Experimentally guided dynamic modeling and cross-current flight projections of a marine hydrokinetic (MHK) energy-harvesting kite

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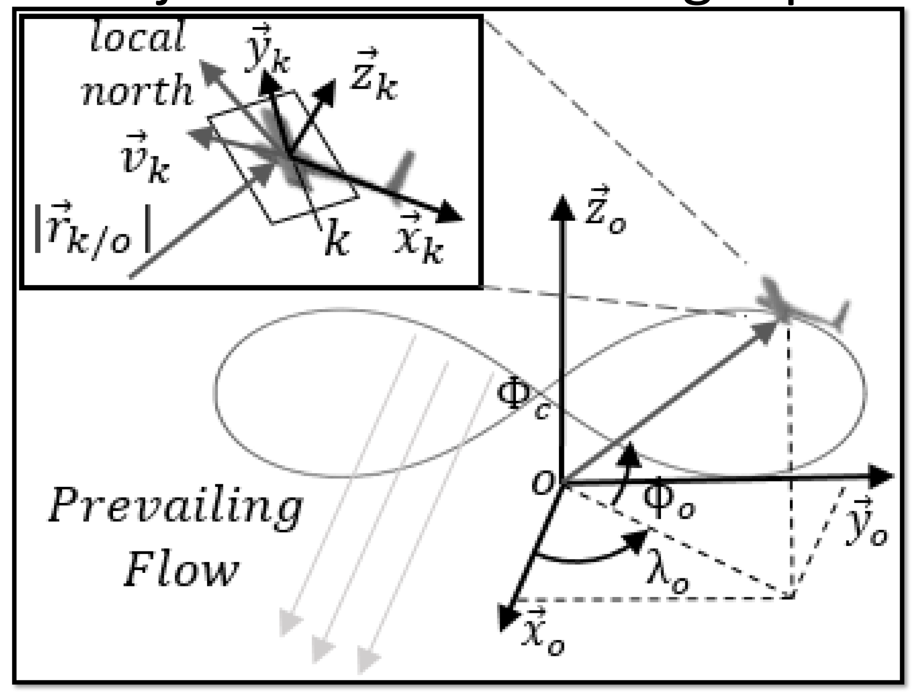
CORE Lab

Objective: Experimentally determine unknown system parameters and refine system dynamic model to project cross-current flight performance for experimental scale MHK kite

Approach:

- Design ***training*** experiments to isolate unknown parameters
- Identify those unknown parameters
- Validate accuracy of parameter identification on separate ***validation*** data
- Project cross-current flight performance



By flying perpendicular to the flow, the well-designed kites can operate at velocities many times that of the prevailing flow.

Power From Kite System :

$$P_k \propto \|\vec{v}_{app}\|^3$$

A little more flow = A *lot* more power

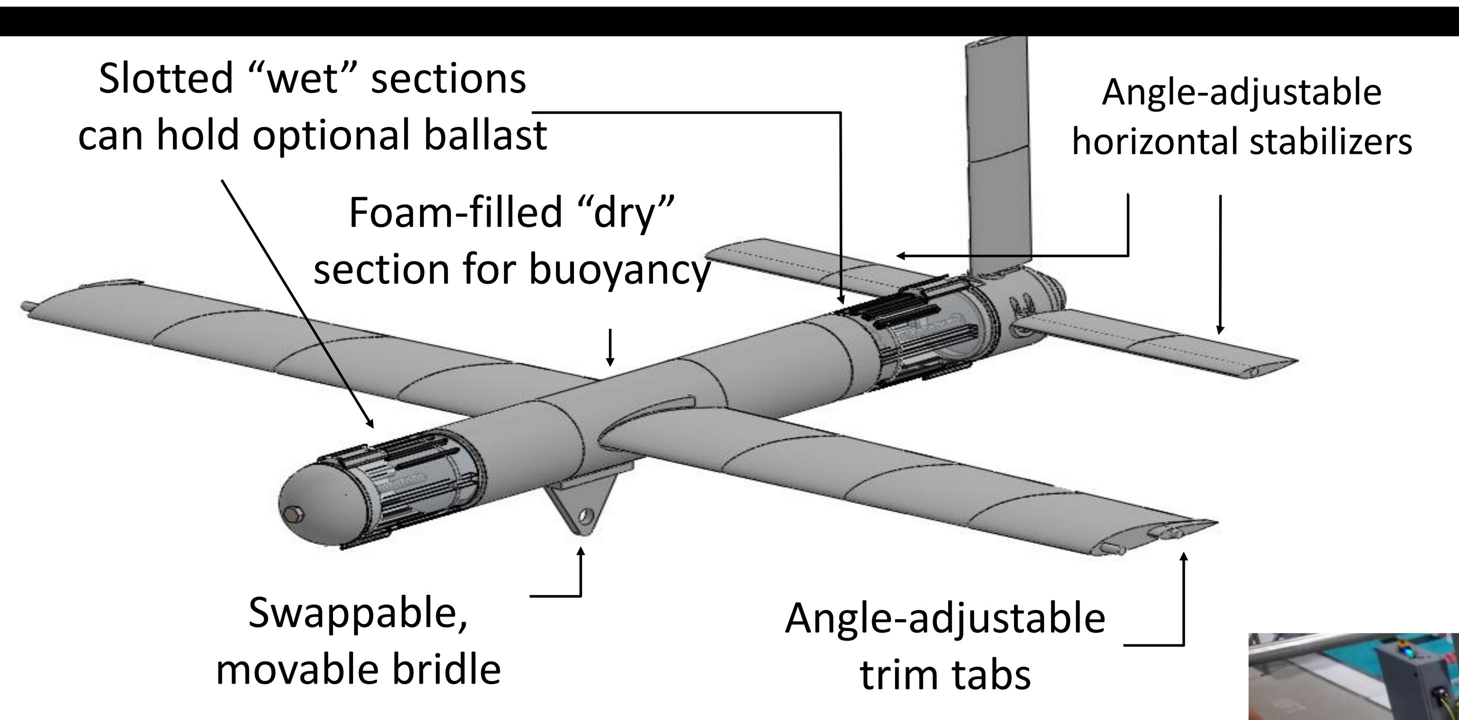
Mechanical System

Ground Station

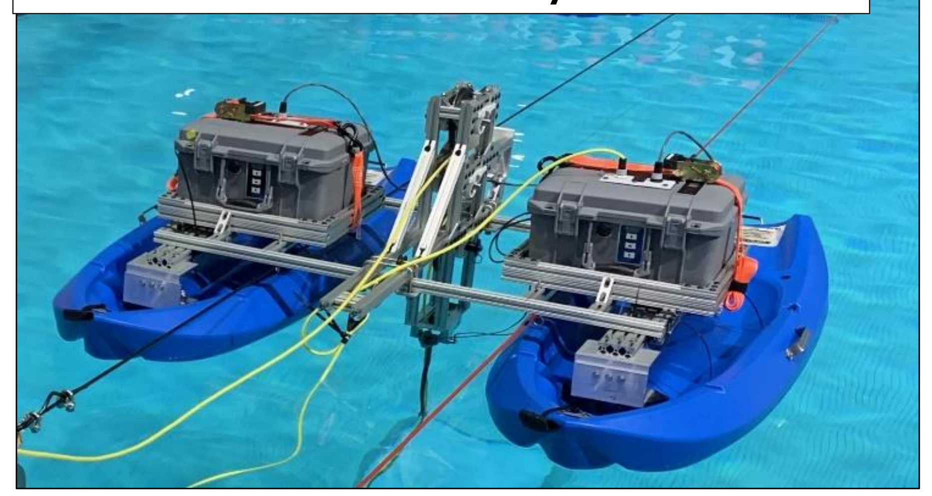
- Catamaran style raft towed across the water by a winch system located on the NCSU pool deck.

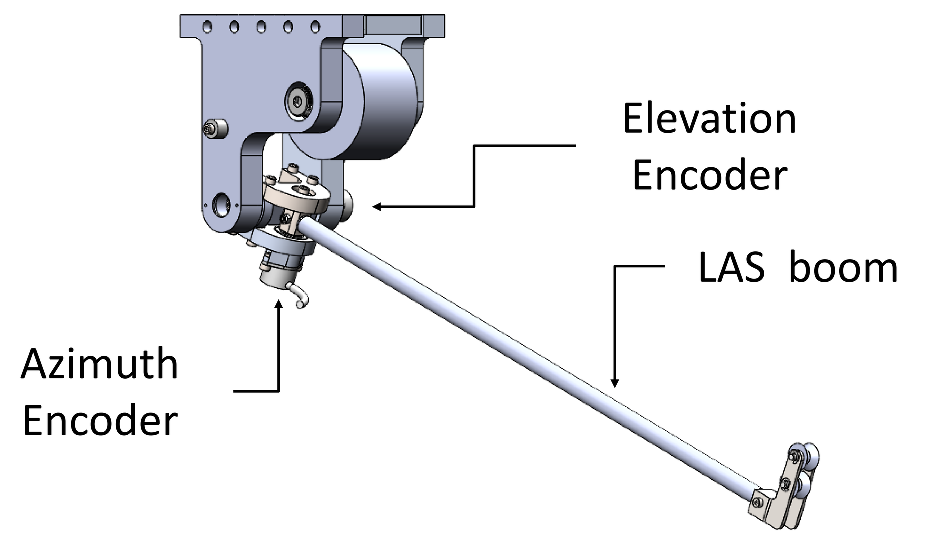
Test Articles

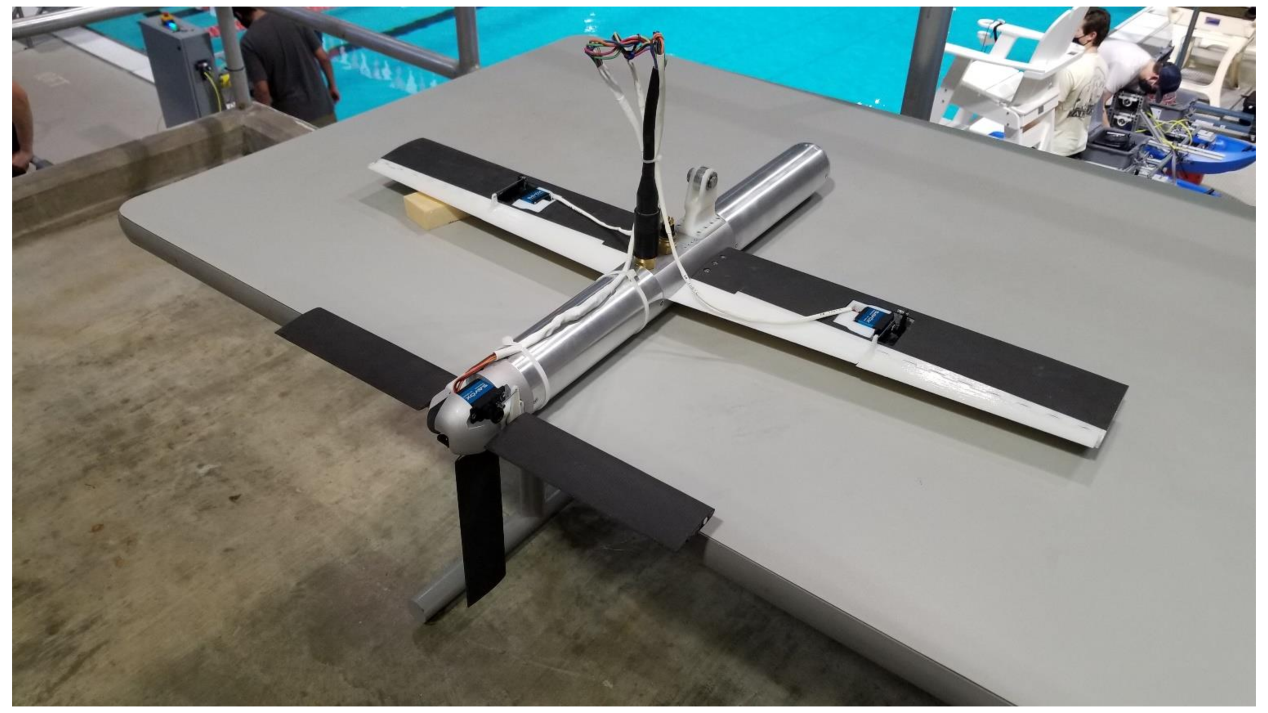
- 3D printed trimmable kite with approximately 98% buoyancy
- Custom fabricated line angle sensor (LAS) use to measure the tether angle at the raft
- Blue Robotics Fathom tether – 7.6mm diameter and neutrally buoyant
- Controllable kite with onboard electronics and independent aileron, elevator, and rudder control



Catamaran – Style Raft





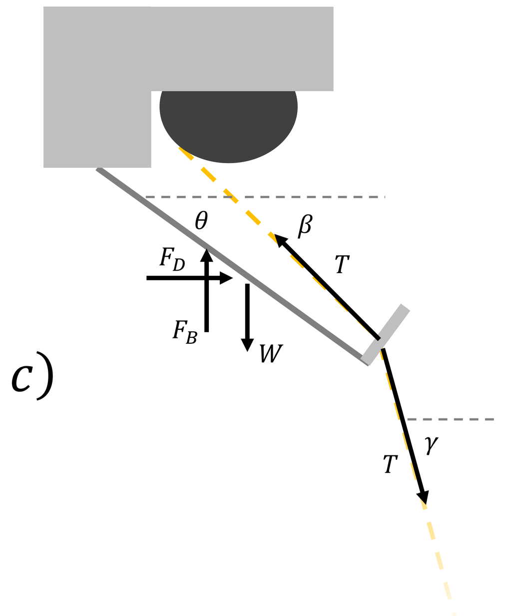


Line Angle Sensor and Tether Drag

- Line angle sensor towed through the water with no test article attached. Sensor inclination angle (elevation) is a function of tow speed and the line angle sensor coefficient of drag.
- Tether drag estimated by towing a cylindrical stainless-steel weight through the water.
- Cylindrical weight is a well characterized drag body giving a test article with a known L/D relationship.
- Iteratively solve the static moment balance acting on the line angle sensor to determine the tether coefficient of drag.

g = acceleration due to gravity
m = LAS boom mass
x_{cg} = LAS boom cg axial location
x_{cb} = LAS boom center of buoyancy axial location
ρ = fluid density
V_{LAS} = LAS boom displaced volume
θ = LAS inclination angle
V_∞ = tow velocity
l = LAS boom length
c = distance from the end of the LAS boom to the elevation pivot

$$C_{D_{LAS}} = \frac{2g\left(mx_{cg} - \rho V_{LAS} x_{cb}\right)\cos(\theta)}{\rho V_\infty^2 A\left(\frac{l}{2} + c\right)\sin^2(\theta)}$$



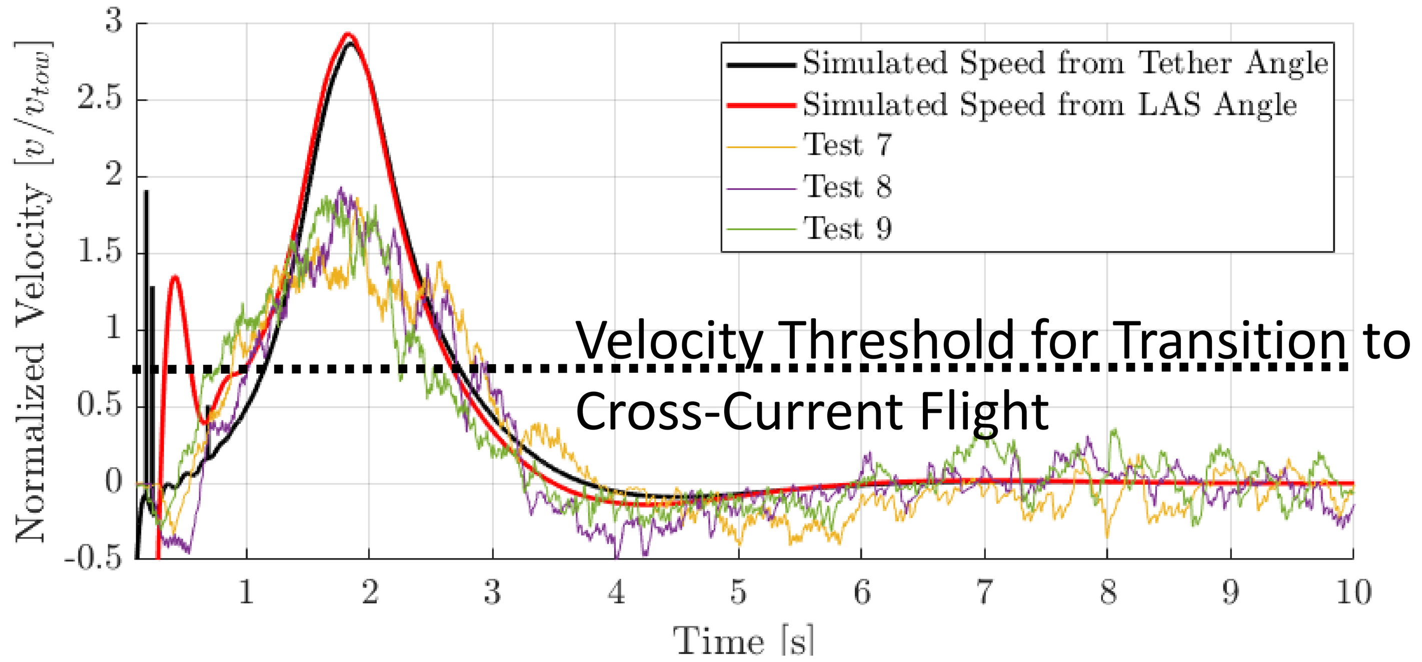
$$0 = -F_D\sin(\theta)\left(\frac{l}{2} + c\right) + T(\sin(\gamma - \theta) - \sin(\beta - \theta))(l + c)$$
$$-g\cos(\theta)(V_{las}\rho x_{cb} - mx_{cg})$$
$$T, \gamma = f(C_{D_{tether}}, V_\infty)$$

Cross Current Flight Initiation

Objective: Achieve sufficient speed during kite acceleration to transition into cross current flight.

Approach: Use launch frame to initiate test run at end of step 1, and record step 2.

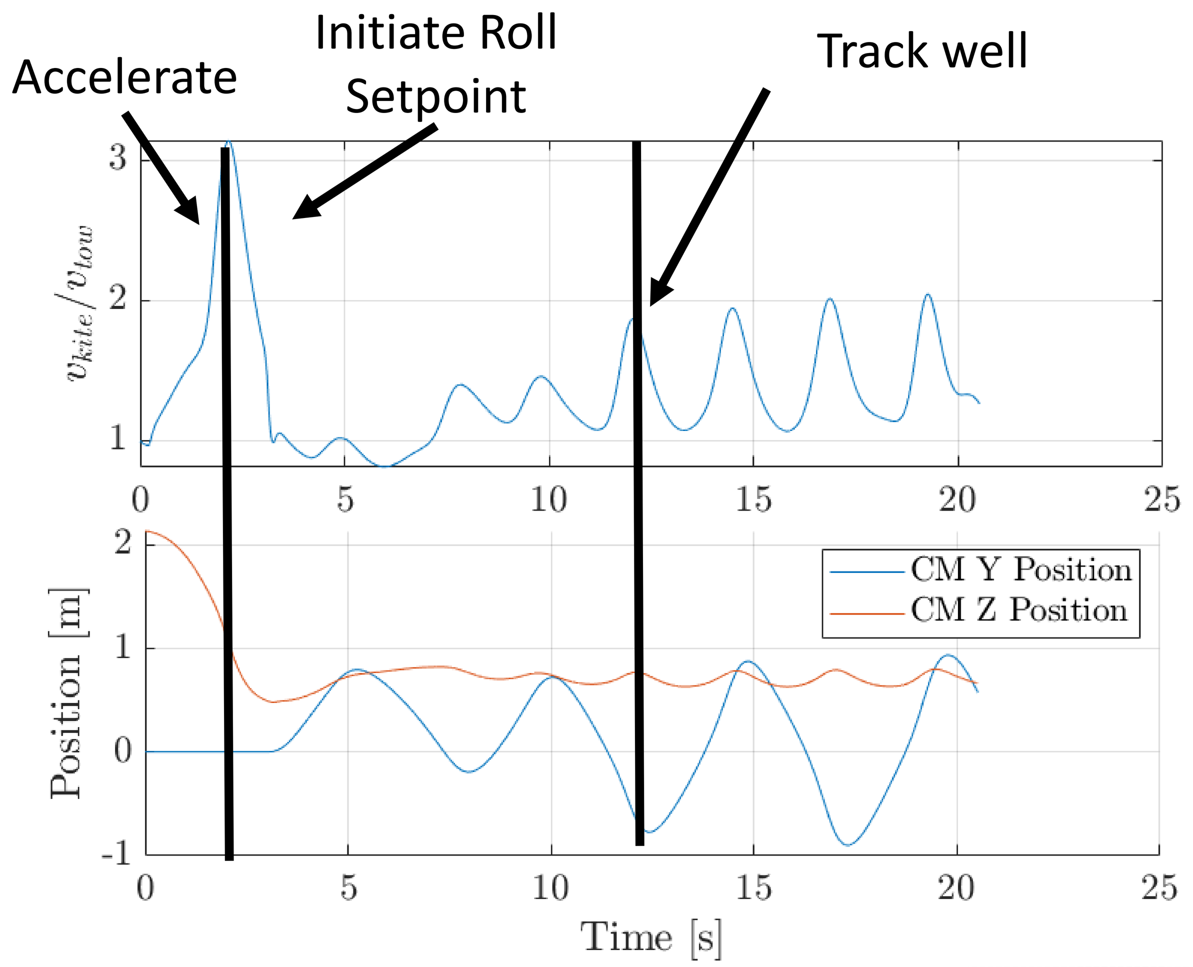
Maneuver to a shallow elevation by trimming to a low L/D configuration → Exercise the elevator to increase L/D, gaining momentum and increasing elevation angle → Exercise ailerons to steer onto the path and initiate cross current flight



Cross Current Flight Projections

Objective: Using refined dynamic model, project cross current flight performance of the MHK kite under a sinusoidal roll setpoint

Experimental kite projected to achieve a peak velocity augmentation of ~2X in the NCSU pool and a peak tether tension of 125 N under cross current flight,



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Citations

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[2] J. Reed, M. Cobb, J. Daniels, A. Siddiqui, M. Muglia, and C. Vermillion, "Hierarchical control design and performance assessment of an ocean kite in a turbulent flow environment," IFAC-PapersOnLine, vol. 53, no. 2, pp. 12 726–12 732, 2020.
[3] D. J. Olinger and Y. Wang, "Hydrokinetic energy harvesting using tethered undersea kites," Journal of Renewable and Sustainable Energy, vol. 7, no. 4, p. 043114, 2015.