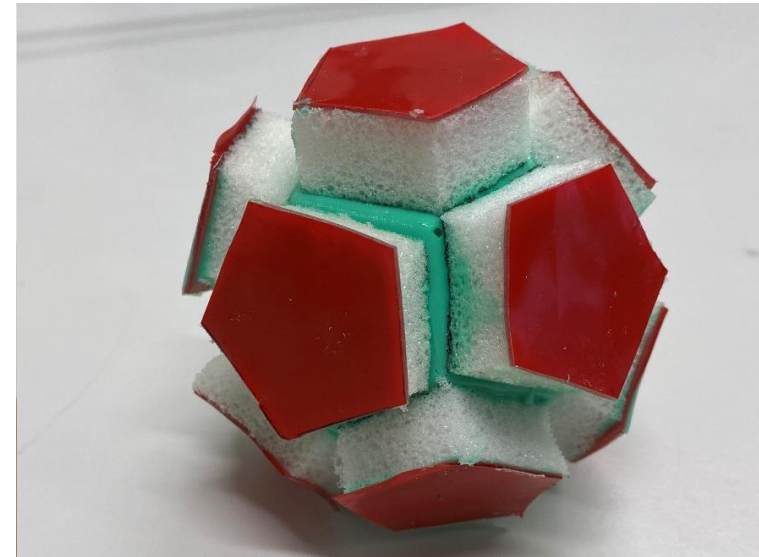
Principles

Scenarios

Top 3

Geckotape from two companies integrated and tested

Abstracted with sponge foam to achieve similar effect of energy dissipation



Task 4 – Final Concepts Presentation

3 Subsystems from Top 3 Scenarios

Concepts

Principles

Scenarios

Top 3

Grasshopper Catapult
for Deorbiting Kit



Drag Augmenting
Sail after a Leaf



Wood Wasp
Reciprocating Drill



Subsystem 2

Drag augmenting sail

Concepts

Principles

Scenarios

Top 3

Diverse options to efficiently fold leaves dependent on shape of available storage¹⁸

Increase in area achieved by pushing water into leave veins



Subsystem 2

Drag augmenting sail

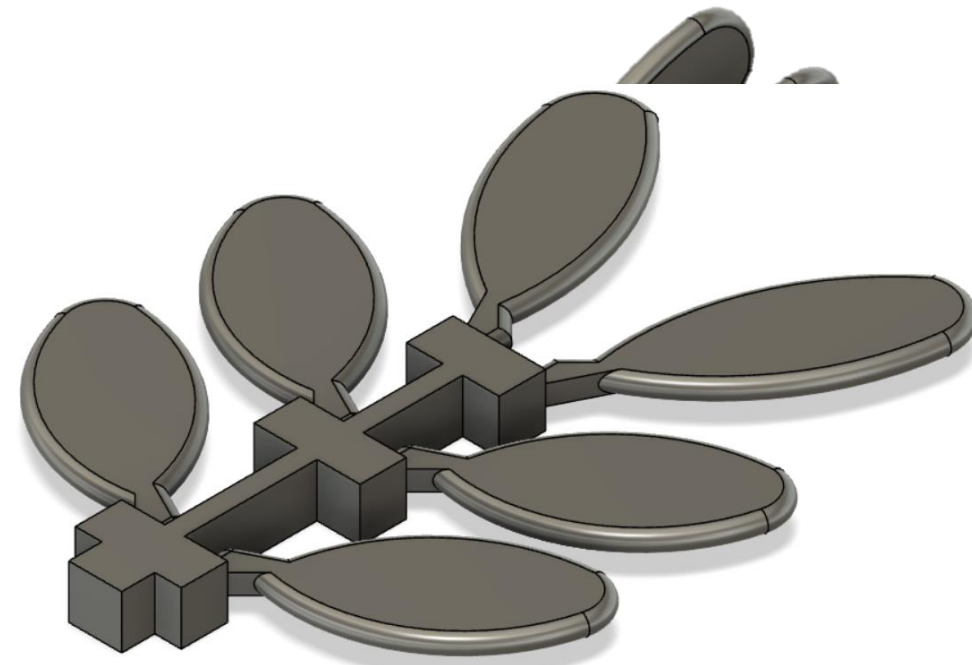
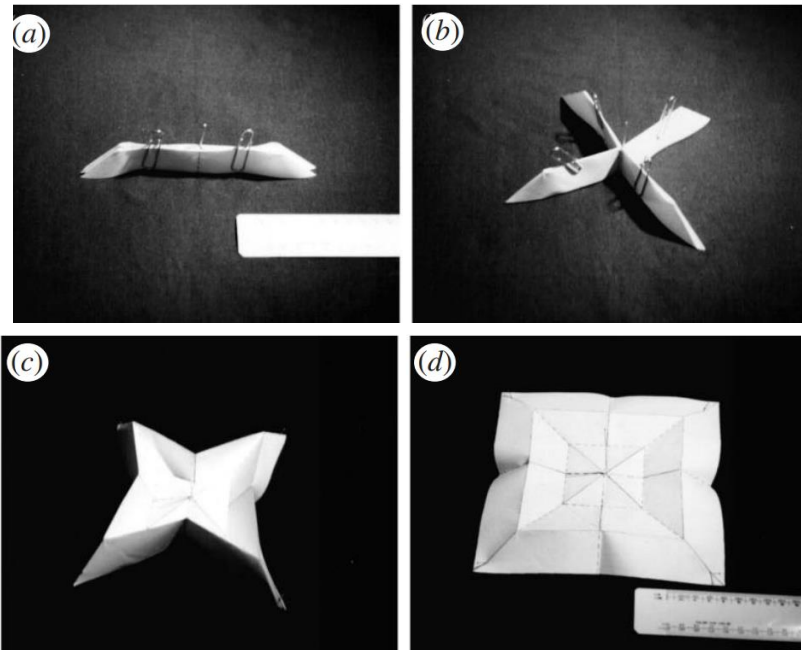
Concepts

Principles

Scenarios

Top 3

Efficient packing and increasing size significantly when unfolding
System is stored enroled and is extended using pressurised system



Subsystem 2

Drag augmenting sail

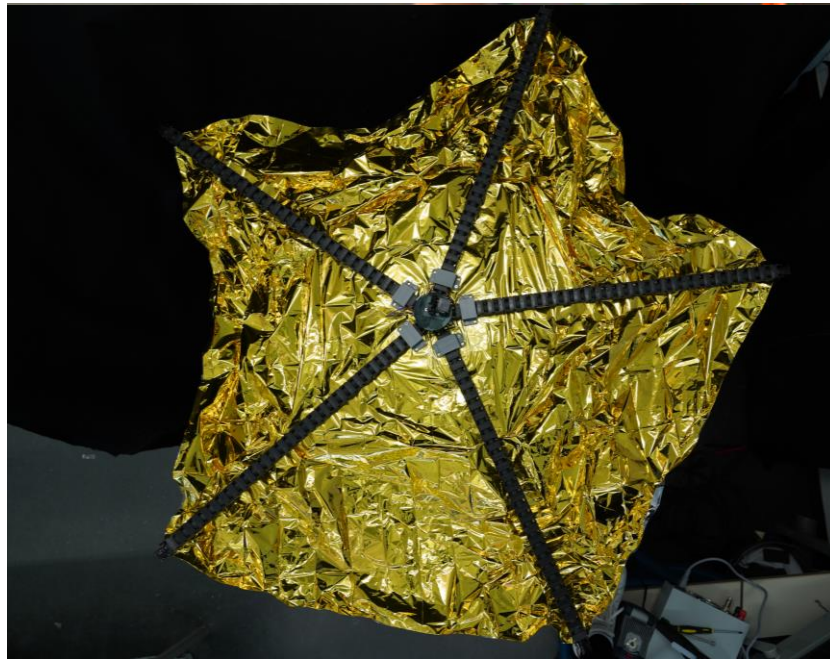
Concepts

Principles

Scenarios

Top 3

Efficient packing and increasing size significantly when unfolding
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Task 4 – Final Concepts Presentation

3 Subsystems from Top 3 Scenarios

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Top 3

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for Deorbiting Kit



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Wood Wasp
Reciprocating Drill



Subsystem 3

Wood Wasp Reciprocating Drill

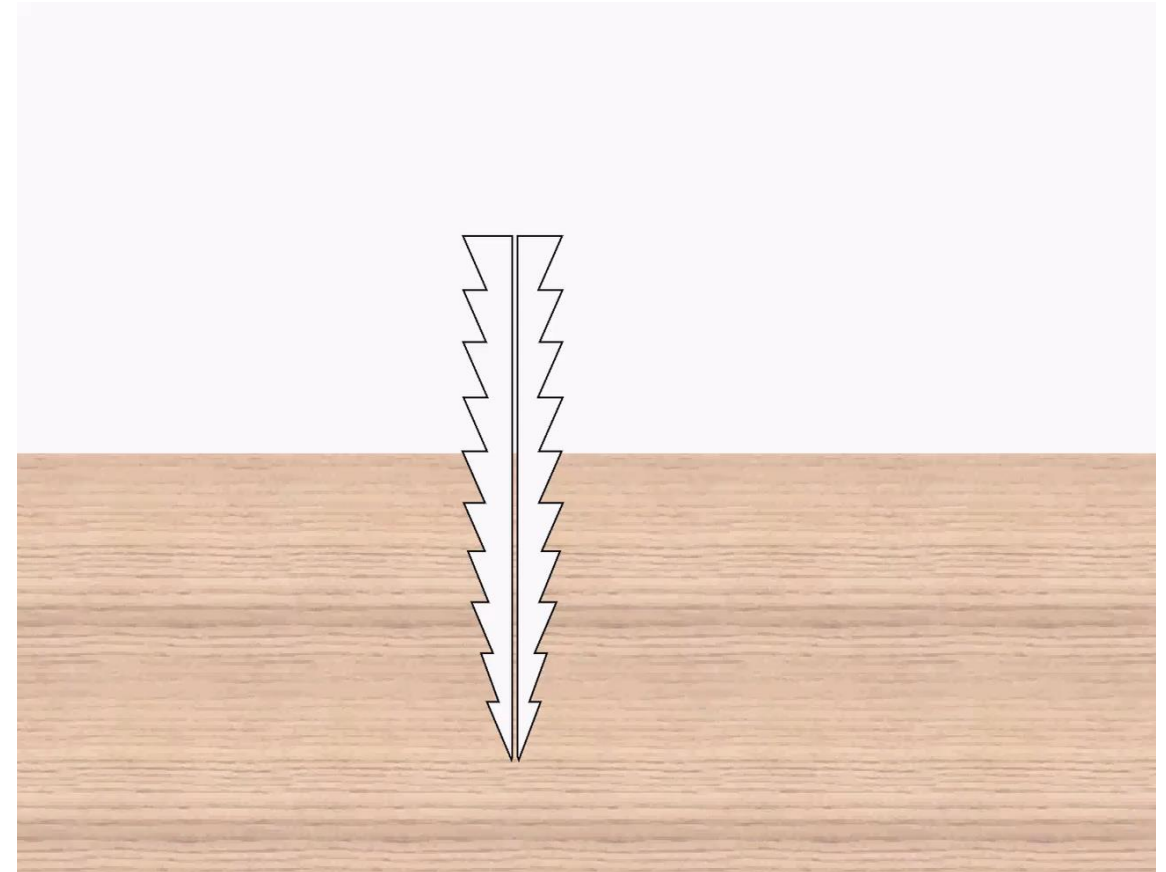
Concepts

Principles

Scenarios

Top 3

- two ovipositor valves move in reciprocating motion to drill into the bark of trees²⁷
- Halves are lined with teeth to hook into the surrounding material
- Distal and proximal facing teeth
- Hook at the end for interlocking
- Very energy efficient

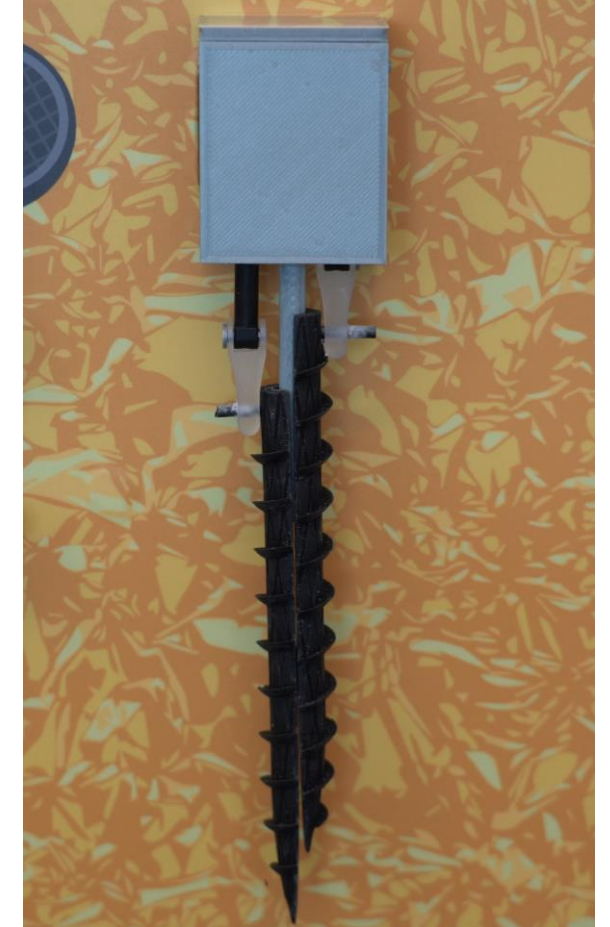


Subsystem 3

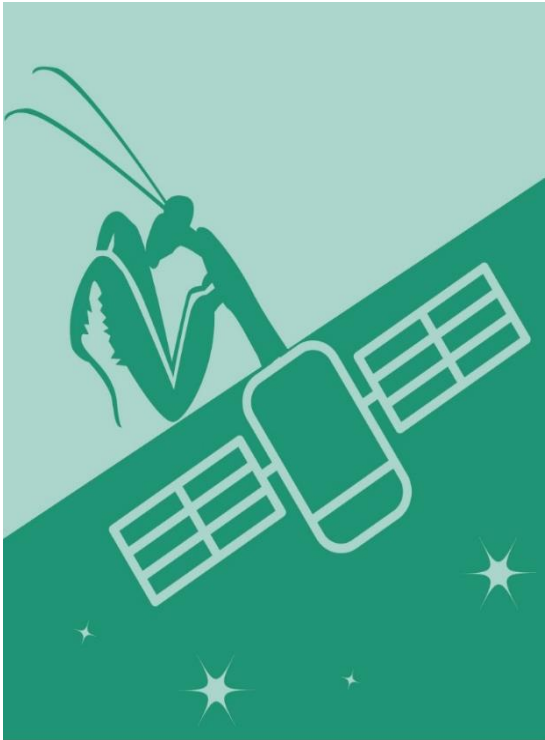
Wood Wasp Reciprocating Drill



- Simple slider-crank linkage as drive to achieve linear motion
- Two 3D printed drill bit halves with upwards facing teeth
- Reciprocating motion drilling into substrates



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Grasshopper Catapult for Deorbiting Kit

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Live Demonstration

Demonstrator Validation and Testing

Catapult Experiments

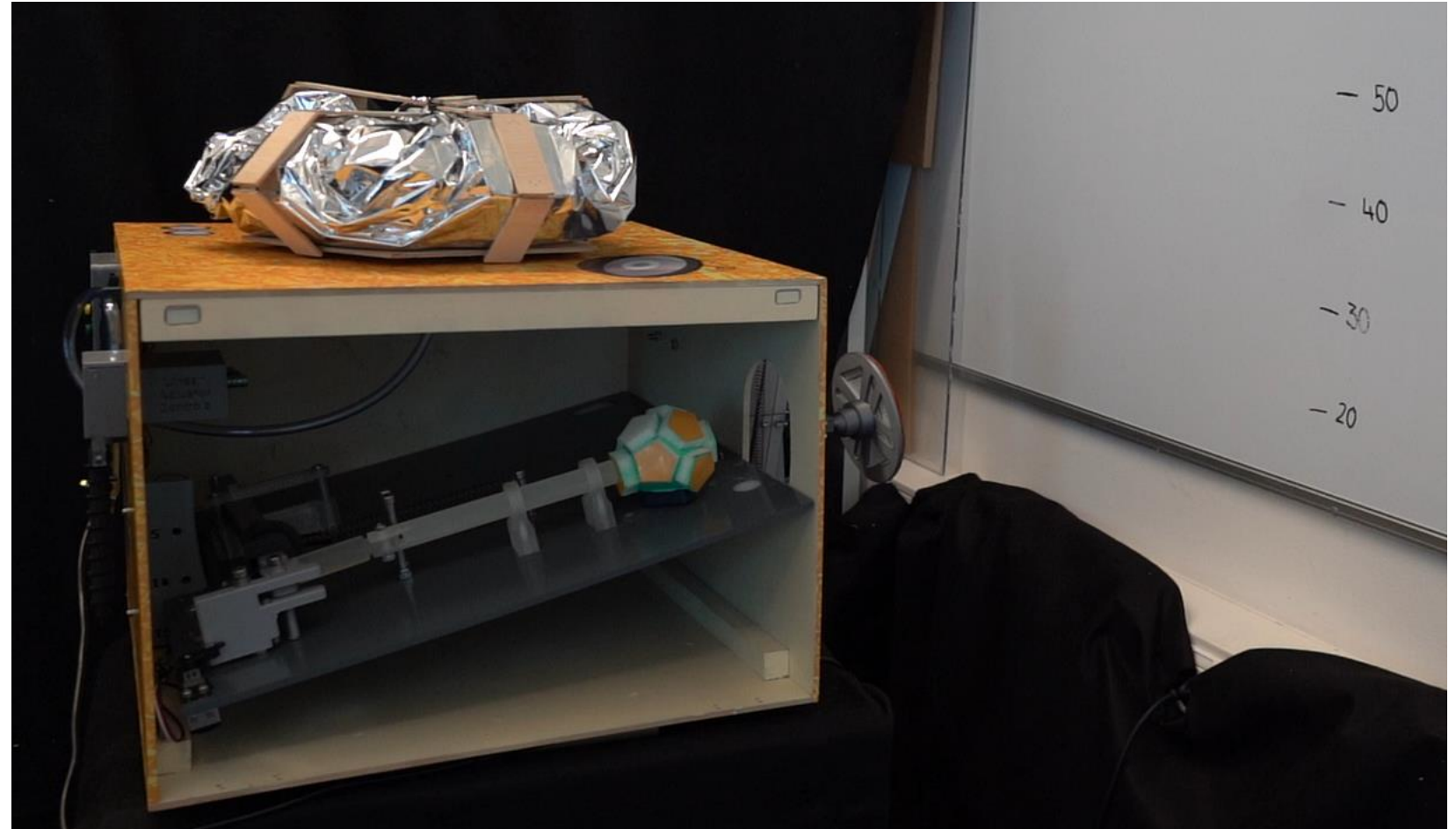
Concepts

Principles

Scenarios

Top 3

- Catapult firing the deorbiting kits against a wall to test their adhesion



Demonstrator Validation and Testing

Gecko Tape Experiments

Concepts

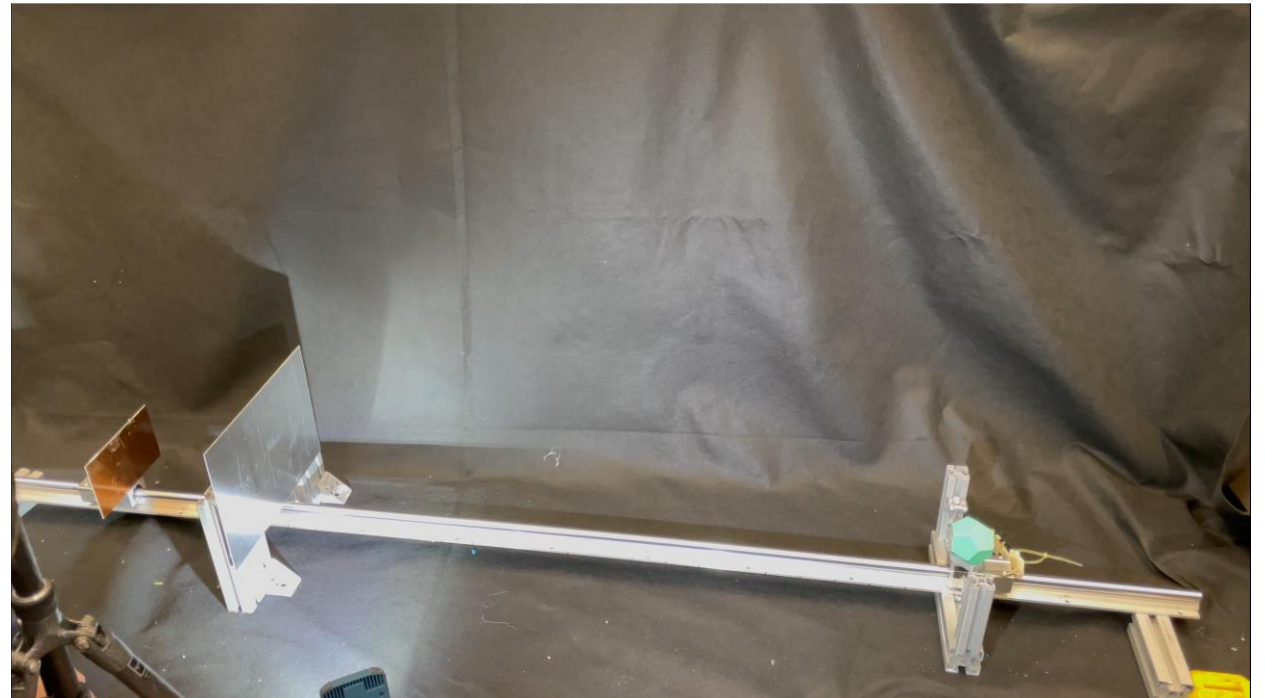
Principles

Scenarios

Top 3

- 3 different types of tape tested
 - Gecko Tape 1 (binder.de)
 - Gecko Tape 2 (Innocise GmbH)
 - Conventional double-sided tape
- Stationary and moving target (constraint to 1D motion)
- Enables one dimensional tests of the docking behavior between two systems

Experimental Setup



Demonstrator Validation and Testing

Gecko Tape 1 – Stationary Target

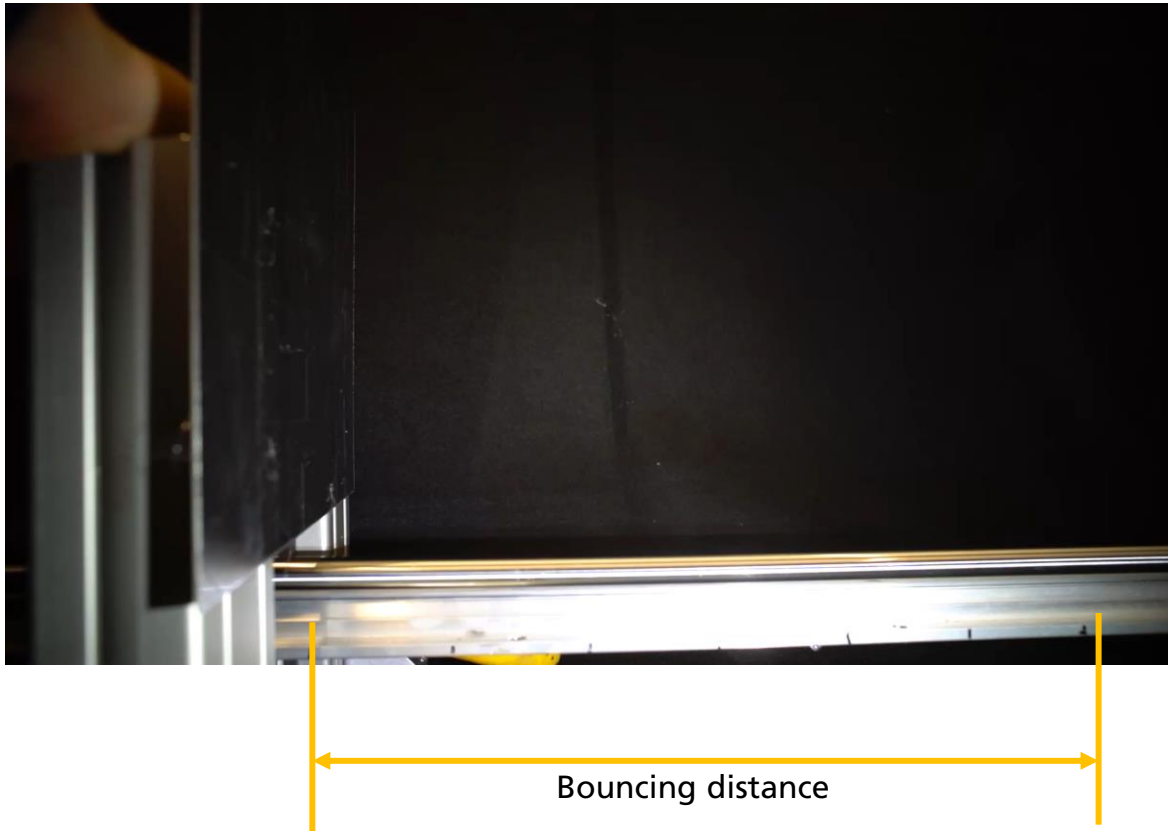
Concepts

Principles

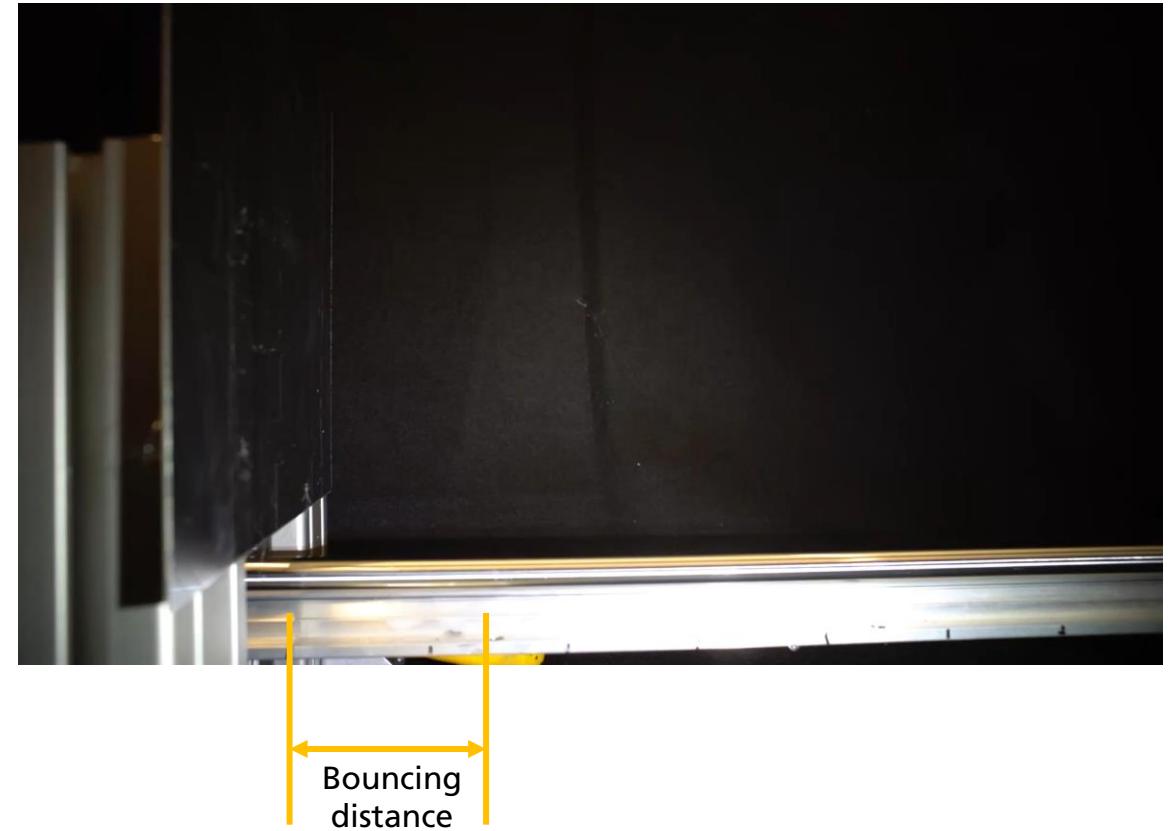
Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Gecko Tape 1 – Moving Target

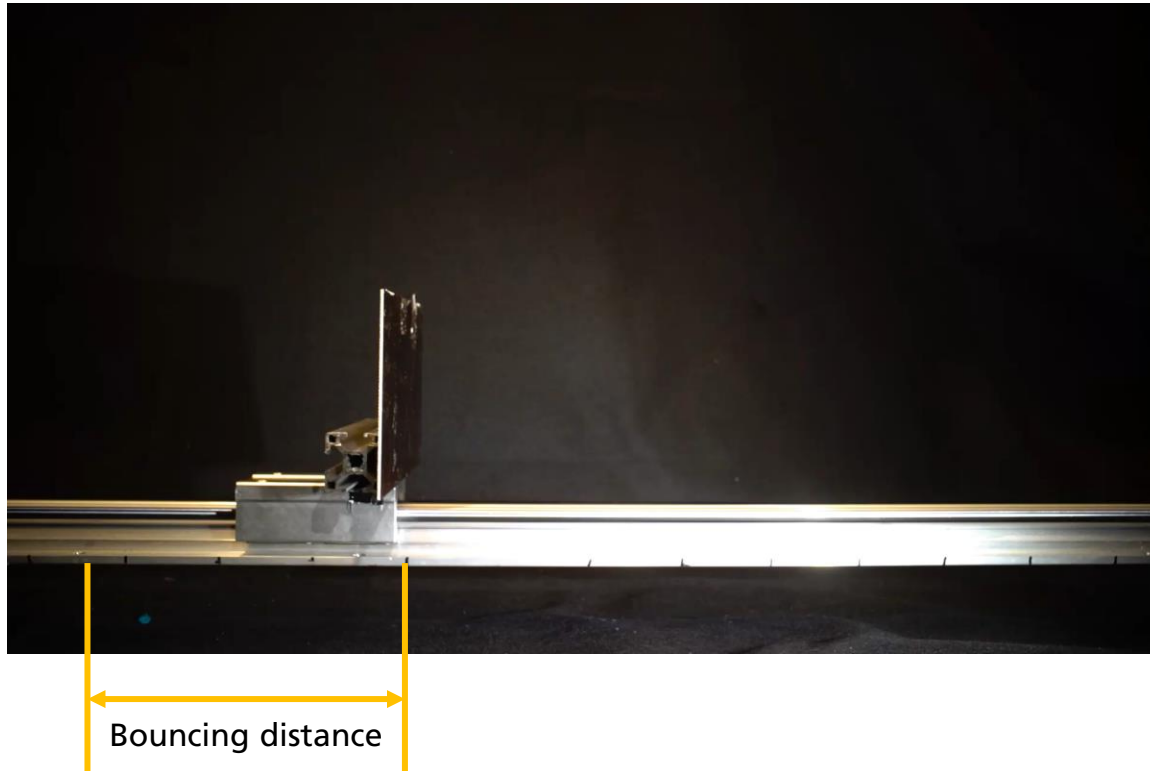
Concepts

Principles

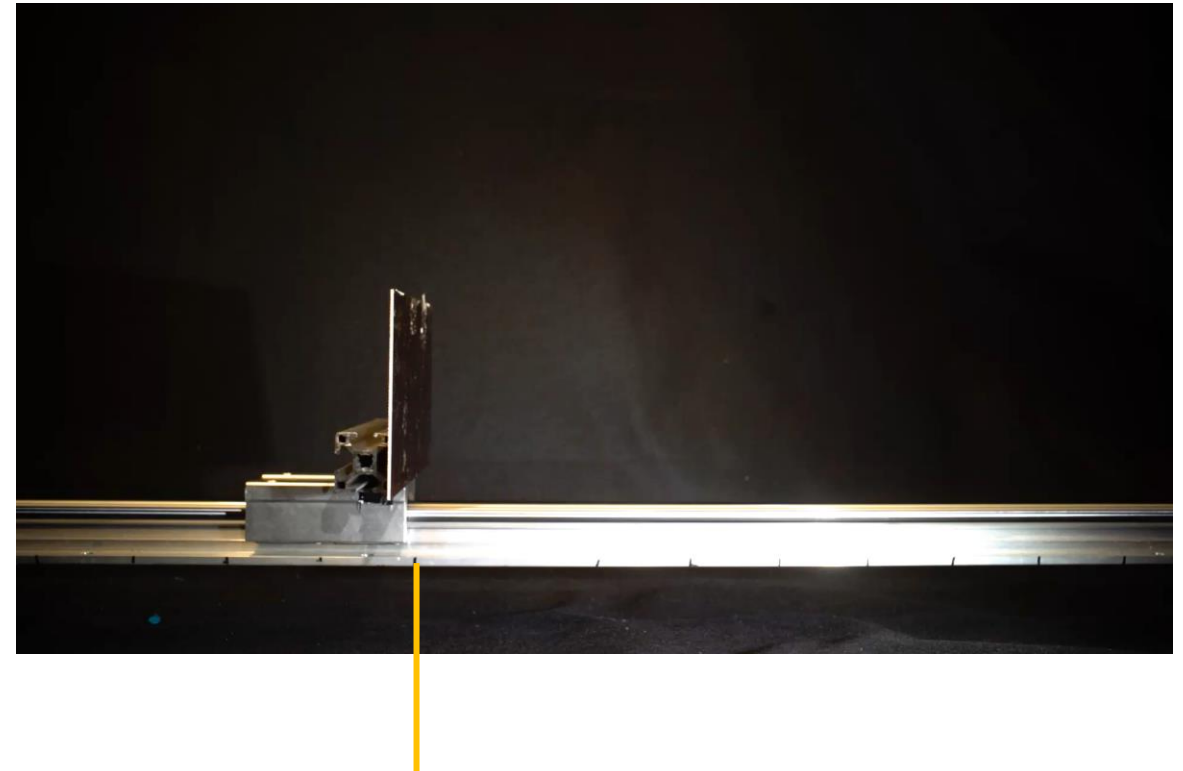
Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Gecko Tape 1 with Memory Foam – Stationary Target

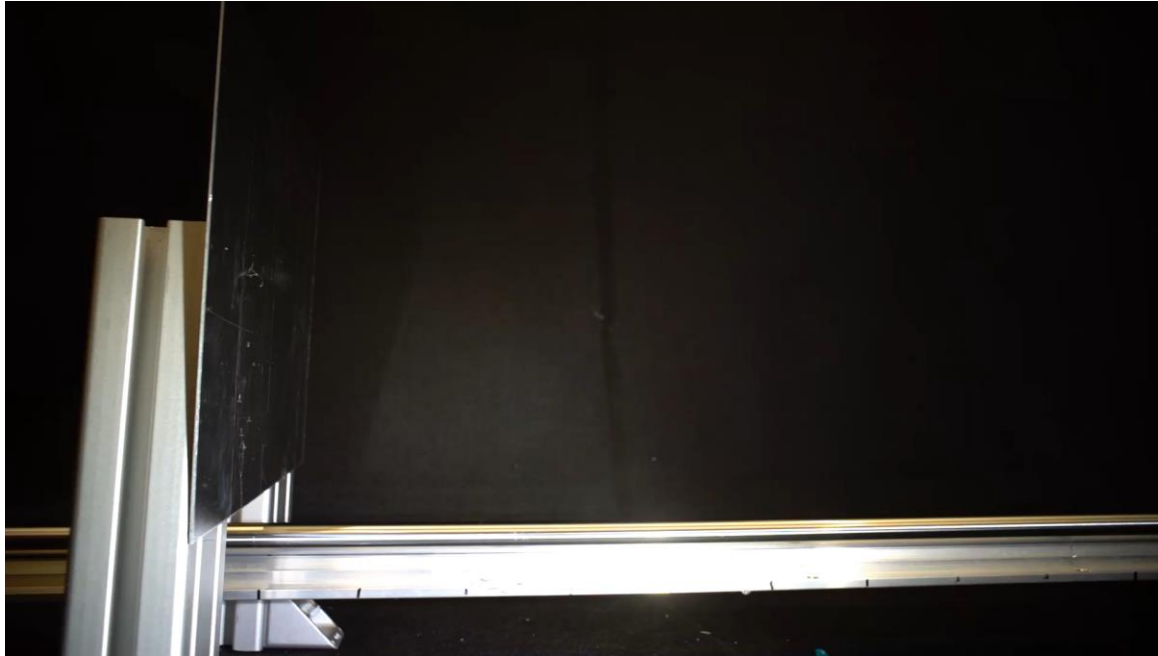
Concepts

Principles

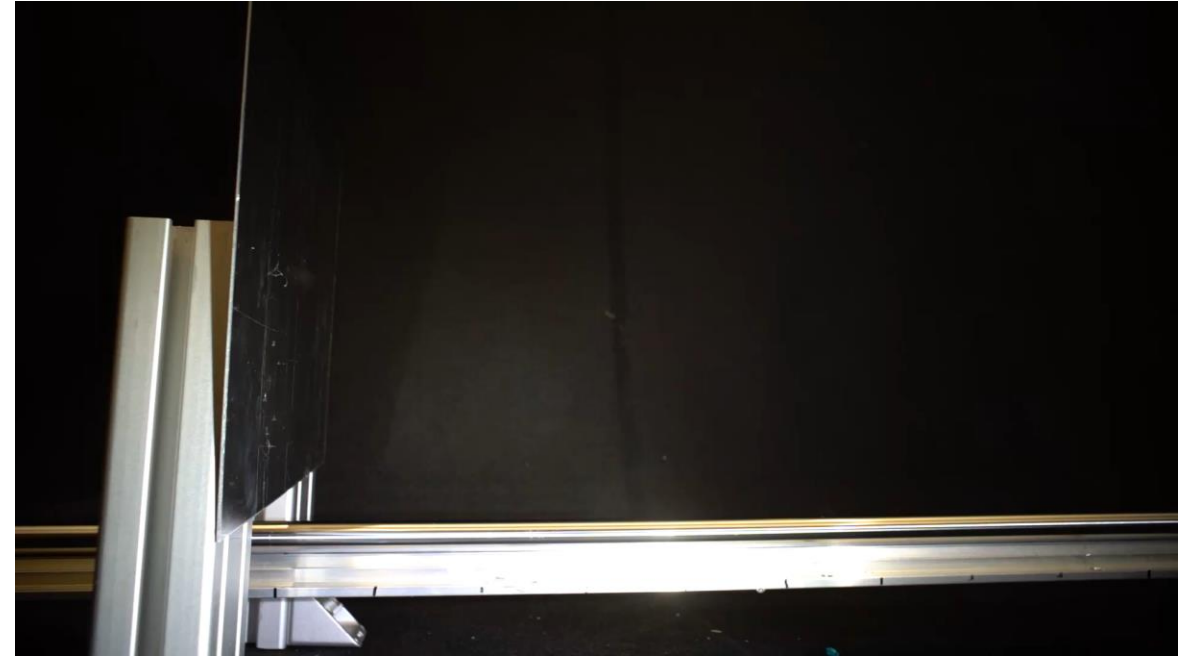
Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Gecko Tape 1 with Memory Foam – Moving Target

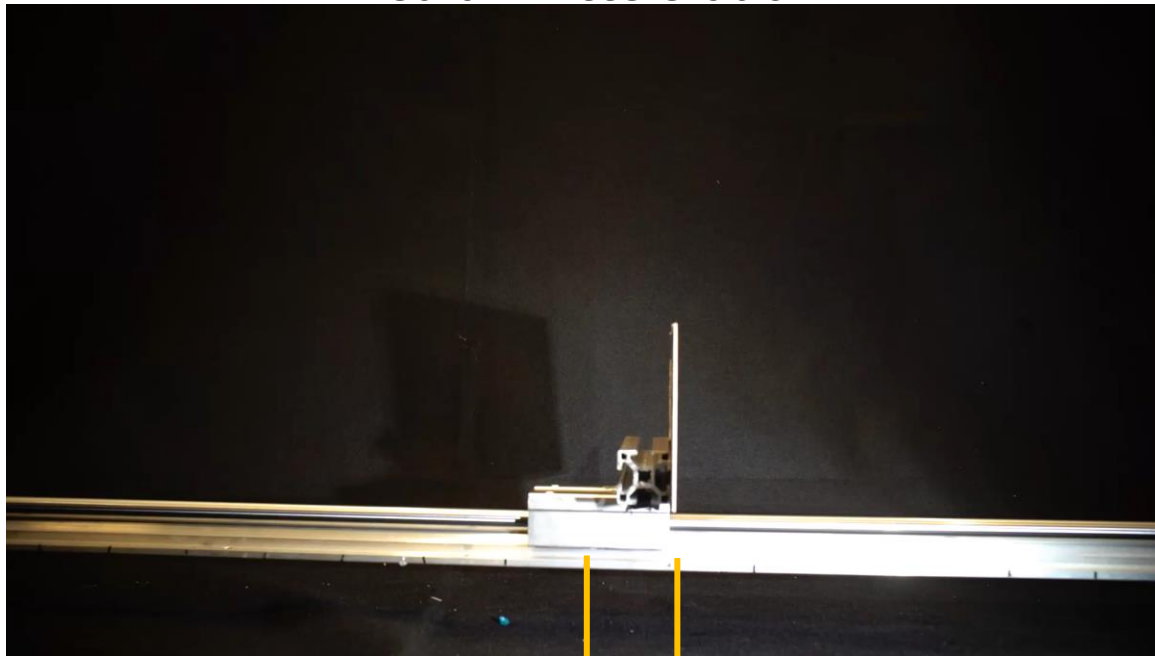
Concepts

Principles

Scenarios

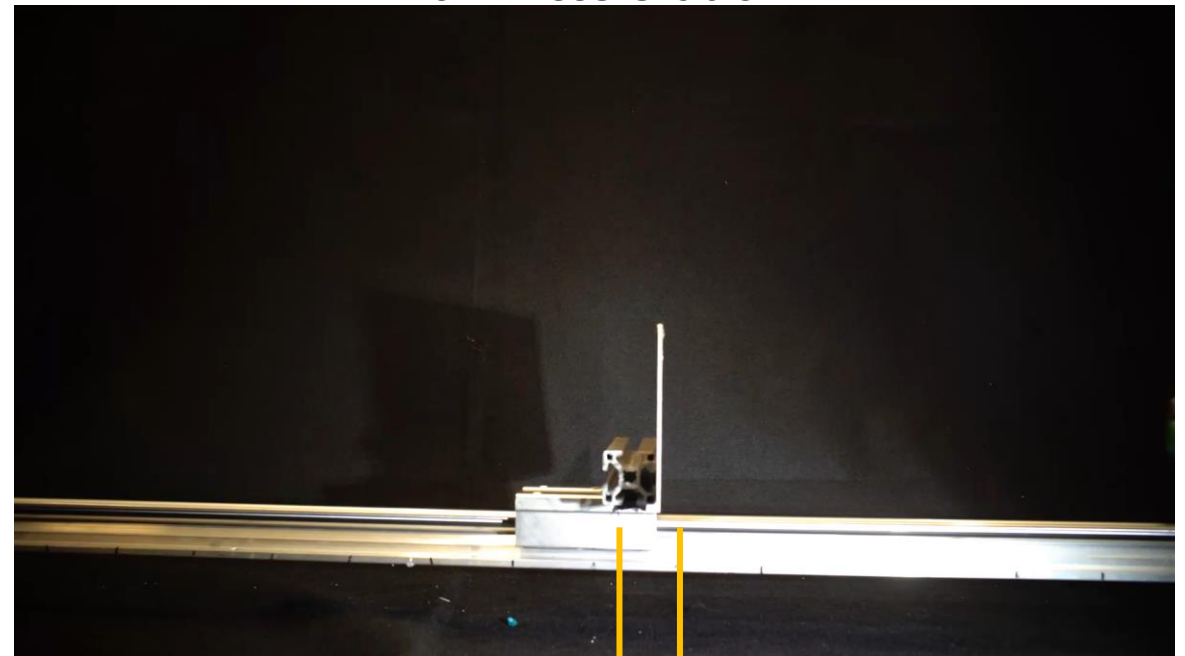
Top 3

Medium Acceleration



Moving distance

Low Acceleration



Moving distance

Demonstrator Validation and Testing

Double-Sided Tape – Stationary Target

Concepts

Principles

Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Double-Sided Tape – Moving Target

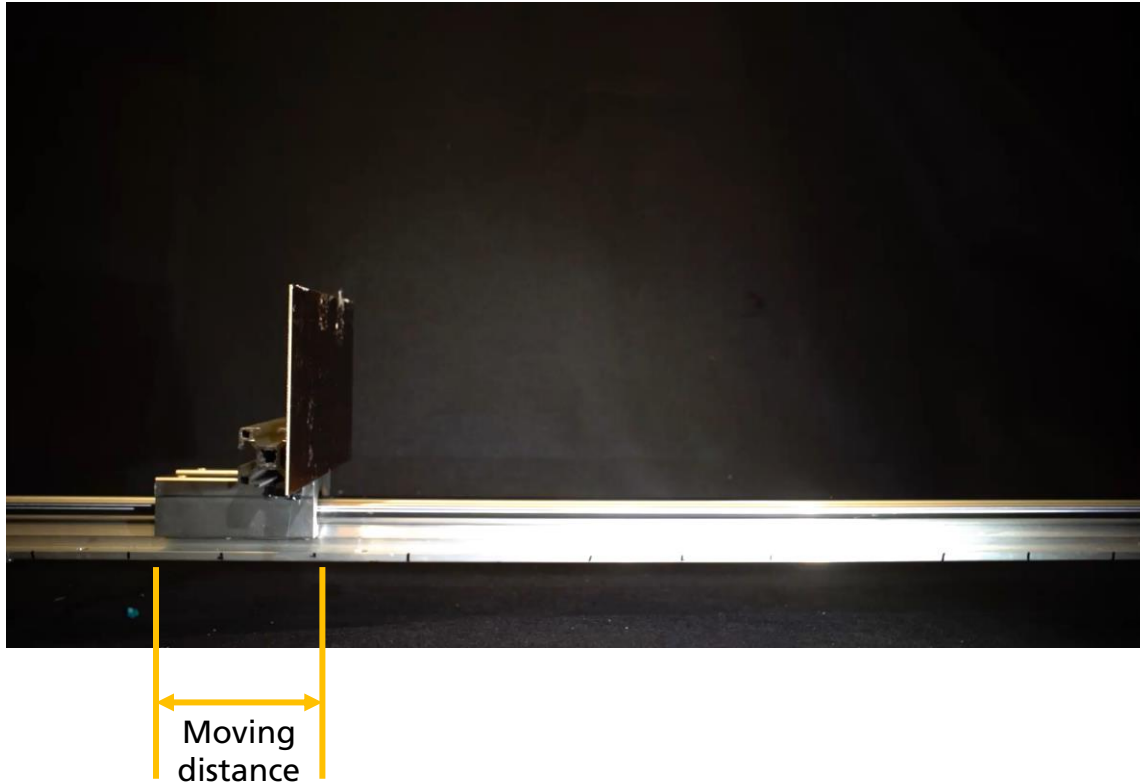
Concepts

Principles

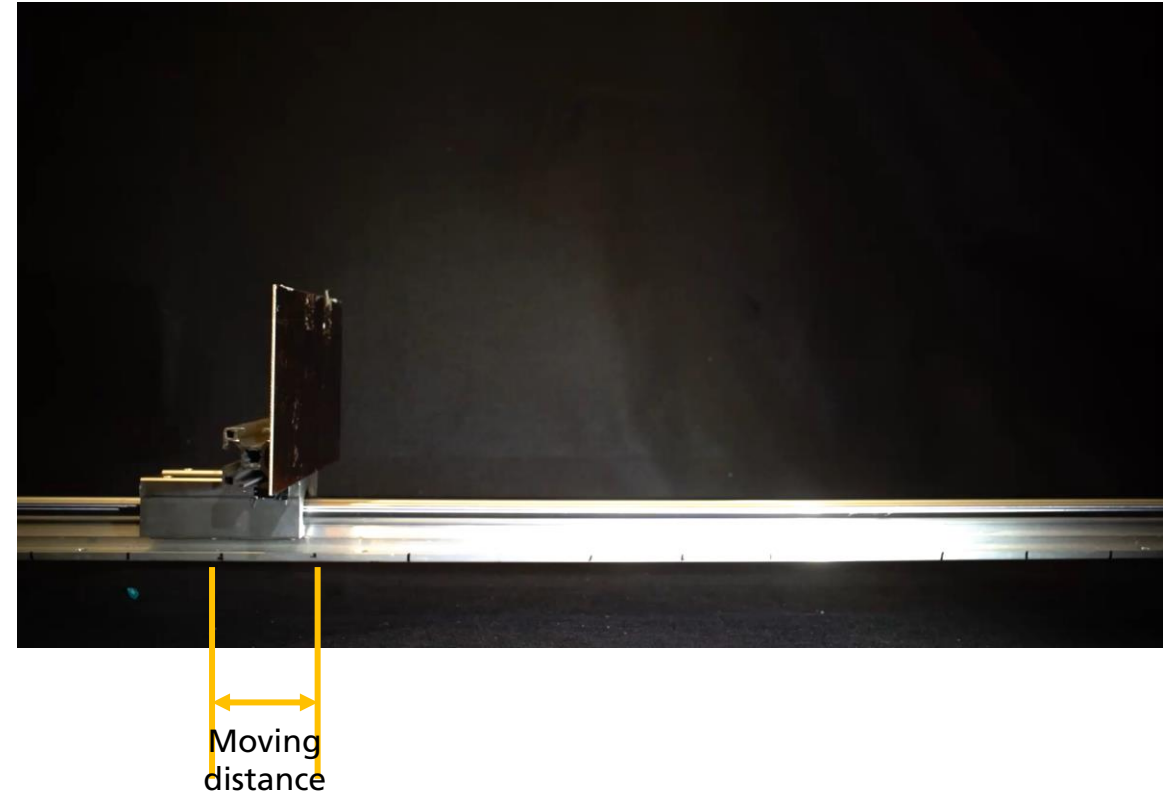
Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Gecko Tape 1 with Memory Foam – Round Moving Target

Concepts

Principles

Scenarios

Top 3



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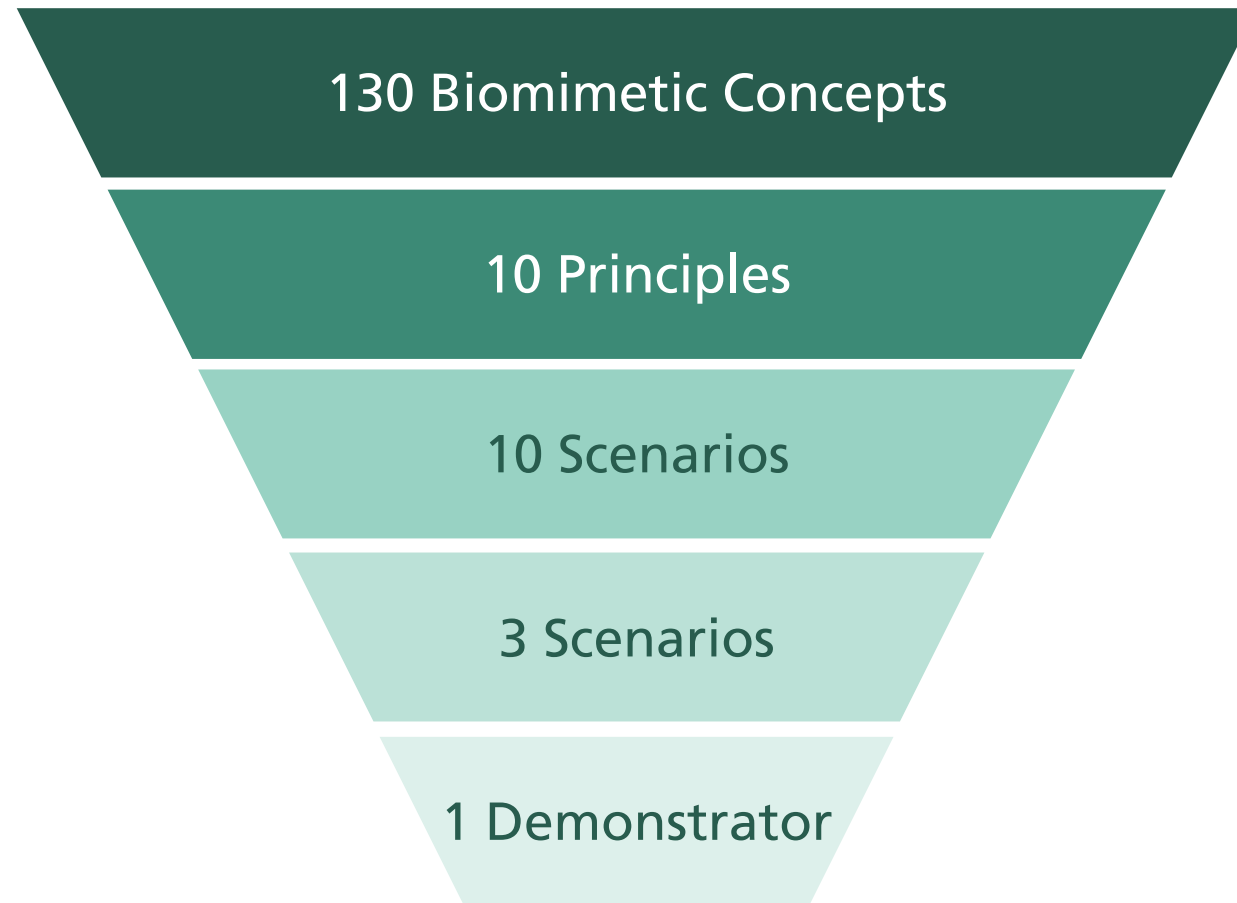
Subsystem 2: Drag Augmenting Sail

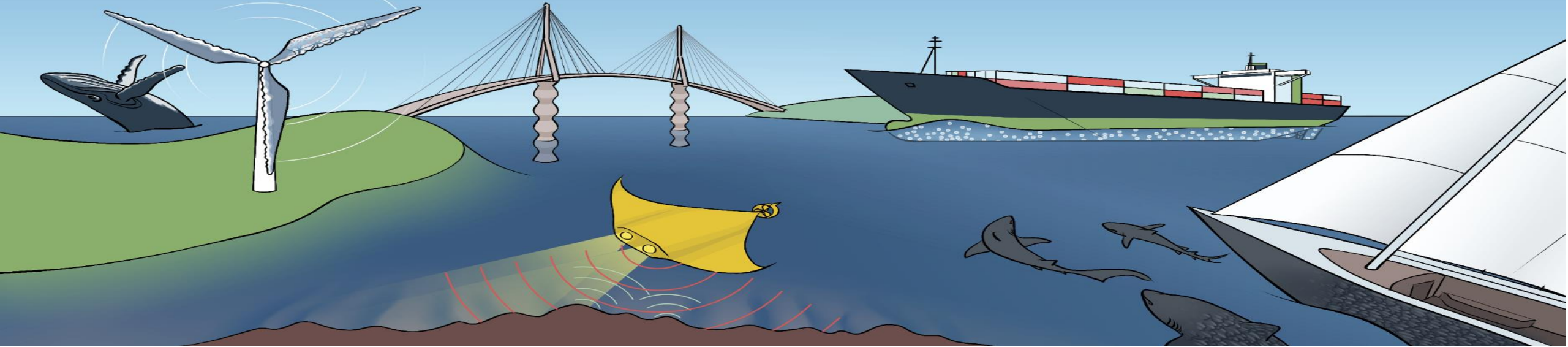
Subsystem 3: Wood Wasp Reciprocating Drill

3 Test and Validation

4 Live Demonstration

Task 3 – Top 10 Scenarios





CONTACT

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Literature

Literature

Demonstrator Validation and Testing

Gecko Tape 2 – Stationary Target

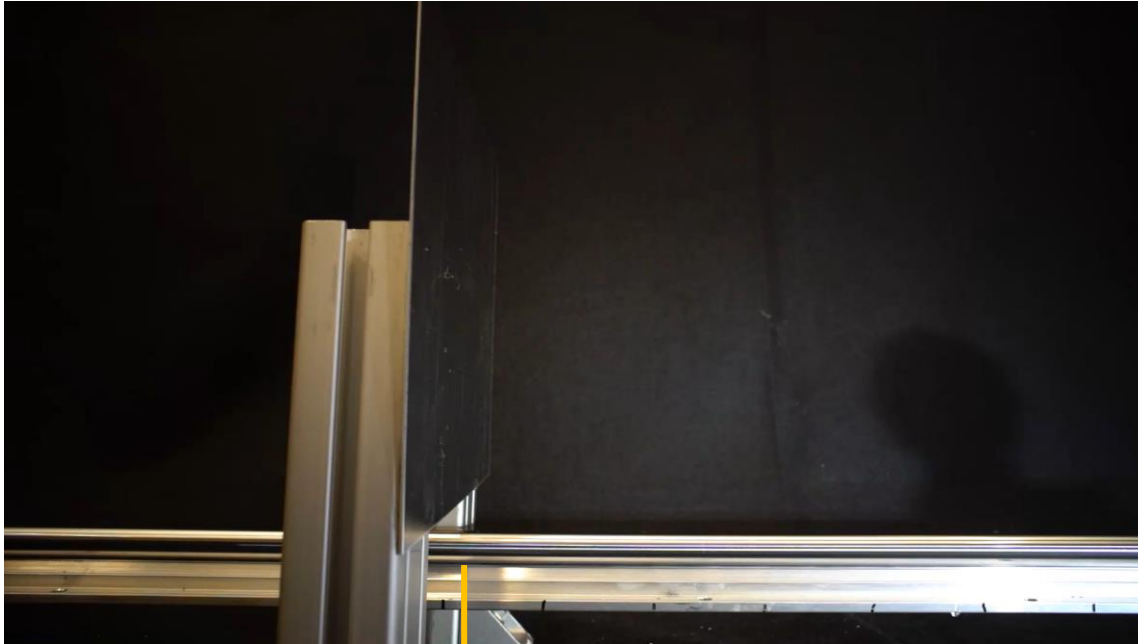
Concepts

Principles

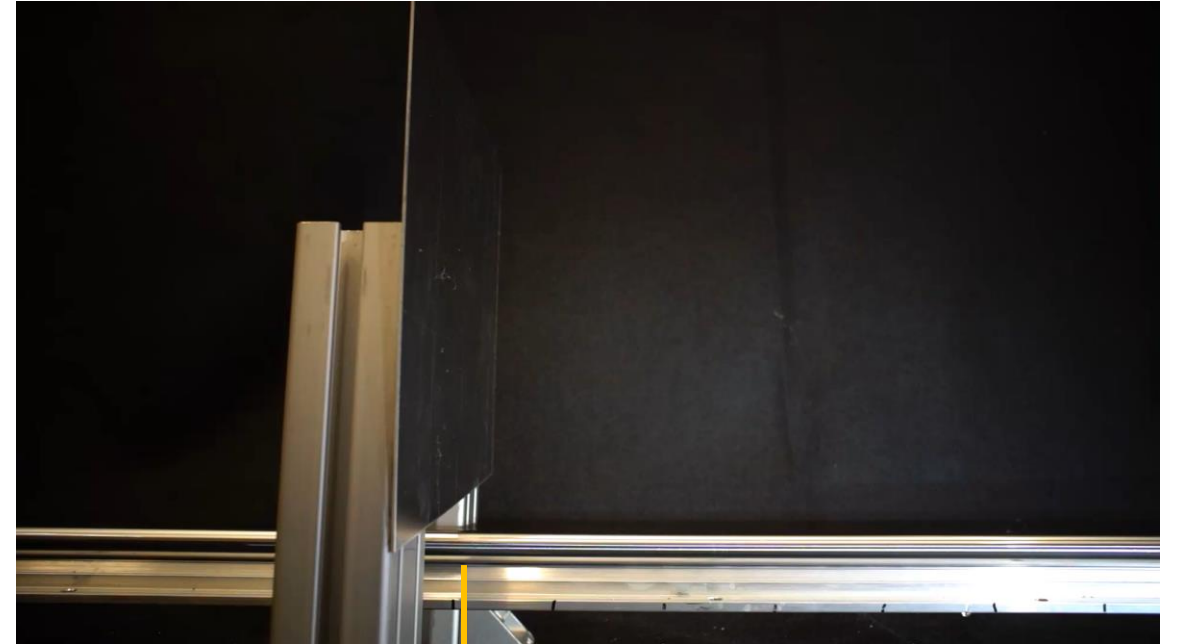
Scenarios

Top 3

Medium Acceleration



Low Acceleration



Demonstrator Validation and Testing

Gecko Tape 2 – Moving Target

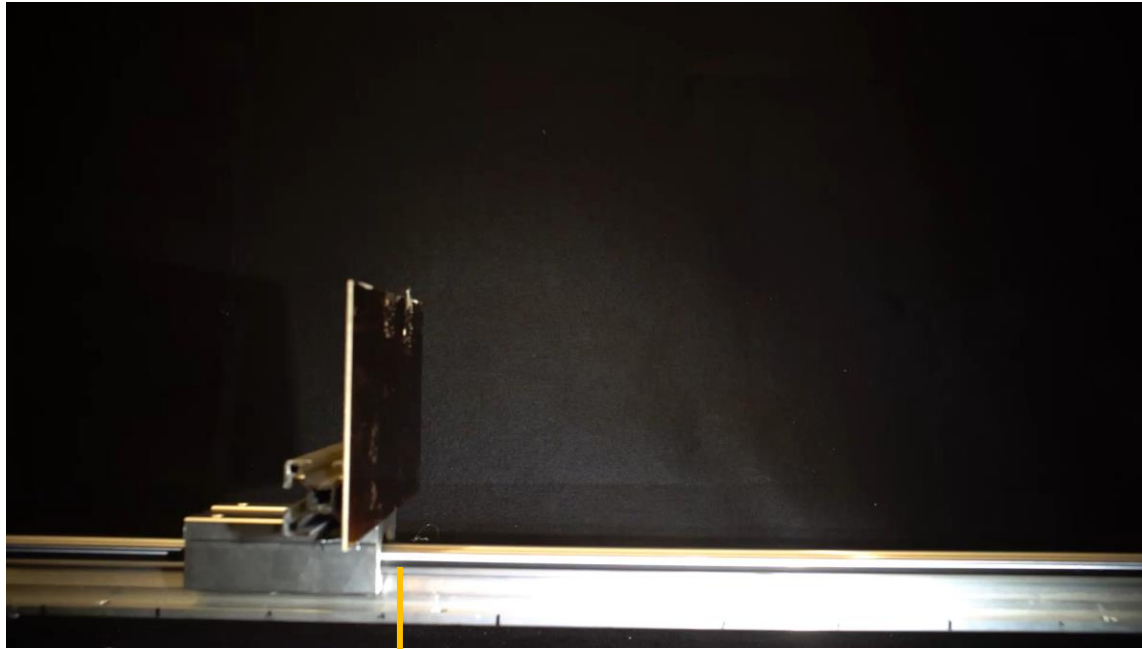
Concepts

Principles

Scenarios

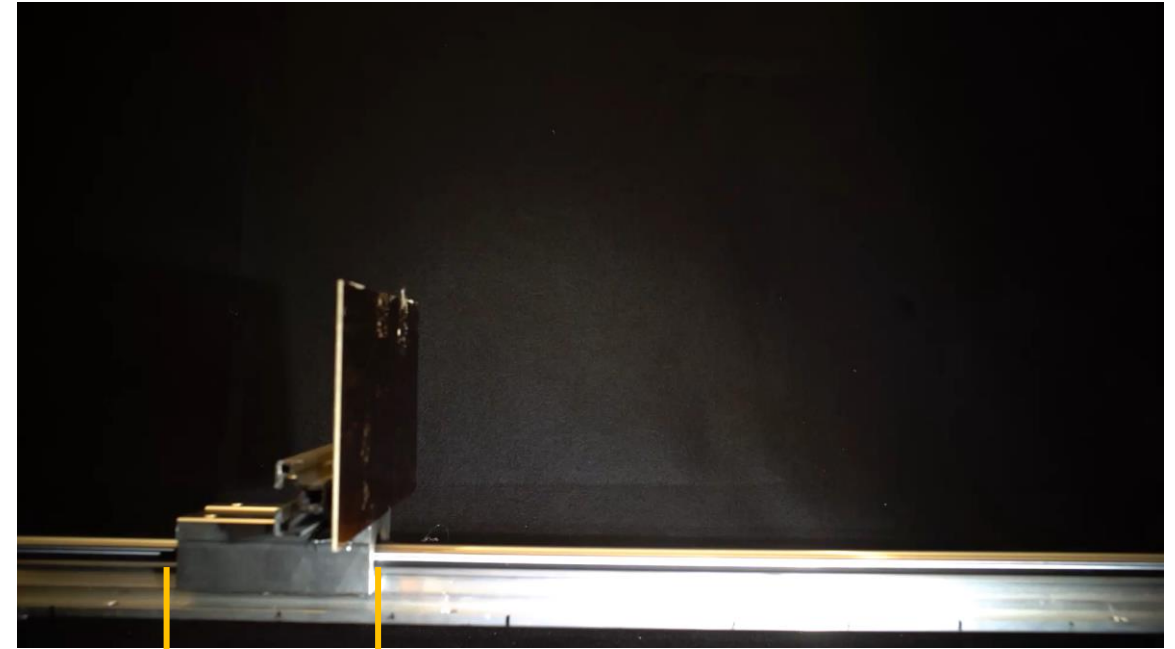
Top 3

Medium Acceleration



Bouncing distance

Low Acceleration



Bouncing distance

Demonstrator Validation and Testing

Gecko Tape 2 with Memory Foam – Stationary Target

Concepts

Principles

Scenarios

Top 3

Medium Acceleration



Bouncing distance

Low Acceleration



Bouncing distance

→ Manual test = no noticeable adhesion present → abandoned