Mobile, self-anchoring robots with high-force capability

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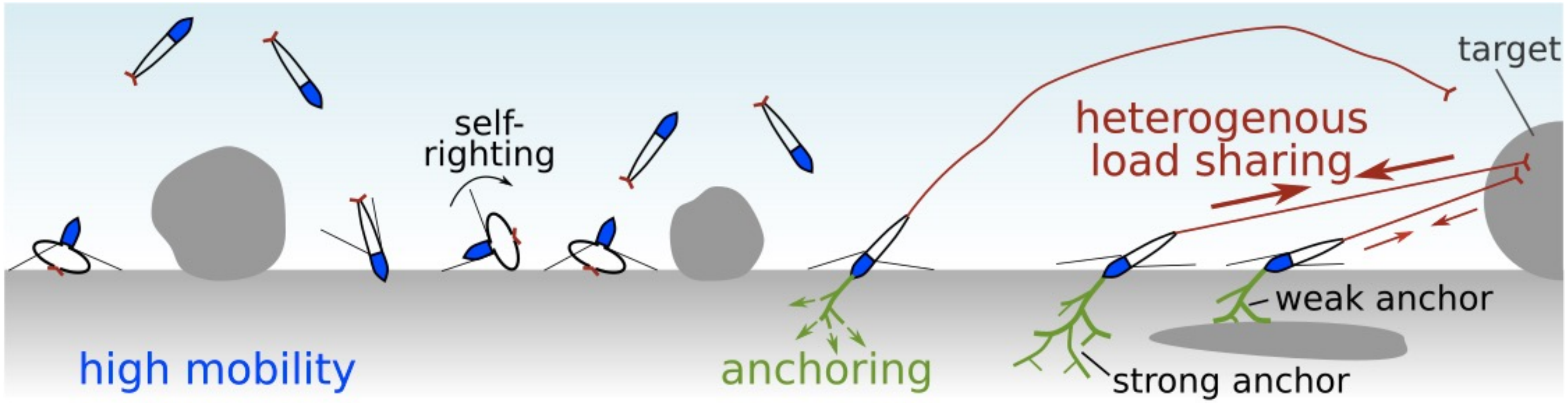
Project Overview

A. High-performance jumpers-

will enable **mobility over extreme terrain**, especially in low-gravity environments, **advancing space science and exploration** through improved access.



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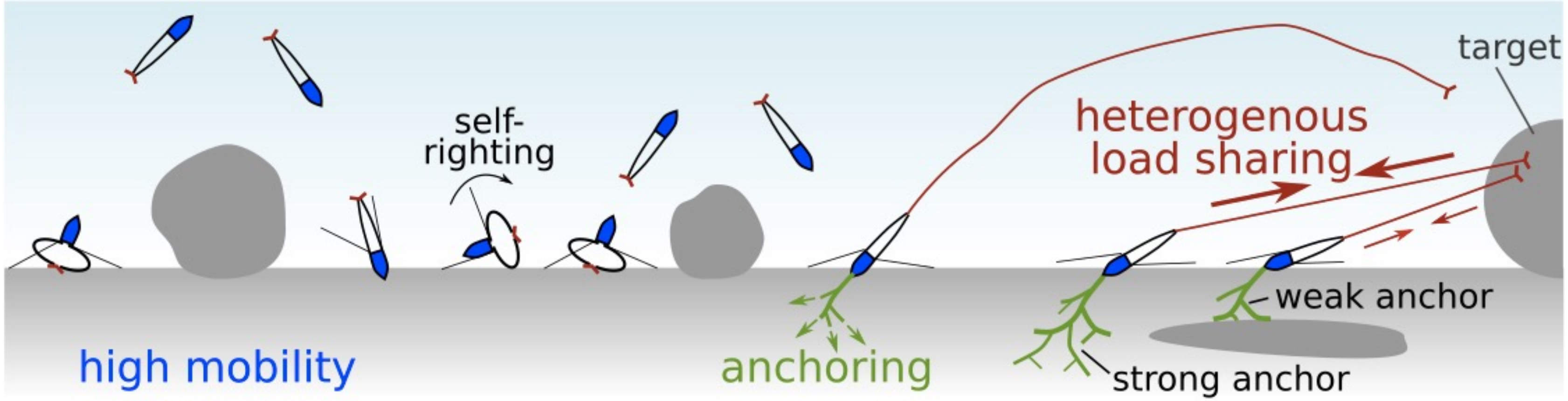
B. Root-like burrowing-

to form branched anchors that will enable **small, low-cost, and low-mass robots** to apply **high forces** to their environment.



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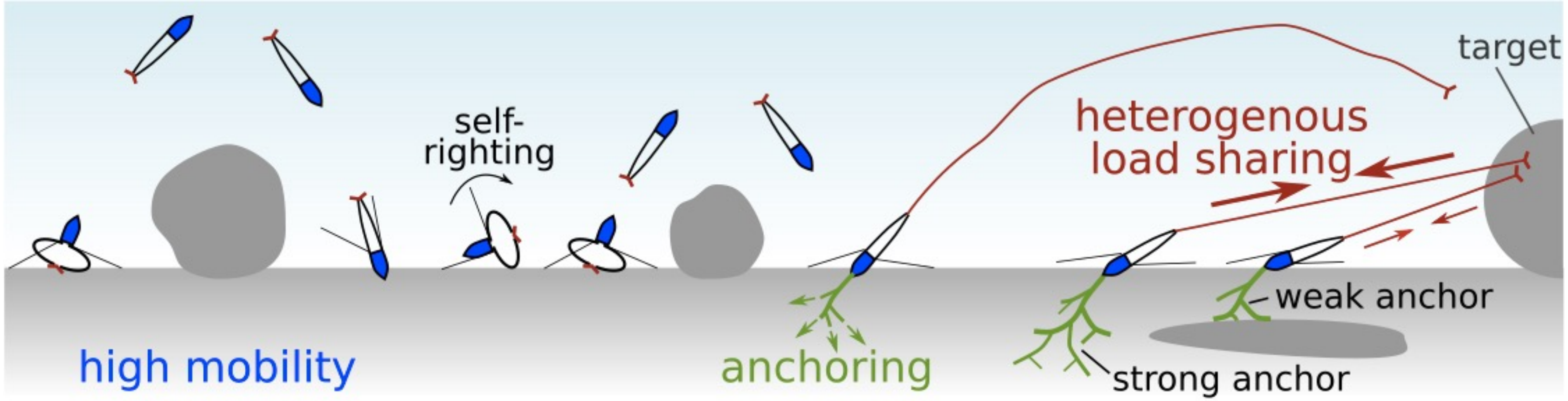
C. Load sharing mechanisms-

will enable **maximum load** application from a **team of robots** with heterogenous anchoring strengths.



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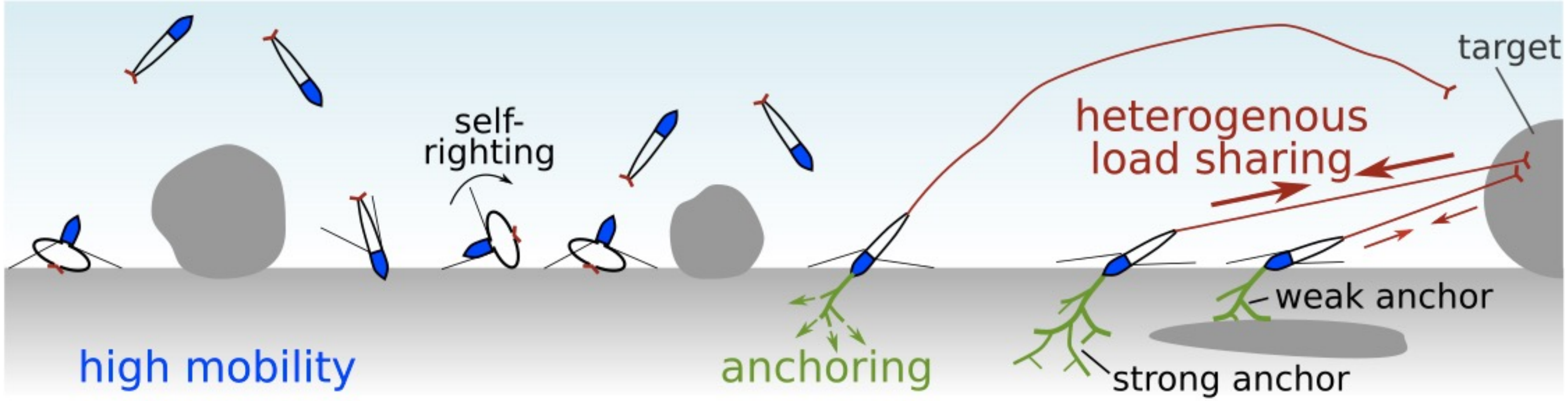

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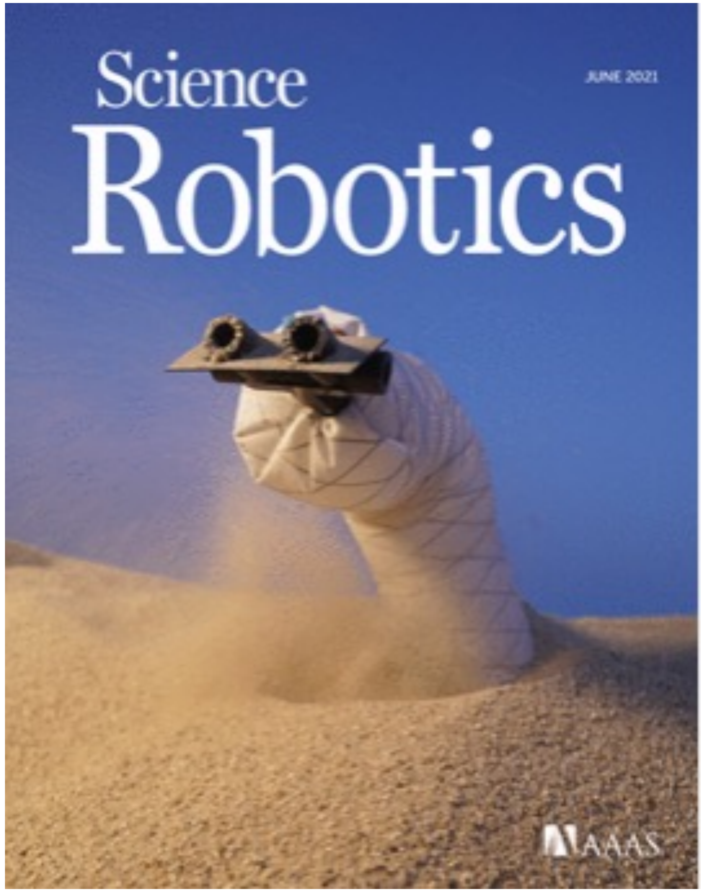

Work of Nicholas Naclerio (NSTRF)

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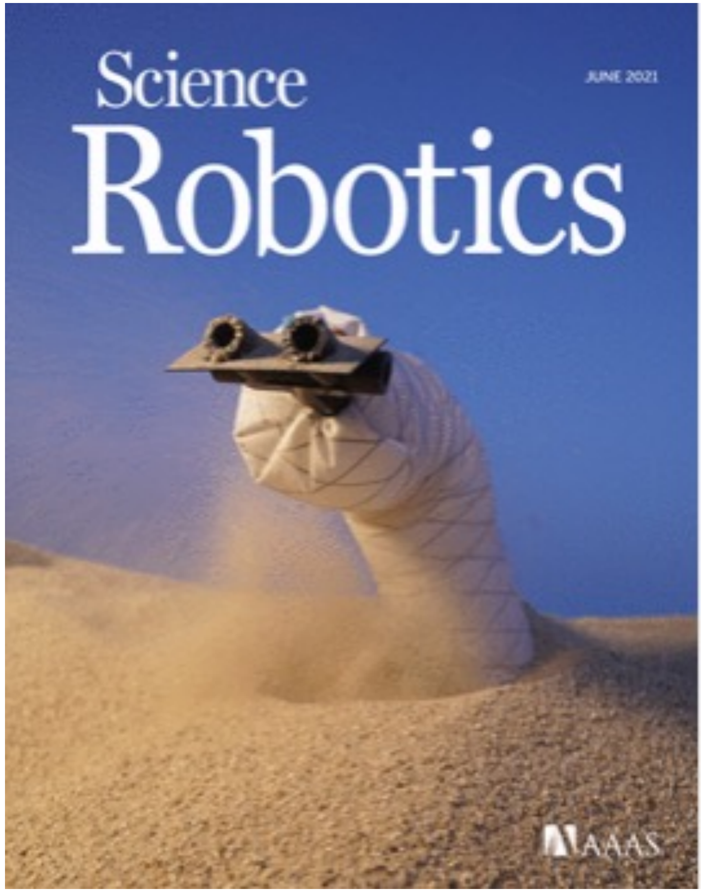


Jumping: background

"lunar grasshopper"

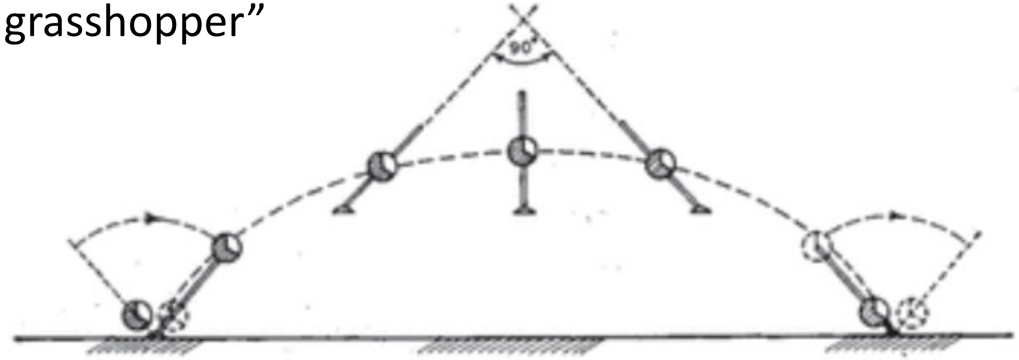


Fig. 1 Flight with oscillatory motion of pole, using one traction foot.

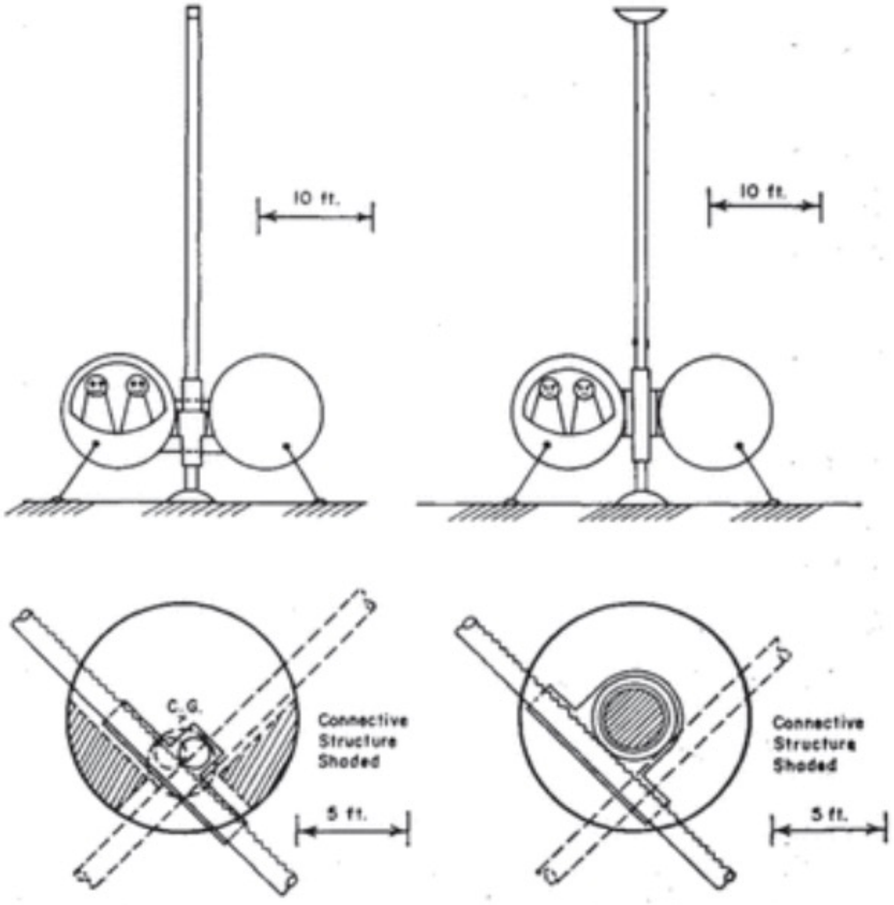
The Lunar Pogo Stick

H. S. Seifert*

Stanford University, Stanford, Calif. and United Technology Center, Sunnyvale, Calif.

VOL. 4, NO. 7, JULY 1967

J. SPACECRAFT



a) Oscillating pole. **b) Rotating pole.**

Fig. 3 Plan views and midplane sections.

Jumping: background

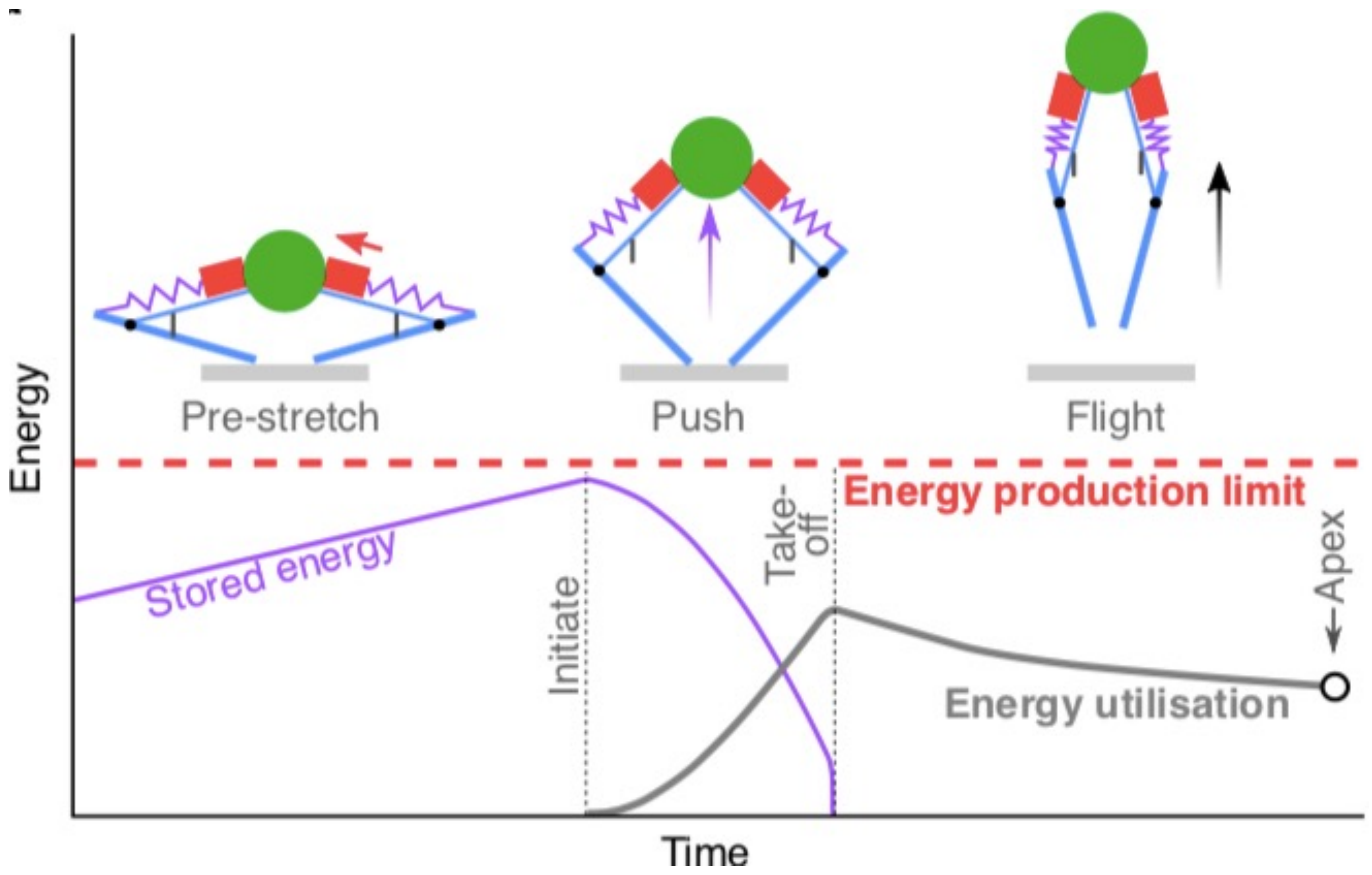
50 years later:

-there are many impressive bio-inspired jumping machines;

-there are many thorough models of biological jumping across scale;

-but there lacks modeling that captures the phenomena of **both** biological and engineered jumping that could inform **general engineered jumper design** compared to biological jumper design

Jumping: Energetic Model



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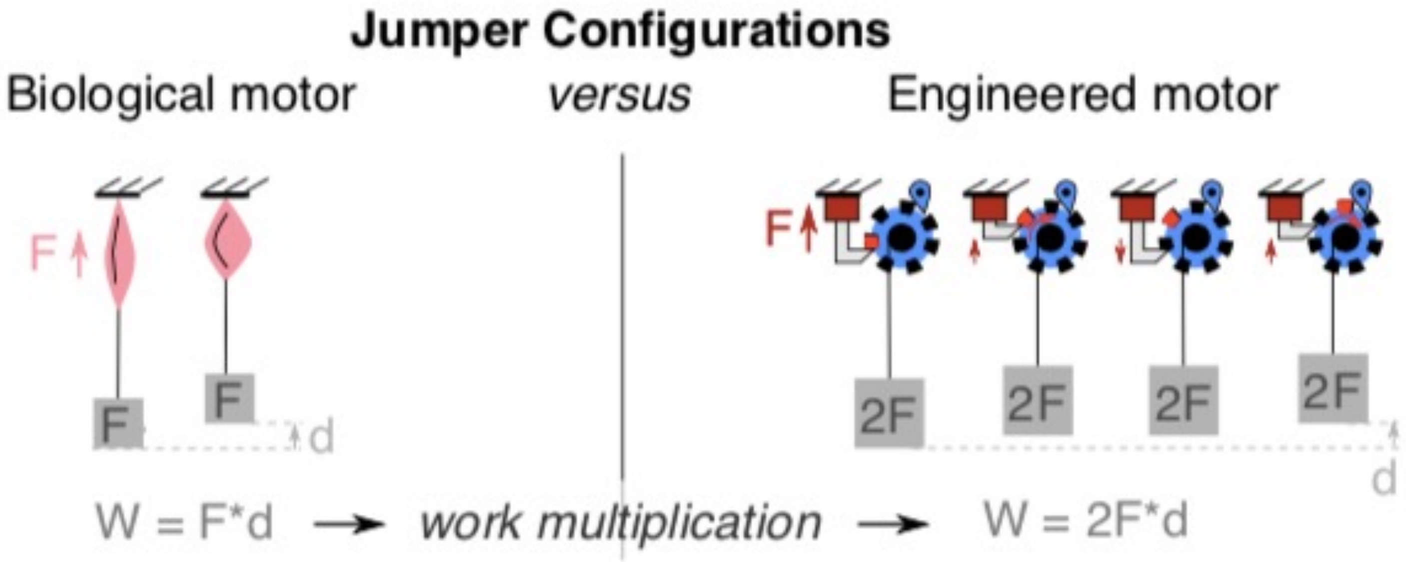

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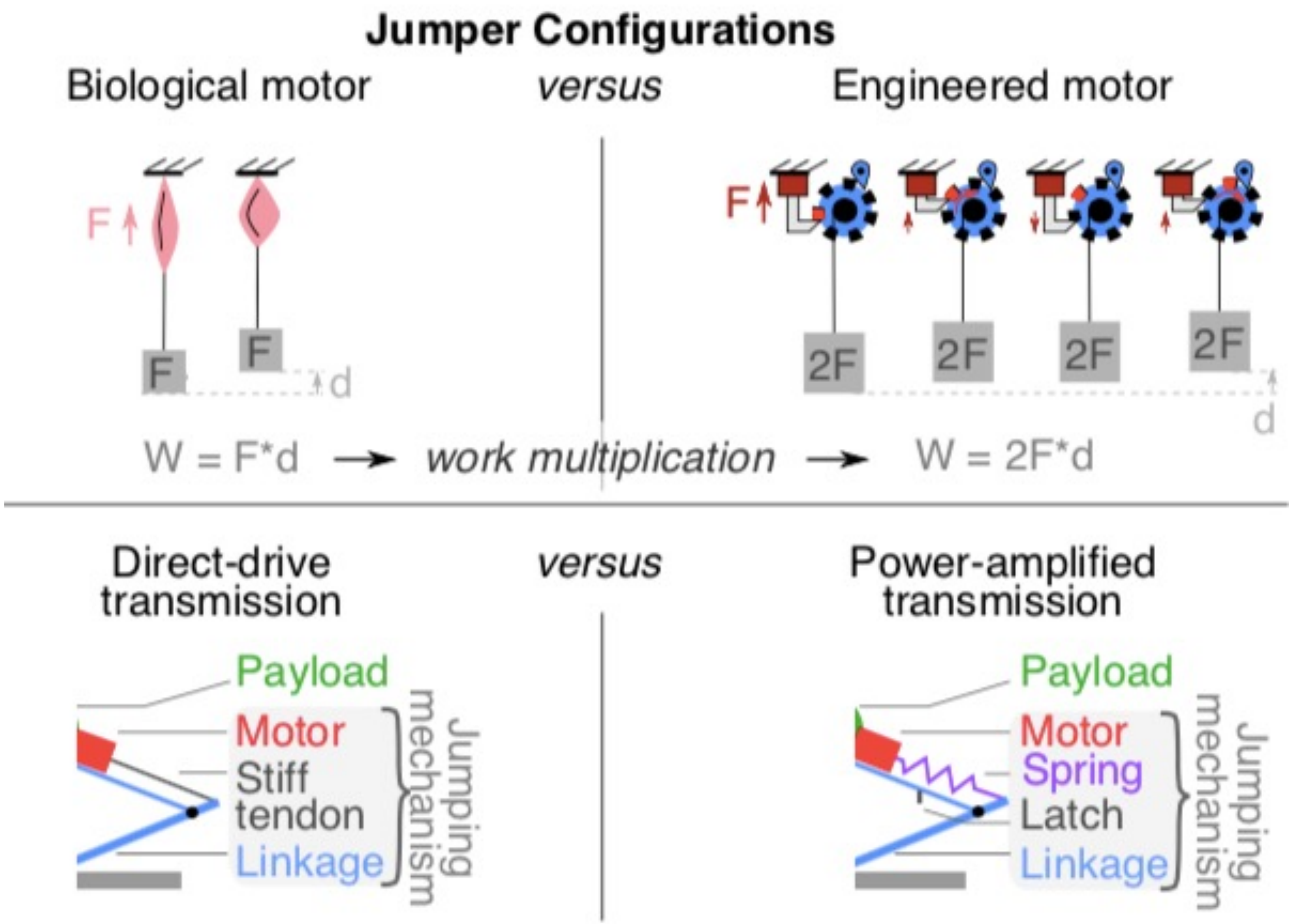
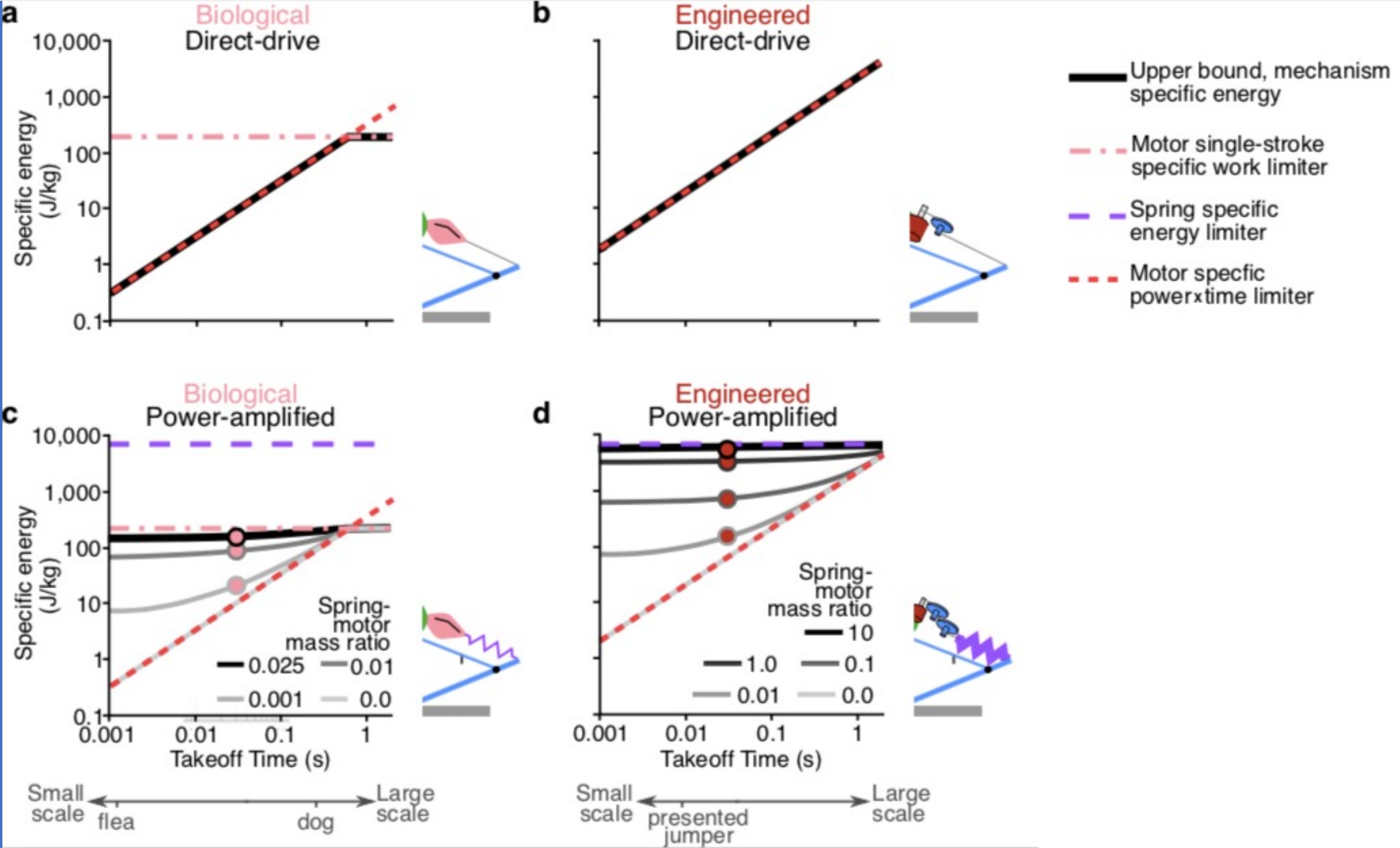




a
Biological
Direct-drive
b
Engineered
Direct-drive
c
Biological
Power-amplified
d
Engineered
Power-amplified
Specific energy (J/kg)
10,000
1,000
100
10
1
0.1
0.001
0.01
0.1
1
Takeoff Time (s)
Upper bound, mechanism specific energy
Motor single-stroke specific work limiter
Spring specific energy limiter
Motor specfic power×time limiter
Spring-motor mass ratio
0.025
0.01
0.001
0.0
10
1.0
0.1
0.01
0.0
Small scale
Large scale
flea
dog
presented jumper

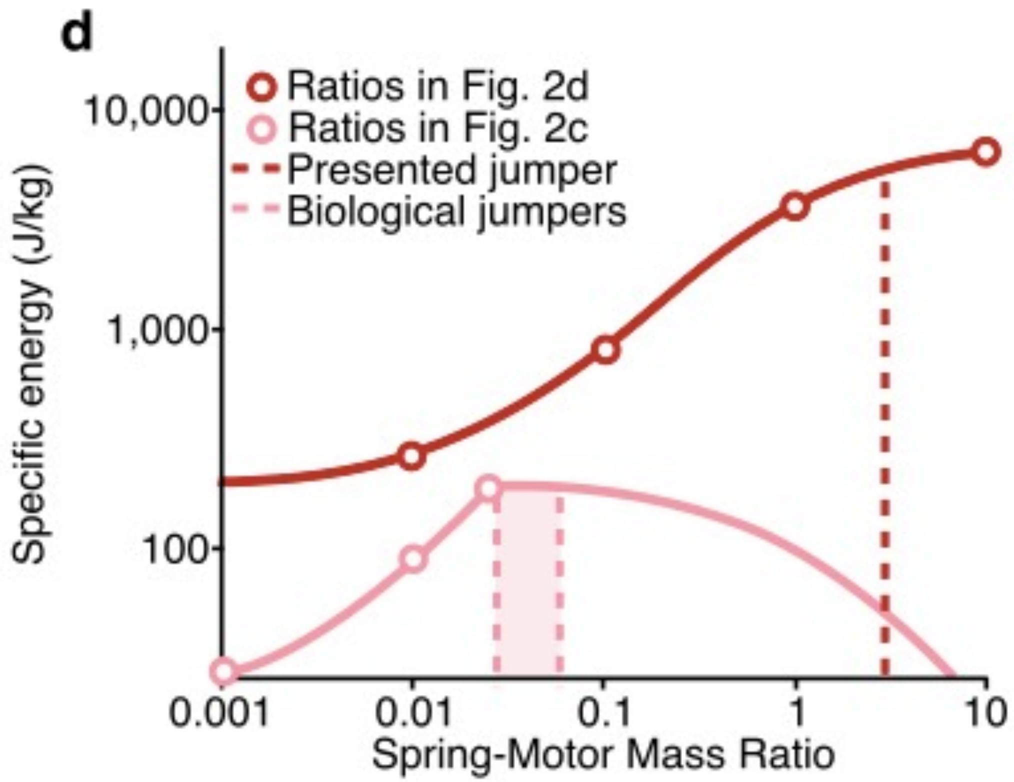
Jumping: Energetic Model- Insights

Key Takeaway:

Biological jumpers are limited primarily by the **motor specific work**;

Engineered jumpers by the **spring specific energy;** thus focus on this to jump higher.

Jumping: Energetic Model- Insights



Jumping: Energetic Model- Insights

Key Takeaway:
Engineered jumpers should have a
spring-motor mass ratio
100-fold larger than
biological jumpers.

Jumping: Energetic Model- Utilization Model

$$h = \frac{1}{g} e_{apex} = \frac{1}{g}\left[e_{max}\,\eta_{prod}\left(1 - \frac{m_{payload}}{m}\right) - Lg\,\frac{m_{body}}{m}\right][1 - \beta_x - \beta_\theta]\left[1 - \frac{m_{foot}}{m}\right]\left[1 - \frac{D_s e_{COM}}{2}\right]$$

where the stages are:

1	Production:	$e_{prod} = e_{max}\,\eta_{prod}$	*(production efficiency)*
2	Available Energy:	$e_0 = e_{prod}\left(1 - \frac{m_{payload}}{m}\right)$	*(payload apportionment)*
3	KE, Total:	$e_{KE} = e_0 - Lg\,\frac{m_{body}}{m}$	*(less energy-to-stand)*
4	KE, Vertical:	$e_{vert} = e_{KE}[1 - \beta_x - \beta_\theta]$	*(less non-vertical)*
5	KE, Centre of Mass:	$e_{COM} = e_{vert}\left[1 - \frac{m_{foot}}{m}\right]$	*(less energy transfer losses)*
6	PE, Centre of Mass:	$e_{apex} = e_{COM}\left[1 - \frac{D_s e_{COM}}{2}\right]$	*(less aerodynamic drag)*

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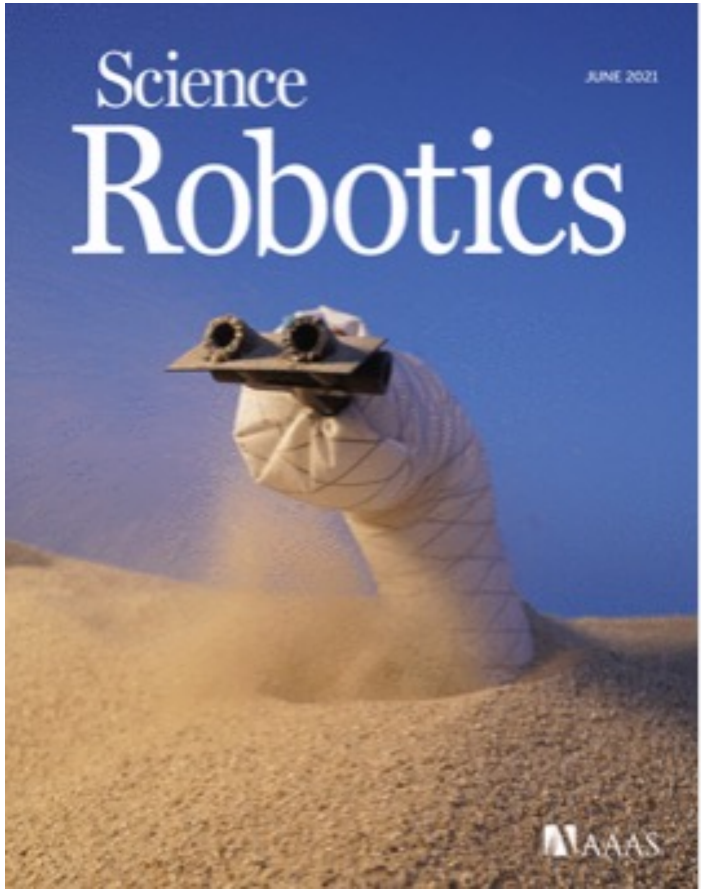
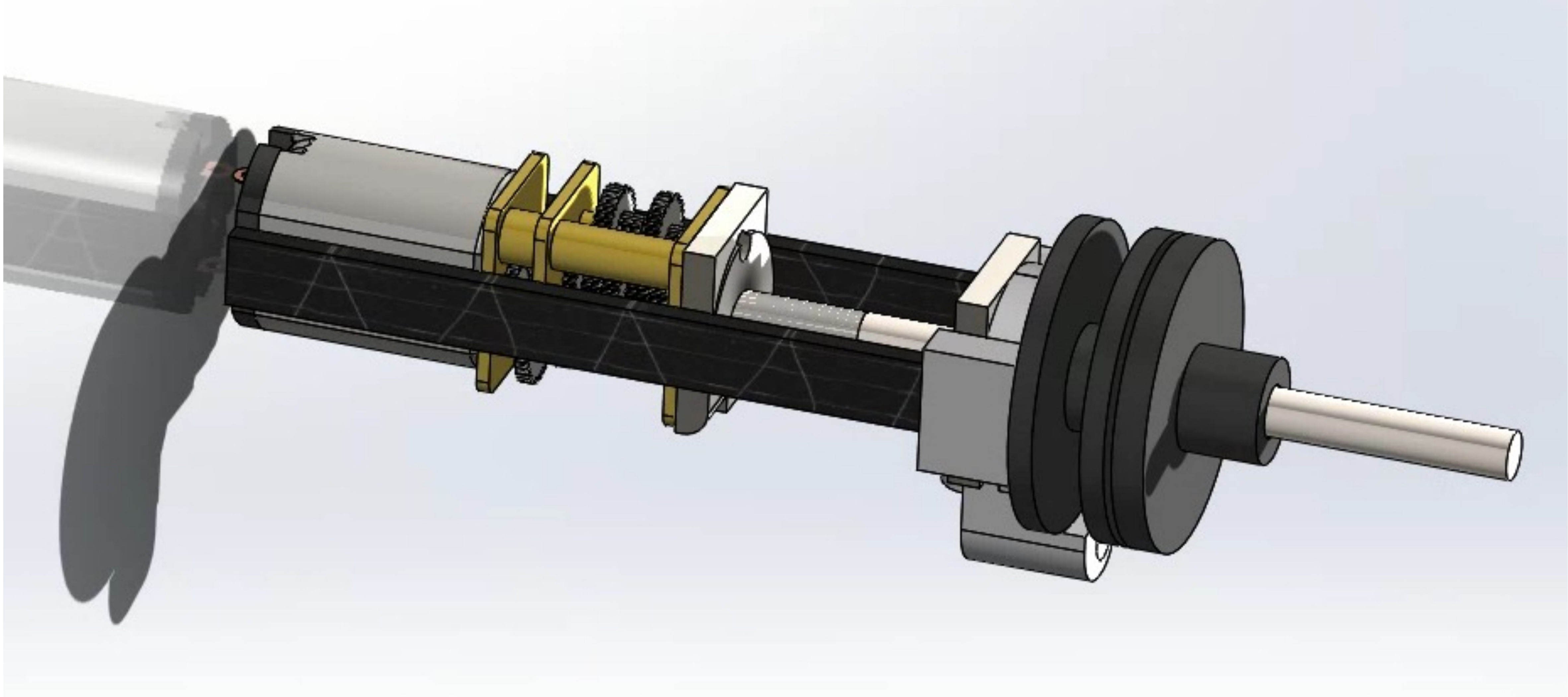


High-load winding mechanism



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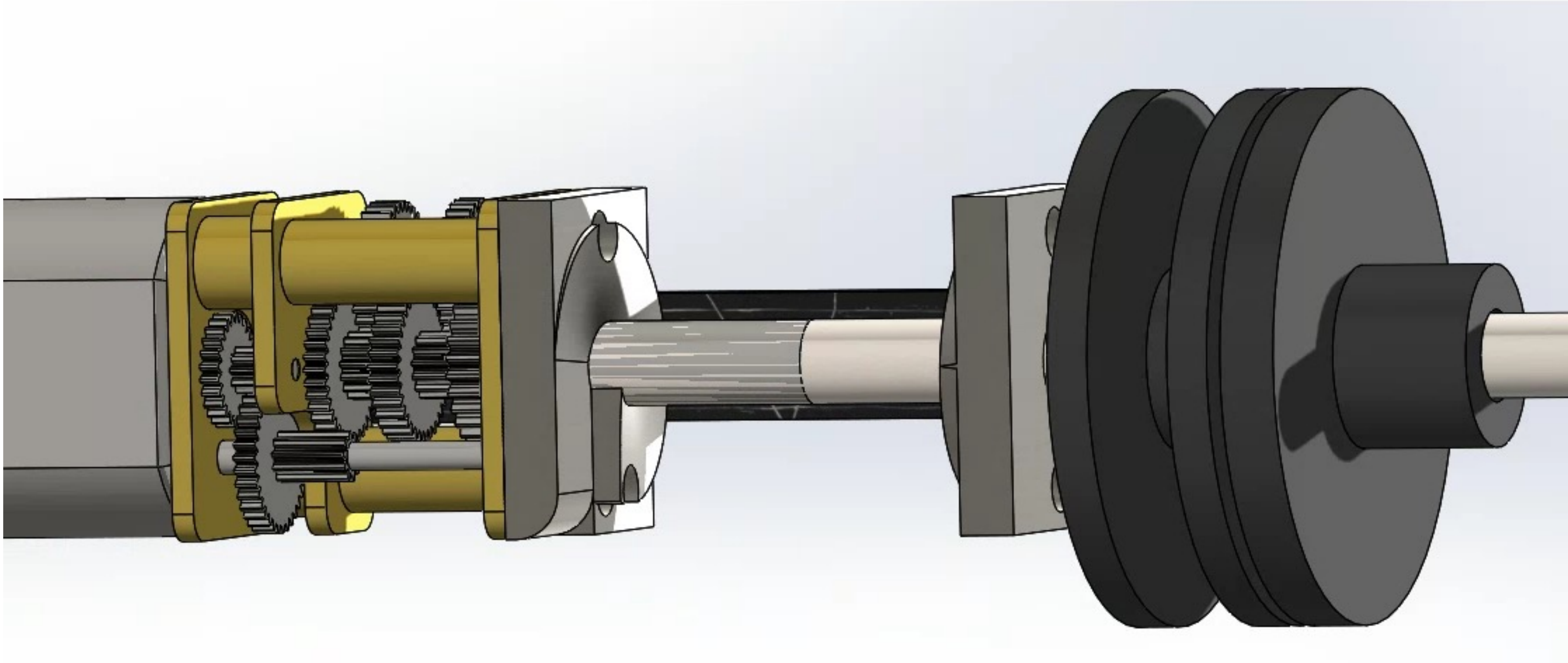

High-load winding mechanism

Specifications:

-Mass: 17 g

-180 N pulling force

-Stroke: unlimited (limited by length of string)

180N

Repeated 5 times

Video 5x

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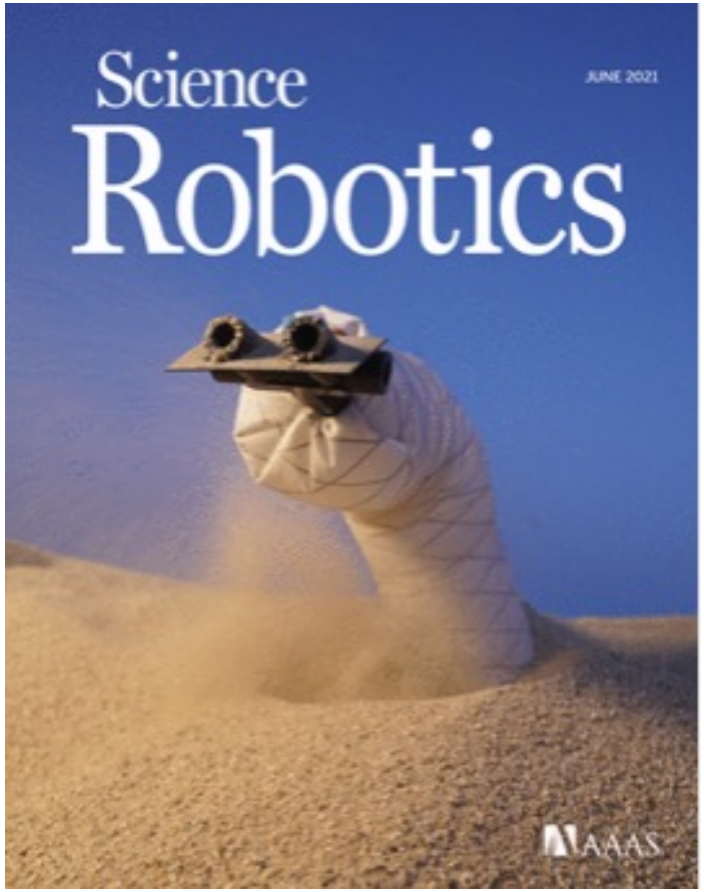
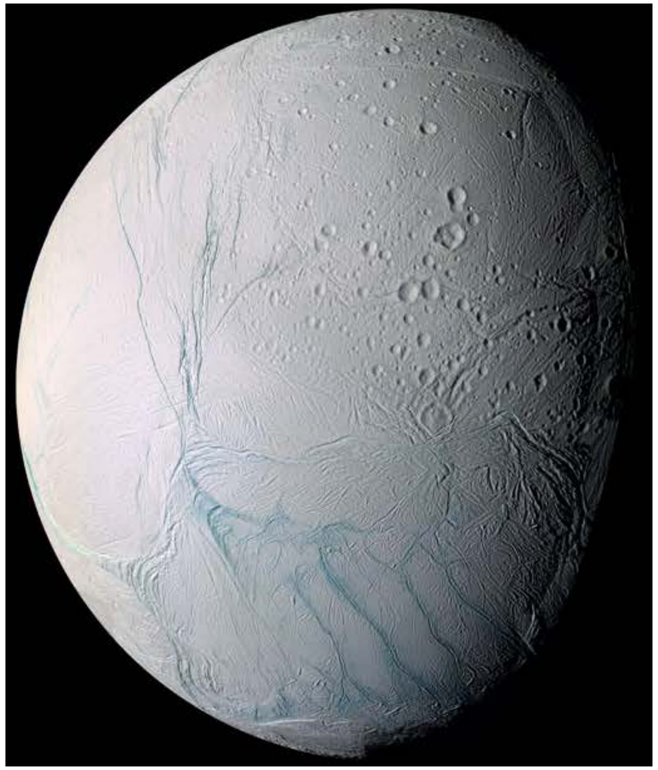


Burrowing

Motivation

Martian sensor placement

Lunar cave exploration



Exploring granular ice on Enceladus

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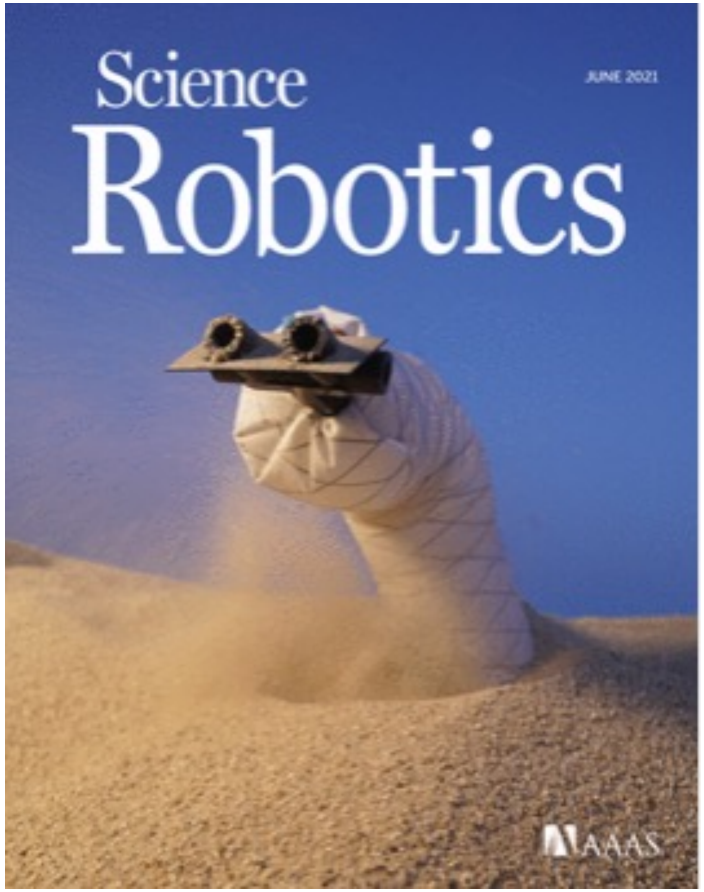

Burrowing: Bio-inspiration

Tip Extension

Granular Fluidization

Asymmetry

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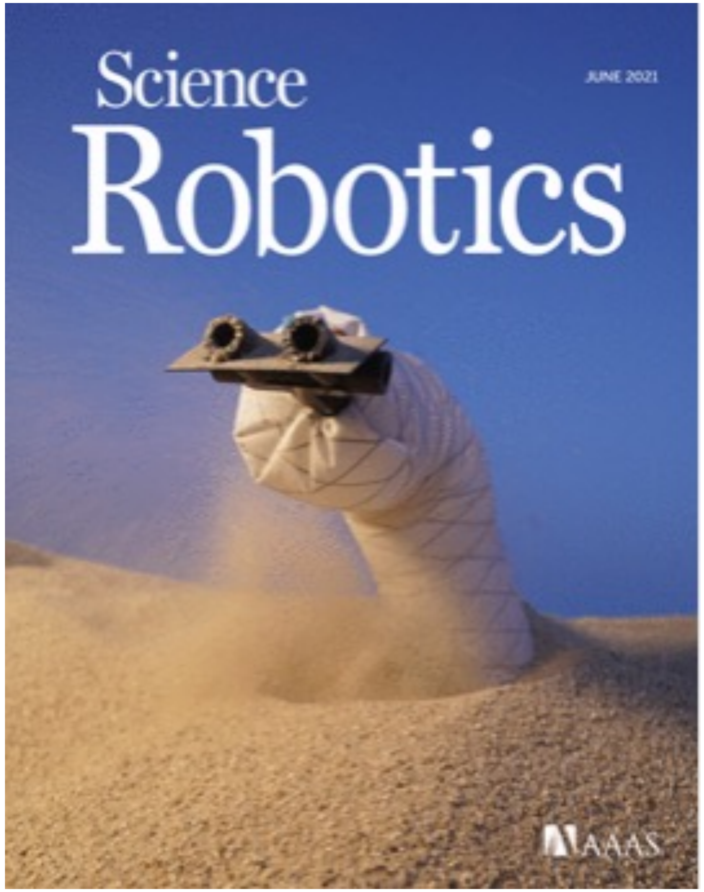

Burrowing: Hypothesis Testing

Summary of results

- H1: Tip extension reduces drag by amount equal to skin drag.
- H2: Forward fluidization reduces drag, but (i) saturates with depth, and (ii) even works when perpendicular to motion.
- H3: Downward fluidization reduces lift, but shows non-monotonic relationship with flow angle.

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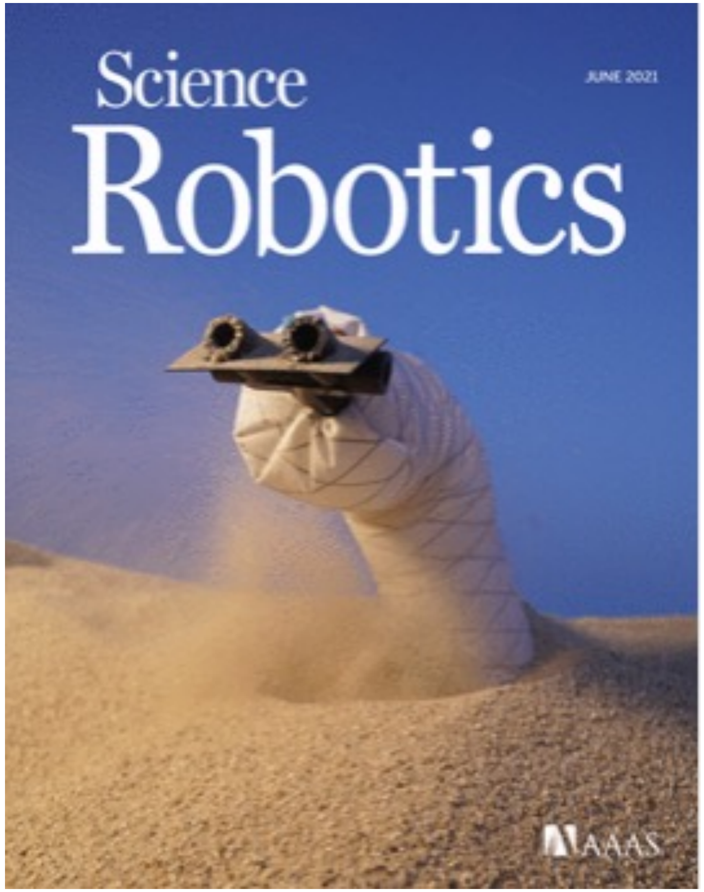
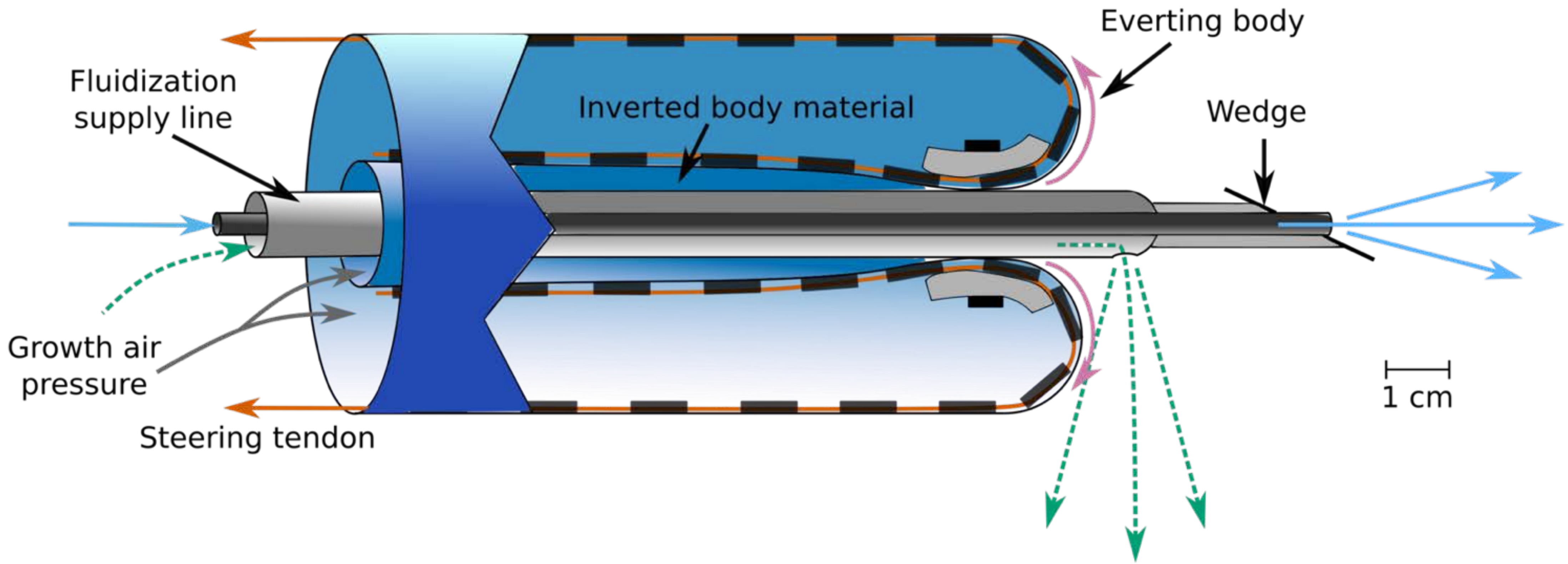


Burrowing: Robot Design



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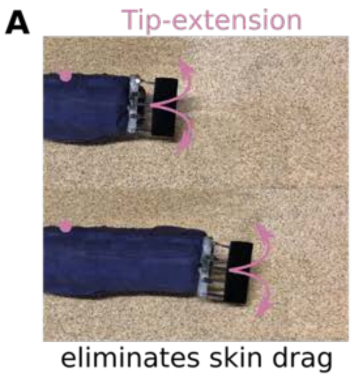

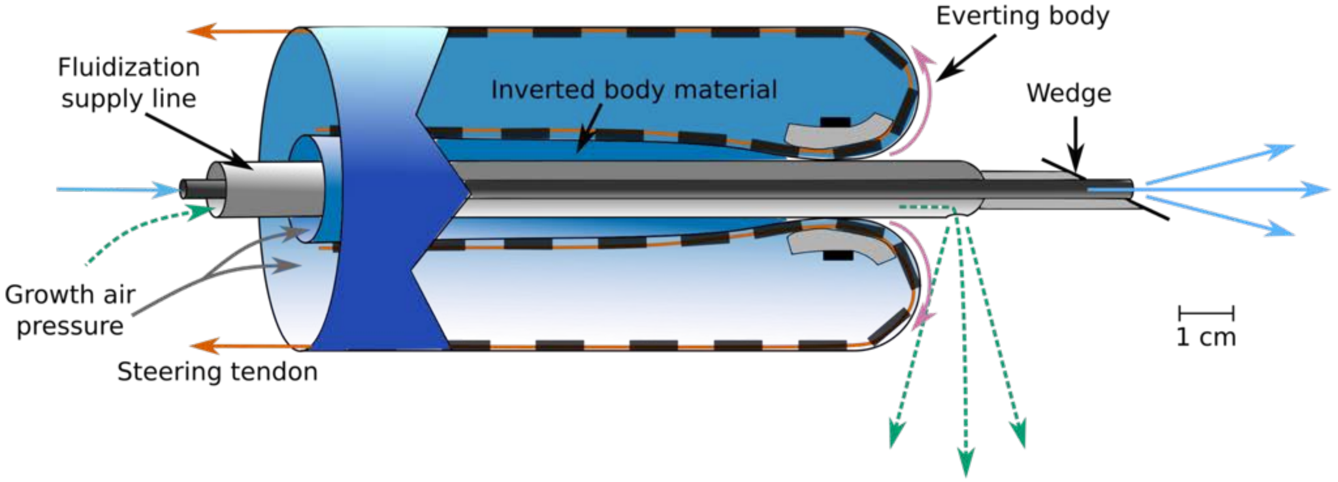

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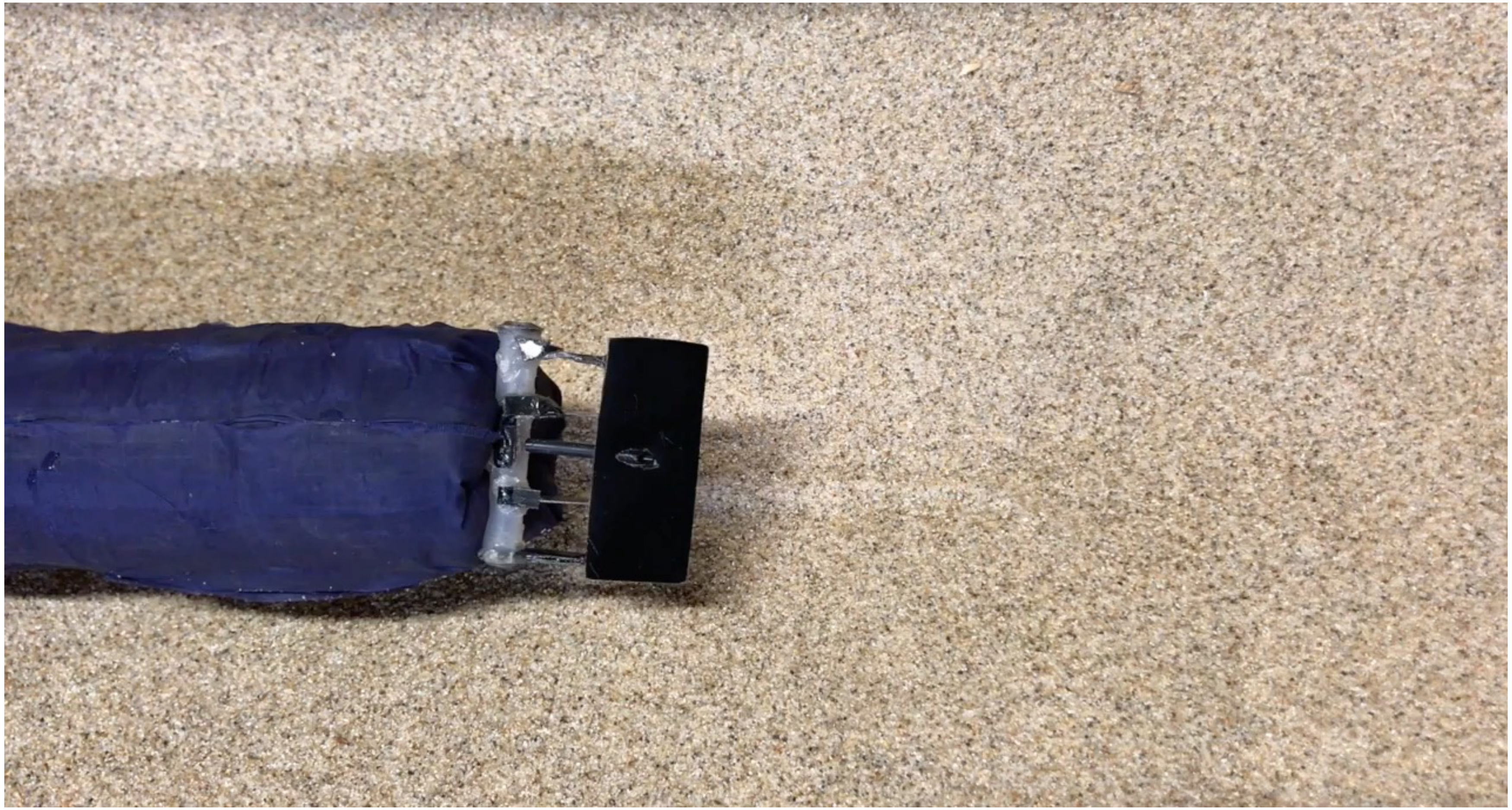

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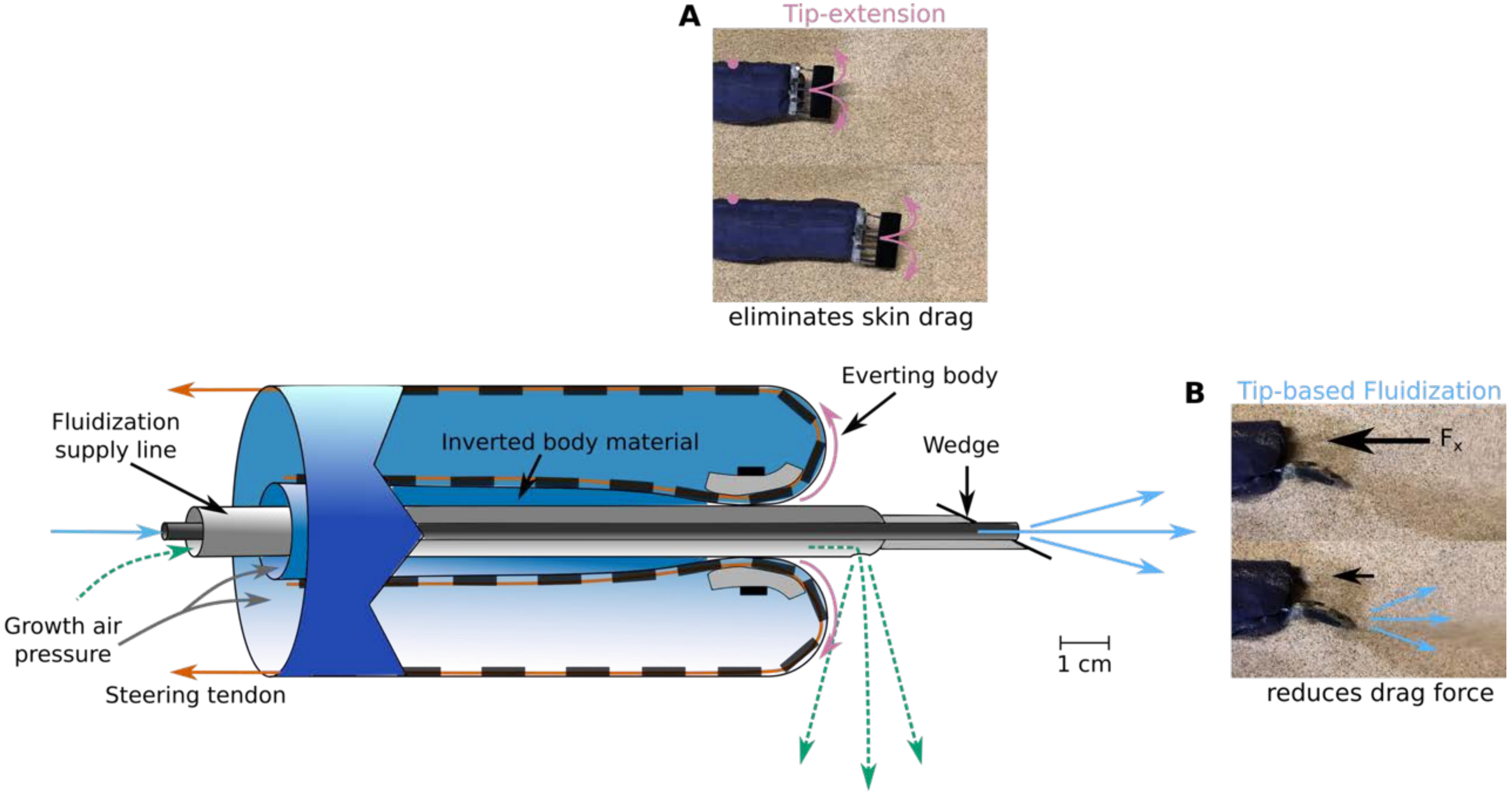

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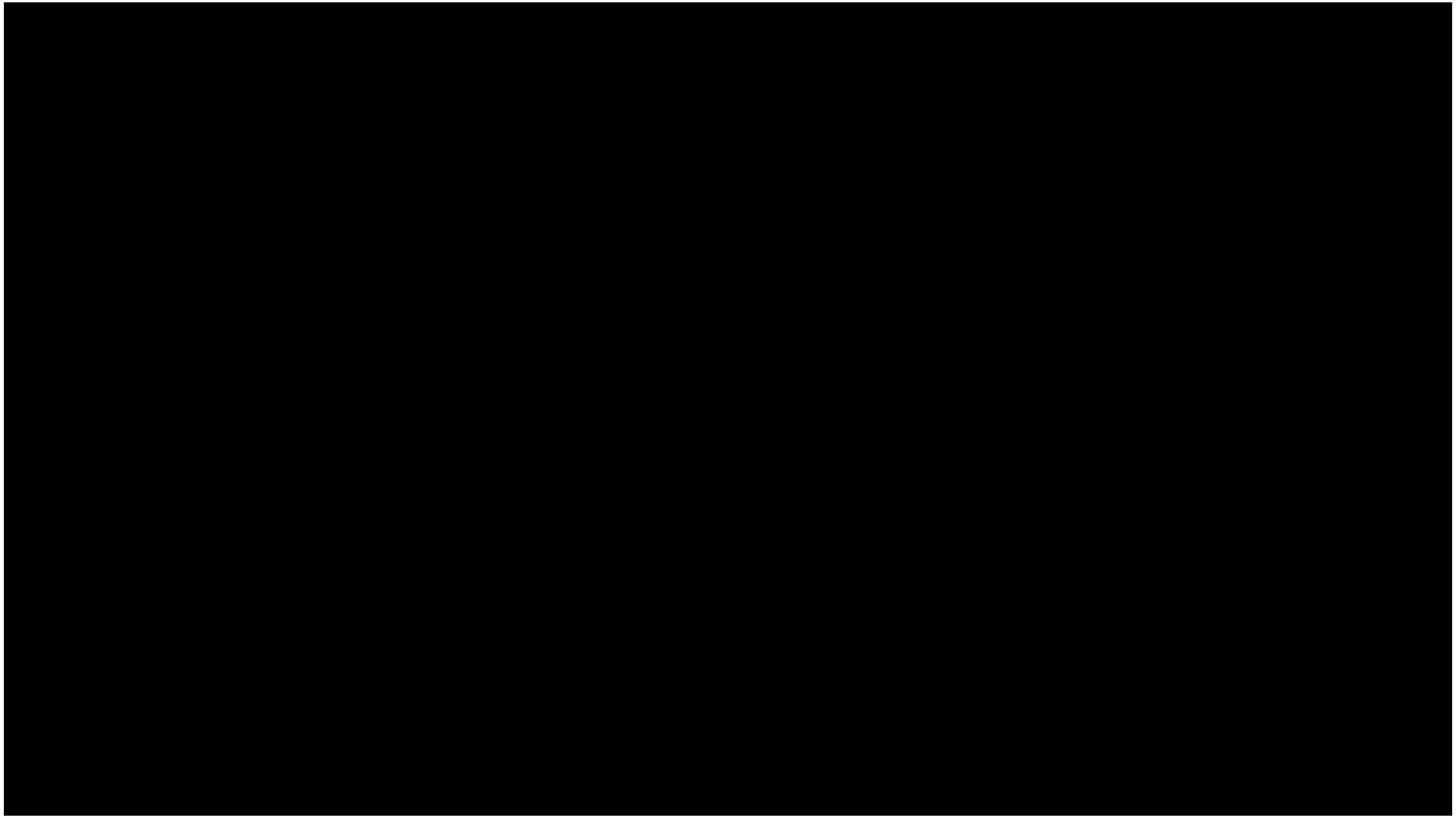

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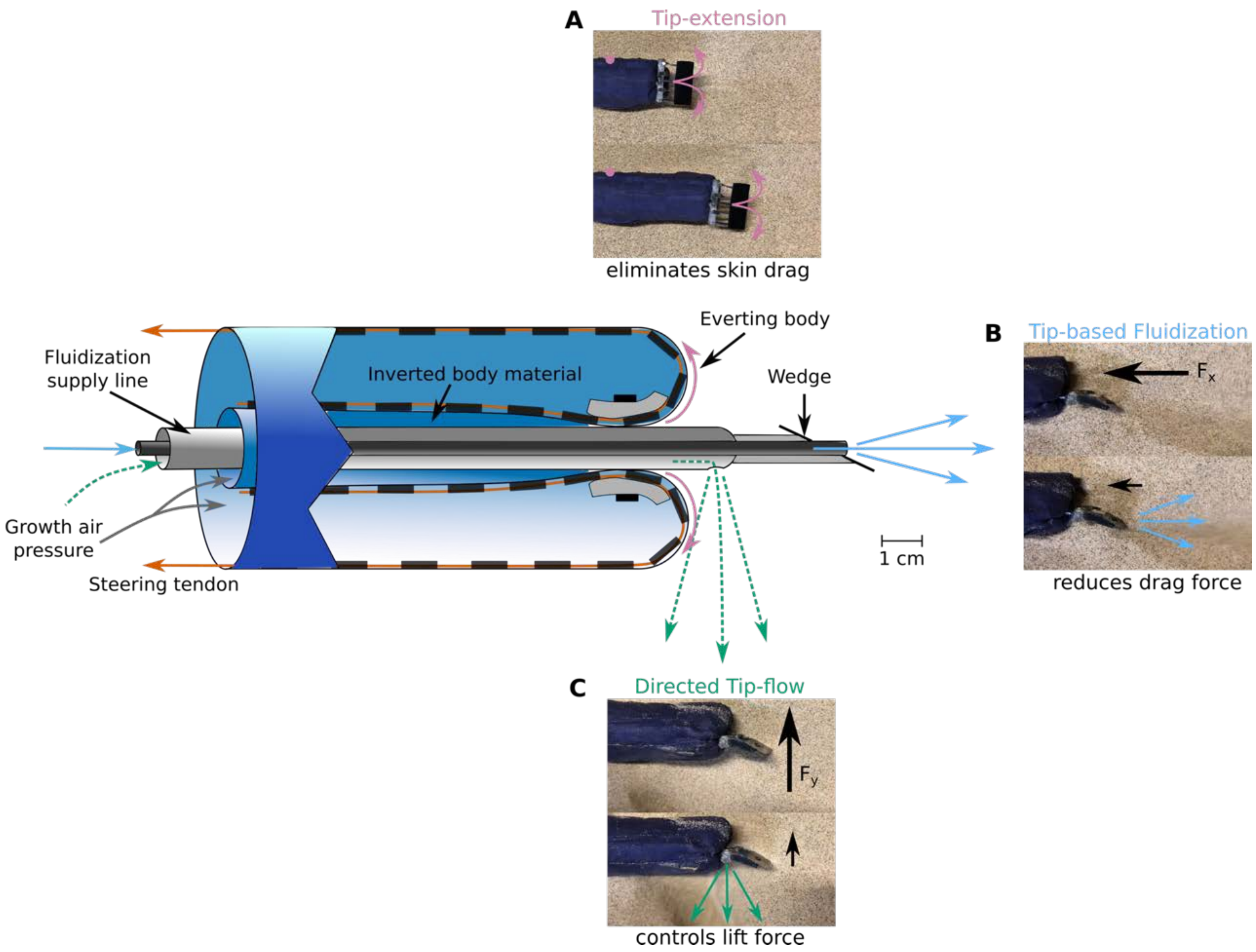

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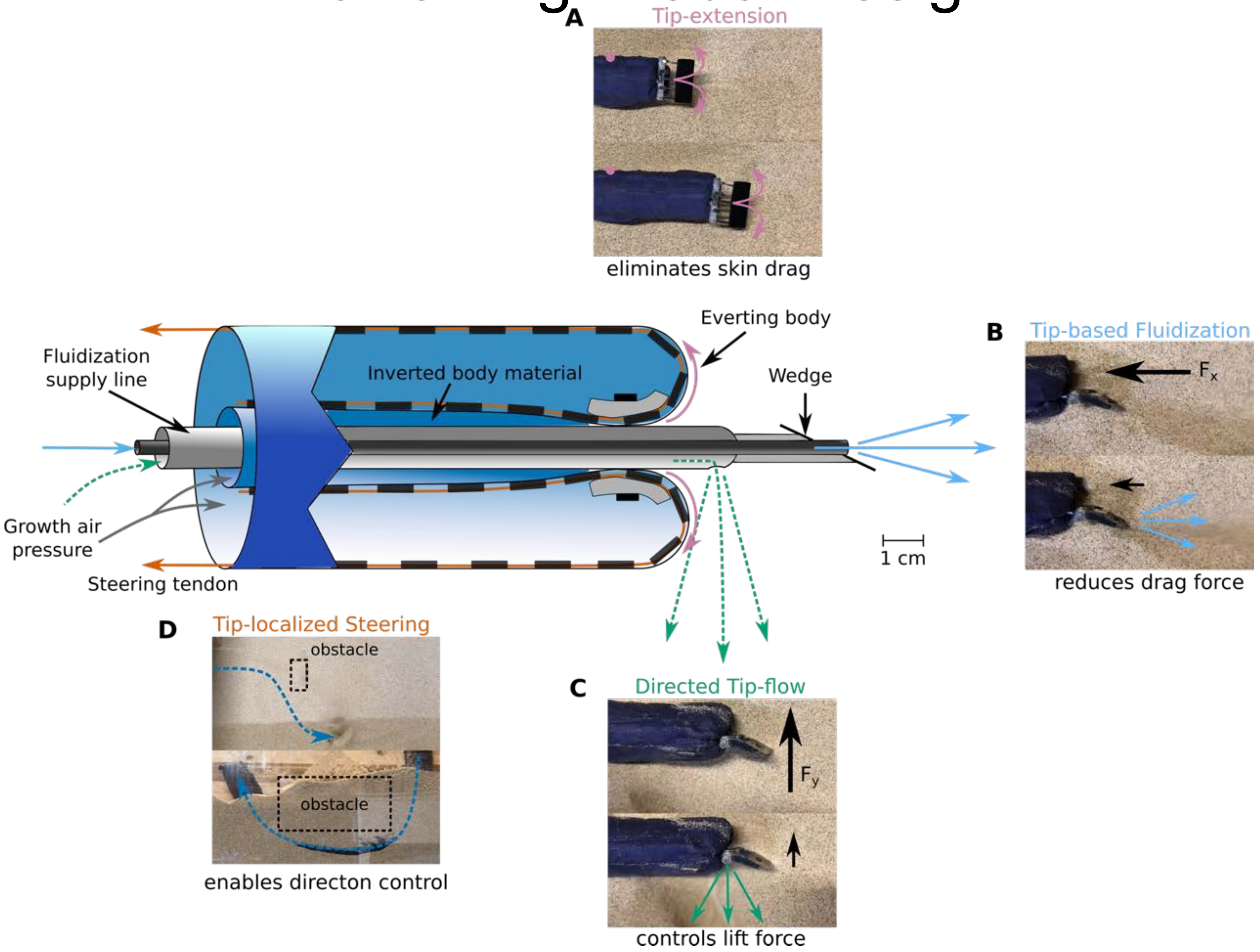

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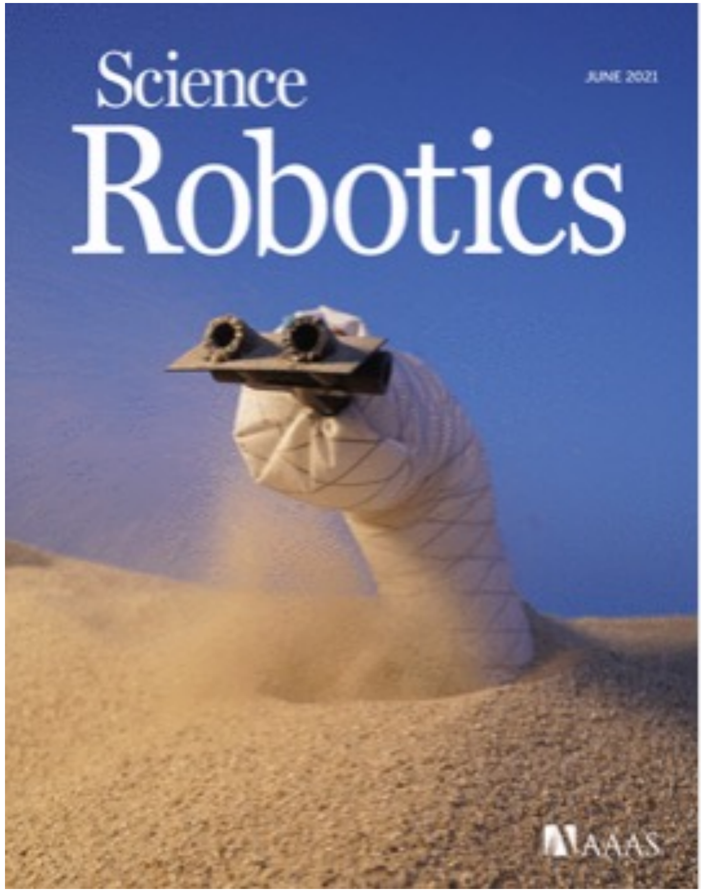
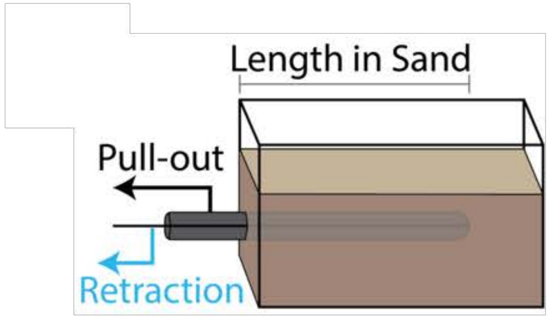
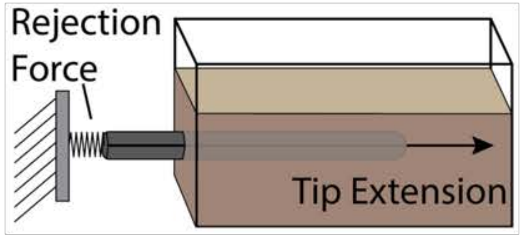
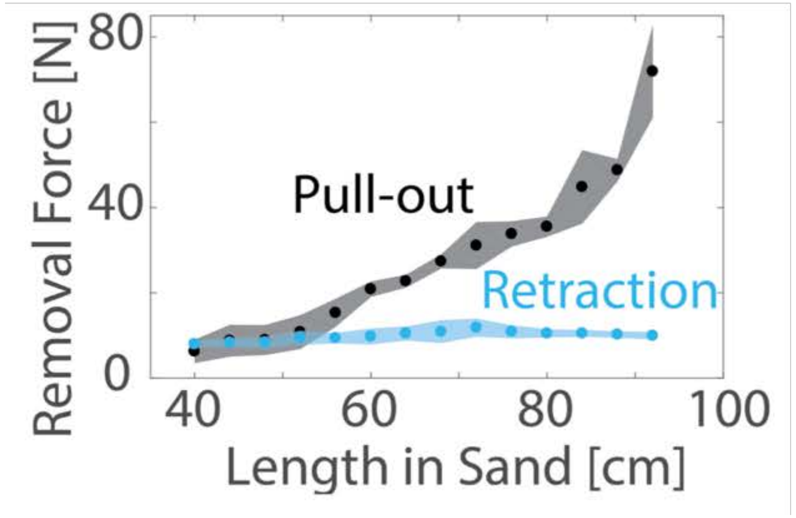


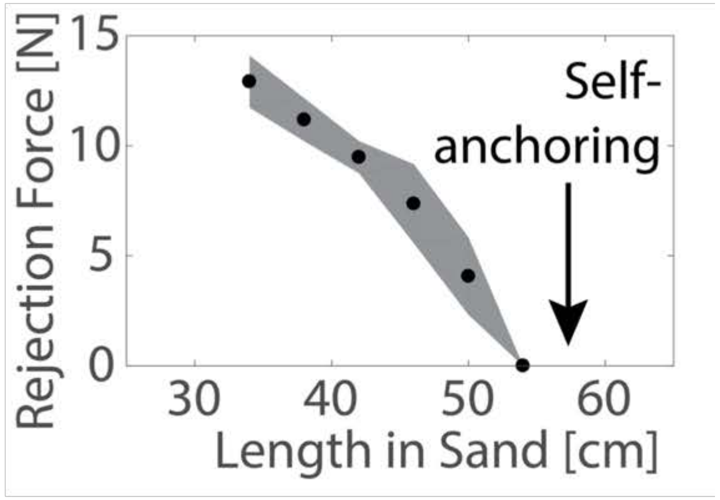
Burrowing: Robot Characterization

Self Anchoring



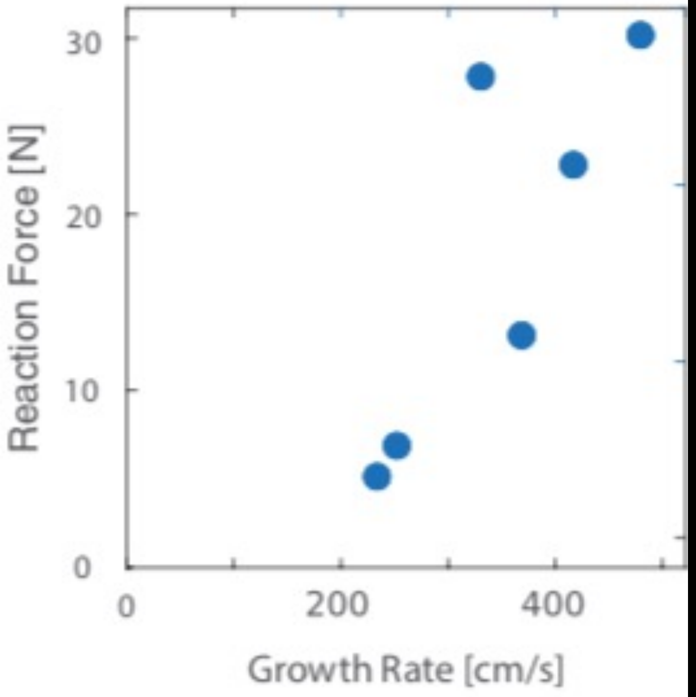






Burrowing: Robot Characterization

Effect of growth rate



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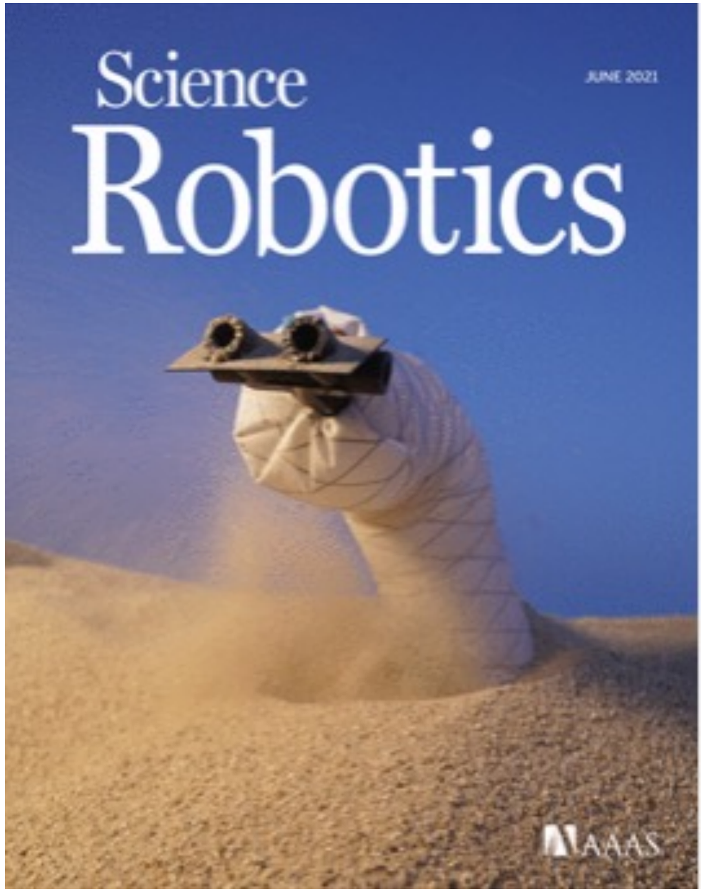

Burrowing: Robot Demonstrations

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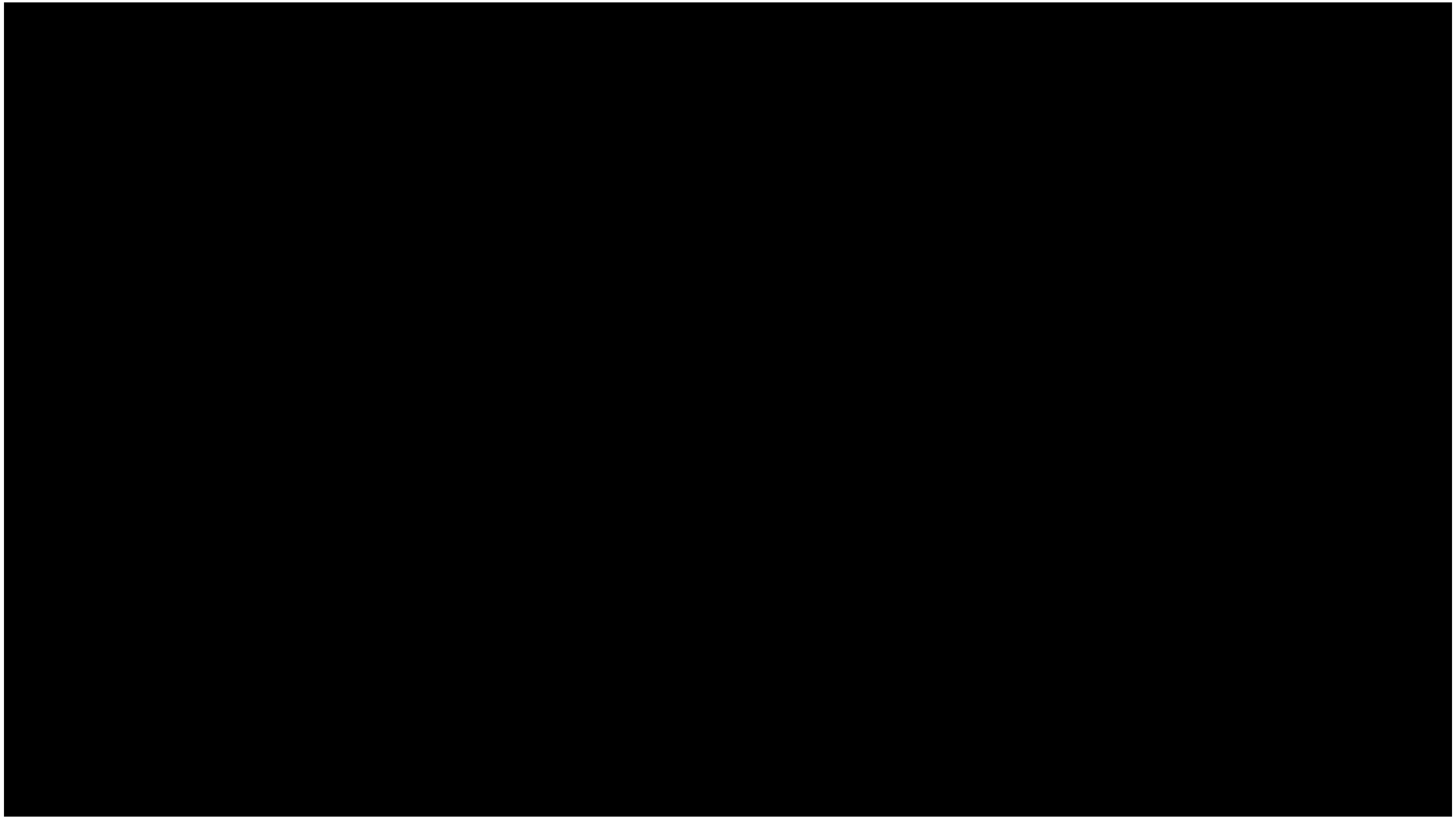

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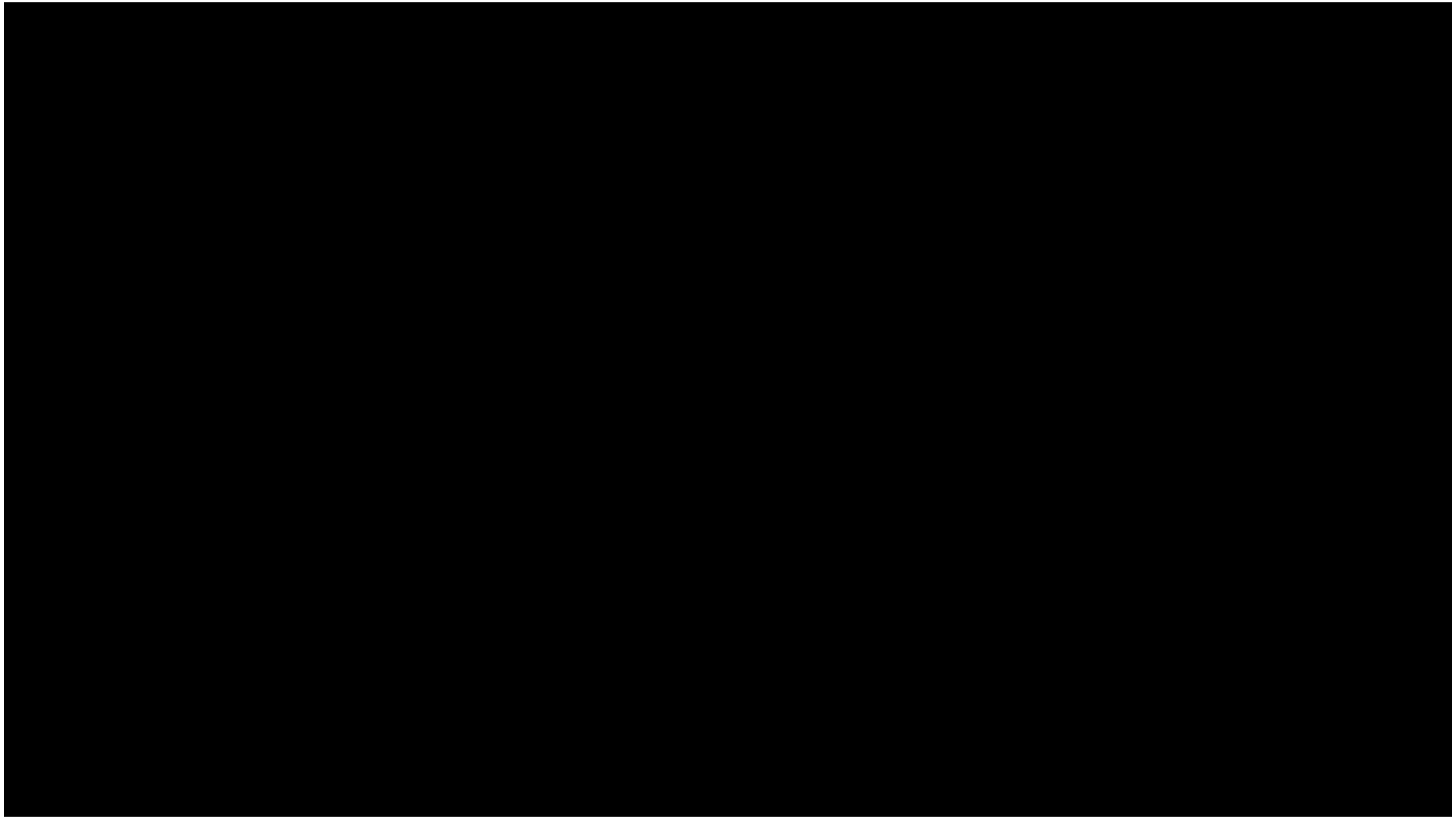

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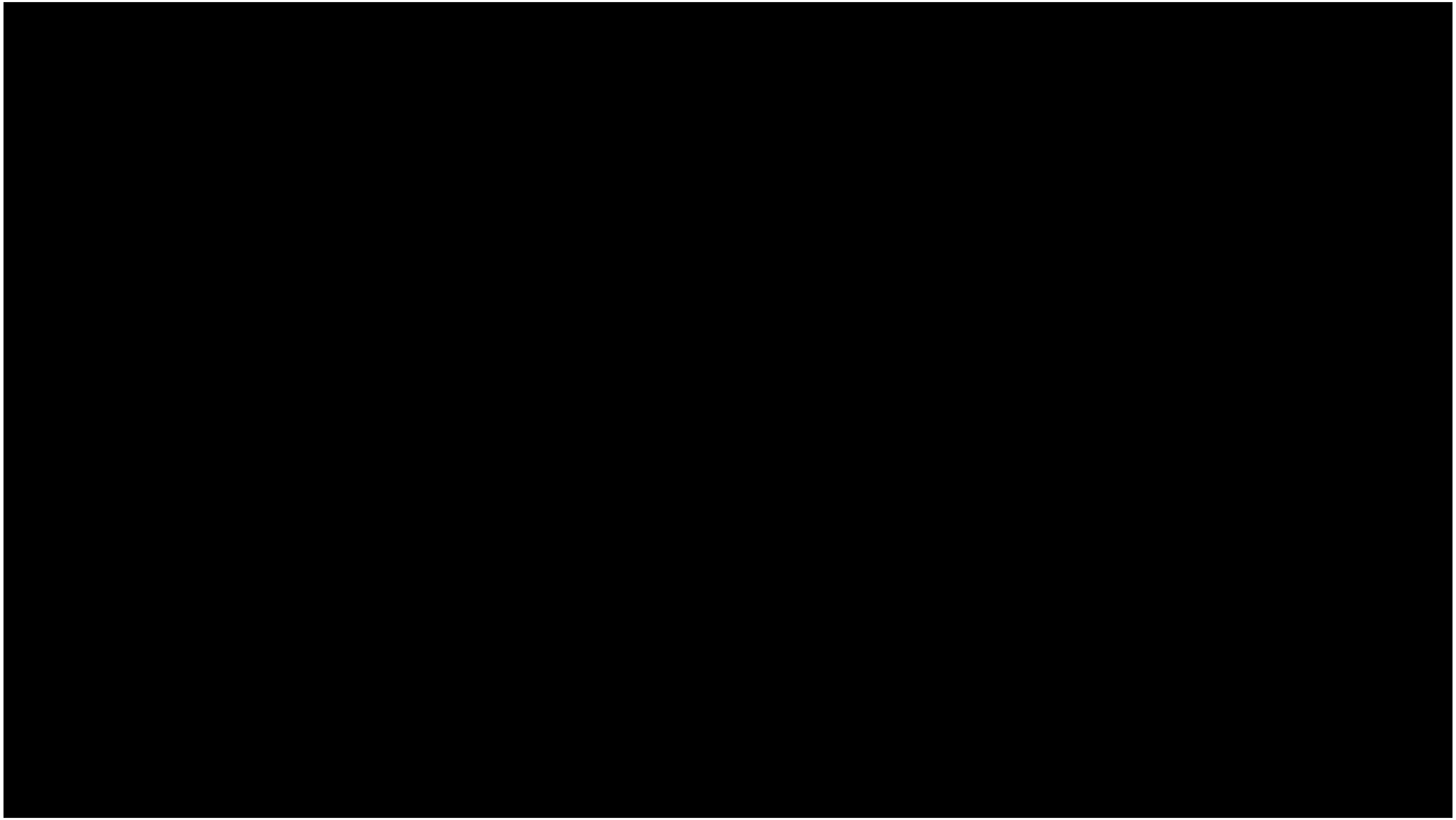

Questions, Comments?

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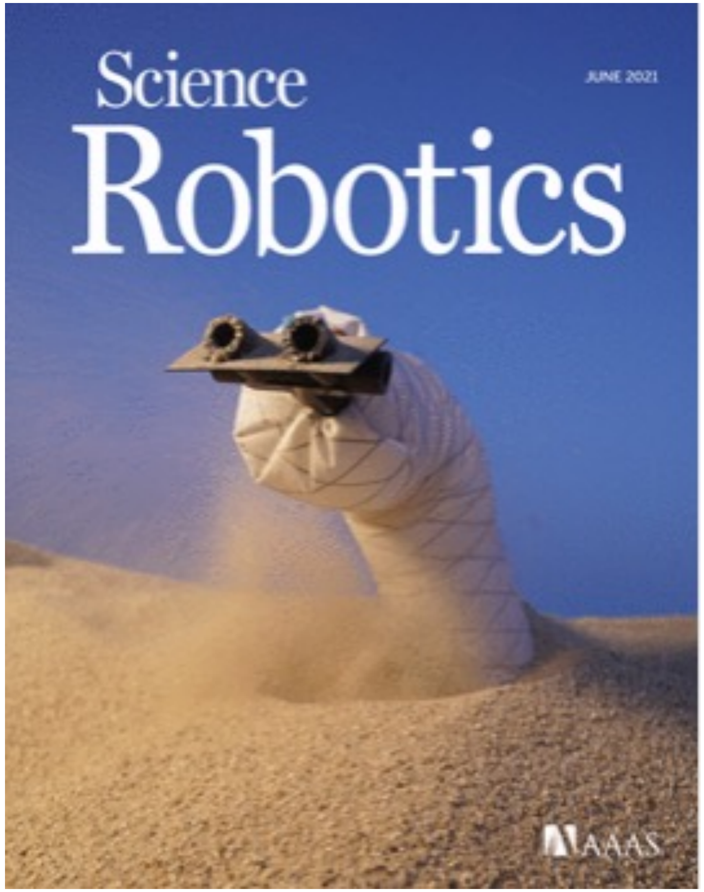


Title and Research Team:

Highly mobile, self-anchoring robots for coordinated, high-force environmental interaction

Short title: Mobile, self-anchoring robots with high-force capability

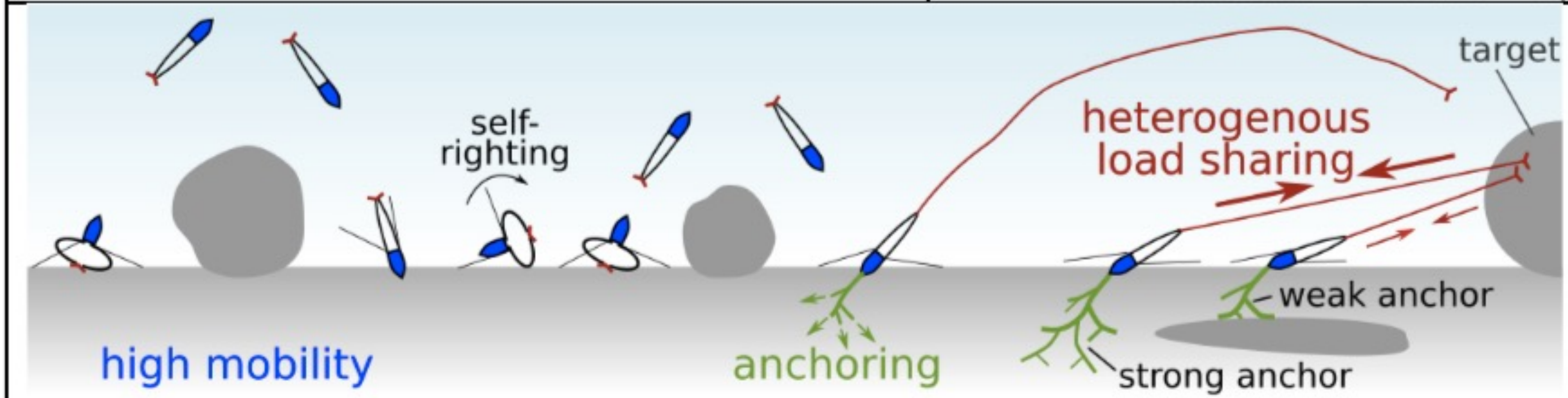
PI Elliot W. Hawkes
Assistant Professor of Mechanical Engineering
University of California, Santa Barbara

Research Objectives:

I. Advance state of knowledge in (TRL 1-2):
   1. Mechanics of jumping
   2. Root-like anchoring and burrowing in low gravity
   3. Load-sharing for heterogenous anchoring strength

II. Develop new hardware (TRL 3):
   1. Jumper
   2. Burrowing and anchoring device for low gravity soils
   3. Load-sharing mechanisms

III. Integrate and evaluate (TRL 4)
   1. Integrate subcomponents into working robot team
   2. Evaluate team of robots in capstone demonstration



We propose to develop a team of highly mobile robots that are capable of jumping across extreme terrains, self-anchoring using root-like structures, and applying significant forces in a coordinated manner, despite heterogeneity in anchor strength.

Approach:

Phase I: Test hypotheses and models via controlled experiments, including using regolith-like soils

Phase II: Design, prototype, test, analyze and iterate to create sub-component hardware

Phase III: Integrate sub-components to create functional robots; demonstrate and evaluate team of coordinated robots performing representative task (rolling a boulder)

Potential Impact:

- Will enable robots capable of both:
  - high mobility to traverse extreme terrain, and
  - high force environmental interactions to move heavy objects.
- Will advance space science and exploration:
  - mobility opening access to new locations,
  - burrowing enabling sampling of subsurface soils,
  - force-application enabling tasks that involve heavy objects.
- Fundamental knowledge created during this work will enable future space applications that involve jumping, anchoring/burrowing, and load sharing.