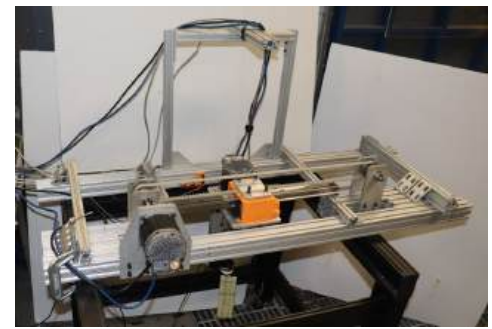
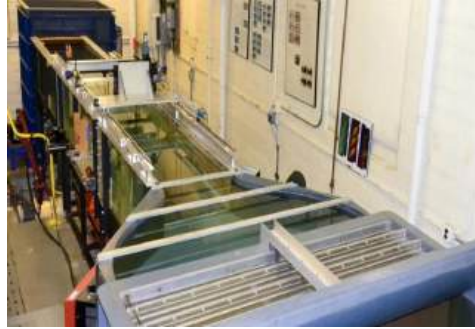
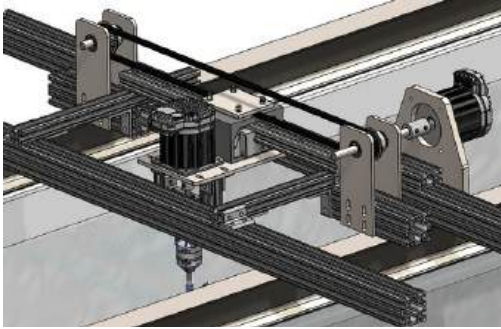


PITCH AND HEAVE SETUP FOR BIO-PROPULSION STUDIES



What?

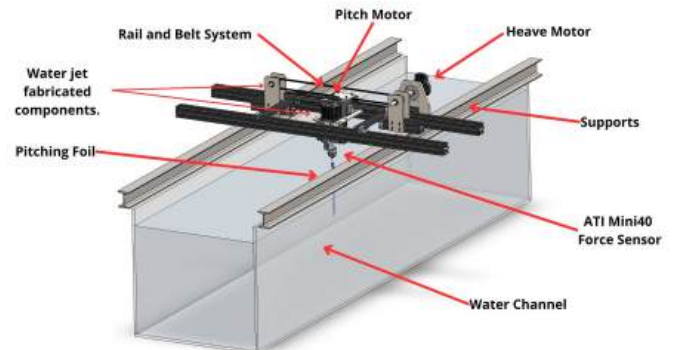
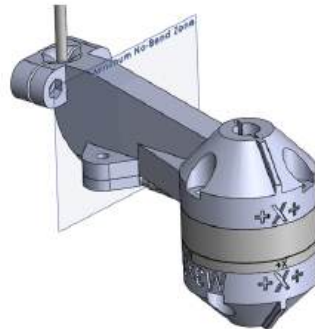
- Design a setup to mimic robotic swimmers, leading investigations into their hydrodynamic performance and development of quiet underwater vehicles, a part of a \$7.5M U.S. DOD-funded MURI project.

How?

- Designed and built the setup using SOLIDWORKS, CNC, waterjet cutting, and 3D printing.
- Applied GD&T to all drawings.
- Integrated systems such as PIV system, 6-axis force sensor, NI DAQ data acquisition card, high-torque motors.

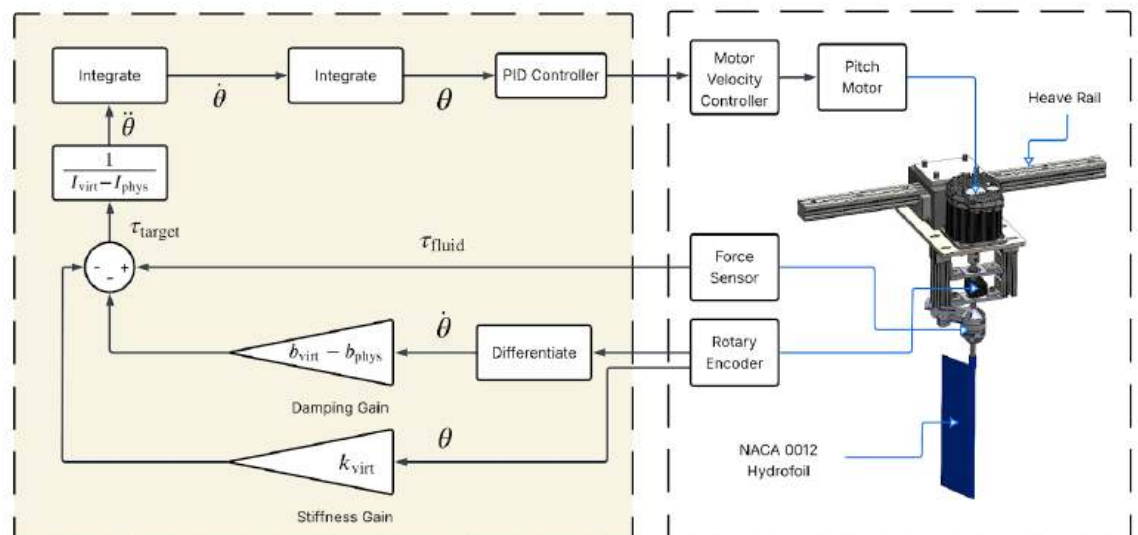
Results

- Gathered and analyzed 35 data sets using MATLAB and NI DAQ for tests.
- Improved movement accuracy to 98.2%, a 1.75x increase over previous designs.
- Reduced operational noise by 32% through optimized control systems.



Cyber System

Physical System



CARBON FIBER SUSPENSION SYSTEM FOR FORMULA SAE



What?

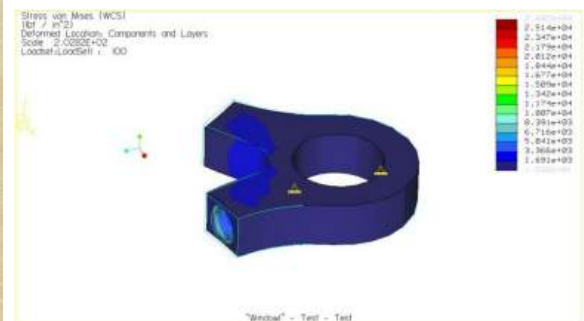
- Designed and manufactured a carbon fiber-aluminum hybrid suspension control arm for a Formula SAE vehicle.
- Replaced steel members to reduce mass while maintaining required load capacity.

How?

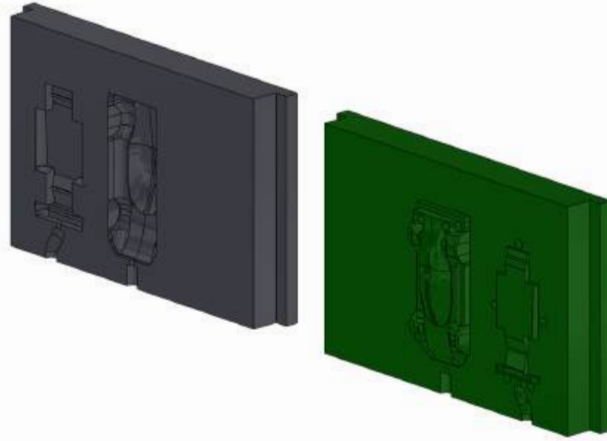
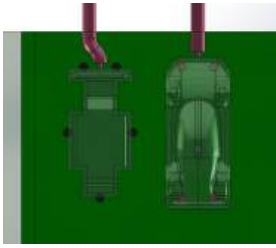
- Modeled geometry in SolidWorks and conducted FEA to evaluate stress and deflection under braking and cornering loads.
- Machined aluminum end joints and bonded them to carbon fiber tubes using structural epoxy.

Results

- Reduced component mass compared to steel baseline.
- Measured strain and load response were consistent with FEA predictions.
- Component sustained expected loads without material failure or joint separation.



RACE CAR INJECTION MOLDING PROJECT



What?

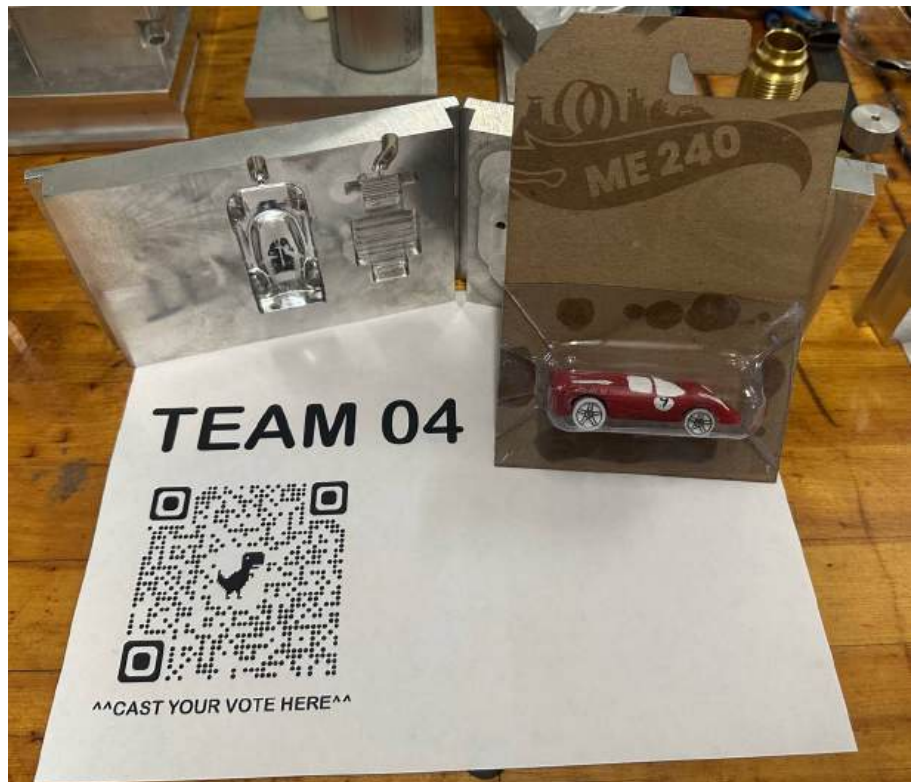
- Designed and manufactured a two-part aluminum injection mold for a race car body component.
- Developed a complete molding workflow including part design, gating, and runner system.

How?

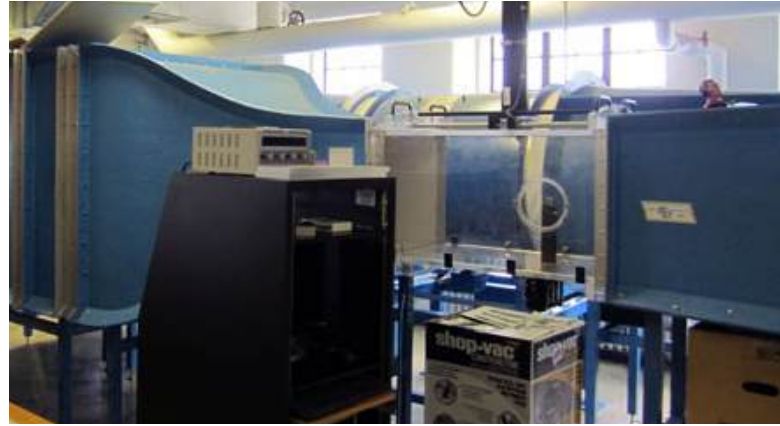
- Modeled part and mold assembly in SolidWorks.
- Fabricated mold using CNC machining and waterjet cutting.
- Applied GD&T to ensure dimensional accuracy and proper part ejection.
- Conducted molding trials and evaluated part quality and repeatability.

Results

- Successfully produced molded race car components with consistent geometry and surface finish.
- Achieved proper mold alignment and clean part release.
- Validated manufacturability through multiple successful production cycles.



WIND TUNNEL DRONE TESTING - AEROTARGETS INTERNATIONAL



What?

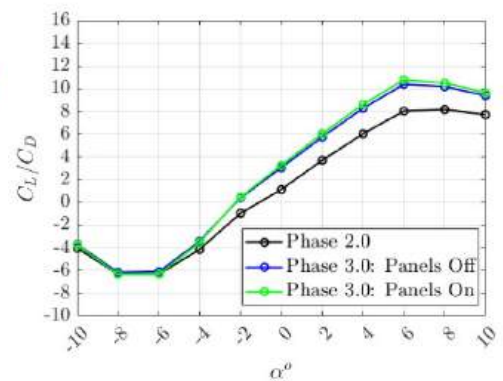
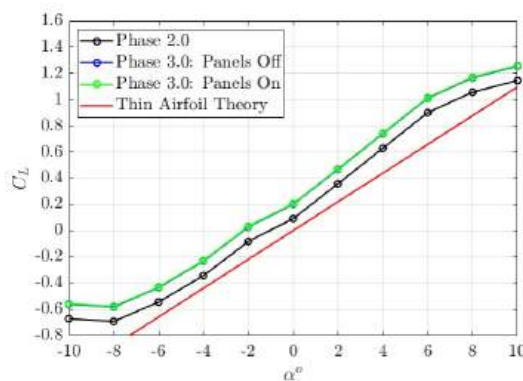
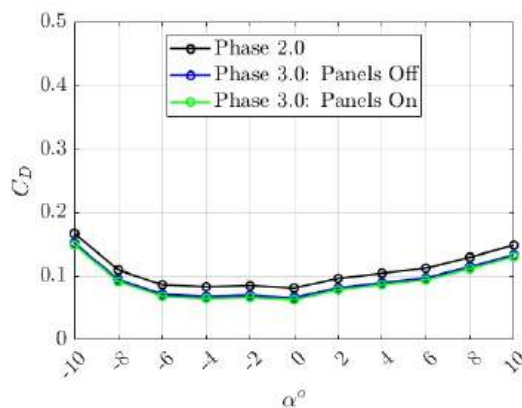
- Scaled down a military-use drone to perform tests in a wind tunnel to evaluate performance characteristics.
- Split experiment into 3 phases focusing on (1) preliminary aerodynamic stability studies, (2) a scaled up model at a higher Re used for extensive drag tests with panels off and (3) with panels on.

How?

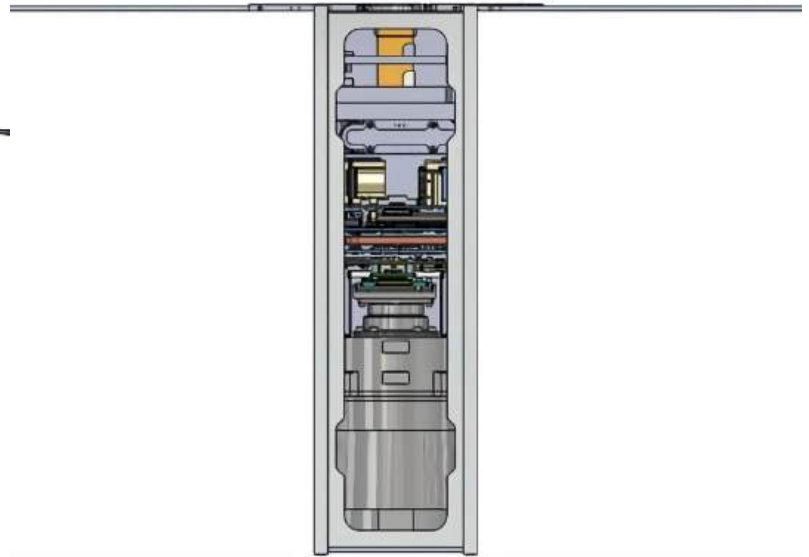
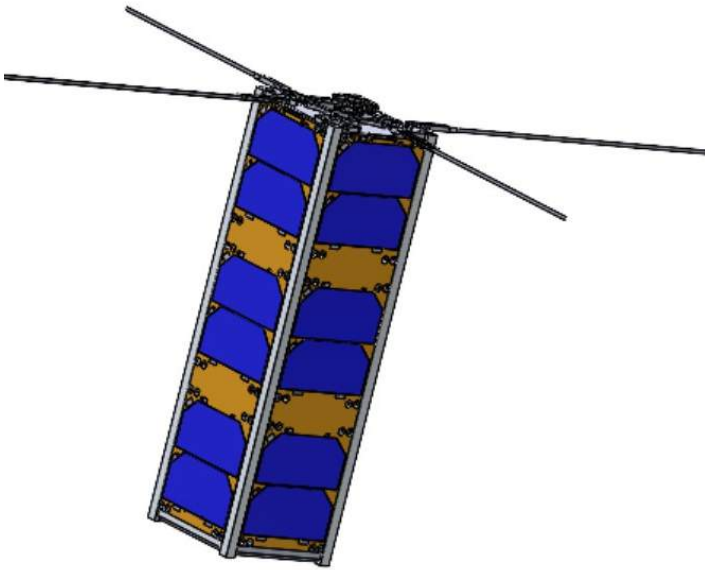
- Build a 4-bar linkage structure that allows change to all angles needed.
- Used SolidWorks to scale down and alter model for compatibility with force sensor / wind tunnel.
- Utilized an NI DAQ card and MATLAB to acquire and process data.

Results

- Phase 1 revealed that the model is dynamically stable in both pitch and roll motions around its CG and weakly stable in yaw.
- Phase 2 and 3 showed a lower drag coefficient, increasing its L/D ratio.
- Communicated with AeroTargets engineers to recommend fuselage design modifications, achieving a 10% drag reduction.



OSPREY CUBESAT - LEHIGH UNIVERSITY'S FIRST NANOSATELLITE



What?

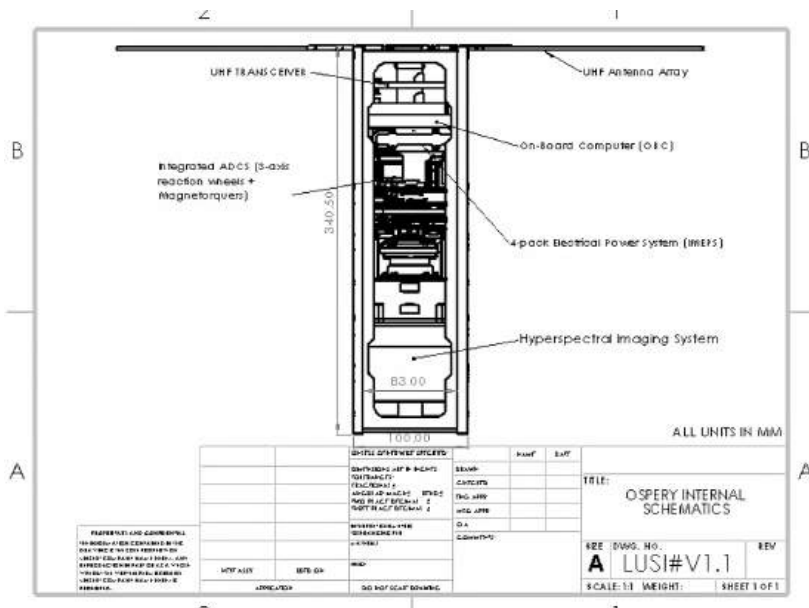
- Designed and led the development of Lehigh University's first CubeSat, OSPREY, a 3U satellite using a VS/SWIR camera system to detect ocean plastic within a 1-square-meter area for ocean trash monitoring.

How?

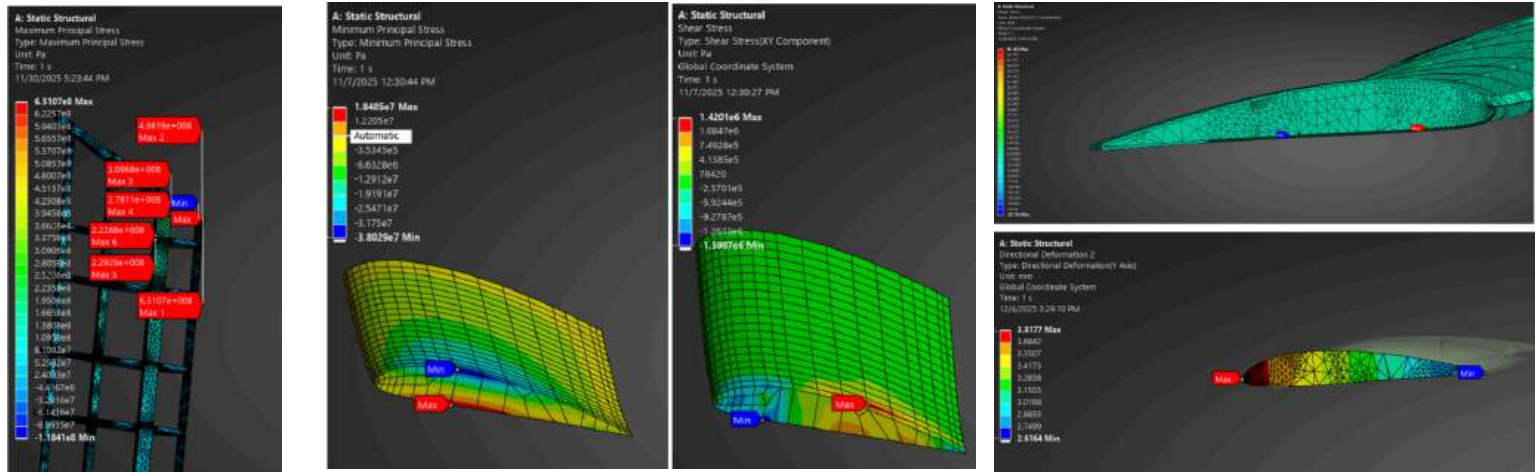
- Lead CAD modelling in SolidWorks, optimizing the center of mass and moments of inertia.
- Used GD&T principles, applied material selection, mass budgeting, to ensure tolerance and compliance with NASA standards.
- Managed a team of 6 students and coordinated with other sub-teams to integrate deployable solar cells and antenna systems

Results

- Raised \$150,000 in funding from Lehigh alumni and sponsors.
- Optimized the mass budget by 23% and increased payload volume by 33%.
- Successfully submitted a proposal for NASA's 2024 CubeSat Student Launch Initiative.



AEROELASTIC WING DESIGN - LEHIGH UNIVERSITY



What?

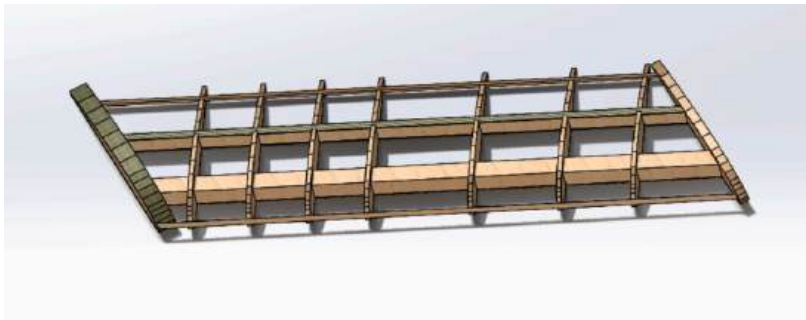
- Designed and analyzed three Gottingen 398 balsa wood wing models (straight, swept-forward, rib & strut).
- Evaluated torsional stiffness, aeroelastic coupling, and divergence speed under a 100 N/m distributed lift load.
- Fabricated rib-strut structure using a laser cutter and reinforced critical regions with carbon fiber epoxy.

How?

- Modeled geometry in SolidWorks.
- Performed structural analysis using ANSYS Workbench FEA to extract deflections and stresses.
- Computed twist, torsional stiffness, shear center, and divergence speed in MATLAB.
- Conducted wind tunnel testing.

Results

- Showed that aggressive weight reduction (to 0.247 N) led to a ~98% stiffness drop, lowering divergence speed to 26.2 m/s.
- Identified the base shear interface as the critical failure location during wind tunnel testing (~90 mph).
- Established quantitative relationship between mass reduction, stiffness penalty, and aeroelastic stability.



SKILLSAT STARTUP



What?

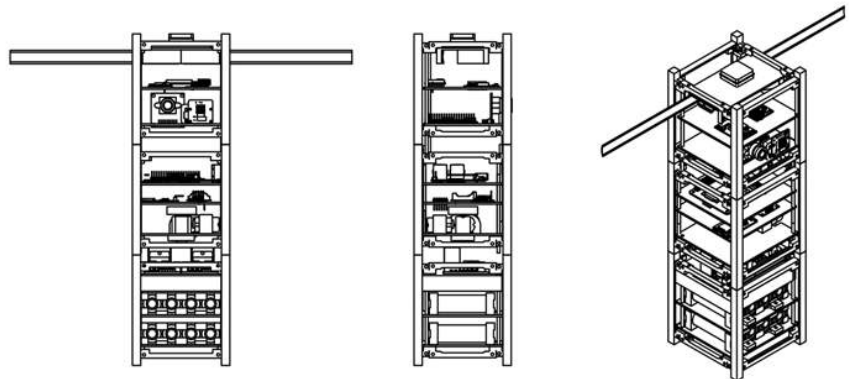
- Founded SkillSat, an EdTech startup to manufacture STEM kits that teach students to build stratospheric satellites.

How?

- Used Arduino and Raspberry Pi as the base for satellite systems.
- Utilized additive manufacturing to prototype 25+ designs.
- Applied DFA and DFM principles to reduce production costs by 44%.
- Tested prototypes at the National Space Center of Kazakhstan.

Results

- Launched satellites to Near Space (40 km+) via stratospheric balloons.
- Raised \$15K in funding and distributed 80+ kits to 240+ students across 25+ schools.
- Recognized as a Top-3 SpaceTech and Top-15 EdTech Startup by Forbes Kazakhstan.





Uncovering the Fluid-Structure Interactions of Wave-Assisted Propulsion via Cyber-Physical Fluid Dynamics



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¹Department of Mechanical Engineering & Mechanics, Lehigh University, Bethlehem, PA 18015

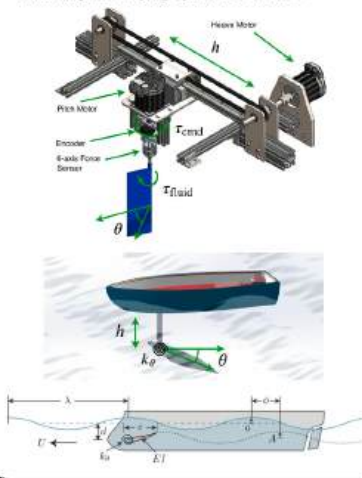
78th Annual Meeting APS DFD
 Nov. 23–25, 2025, Houston, TX

Project Objectives and Goals

- Investigate wave-assisted propulsion (WAP) using controlled heave and passive pitch to transform wave energy into forward thrust and improve stability.
- Develop and validate a cyber-physical testbed that couples a flapping hydrofoil with virtual mass-spring-damper dynamics.
- Implement real-time control of virtual stiffness, damping, and inertia to emulate passive pitching behavior.

Motivation

- Wave-assisted propulsion (WAP) uses oscillating hydrofoils to extract energy from waves and generate forward thrust.
- The flapping motion can also reduce vessel oscillations, improving stability and efficiency in marine systems.
- Studying these fluid-structure interactions (FSI) requires precise control of mass, stiffness, and damping parameters.
- Traditional experiments fix mass, stiffness, and damping through mechanical design, limiting flexibility in studying dynamic behavior.



Methods & Procedures

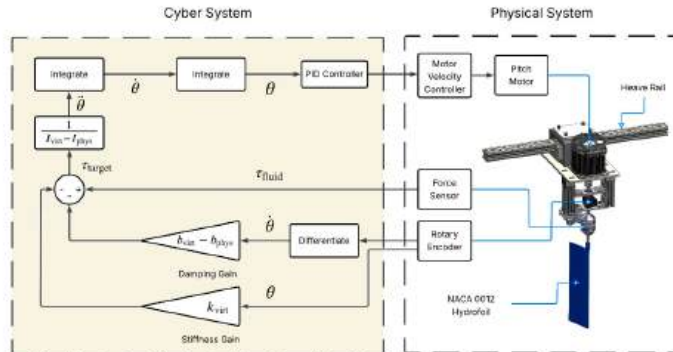
- A cyber-physical system [1] couples the physical actuator-fluid testbed with a computer-based controller that enforces a virtual dynamic model in real time.
- Command signal cancels physical inertia and damping to match desired virtual parameters.
- Physical inertia and damping identified via ring-down experiment.
- Double integration [2] of force/torque removes filtering need and enables stable 4 kHz Simulink Real-Time control loop.

$$\tau = I \ddot{\theta} + b \dot{\theta} + k \theta$$

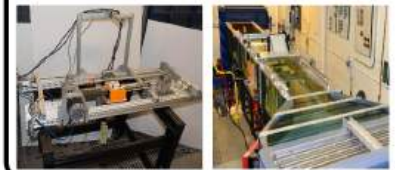
$$\tau_{virt} = - (I_v \ddot{\theta} + b_v \dot{\theta} + k_v \theta)$$

$$I_p \ddot{\theta} = \tau_{fluid} + \tau_{virt}$$

$$(I_p + I_v) \ddot{\theta} + (b_p + b_v) \dot{\theta} + k_v \theta = \tau_{fluid}$$



Experimental Setup



Conclusions

- Developed a working cyber-physical system mimicking passive pitching.
- Any structural parameters can be virtually assigned to the system, including nonlinear stiffness elements and damping characteristics.
- The system accepts real heave motion inputs from naval vessels, enabling experimental investigation and optimization of Wave-Assisted Propulsion (WAP).

Future Studies / Recommendations

- Evaluate propulsion efficiency and stability under varying environmental and structural parameters in the water channel.
- Recreate natural sea-state conditions by coupling heave-wave excitation with vessel motions across multiple degrees of freedom.

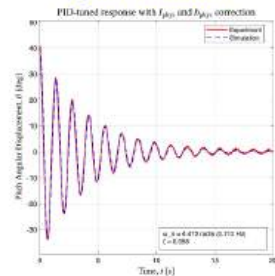
Acknowledgments

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References

- [1] Markowski, A. W., and Williamson, C. H. K., 2011, "Developing a Cyber-Physical Fluid Dynamics Facility for Fluid-Structure Interaction Studies," *J. Fluids Struct.*, 27 (5–6), pp. 748–767.
- [2] Zhu, Y., Su, Y., and Breese, K., 2020, "Nonlinear Flow-Induced Instability of an Elastically Mounted Pitching Wing," *J. Fluid Mech.*, 899, A35.

System Validation



Air Experiment Results

