Imperial College London

AERIAL ROBOTICS LAB

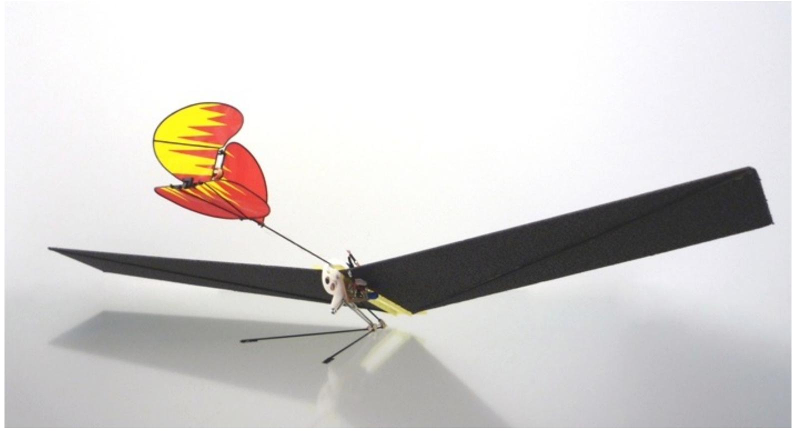
Bio-inspired Aerial Robotics for Future Cities

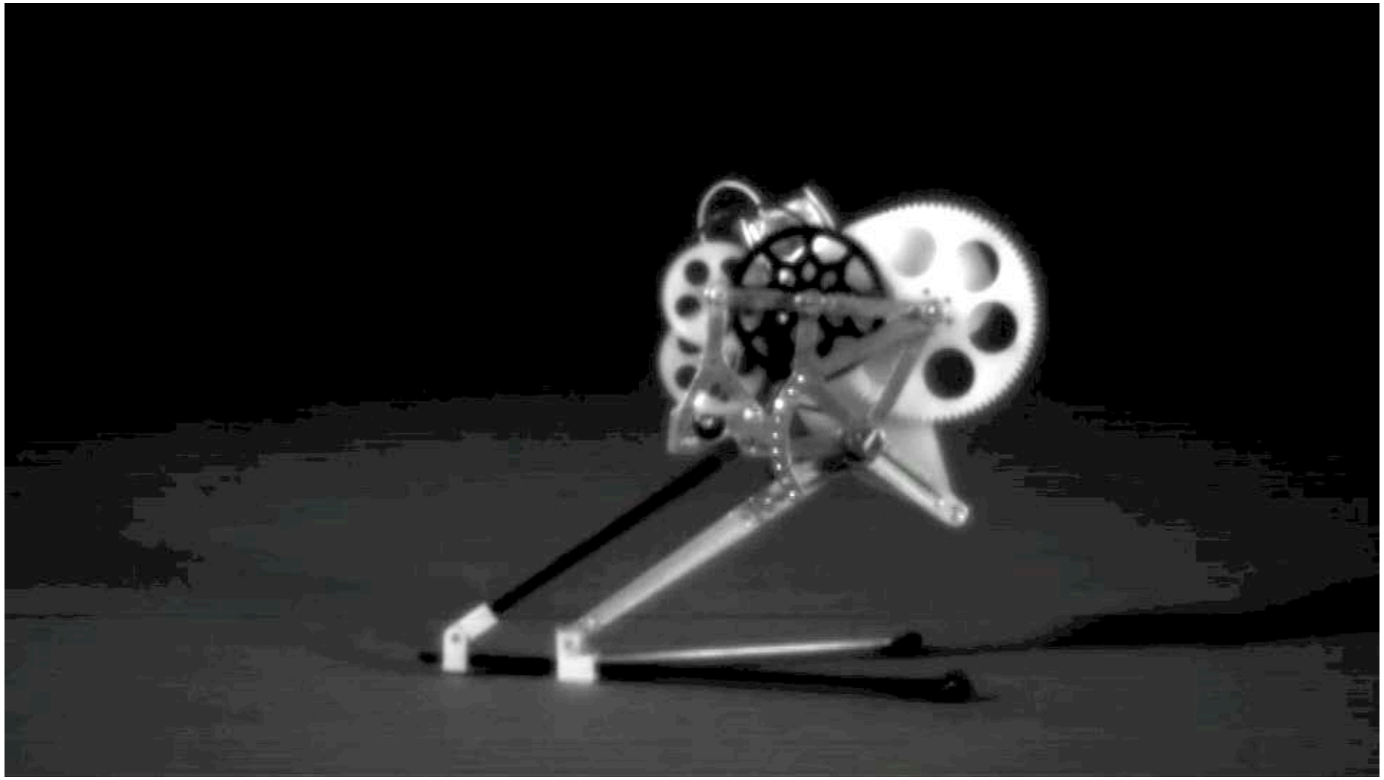
Mirko Kovac

Aerial Robotics Laboratory
Department of Aeronautics
Imperial College London

Aerial Robotics Laboratory



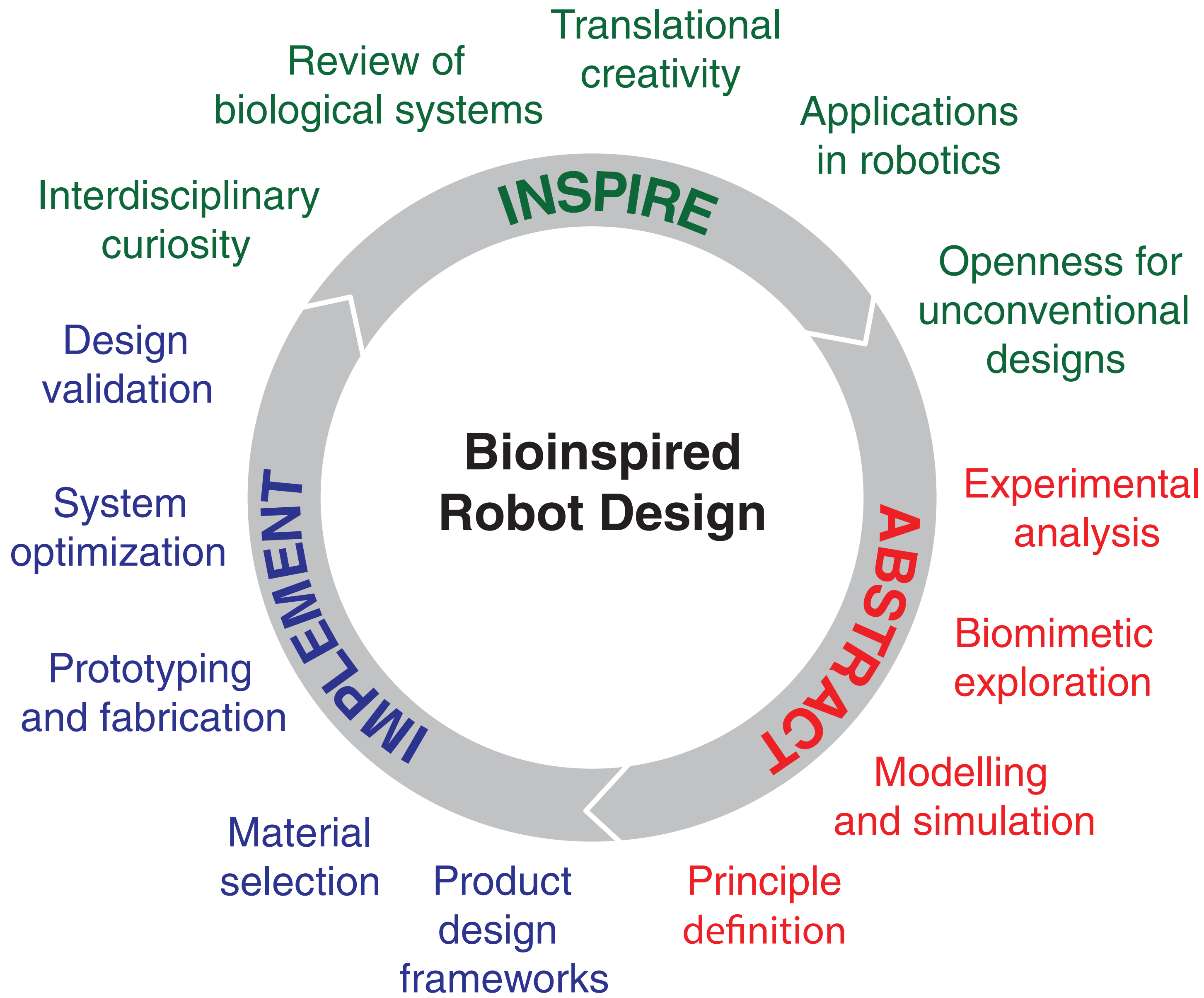




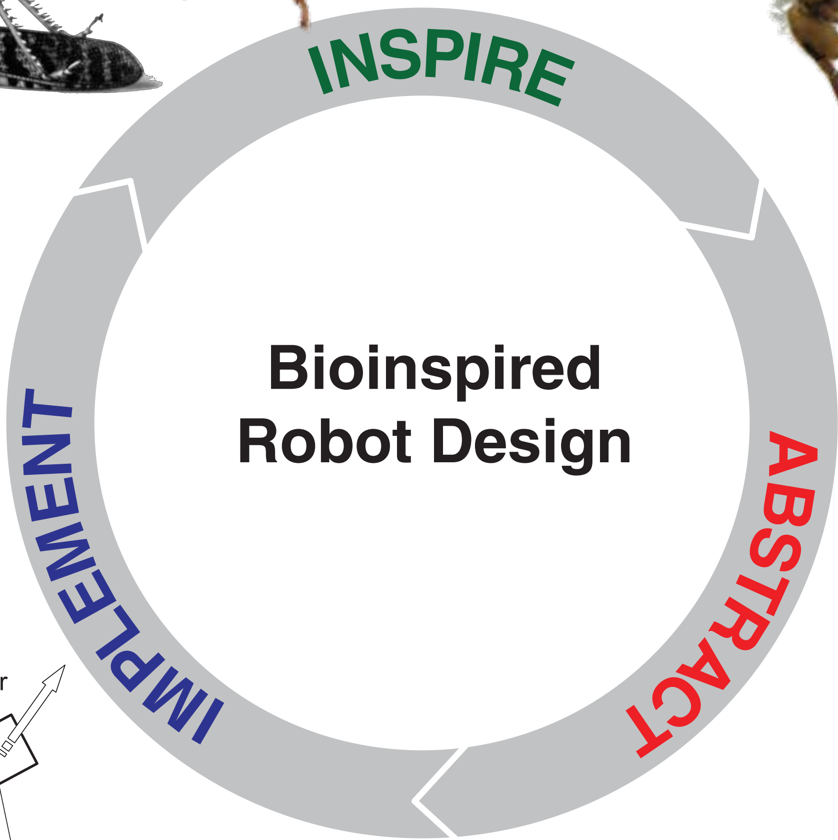
Kovac, M., Schlegel M., Zufferey J.-C., Floreano, D. (2011)
IEEE/RSJ Int. Conf. on Intelligent Robots and Systems
-Best paper award at IROS 2011

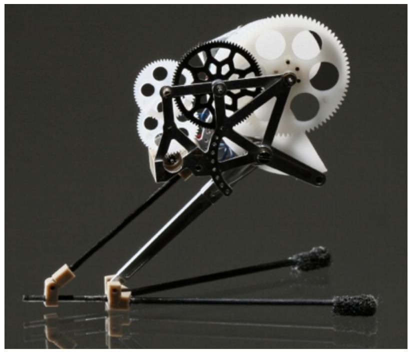
Kovac, M., Schlegel, M., Zufferey, J.-C. and Floreano, D. (2010)
Autonomous Robots
-Featured on cover page, PhD thesis nominated for best thesis award

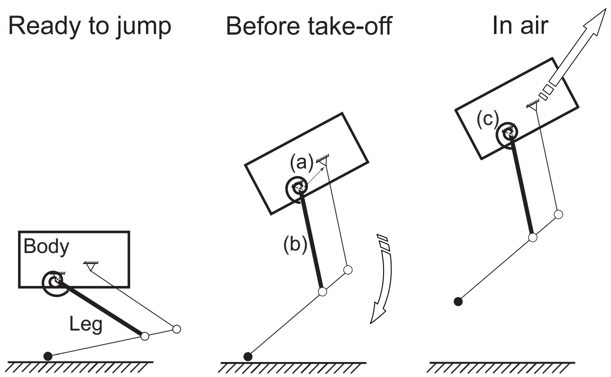
Kovac, M., Floreano, D., et al (2011)
IEEE Intern. Conf. on Robotics and Biomimetics
-Best paper award at Robio 2011



Kovac, M. (2013) The Bio-inspired Design Paradigm, A perspective to soft robotics, *Journal for Soft Robotics*







Energy storage

Light weight
body and legs

Four bar mechanism

Kovac, M. (2013) The Bio-inspired Design Paradigm, A perspective to soft robotics, *Journal for Soft Robotics*

Aerial Robotics Laboratory

Imperial College London

Aerial Robotics Lab

EPSRC

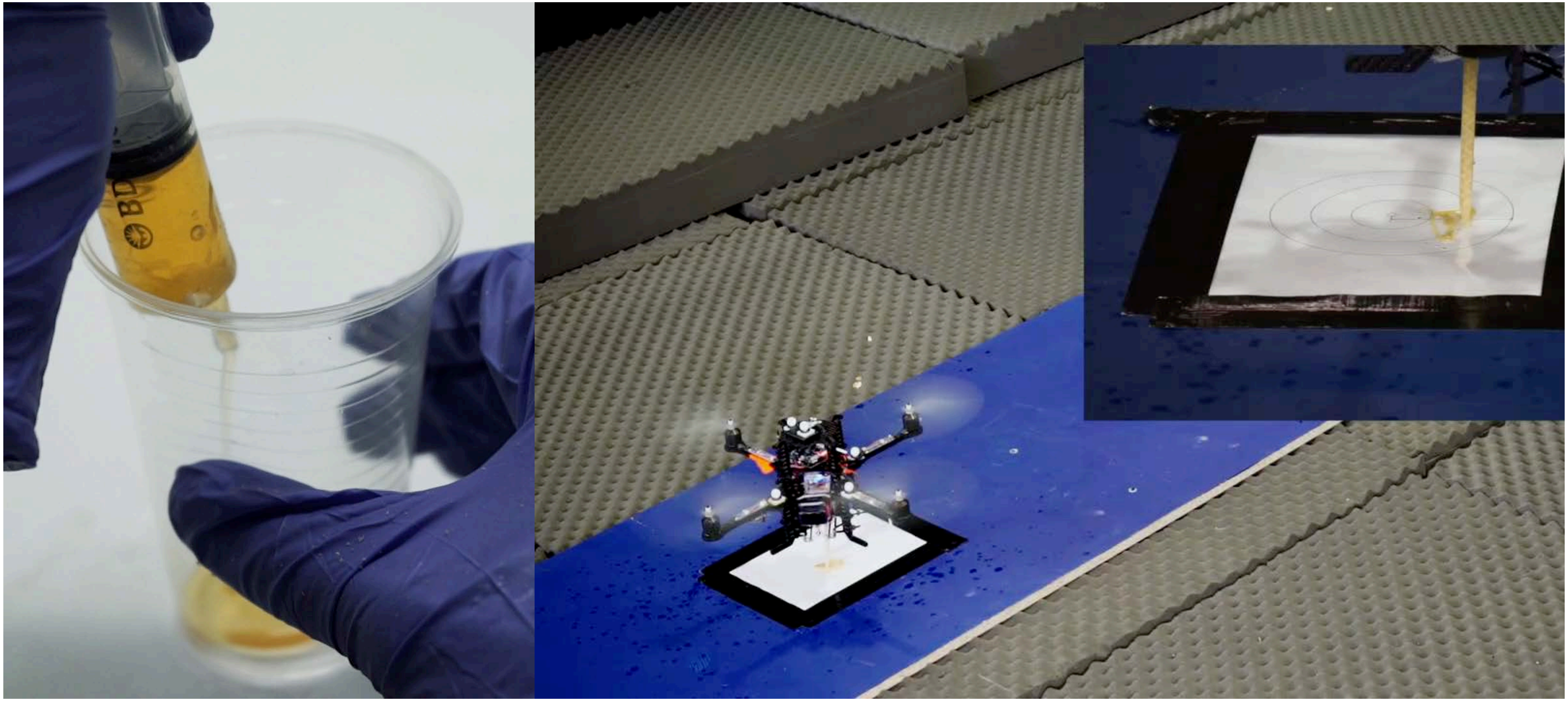
Engineering and Physical Sciences Research Council

£3.4m total value

PI: Imperial College

Co-I: UCL, U. Bath, AA

Industry partners:
Dyson, BRE, Buro Happold,

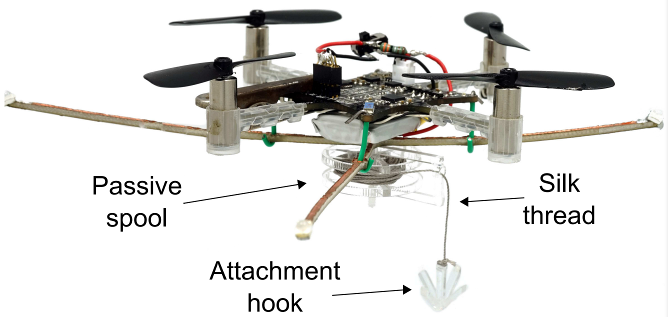


Hunt, G., Mitzalis, F., Alhinai, T., Hooper, P., Kovac, M., (2014) 3D Printing with Flying Robots.
IEEE International Conference on Robotics and Automation, (ICRA 2014)

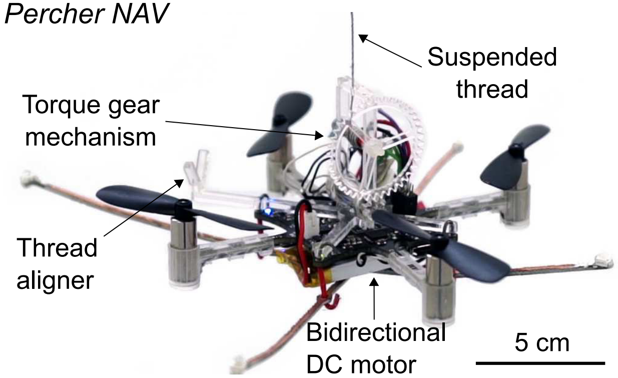
UAE Drones for Good Award Winner
(1017 submissions in two categories)

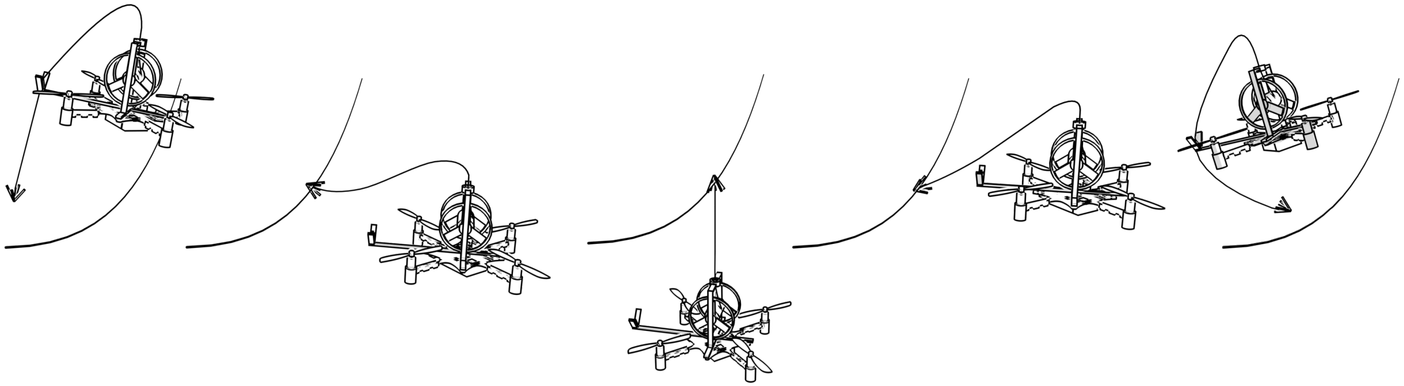
Braithwaite, A., Alhinai, T., Haas-Heger, M., McFarlane, E., Kovac, M., Spider Inspired Construction and Perching with a Swarm of Nano Aerial Vehicles, *International Symposium on Robotics Research 2015*

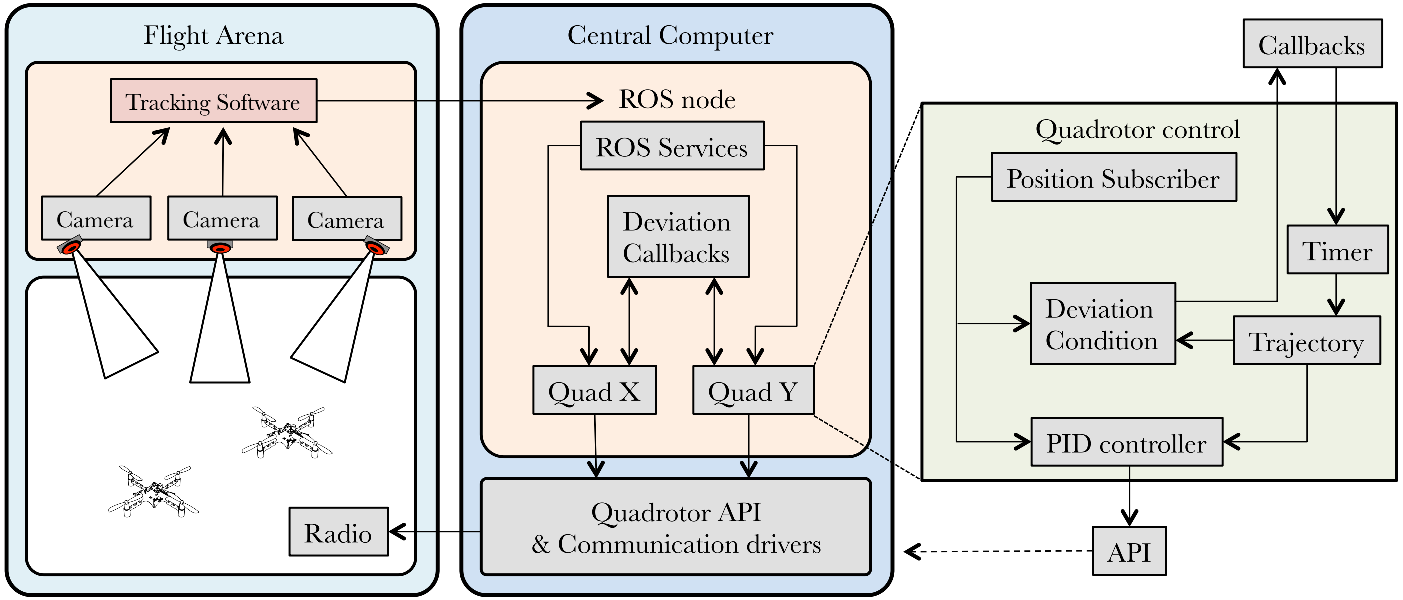
Constructor NAV



Percher NAV

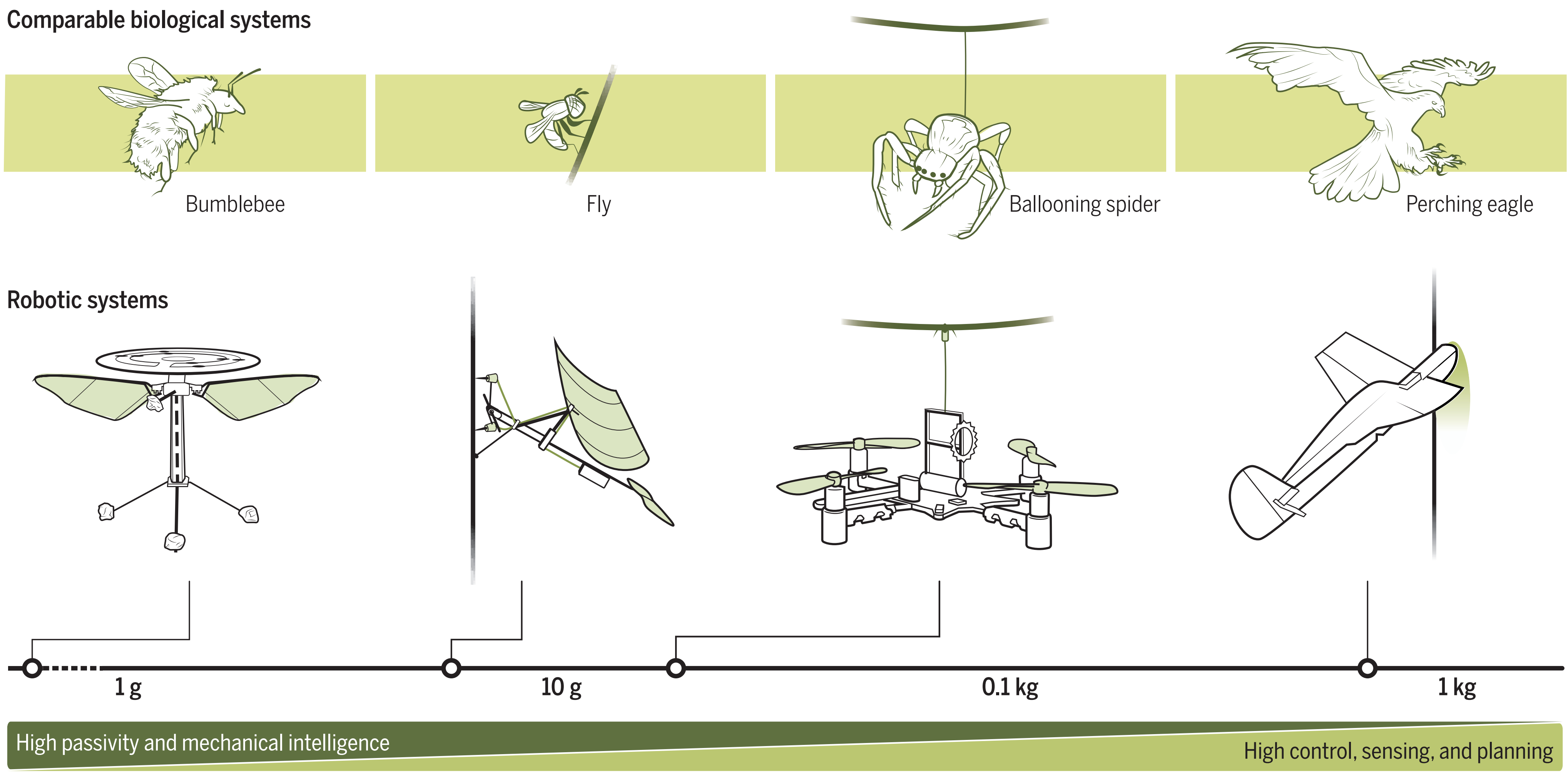






Braithwaite, A., Alhinai, T., Haas-Heger, M., McFarlane, E., Kovac, M., Spider Inspired Construction and Perching with a Swarm of Nano Aerial Vehicles, *International Symposium on Robotics Research 2015*

From complex control to mechanical intelligence



M. Kovac, Learning from nature how to land aerial robots,
Science, Vol. 352, Issue 6288, pp. 895-896, 2016

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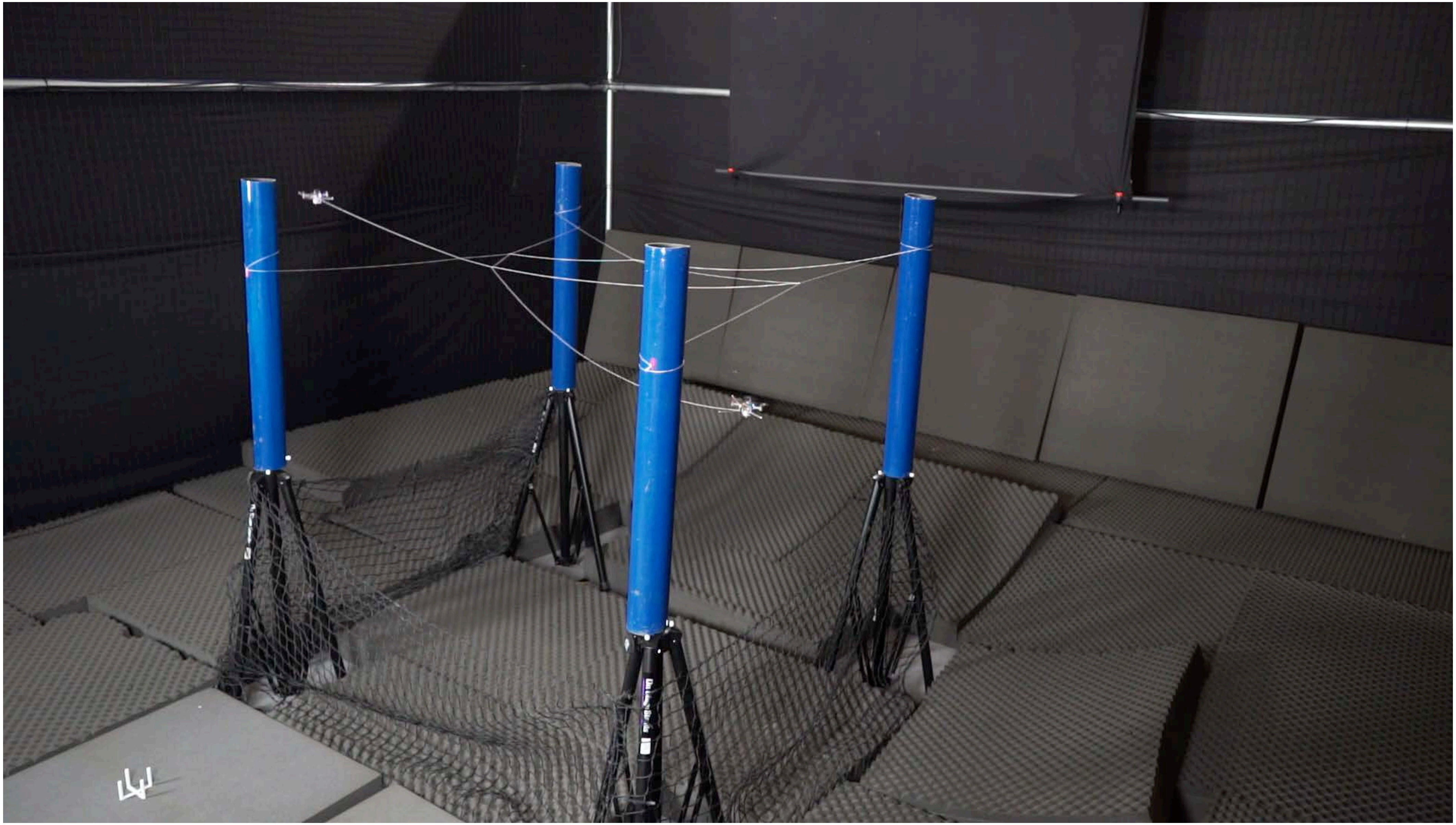


Braithwaite, A., Alhinai, T., Haas-Heger, M., McFarlane, E., Kovac, M., Spider Inspired Construction and Perching with a Swarm of Nano Aerial Vehicles, *International Symposium on Robotics Research 2015*

Aerial-Aquatic Mobility

Research questions

Multiple modes of propulsion?

Motion of interfaces?

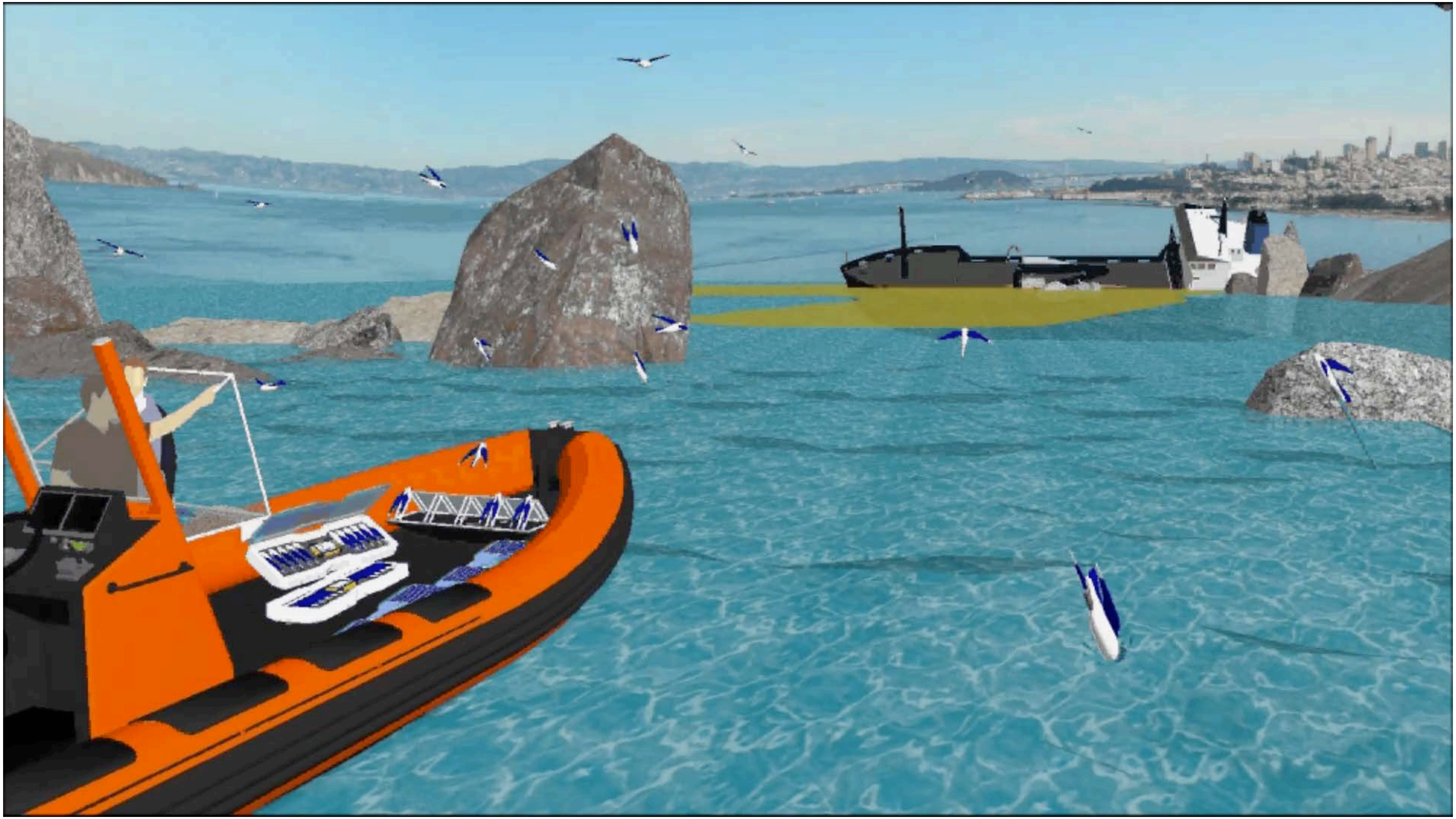
Design trade-offs?

Energetics of locomotion?

Transition between modes?

Scaling?

Concept: AquaMAV



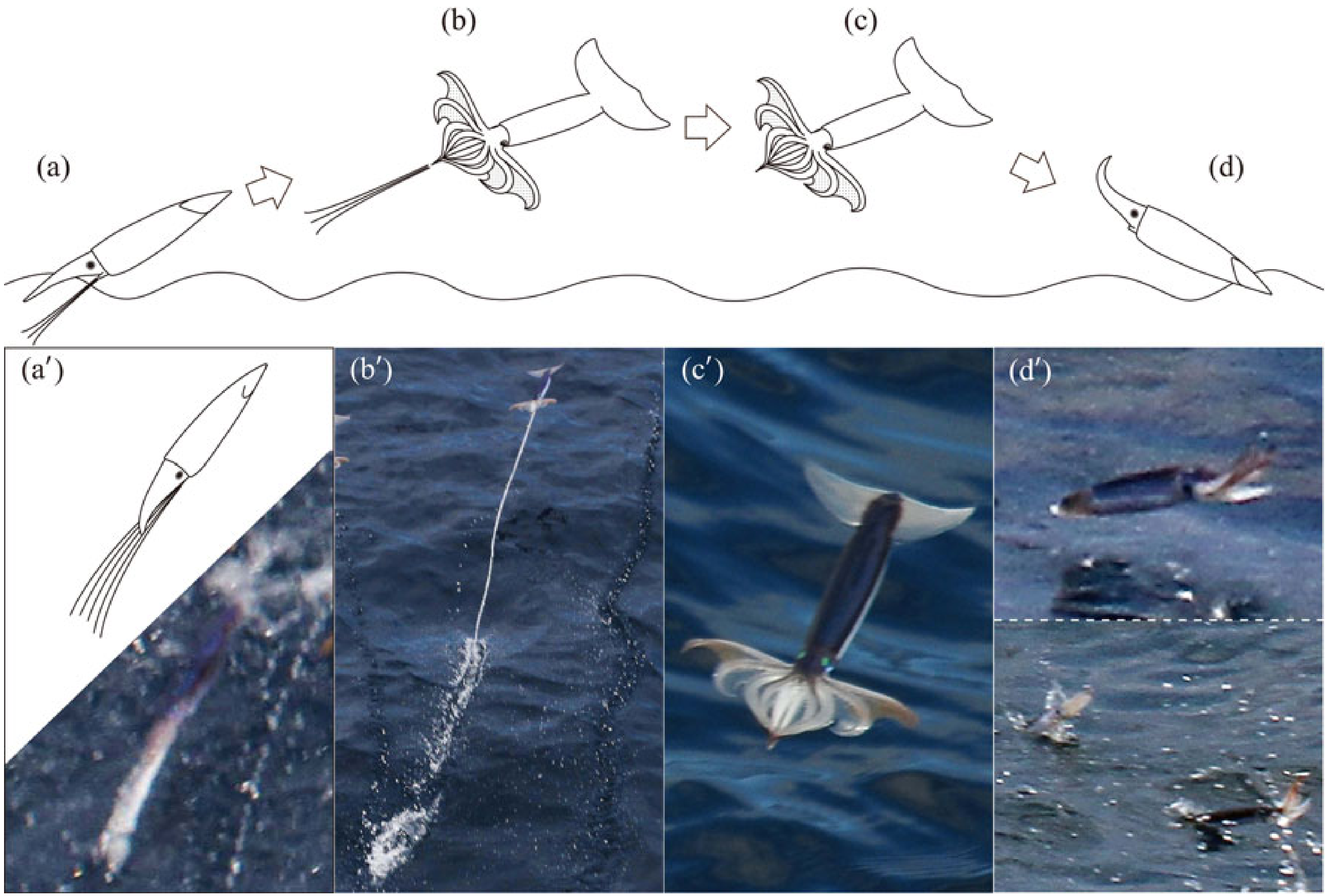
Biological design strategy: Plunge Diving

R. Siddall and M. Kovac, 'Launching the AquaMAV: Bioinspired design for Aerial-Aquatic Robotic Platforms', *Bioinspiration and Biomimetics*, 2013

Biological design strategy: Plunge Diving

Video Credit: PLC Cameras

Aquatic Jumping: Flying Squid



Oceanic Squid Do Fly, Miramatsu et al, 2013

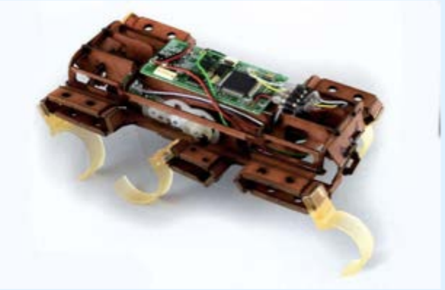
Biological design strategy: Aquatic Escape by Jet Propulsion

- Demonstrated by several species of flying squid
- Does not require a vehicle to be highly buoyant
- Can produce thrust in air and water.
- Rapid thrust response (compared to propellers or flapping), ideal for short take-off.
- Propellant water can be collected in situ.
- Mechanically simple to implement (compared to teleost swimming, for example).

Squid Rocket Science, O'dor et al., 2012
Oceanic Squid Do Fly, Miramatsu et al, 2013

Power Density in Robots and Animals

Terrestrial Running



Cockroach
25 W/kg

VelociRoach
45 W/kg

Hovering

Hummingbird
309 W/kg

Miniature Quad
283 W/kg

Terrestrial Jumping

Desert Locust
500 W/kg

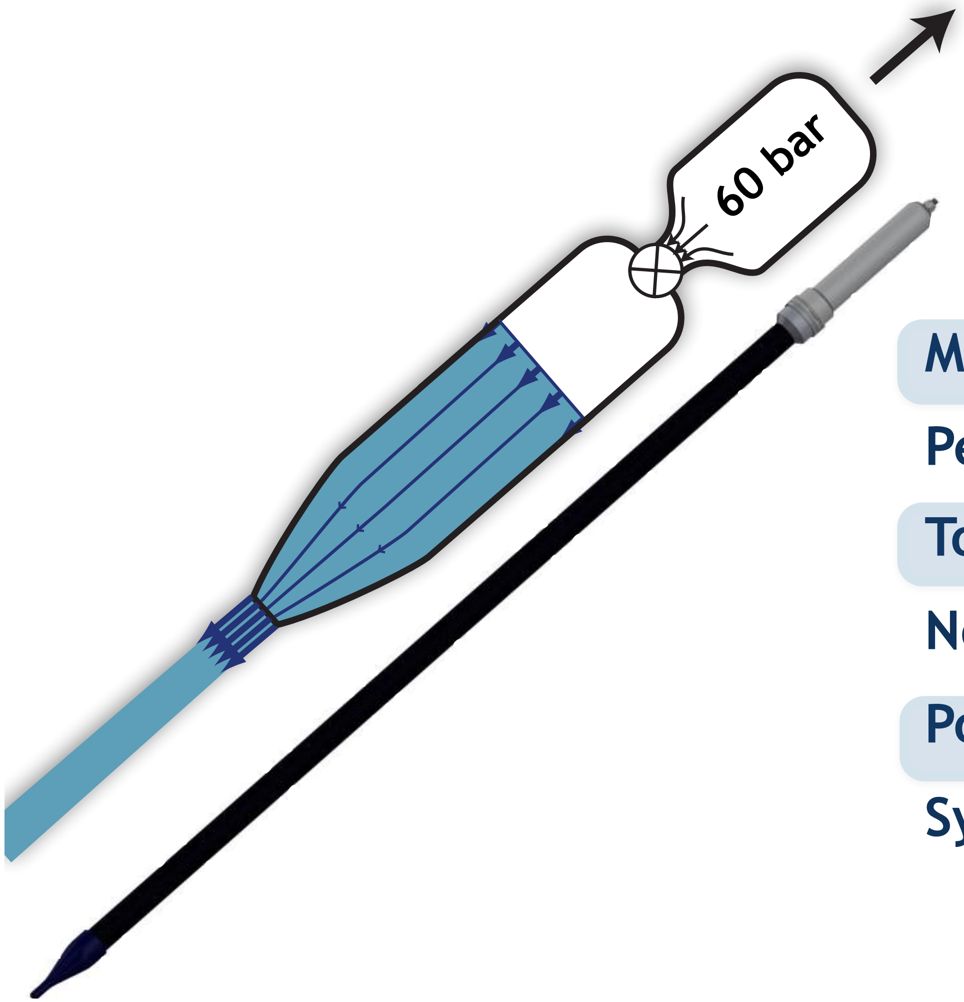
EPFL Jumper
980 W/kg

Impulsive Aquatic Take off

Flying Fish
2800 W/kg

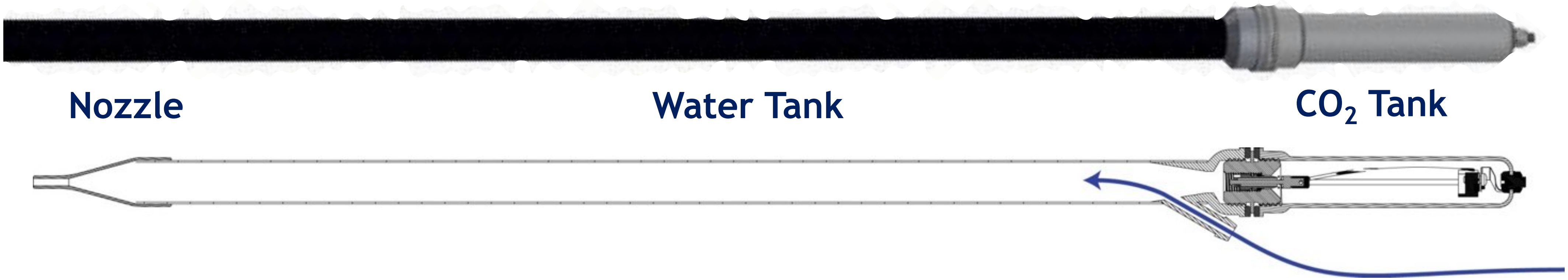
AquaMAV
2100 W/kg

Aquatic Escape: Compressed Gas Jet Thruster



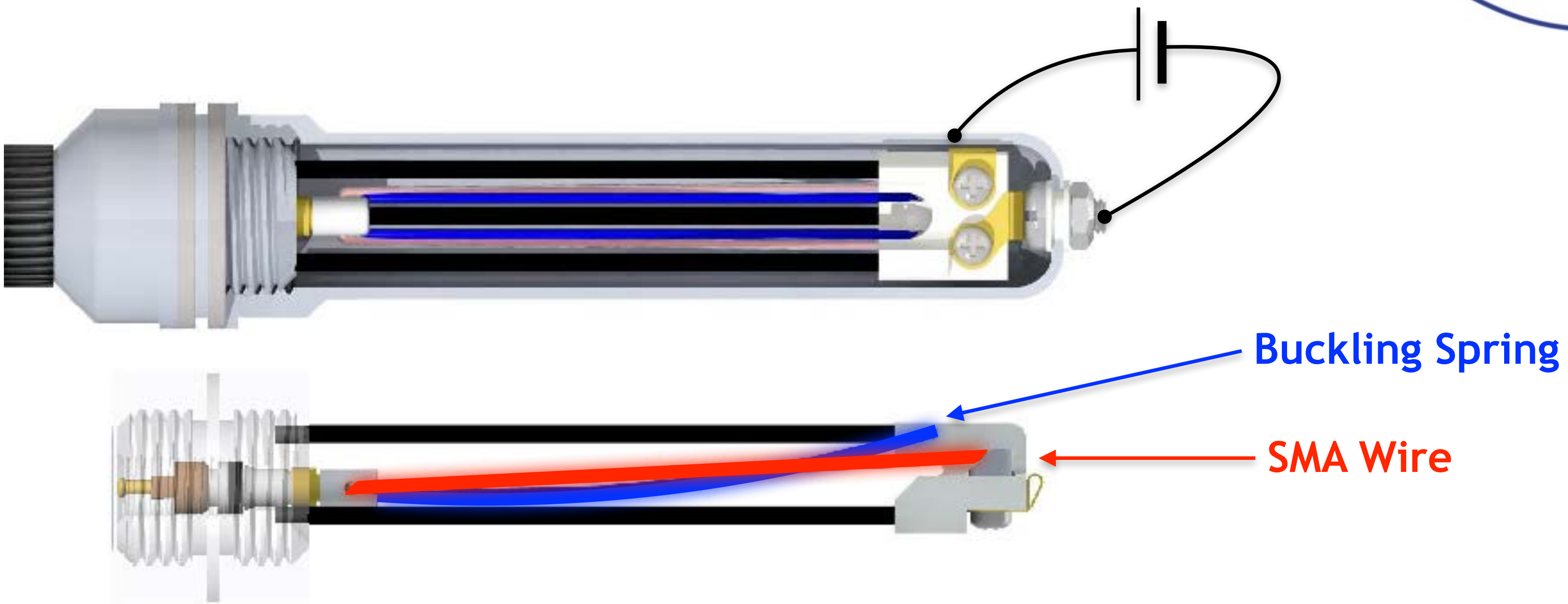
Mass	40.1 g
Peak Thrust	5 N
Total Impulse	0.8 Ns per shot
No. of Actuations	1
Power Density	5.2 kW/kg
System Specific Impulse	19 m/s

Prototype



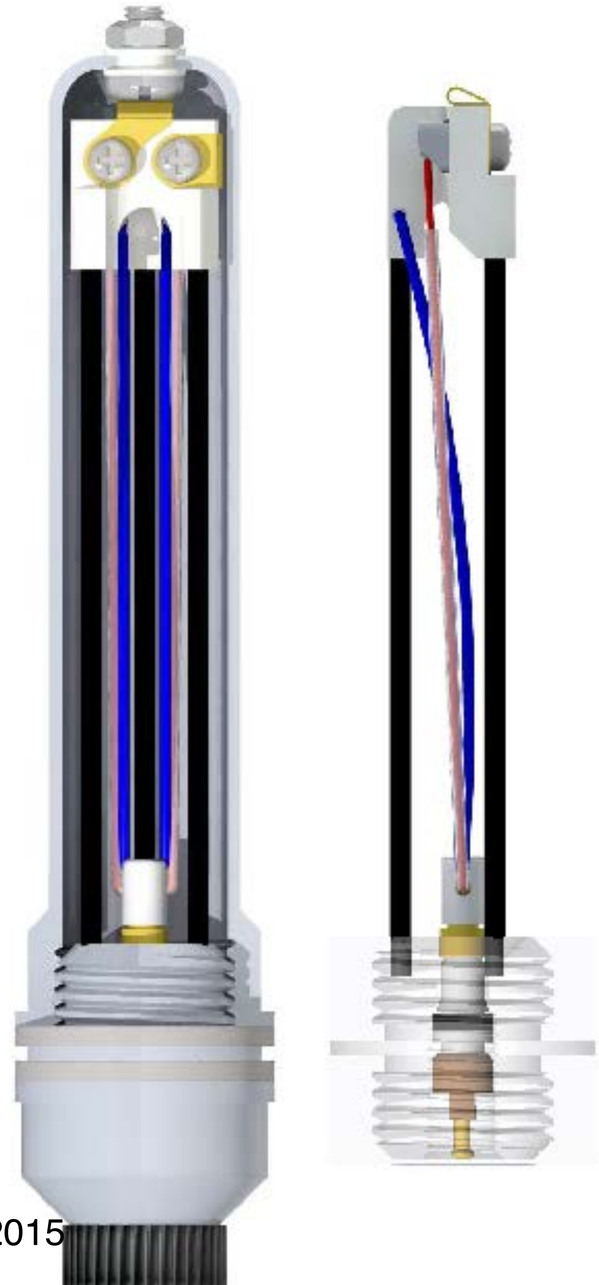
R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Prototype



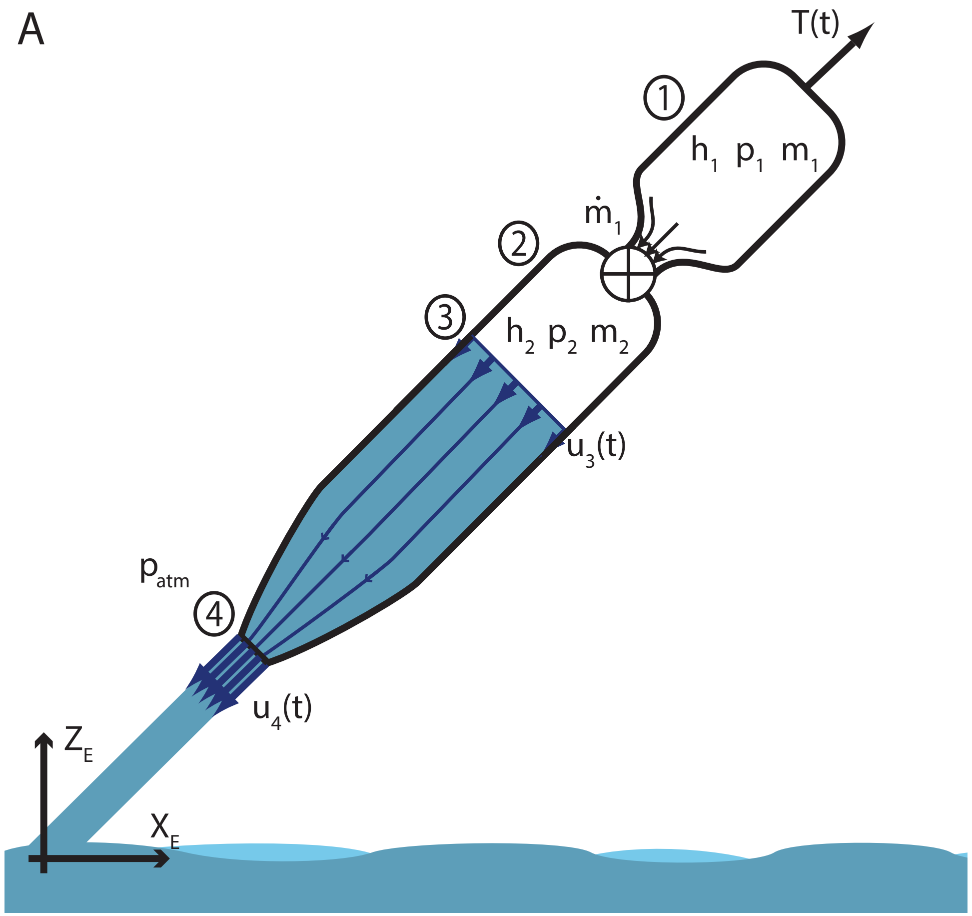
R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Shape memory alloy gas release system



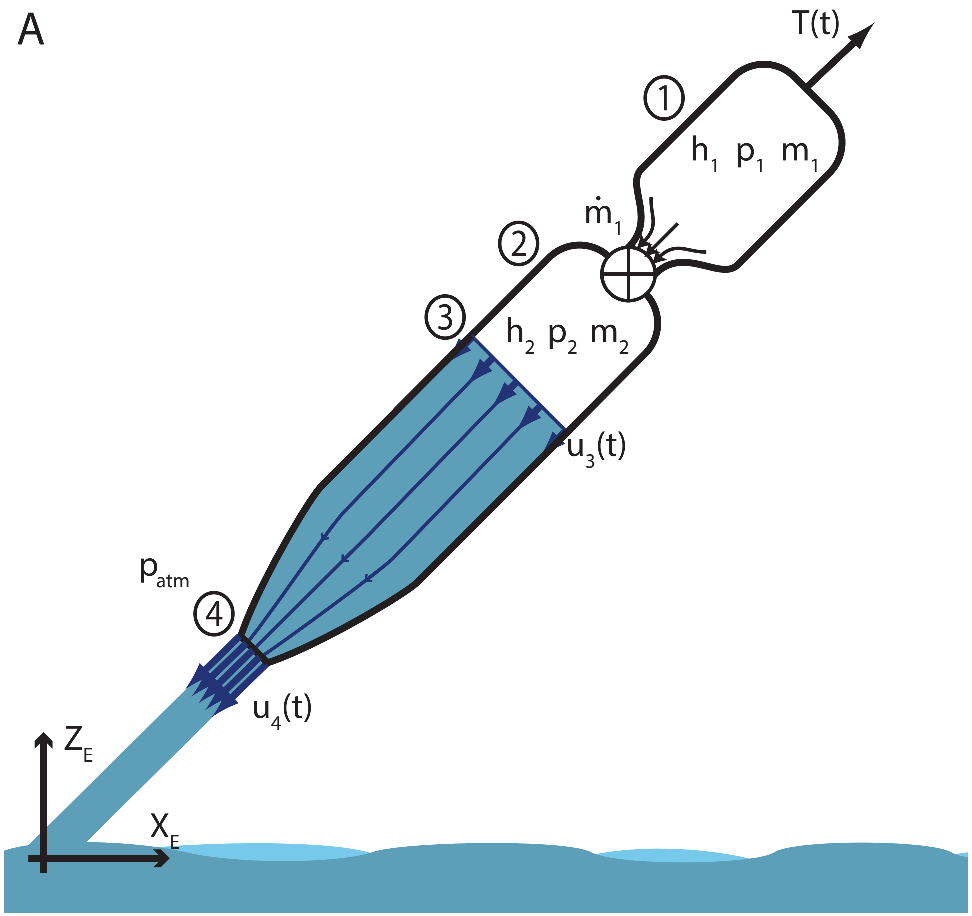
R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Theory



R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Theory



EN-6054 Valve flow equations

$$\dot{m}_1 = K_v \Upsilon \sqrt{\kappa p_1 \rho_1} \tag{5}$$

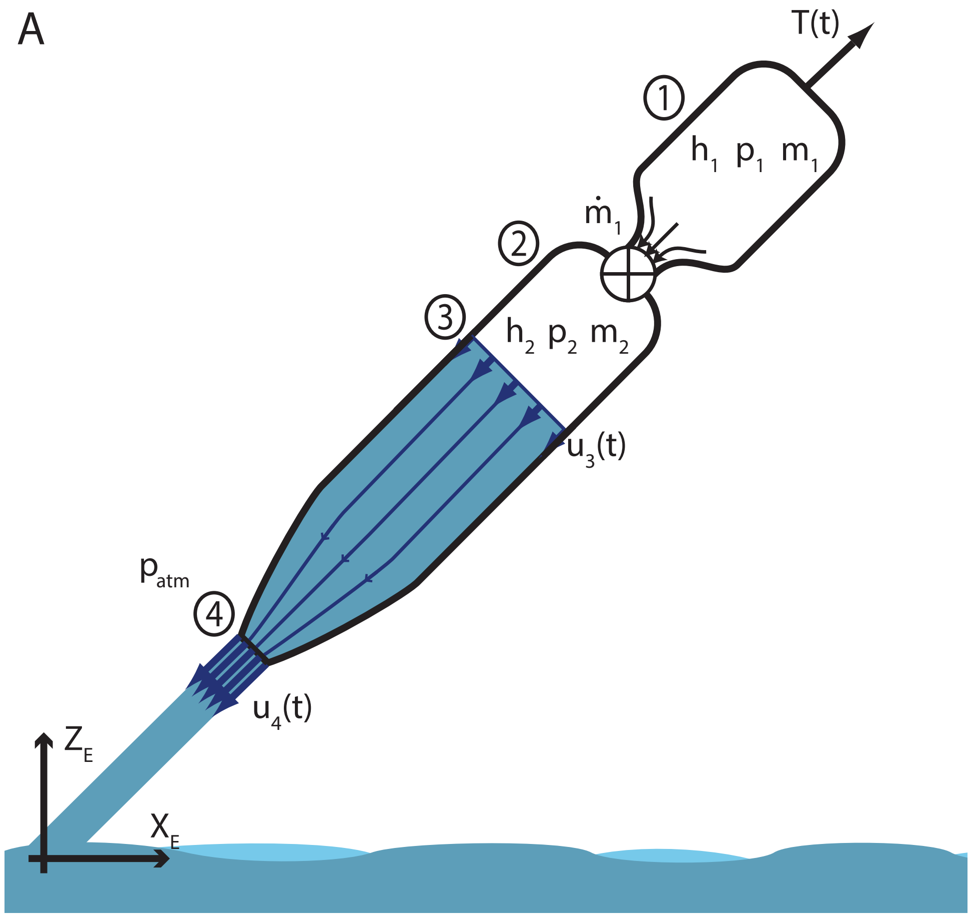
$$\kappa = (p_1 - p_2)/p_1 \tag{6}$$

$$\kappa = \begin{cases} \kappa & \text{if } \kappa < \kappa_{choke} \\ \kappa_{choke} & \text{if } \kappa \geq \kappa_{choke} \end{cases} \tag{7}$$

$$\Upsilon = 1 - \kappa / 3\kappa_{choke} \tag{8}$$

R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Theory



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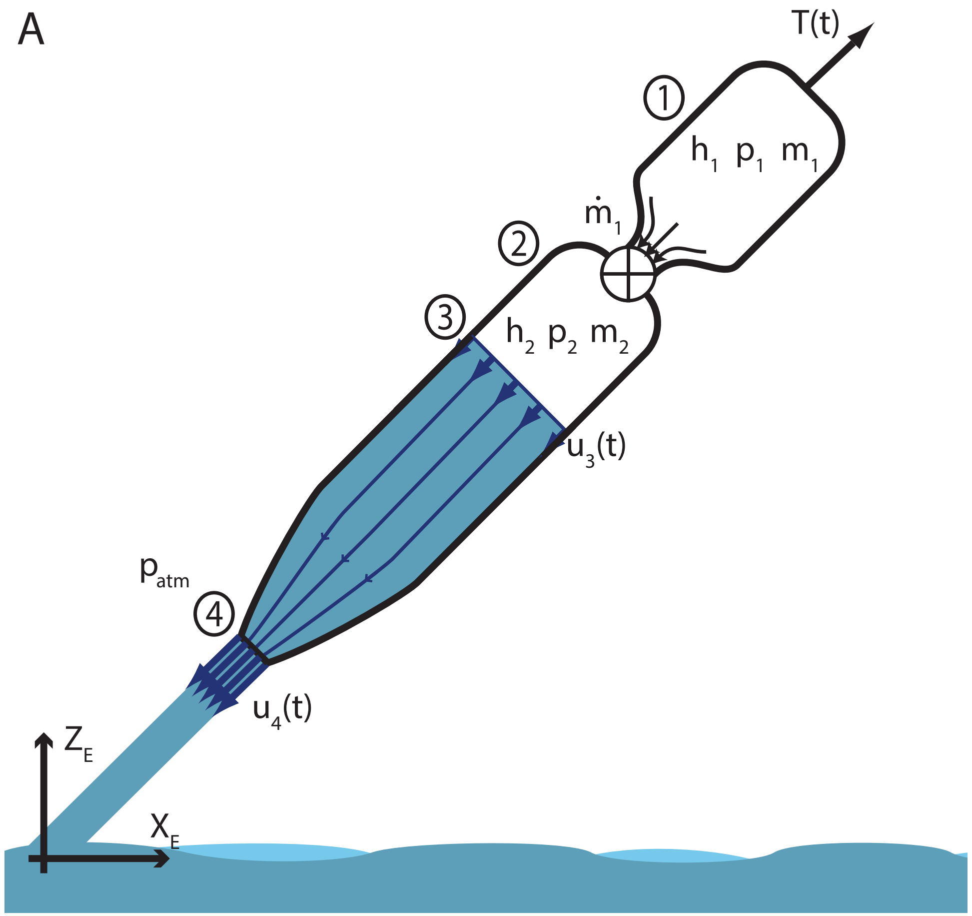
$$\Upsilon = 1 - \kappa / 3\kappa_{choke} \quad (8)$$

1st Law Energy Balance

$$\dot{m}_1 h_{01} = \frac{d}{dt}\left[m_2\left(h_2 + \frac{u_3^2}{2}\right)\right] - p_2 \dot{V}_2 \quad (9)$$

R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Theory



Unsteady Bernoulli Equation for water flow

$$T = \dot{m}_4 u_4 \quad (1)$$

$$u_4 = \dot{V}_2 / A_4 \quad (2)$$

$$A_3(t) u_3(t) = A_4 u_4(t) \quad (3)$$

$$\int_3^4 \frac{\partial u}{\partial t} ds + \frac{p_2}{\rho_w} + \frac{1}{2}(u_4^2 - u_3^2) = 0 \quad (4)$$

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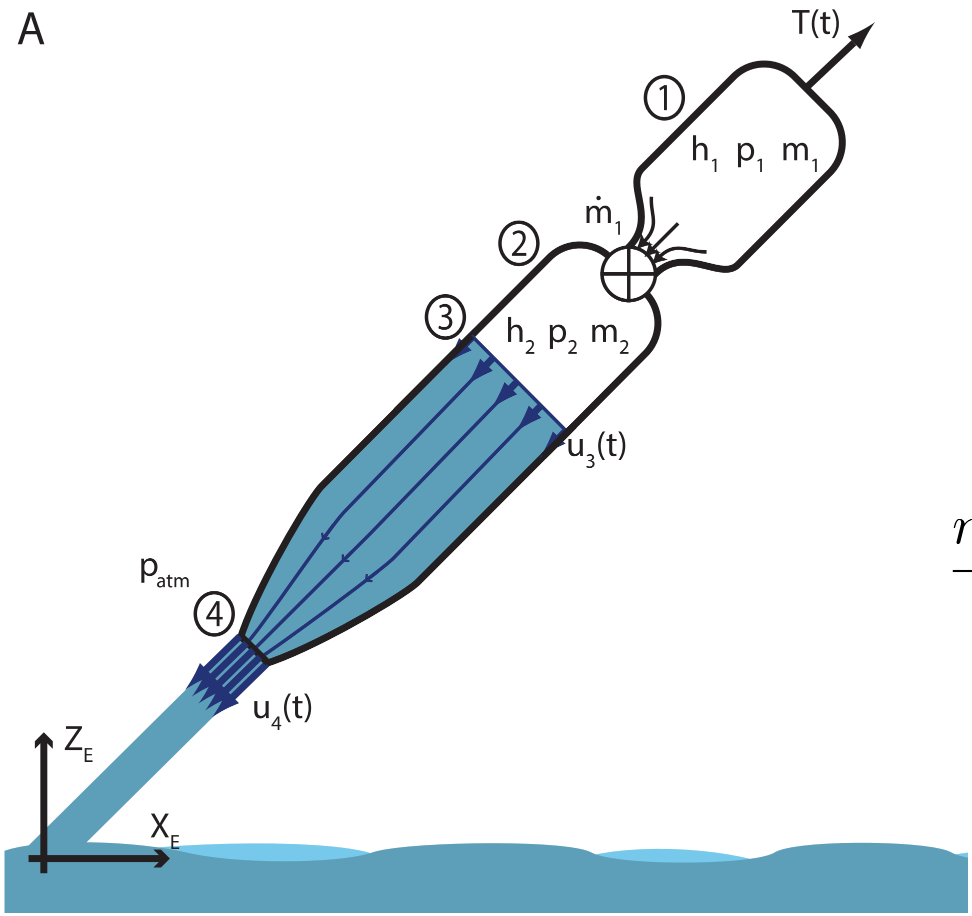
Theory



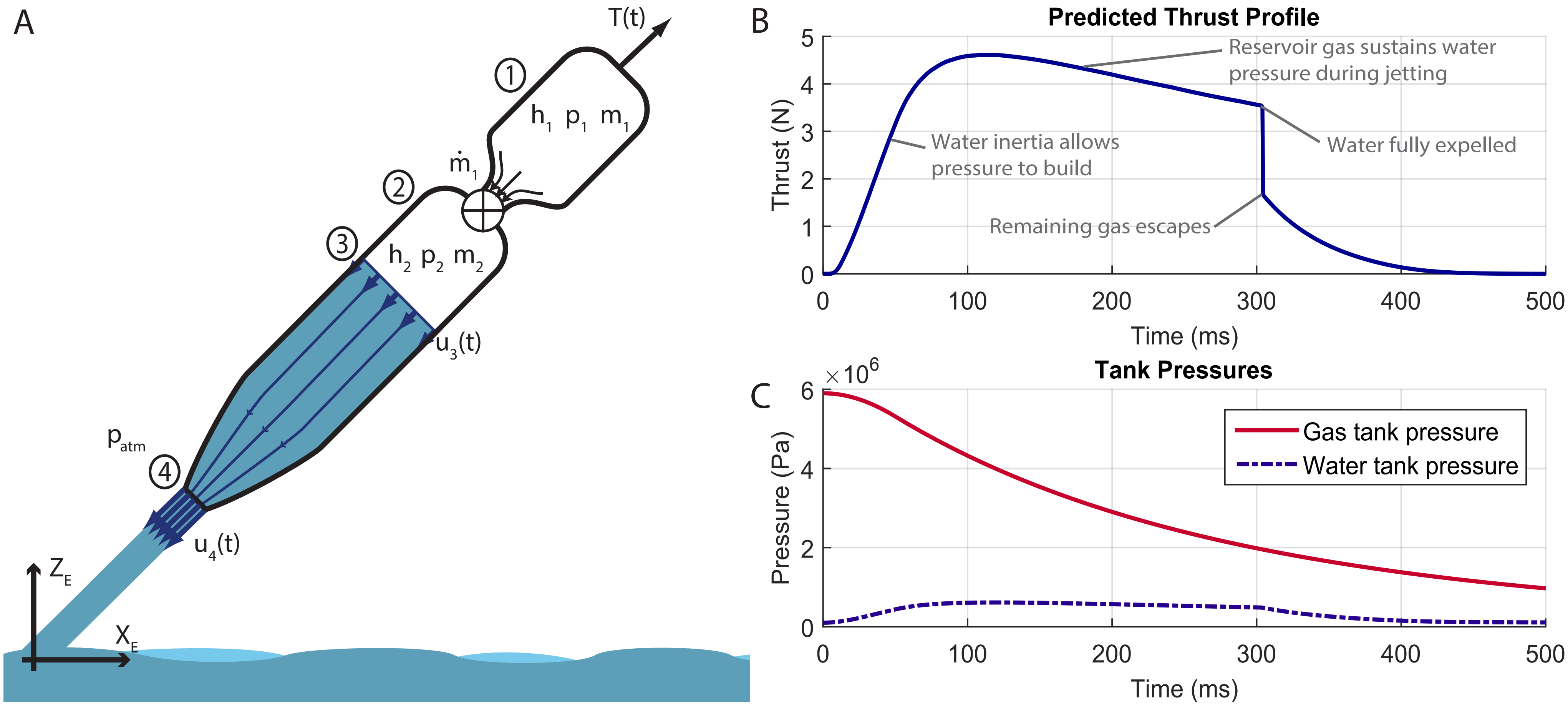
Isentropic Compressible flow relations
(after all water expelled)

$$\frac{p_{atm}}{p_2} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}} \tag{12}$$

$$\frac{\dot{m}_4\sqrt{c_p T_{02}}}{A_4 p_{02}} = \frac{\gamma M}{\sqrt{\gamma-1}}\left(1+\frac{\gamma-1}{2}M^2\right)^{-\frac{1}{2}\frac{\gamma+1}{\gamma-1}} \tag{13}$$

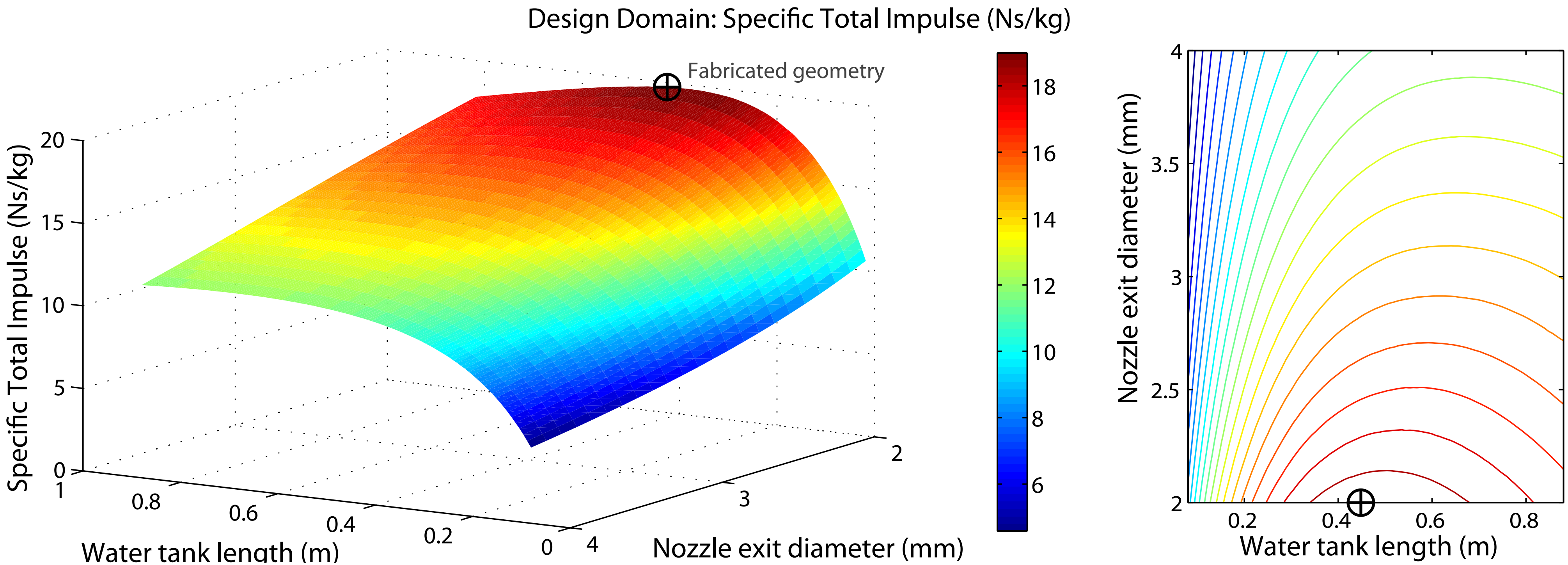
R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Theory



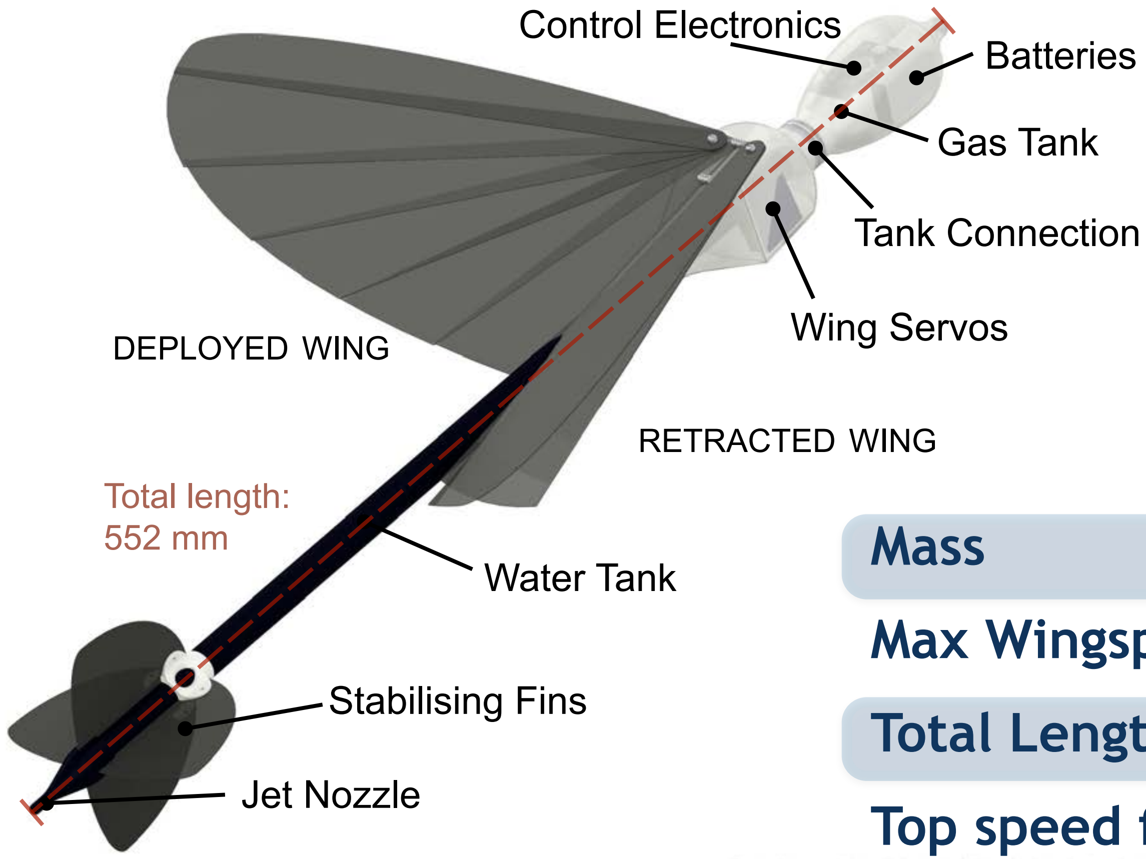
R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

Water Tank Sizing



R. Siddall and M. Kovac, A Water Jet Thruster for an Aquatic Micro Air Vehicle, ICRA 2015

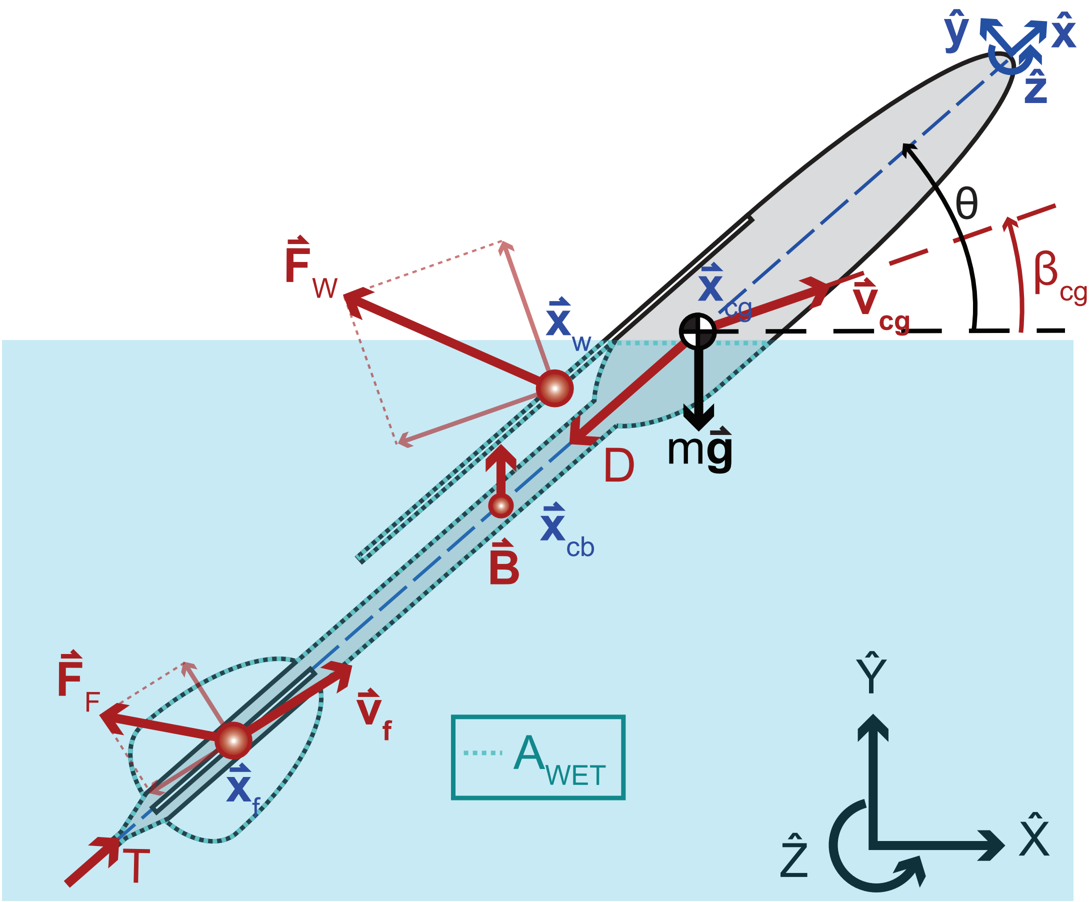
Aquatic Jumpglider



Mass	101 g
Max Wingspan	45 cm
Total Length	55 cm
Top speed from water	13 m/s
Power Density	2.1 kW/kg

R. Siddall and M. Kovac, Fast Aquatic Escape with a Jet Thruster, *IEEE Transactions on Mechatronics*, 2016
Winner, Robot Demo Contest, TAROS 2015

Water Escape Model



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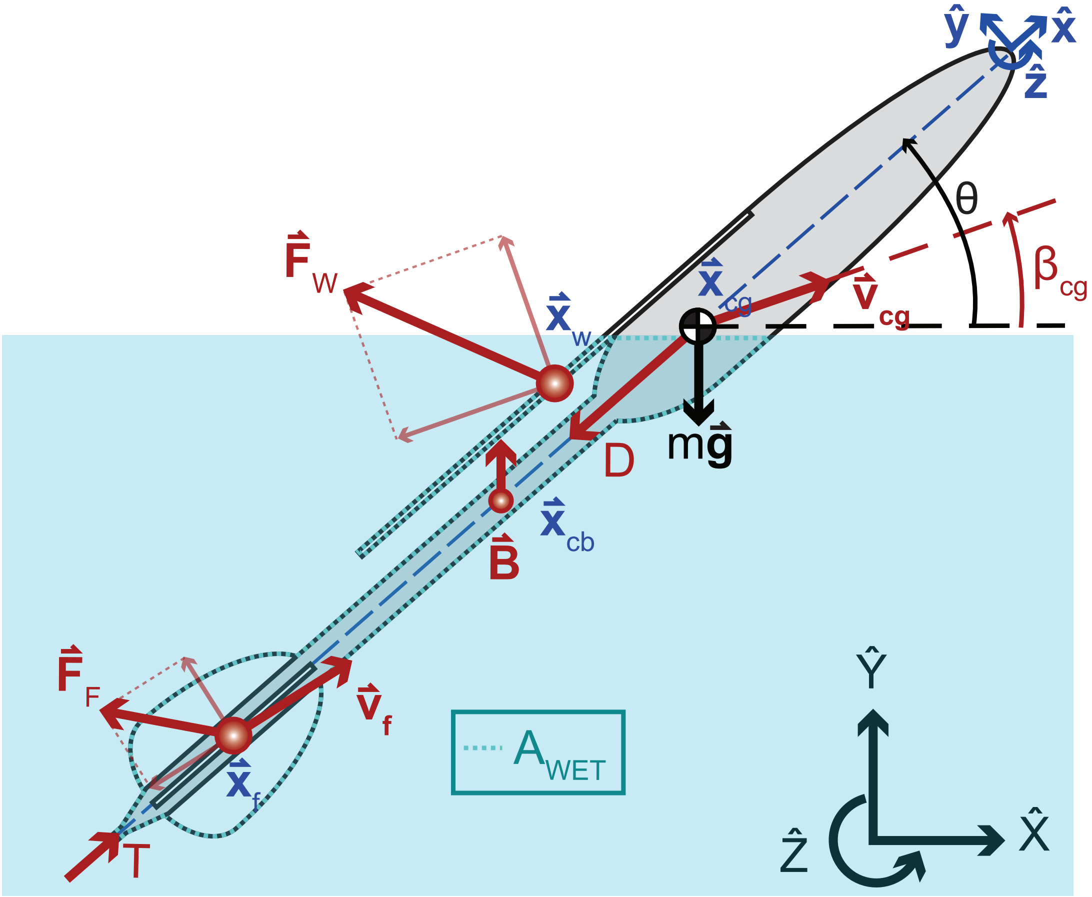

Retracted: Delta Configuration

Polhamus Suction Analogy

$$C_{lw} = k_p sin(\alpha_w) cos^2(\alpha_w) + k_v sin^2(\alpha_w) cos(\alpha_w)$$

$$C_{dw} = k_p sin^2(\alpha_w) cos(\alpha_w) + k_v sin^3(\alpha_w)$$

while: $t < t_{deploy}$

Deployed: Elliptic Configuration

Lifting Line Theory

$$C_{lw} = 2\pi(\alpha_w)/(1 + 2 AR_w^{-1})$$

$$C_{dw} = C_{lw}^2/(\pi AR_w)$$

while: $t \geq t_{deploy}$

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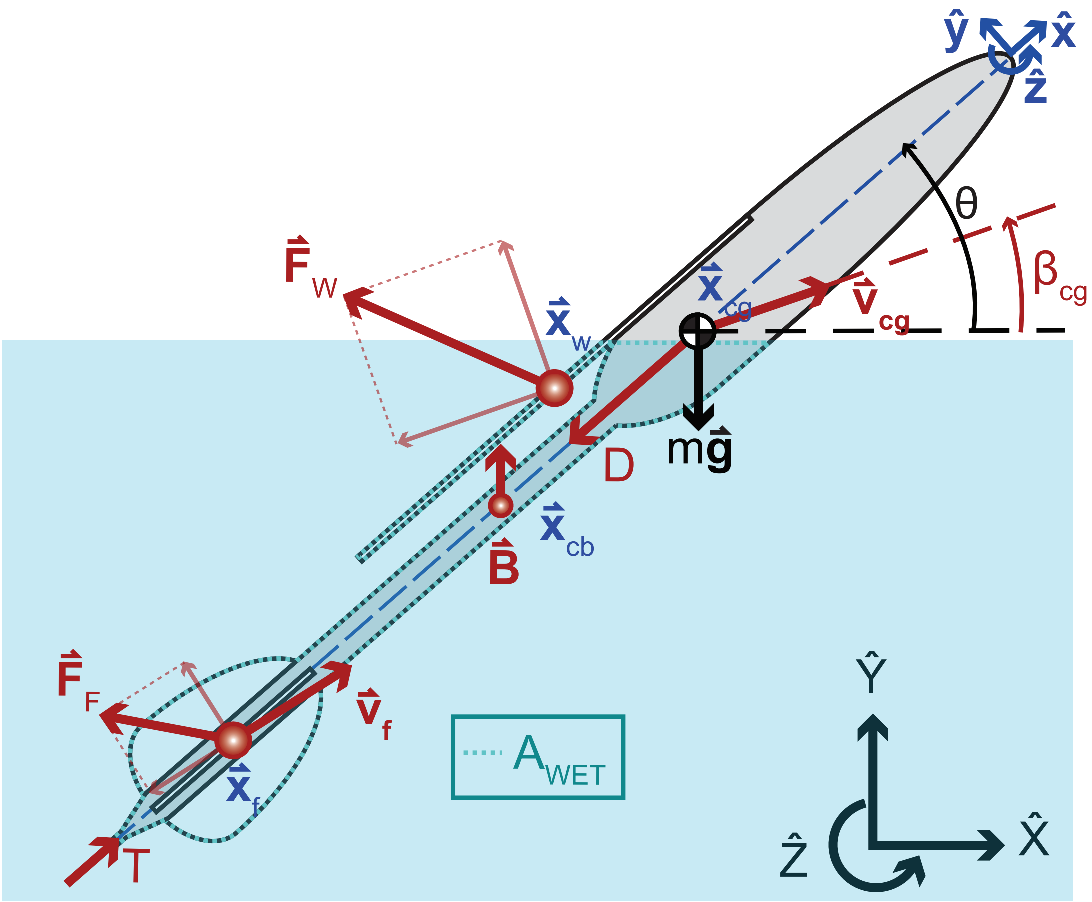
Water Escape Model



Parasitic Drag

$$D = 0.5\rho_a (C_f(2A_w + 4A_f) + C_{fb}A_b)|\vec{v}_{cg}|^2$$

$$C_f = 0.0307 Re^{-1/7}$$

$$C_{fb} = C_f\left(1 + \frac{3}{2}(BW/BL)^{\frac{3}{2}} + 7(BW/BL)^3\right)$$

Partial Immersion Correction

$$Q = \left(\frac{\rho_w}{\rho_a}\frac{A_{wet}}{A_{total}} + \left(1 - \frac{A_{wet}}{A_{total}}\right)\right)$$

Buoyancy

$$\vec{B} = V_{wet}\rho_w\vec{g}$$

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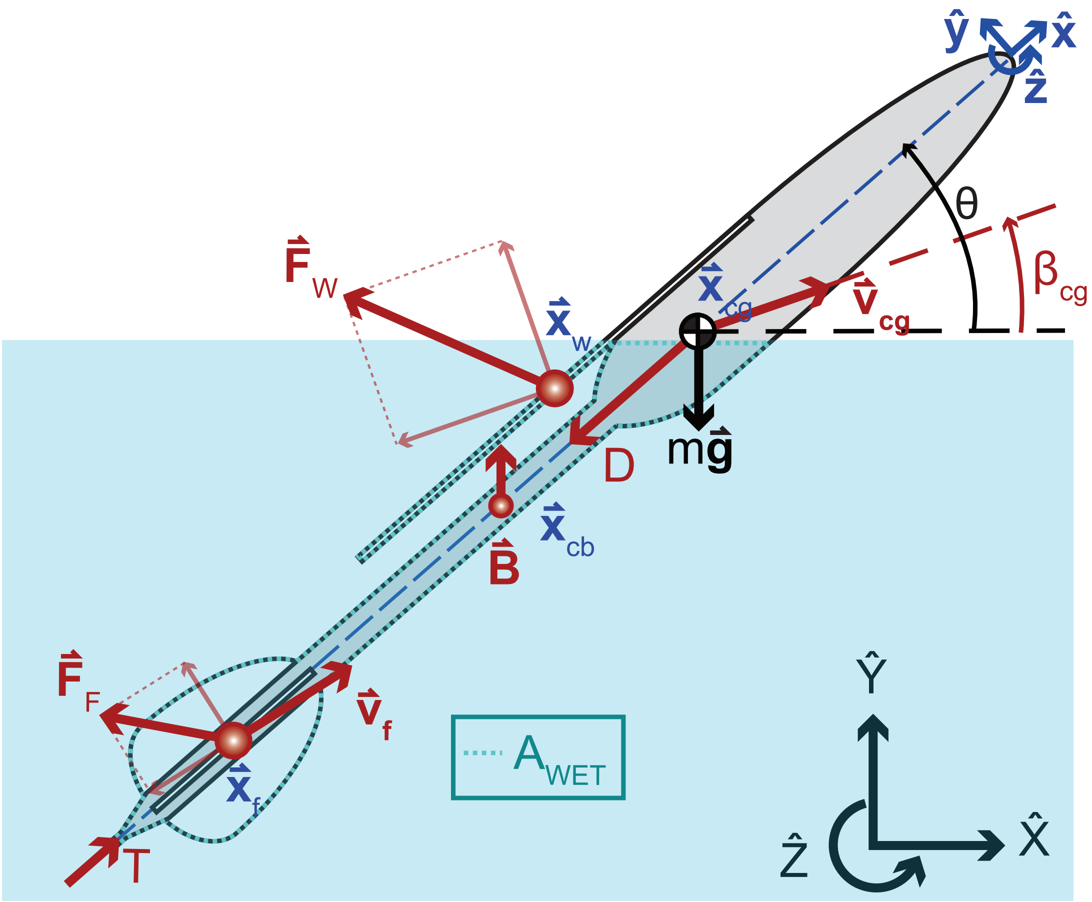
Winner, Robot Demo Contest, TAROS 2015

Water Escape Model



Equations of Motion

$$m\vec{a} = \vec{B} - m\vec{g} + \boldsymbol{R}(\theta - \alpha_w) Q \vec{F}_w + \boldsymbol{R}(\theta)(T - DQ)\hat{x} + \boldsymbol{R}(\theta - \alpha_f) Q_f \vec{F}_f$$

$$I_{yy}\ddot{\theta}\hat{z} = (\vec{x}_w - \vec{x}_{cg}) \times \boldsymbol{R}(\alpha_w) Q_w \vec{F}_w + (\vec{x}_{cb} - \vec{x}_{cg}) \times \boldsymbol{R}(\theta)\vec{B} + (\vec{x}_f - \vec{x}_{cg}) \times \boldsymbol{R}(\alpha_f) Q_f \vec{F}_f - \dot{I_{yy}}\dot{\theta}\hat{z}$$

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Winner, Robot Demo Contest, TAROS 2015

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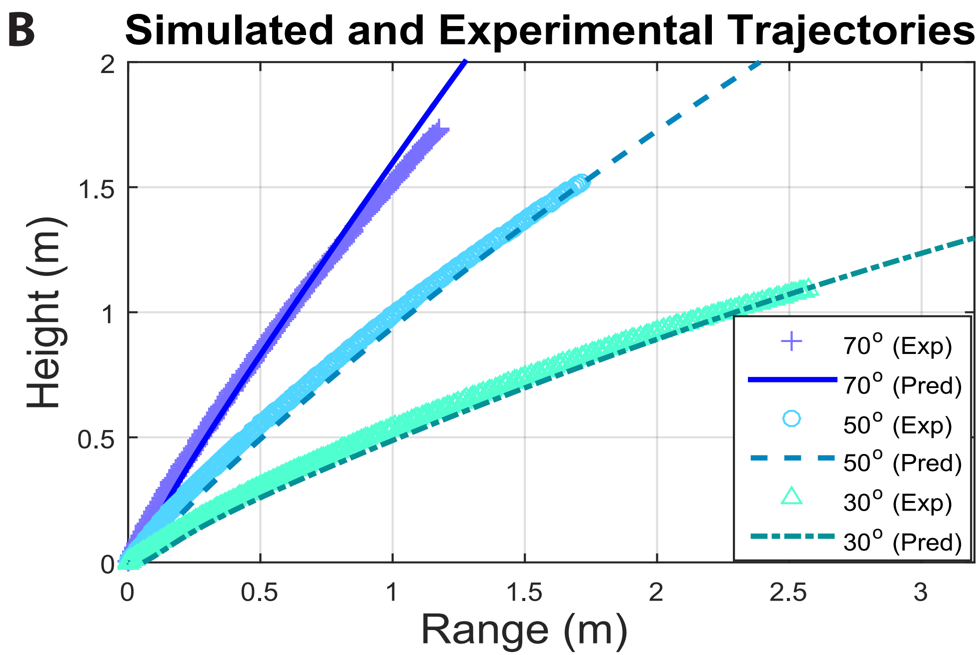
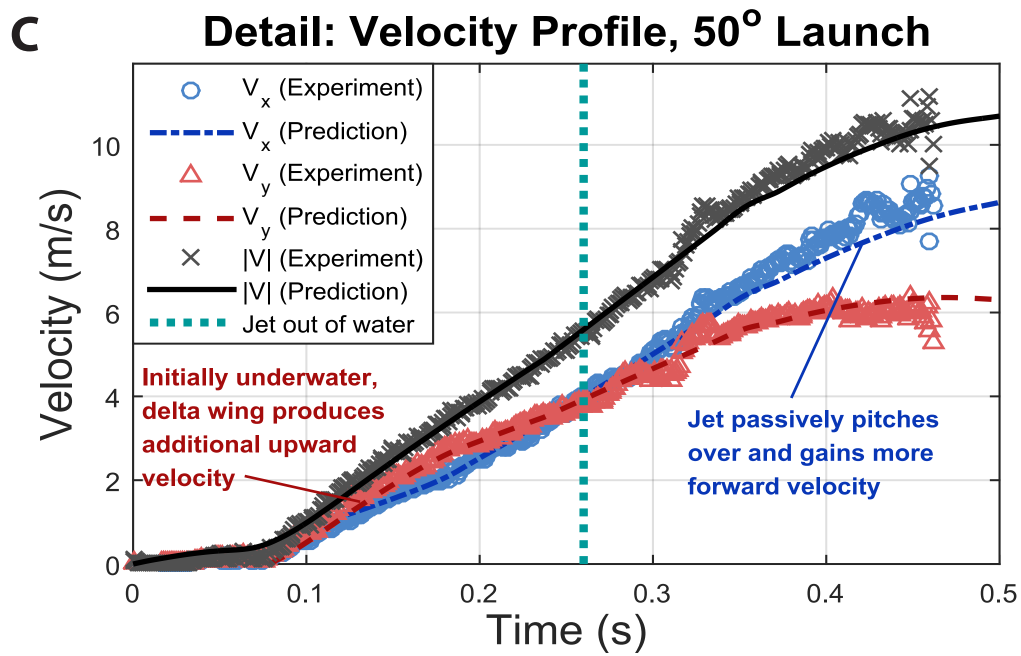
Launch Test vs. Theory





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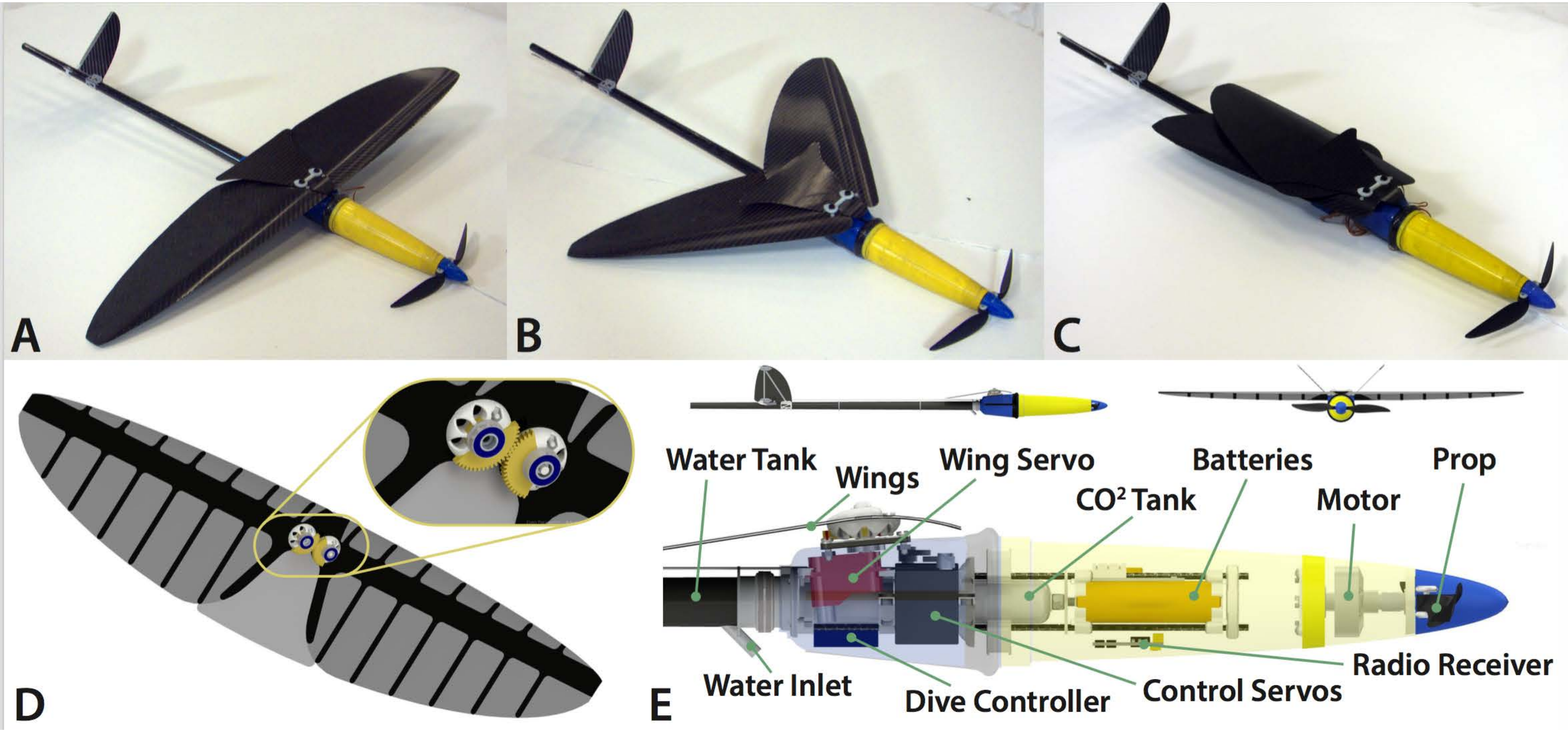
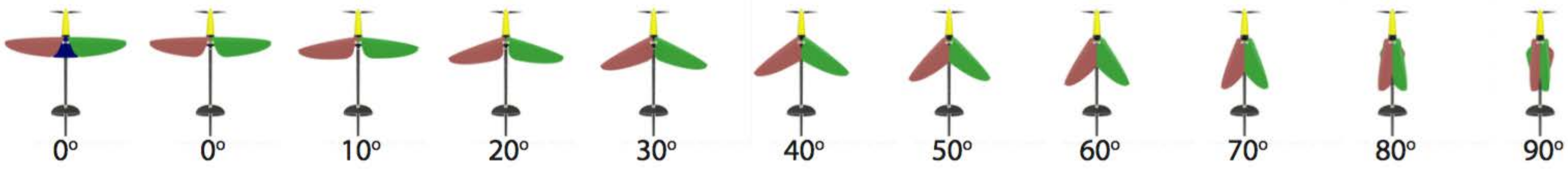
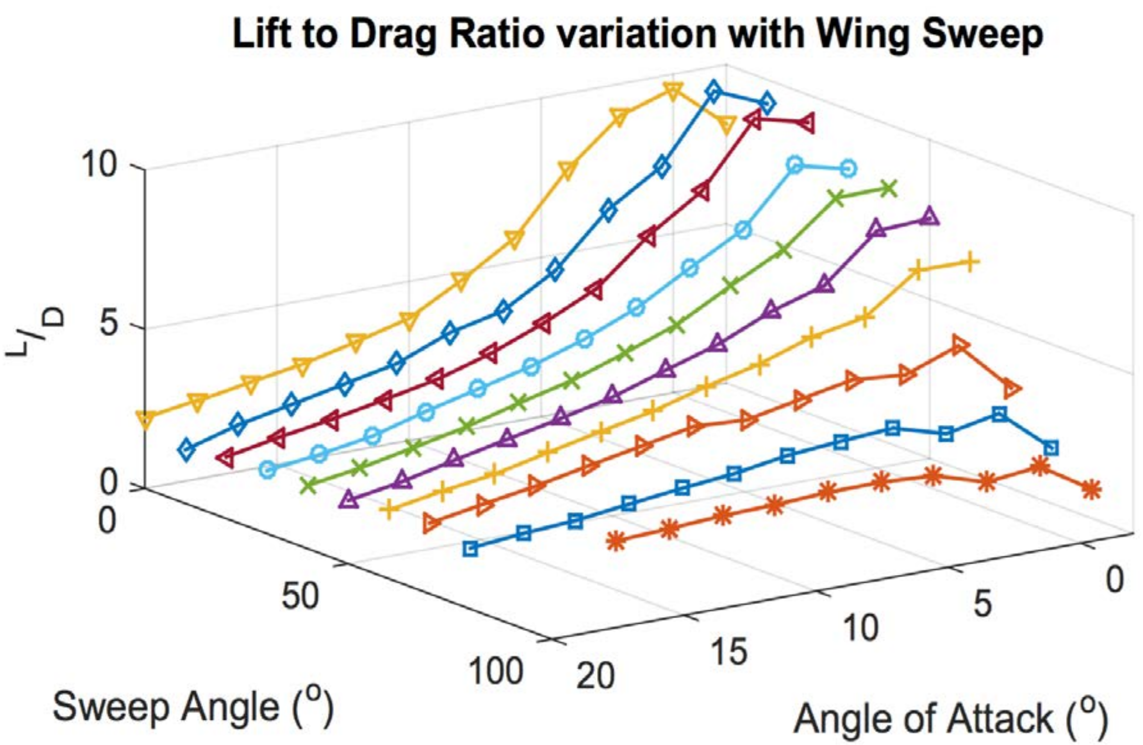
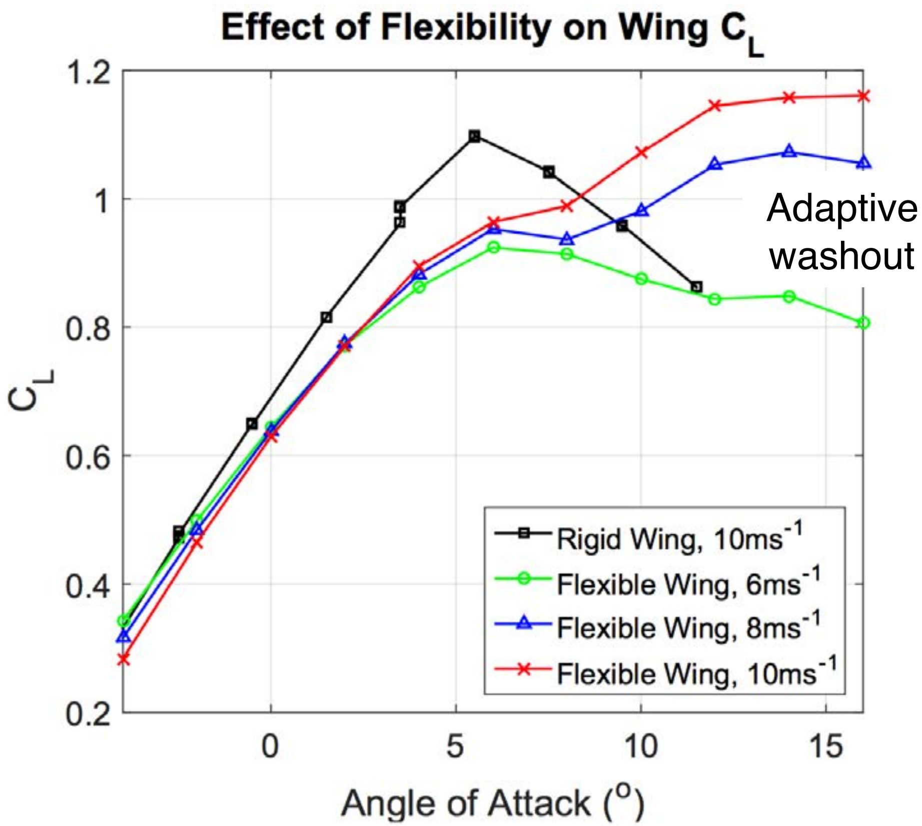


R. Siddall, A. Ortega and M. Kovac., Wind and Water Tunnel Testing of a Morphing Aquatic Micro Air Vehicle,
Journal of the Royal Society Interface Focus, 2016







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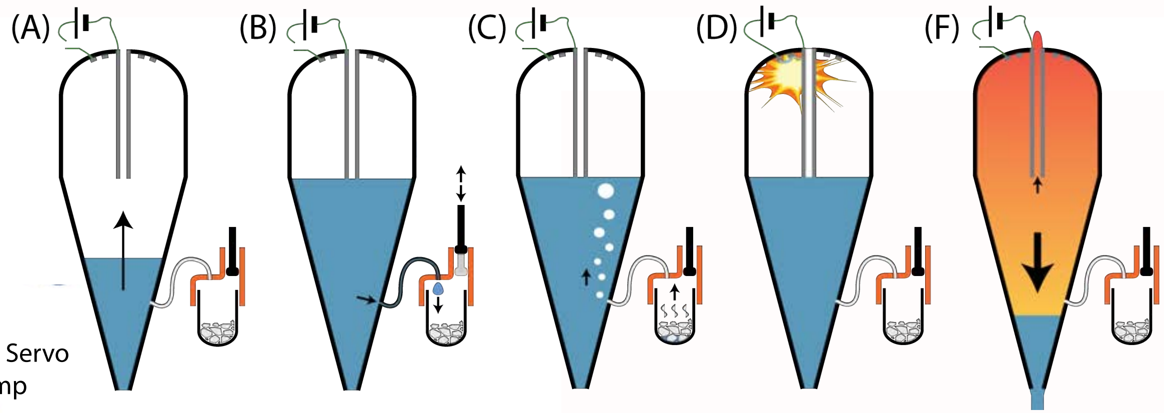
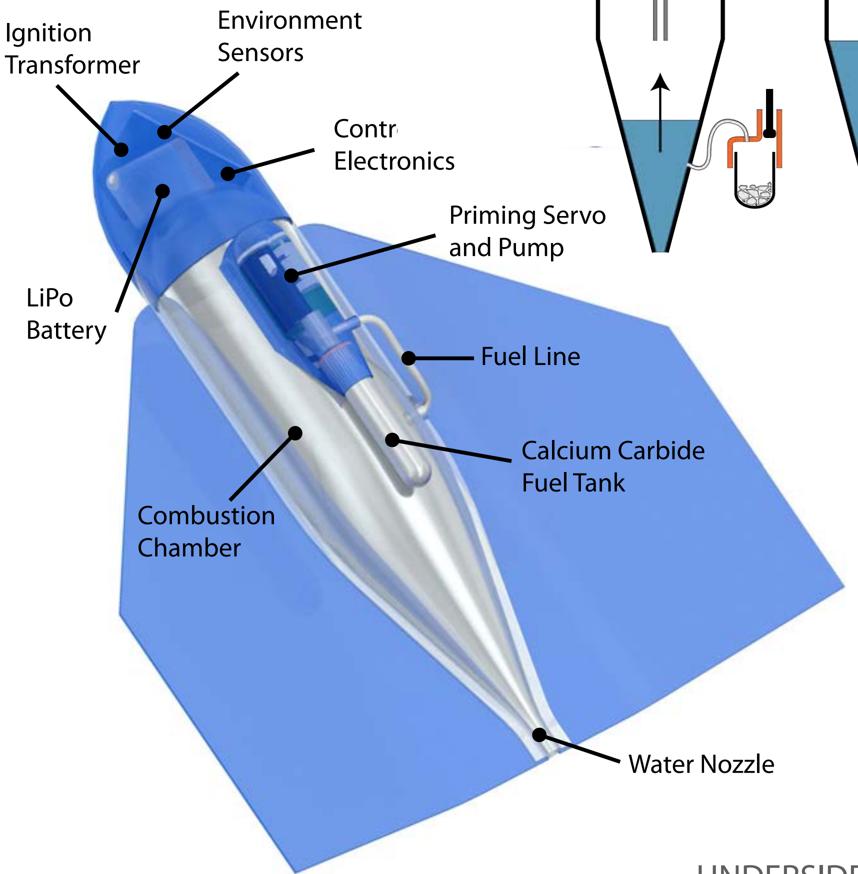
Aerial Robotics Lab

Calcium Carbide + Water -> Acetylene (C_2H_2) -> Thrust + CO_2 + H_20



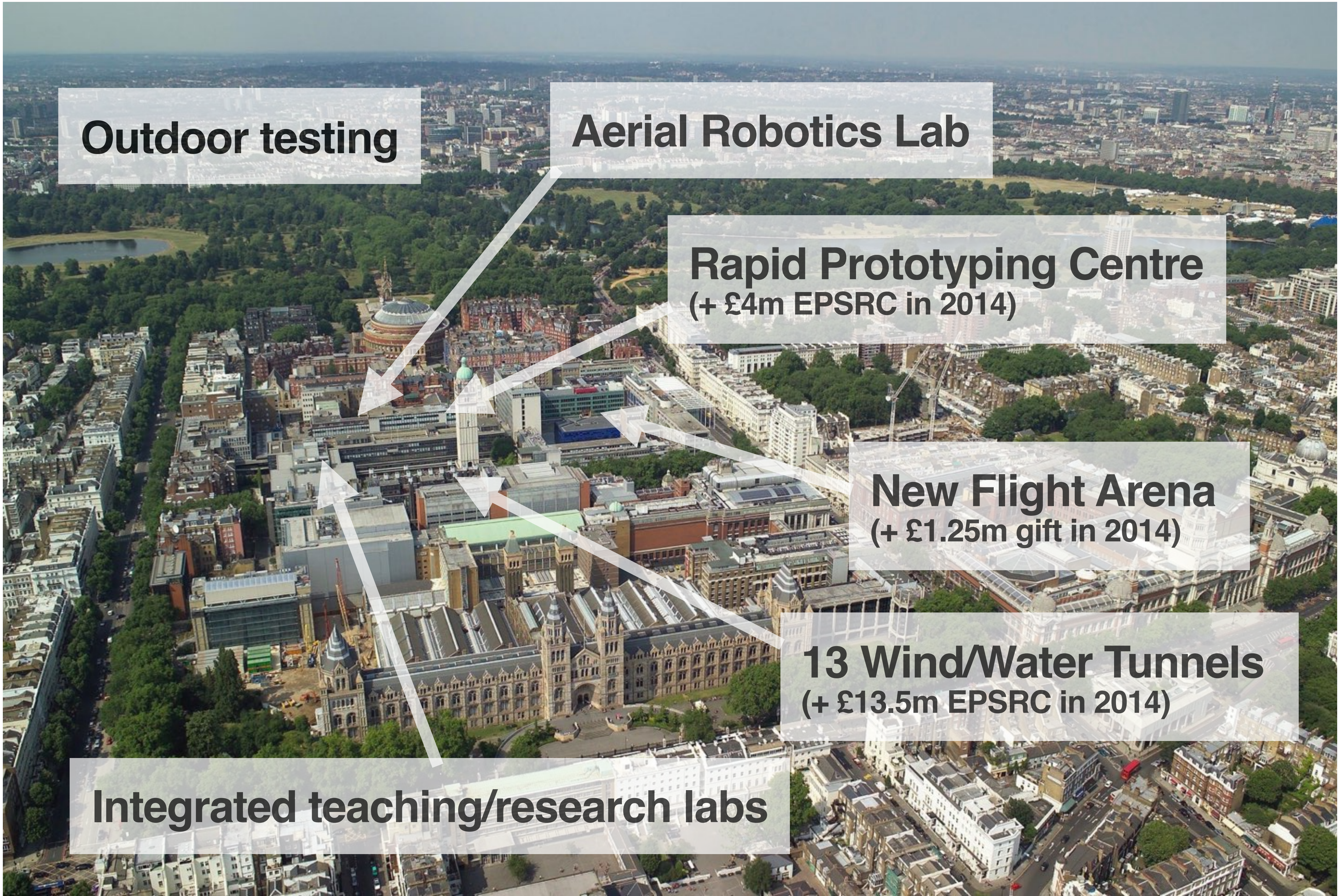


UNDERSIDE VIEW

Siddall, R., Kennedy, G., Kovac, M., A miniature self refuelling explosive water jet for Aquatic Micro Aerial Vehicles, *International Symposium on Robotics Research 2015*

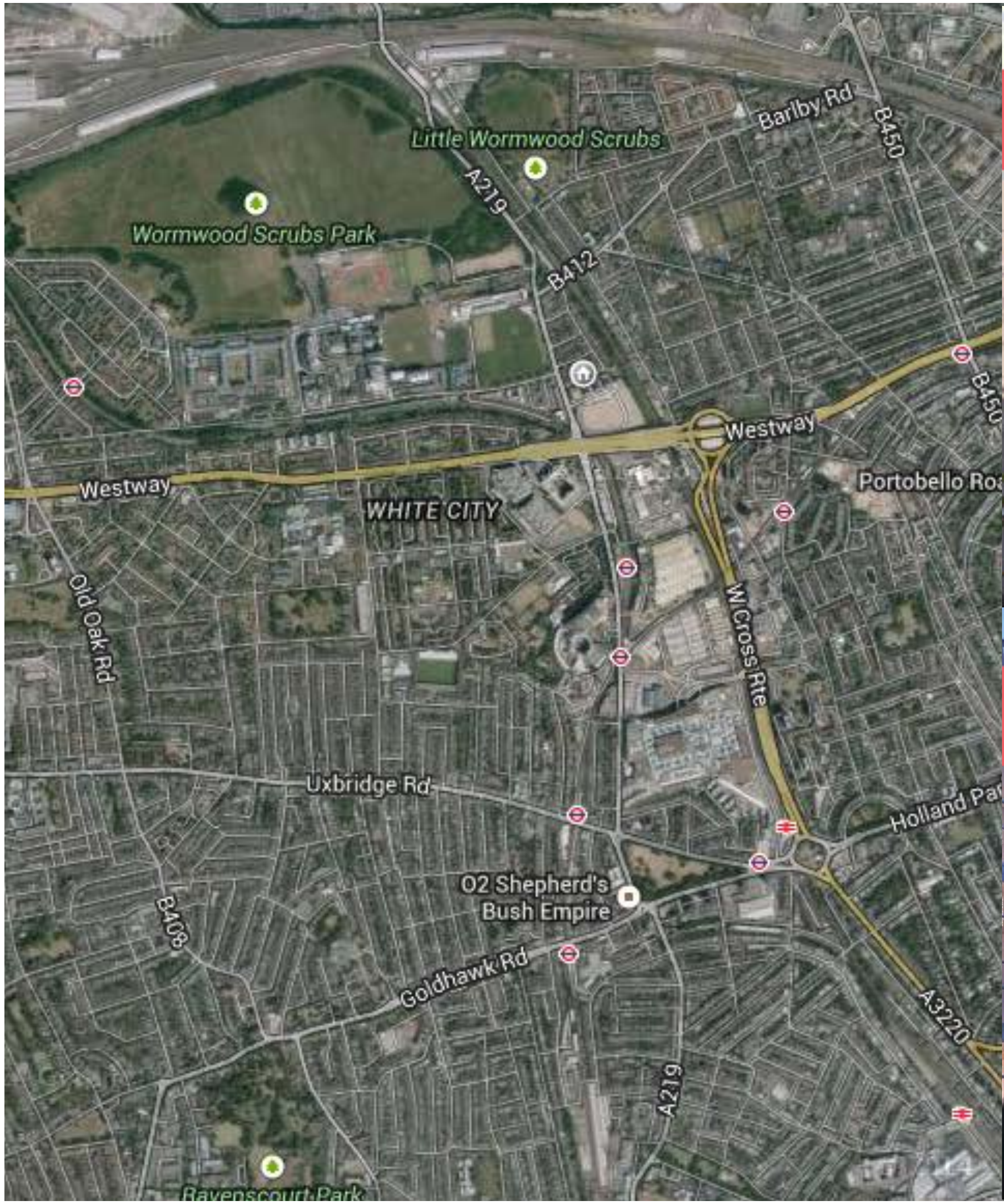
Aerial Robotics Laboratory

Robotics @ Imperial (35 PIs, 150 researchers)

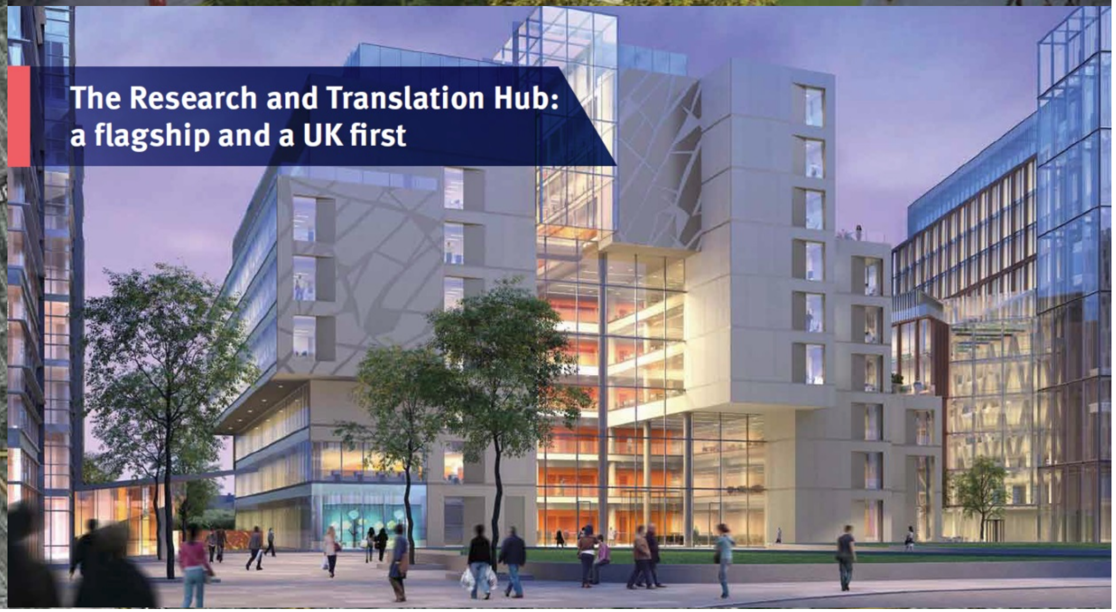



Multi-terrain lab
£1.25 philanthropic gift


Imperial College
London


Barlby Rd
B450
Little Wormwood Scrubs
A219
Wormwood Scrubs Park
B412
B450
Westway
Westway
Portobello Roa
WHITE CITY
Old Oak Rd
W Cross Rte
Uxbridge Rd
Holland Pa
O2 Shepherd's
Bush Empire
B408
Goldhawk Rd
A3220
A219


A £1 billion
campus ecosystem


The Research and Translation Hub:
a flagship and a UK first

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Thank you!

www.imperial.ac.uk/aerialrobotics

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