Evolving Aquatic Robots

Anthony J. Clark, Jared M. Moore,
and Philip K. McKinley

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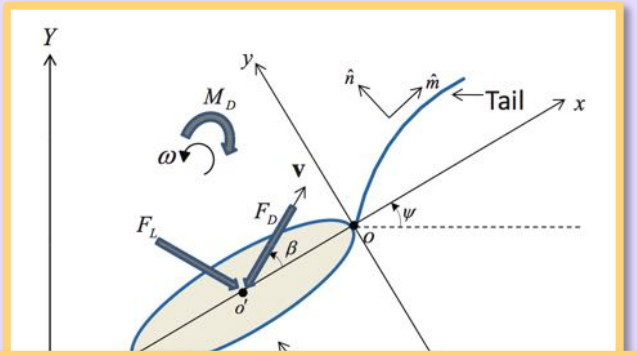
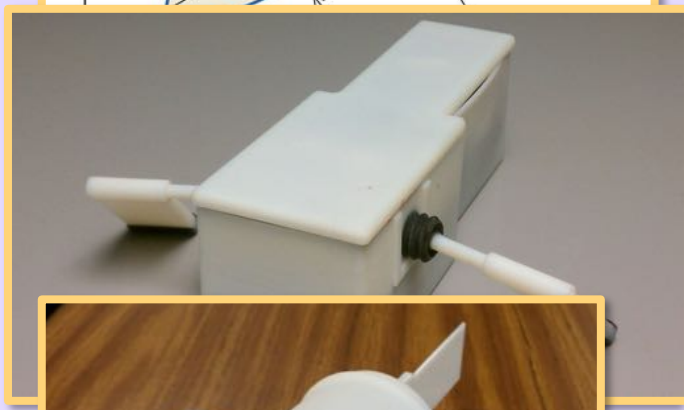
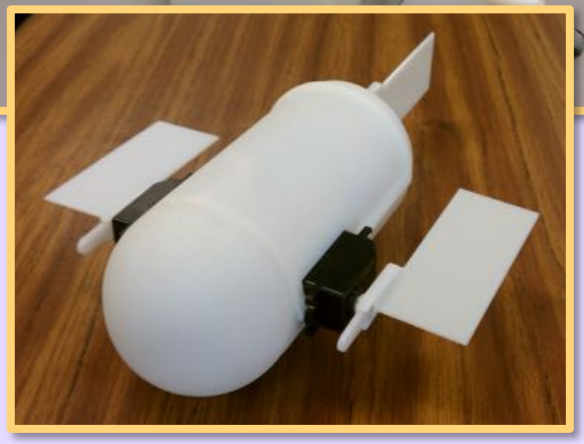
techniques

- Aquatic dynamics
- Passive components
- Flexible components
- Self-modeling uncertainty







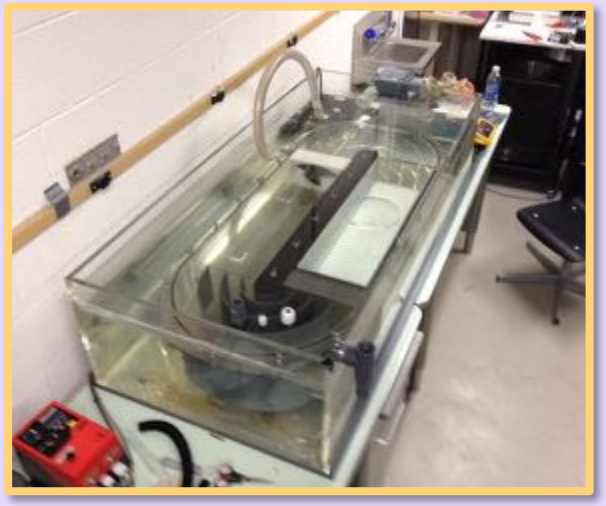
motivations for small aquatic robots

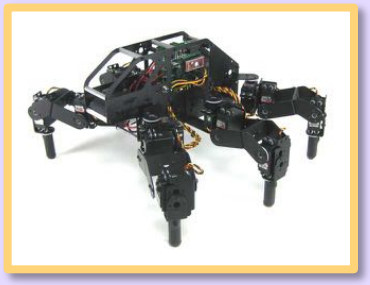
major issues

- Speed and maneuverability
  - Limited actuation capability for small, inexpensive devices
- Accommodating aquatic environment
  - Highly dynamic conditions
  - Uncertainty in external conditions and robot orientation
- Overcoming hardware decay and physical damage
  - Controller designed/evolved for specific morphology
  - How can compensatory behaviors be generated dynamically if the a fin or flipper is damaged?

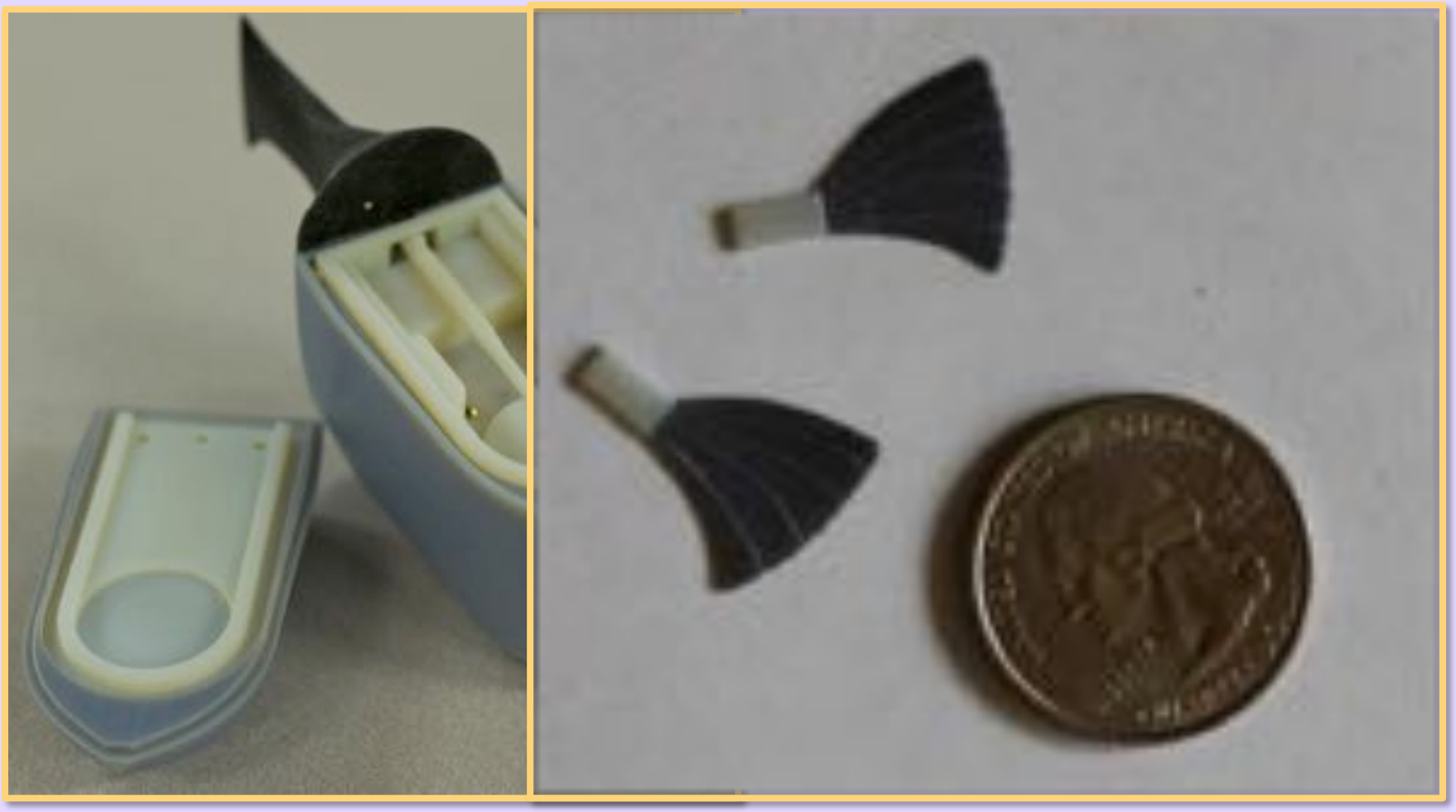
NSF-sponsored testbed

- Facilities
  - Configurable robots
  - 4,500 gallon test tank
  - flow tank
  - Multi-material 3D printer
  - Compute cluster





3D printer



general process

Create Simulation

- Develop models
- Validate model

Evolve solutions

- Evolve in simulation
- Evolve online

target applications

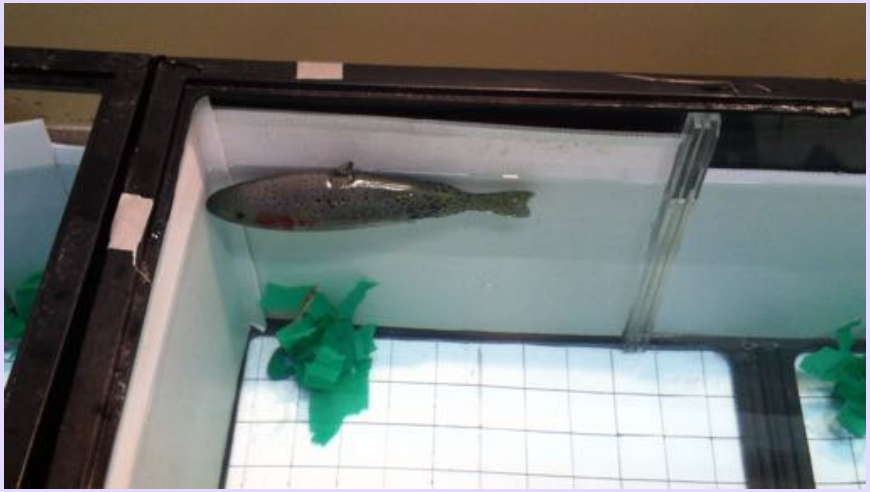
Industrial

- Water quality
- Ecological monitoring

Biological research

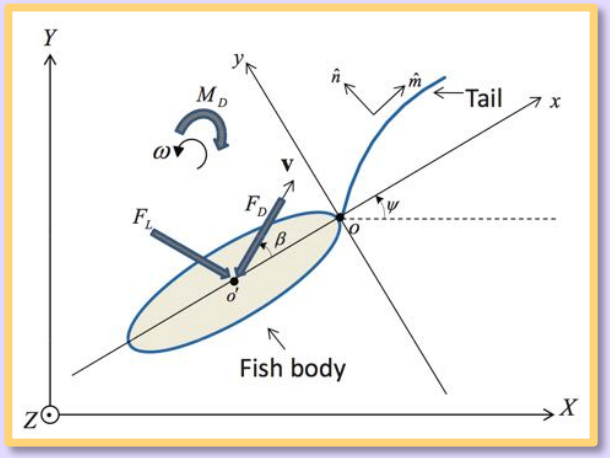
- Elicit schooling
- Act as predator

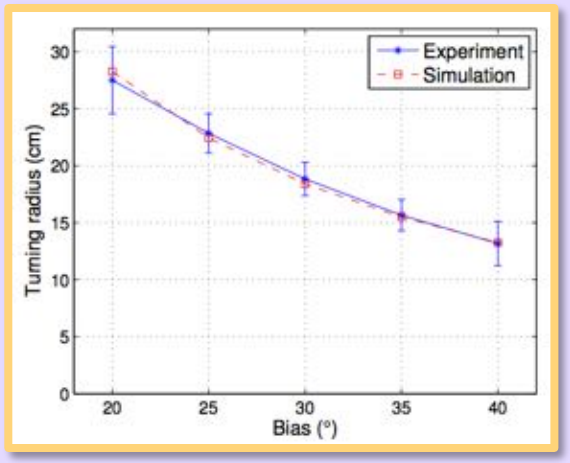
Photograph by the State of Michigan

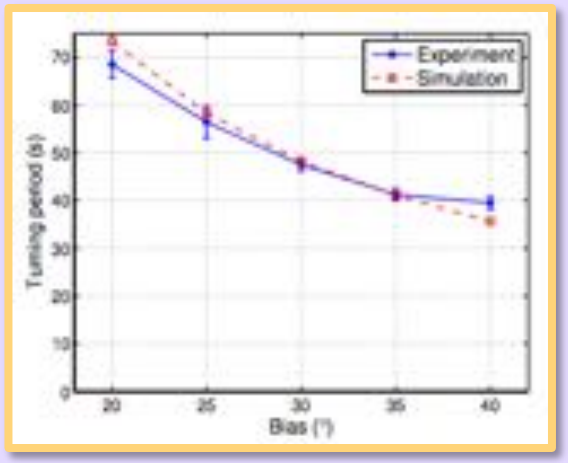


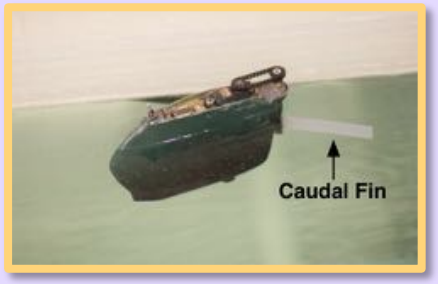
aquatic dynamics

- Lighthill's: Large-amplitude elongated-body theory of fish locomotion (1971)
- Validated on the physical device

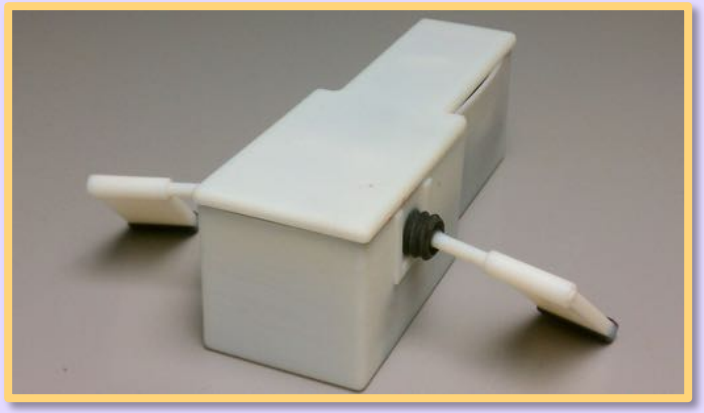


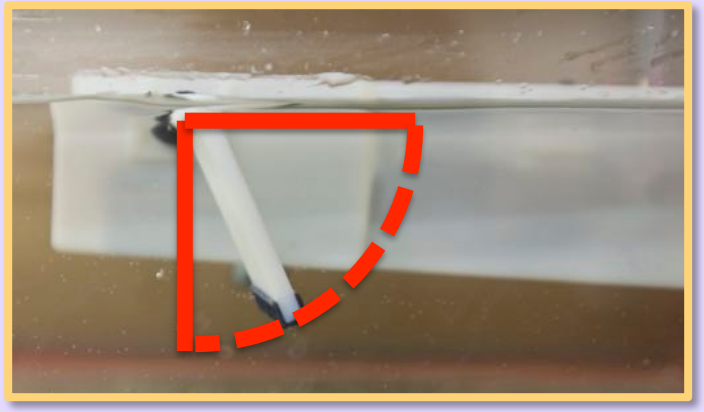






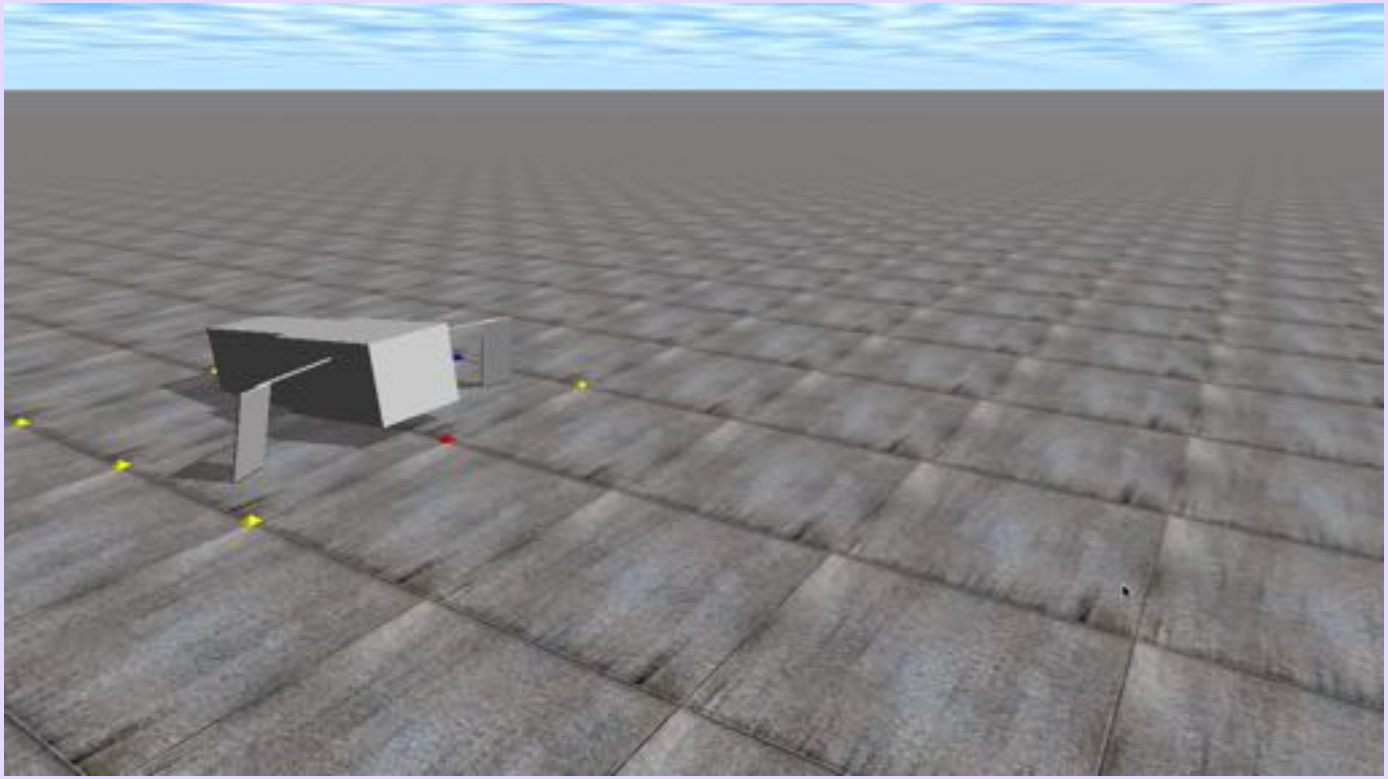
passive components





- Passive joints
- Evolved for flat terrain and water
  - fin dimensions
  - oscillating frequency

Evolved for both ground and aquatic environments



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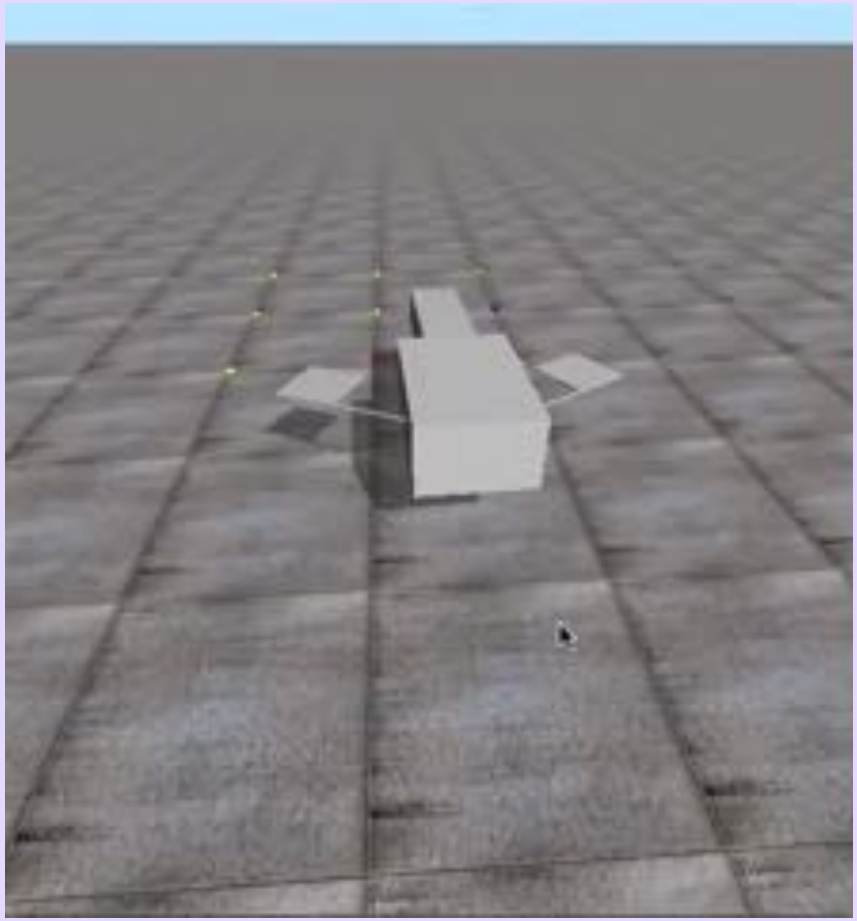
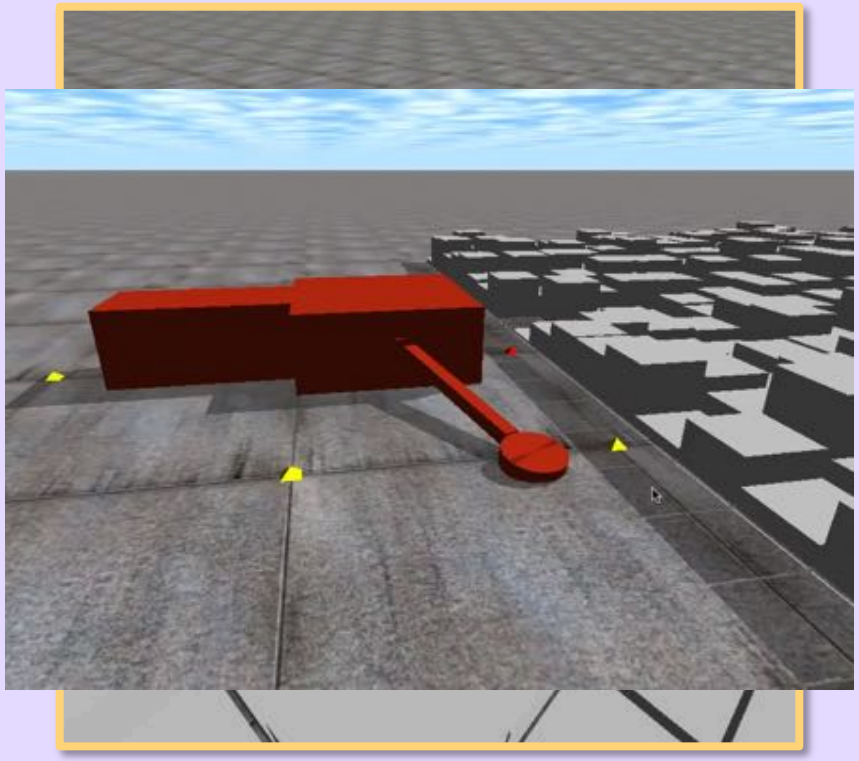


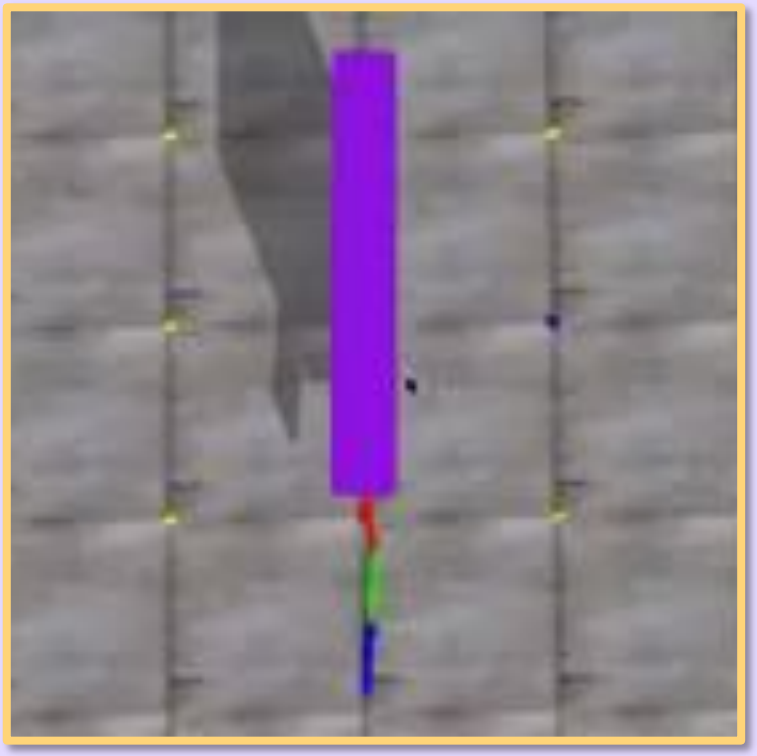
flexible components

- Paddles are flexible and sticky
- Evolution
  - arm length
  - foot radius
  - flexibility

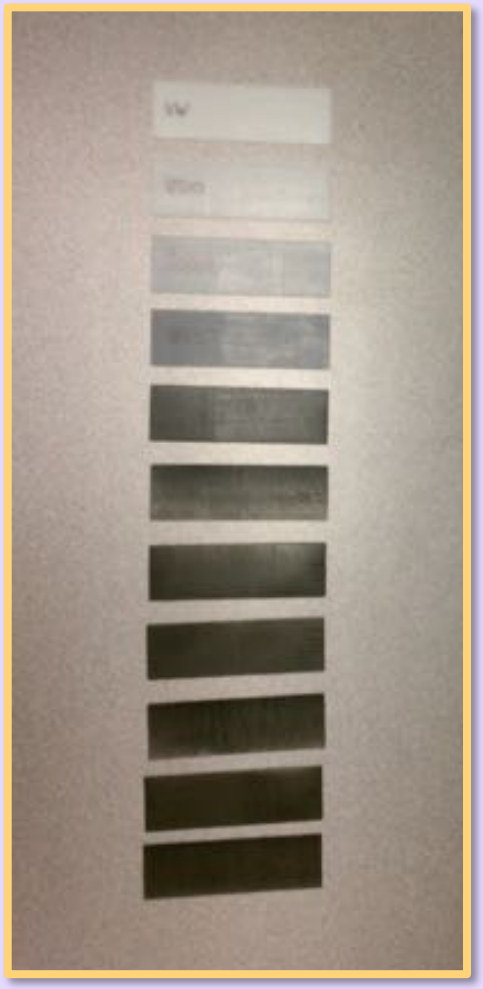


flexible caudal fin

- Flexible caudal fin
  - spring coefficients
  - material properties
- Evolve with control
  - neural oscillators
  - resonant frequency for a given morphology



physical validation

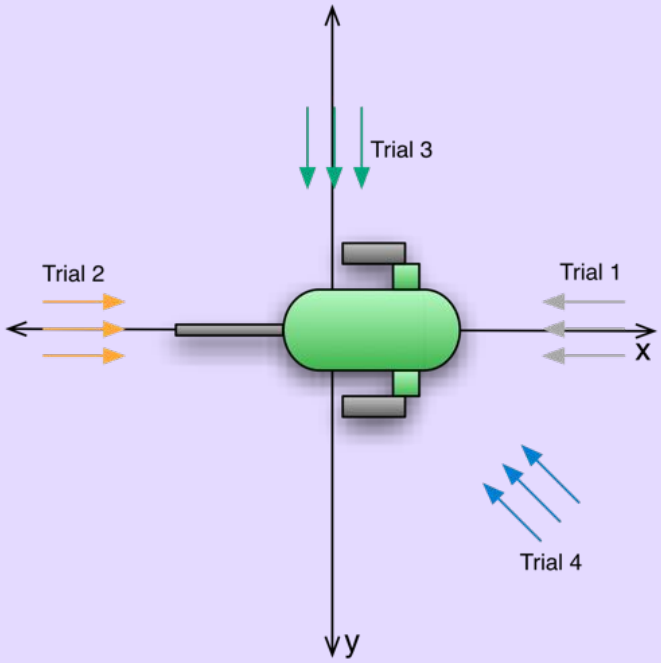


3D maneuvers

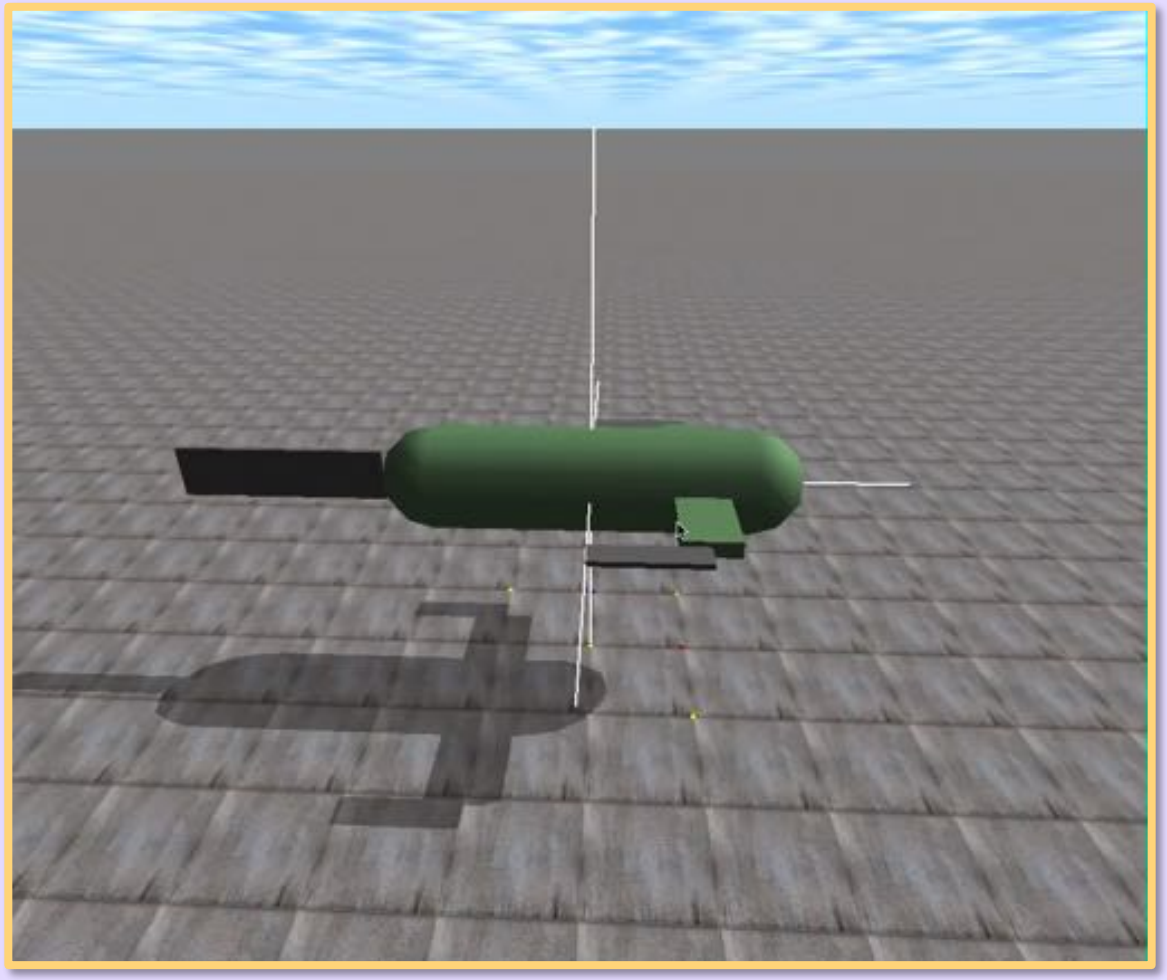
- Increases complexity
  - no longer on the surface
- Station keeping
  - maintain position against laminar flow

3D maneuvers

- Fitness
  - transient phase
  - spherical gradient

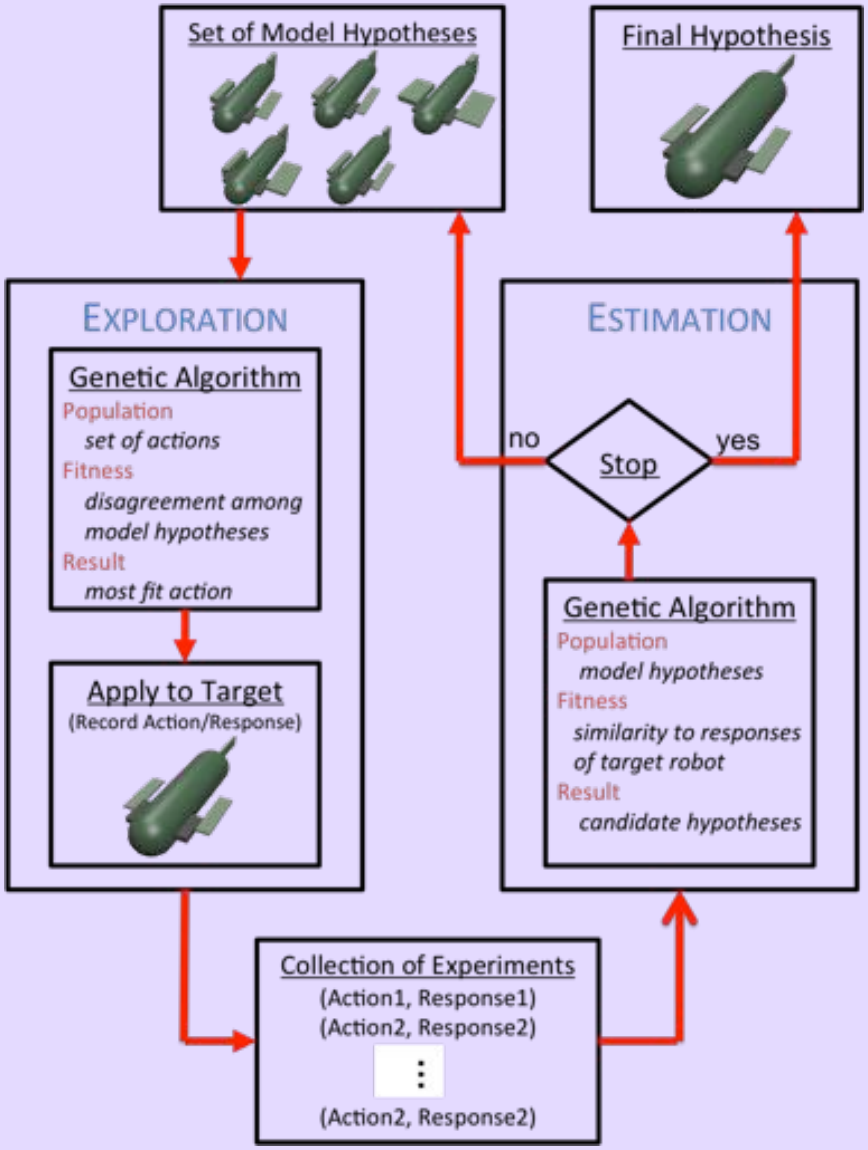


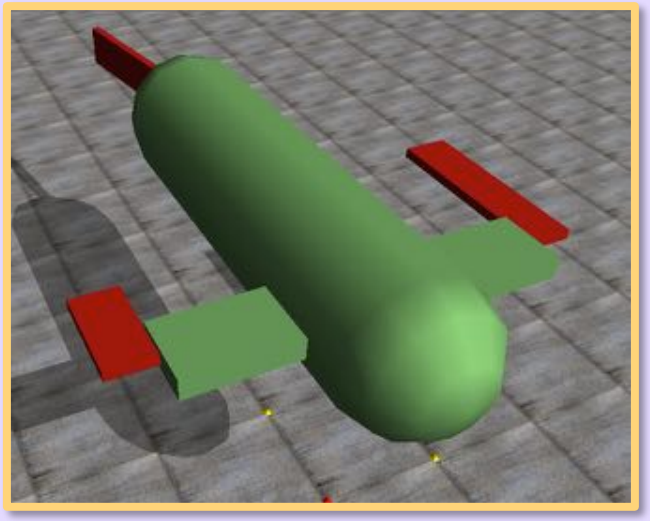
3D maneuvers



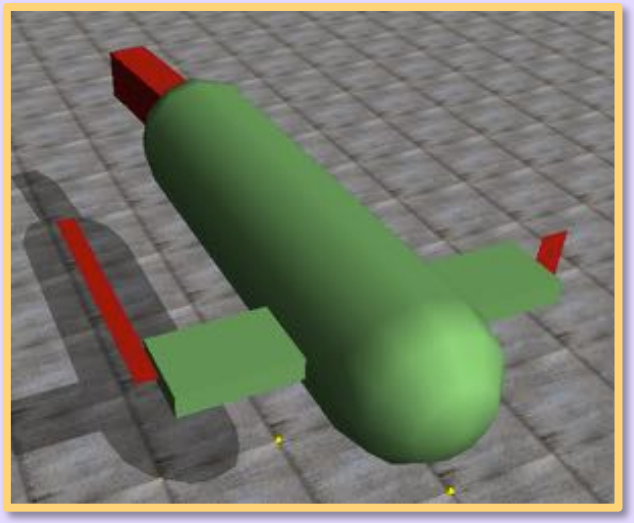
self-modeling and uncertainty

- Physical damage can render a robot helpless
- Need to dynamically generate new behaviors to mitigate or overcome changes in actuation
- Approach based on Bongard-Lipson's Exploration-Estimation Algorithm (EEA)

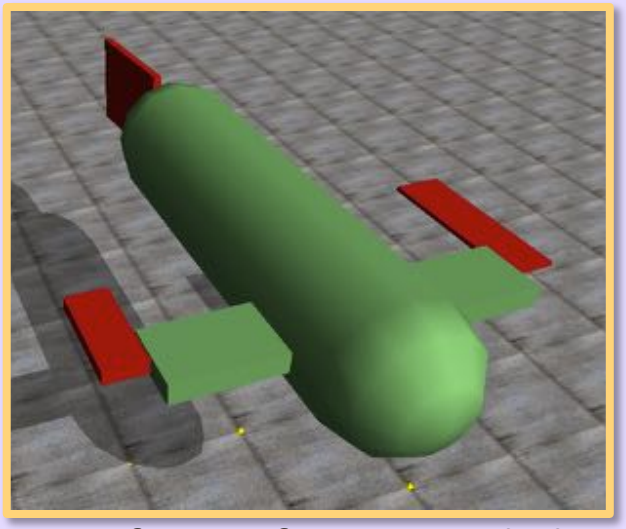




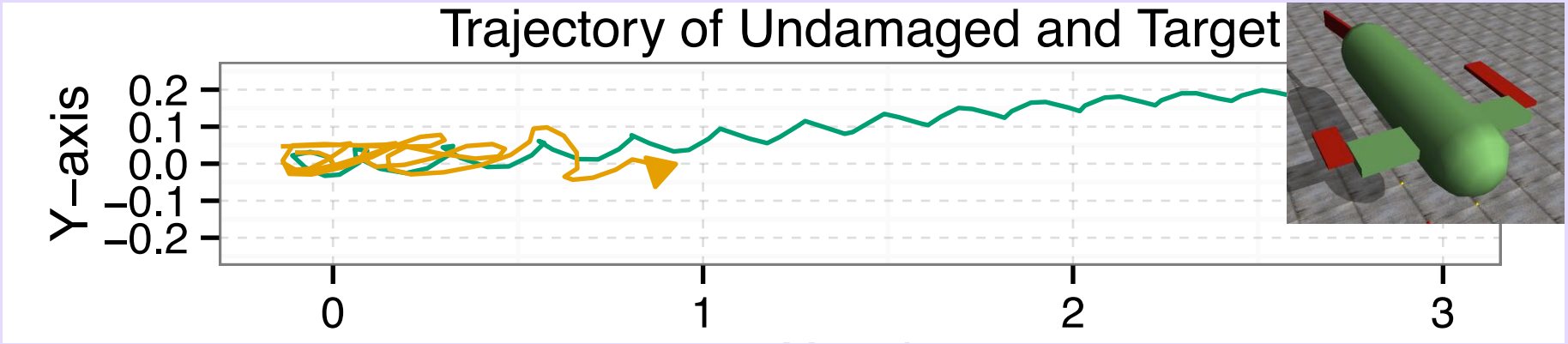
Damaged robot

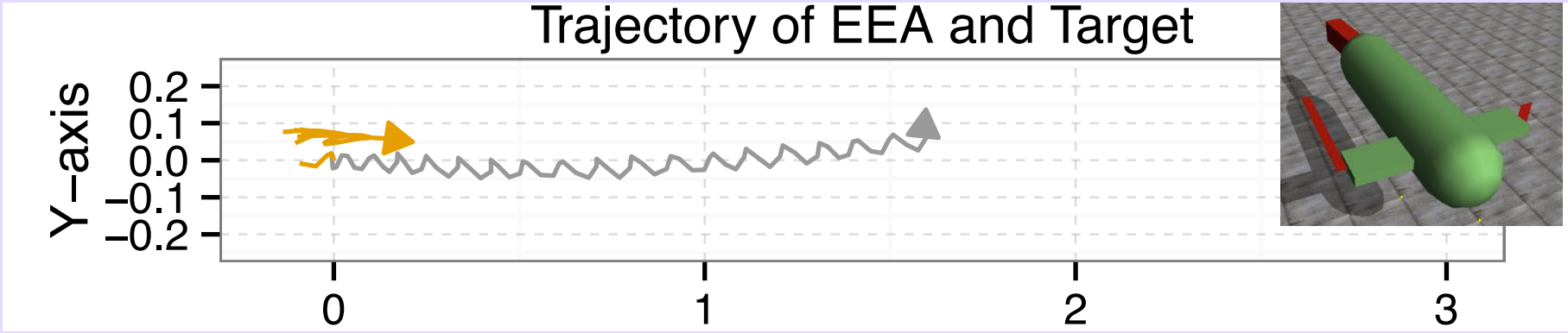


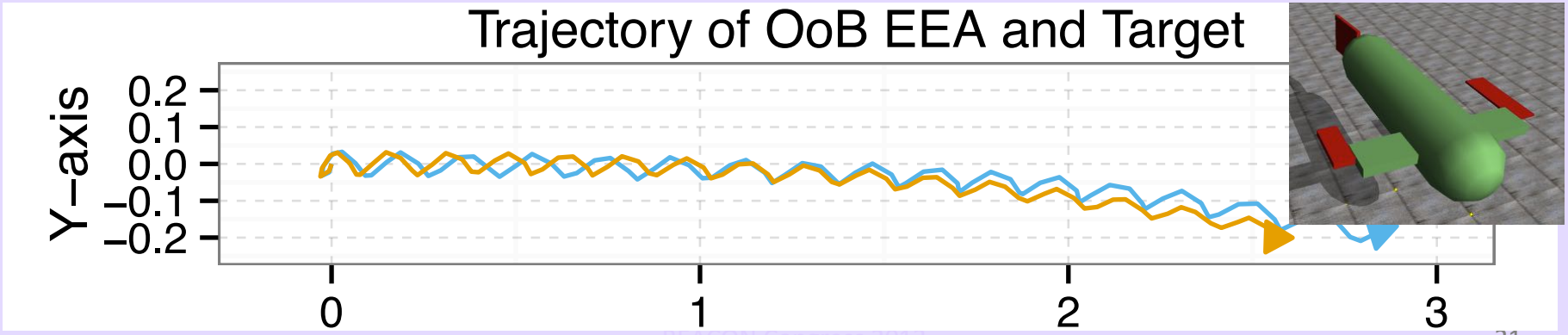
Best performer from original EEA



Best performer from extended EEA


Trajectory of Undamaged and Target
Y−axis
0.2
0.1
0.0
−0.1
−0.2
0
1
2
3


Trajectory of EEA and Target
Y−axis
0.2
0.1
0.0
−0.1
−0.2
0
1
2
3


Trajectory of OoB EEA and Target
Y−axis
0.2
0.1
0.0
−0.1
−0.2
0
1
2
3

future work

- Increased complexity
  - tasks
  - adaptive control
- Continue evolution online
  - refine simulated solutions
  - self-modeling to handle damage

conclusions

- Simulation is course-grain
  - good for prototyping techniques/concepts
    - i.e. flexibility, passive parts, algorithms etc.
  - gain insight into problem before fabrication

- Online evolution will be necessary
  - finer grain evolution

acknowledgements

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Thank You

research projects

- Mathematical modeling
- Amphibious robot
- Crawler with flexible paddles
- Robotic fish
- Aquatic robot