COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE: **NSF 24-580** 09/18/2024

☐ Special Exception to Deadline Date Policy

FOR NSF USE ONLY — NSF PROPOSAL NUMBER: **2446383**

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.): **TI - SBIR Phase II**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	UEI(Unique Entity Identifier)	FILE LOCATION
08/14/2024	1	15030000 TI	537300	YJLFZE6HR993	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN): **831740686**

SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL: **2213250**

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE: **DYNAMIC LOCOMOTION, INC**

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE: **107 CORONA AVE GROTON,NY 13073-1206 US**

AWARDEE ORGANIZATION CODE (IF KNOWN)

NAME OF PRIMARY PLACE OF PERF: **DYNAMIC LOCOMOTION, INC.**

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE: **107 CORONA AVE GROTON,NY 13073-1206 US**

IS AWARDEE ORGANIZATION (Check All That Apply): ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT: **SBIR Phase II: Low-Cost Autonomous Sailboats for Long-Term Ocean Missions**

SHOW LETTER OF INTENT ID IF APPLICABLE

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 1,249,999	24 months	02/15/2025	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☒ TYPE OF PROPOSAL **SBIR**
- ☒ COLLABORATIVE STATUS **Non-Collaborative**
- ☐ BEGINNING INVESTIGATOR
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES
- ☐ PROPRIETARY & PRIVILEGED INFORMATION
- ☐ HISTORIC PLACES
- ☐ LIVE VERTEBRATE ANIMALS IACUC App. Date ____
- PHS Animal Welfare Assurance Number ____
- ☐ HUMAN SUBJECTS Human Subjects Assurance Number ____ Exemption Subsection ____ or IRB App. Date ____
- ☐ FUNDING OF INT'L BRANCH CAMPUS OF U.S IHE
- ☐ FUNDING OF FOREIGN ORGANIZATION OR FOREIGN INDIVIDUAL
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED ____
- ☐ POTENTIAL LIFE SCIENCES DUAL USE RESEARCH OF CONCERN
- ☐ OFF-CAMPUS OR OFF-SITE RESEARCH
- ☐ POTENTIAL IMPACTS ON TRIBAL NATIONS

PI/PD DEPARTMENT

PI/PD FAX NUMBER

PI/PD POSTAL ADDRESS: **107 Corona Ave Groton,NY 13073 US**

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Jason Cortell	MEng	1997	607-898-2205	jason@dynaloco.com
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent)
By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) is: (1) certifying that statements made herein are true and complete to the best of the individual's knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this proposal. Further, the proposer is hereby providing certifications regarding conflict of interest, flood hazard insurance, responsible and ethical conduct of research, organizational support, and safe and inclusive working environments for off-campus or off-site research, as set forth in the NSF Proposal & Award Policies & Procedures Guide (PAPPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section §1001).

Certification Regarding Conflict of Interest
The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of PAPPG Chapter IX.A.; that, to the best of the individual's knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organization's expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organization's conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in Research.gov.

Certification Regarding Flood Hazard Insurance
Two sections of the National Flood Insurance Act of 1968 (42 U.S.C § 4012a and § 4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the: (1) community in which that area is located participates in the national flood insurance program; and (2) building (and any related equipment) is covered by adequate flood insurance. By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations: (1) for NSF awards for the construction of a building or facility, regardless of the dollar amount of the award; and (2) for other NSF awards when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

Certification Regarding Responsible and Ethical Conduct of Research (RECR)
(This Certification applies to proposals submitted prior to July 31, 2023, and is not applicable to proposals for conferences, symposia, and workshops.)
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Chapter IX.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research. The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

Certification Regarding Responsible and Ethical Conduct of Research (RECR)
(This Certification applies to proposals submitted on or after July 31, 2023, and is not applicable to proposals for conferences, symposia, and workshops.)
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies and Procedures Guide, Chapter IX.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduate students, graduate students, postdoctoral researchers, faculty, and other senior/key personnel who will be supported by NSF to conduct research. As required by Section 7009 of the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act (42 U.S.C 1862o-1), as amended, the training addresses mentor training and mentorship.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

Certification Regarding Organizational Support
By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Dual Use Research of Concern
By electronically signing the certification pages, the Authorized Organizational Representative is certifying that the organization will be or is in compliance with all aspects of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern.

Certification Requirement Specified in the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Section 223(a)(1) (42 USC 6605(a)(1))
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that each individual employed by the organization and identified on the proposal as senior/key personnel has been made aware of the certification requirements identified in the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Section 223(a)(1) (42 U.S.C § 6605(a)(1)).

Certification Regarding Safe and Inclusive Working Environments for Off-Campus or Off-Site Research
(This certification applies only to proposals in which data/information/samples are being collected off-campus or off-site, such as fieldwork and research activities on vessels and aircraft.)
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies and Procedures Guide, Chapter II.E.9, the organization has a plan in place for this proposal regarding safe and inclusive working environments.

Certification Regarding Malign Foreign Talent Recruitment Programs
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with Section 10632 of the CHIPS and Science Act of 2022 (42 U.S.C. 19232), all senior/key personnel associated with the proposal have been made aware of and have complied with their responsibility under that section to certify that they are not a party to a malign foreign talent recruitment program.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Jason Cortell	Electronic Signature	Aug 14 2024 04:42 PM

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
607-898-2205	jason@dynaloco.com	

Not for distribution

NATIONAL SCIENCE FOUNDATION
Program Solicitation/Instruction Guide Number: **NSF 24-580**

SBIR/STTR PHASE II - QUESTIONNAIRE

Phase I Award No. **2213250**		
SBIR/STTR Phase II Topic **R - Robotics**		SBIR/STTR Phase II Subtopic **R3**
AUTHORIZED COMPANY OFFICER INFORMATION		
First Name **Jason**	Middle Initial	Last Name **Cortell**
Job Title		
Email		
Phone Number		

PROPOSING SMALL BUSINESS INFORMATION

Number of Full-time Employees (FTEs) at the Proposing Small Business

7 Current Number Of Employees

2018 Year of Small Business First Operations (YYYY)

5 Average Number Of Employees For Previous 12 Months

2018 Year Small Business Founded (YYYY)

Small Business Corporate Website Address

SBIR/STTR AWARD HISTORY

Number of SBIR/STTR Phase 1 prior submissions by the proposing small business in the past 5 years, excluding this proposal:

1 Phase I full proposal submissions

Number of SBIR/STTR awards received by the proposing small business in the past 5 years

1 Phase I awards

0 Phase II awards

Total number of SBIR/STTR awards received by the proposing small business

1 Phase I awards

0 Phase II awards

Year of first SBIR/STTR award to the proposing small business
2022

AFFILIATED COMPANIES

Affiliated Company Name (Parent, Subsidiary, Predecessor; Up to 4 can be specified)

1.

2.

3.

4.

RESEARCH INSTITUTION INVESTIGATOR (STTR only)

Research Institution (Must be located in the US)

Research Institution Type of Organization

☐ Nonprofit College or University

☐ Domestic Nonprofit Research Organization

☐ Federally Funded R&D Center (FFRDC)

Research Institution Investigator

First Name	Middle Initial	Last Name	Phone Number

OTHER INFORMATION

Check appropriate box(es) if this proposal includes any of the items listed below. Some selections may require additional information.

☒ The proposal contains proprietary information

The following are for statistical purposes only:

☐ This project has been the focus of an Innovation Corps(I-Corps) effort

Type(s) of I-Corps Efforts: (Check all that apply)

☐ NSF-funded National I-Corps program
I-Corps Award Number
☐ The award number is unknown

☐ Local or Regional I-Corps

☐ Other I-Corps

☐ This effort is related to a prior Partnerships for Innovation (PFI) award from NSF
PFI Award Number

☐ This effort is related to a prior Industry-University Cooperative Research Centers (IUCRC) award from NSF
IUCRC Award Number

☐ Other NSF awards contributed to the creation or development of the underlying technical innovation or approach featured in this proposal
NSF Award Numbers: (list up to 3 that are most relevant)

1. ☐ The award number is unknown

2.

3.

SBIR PHASE II - PROPOSAL CERTIFICATION QUESTIONS

THE SMALL BUSINESS CONCERN CERTIFIES THAT:	Y/N
1. It is a small business as defined in the SBIR/STTR policy directive as noted in the solicitation.	Y
2. It qualifies as a socially and economically disadvantaged business as defined in the SBIR/STTR policy directive. (For statistical purposes only)	N
3. It qualifies as a women-owned business as defined in the SBIR/STTR policy directive. (For statistical purposes only)	N
4. NSF is the only funding entity that has received this proposal (or overlapping or equivalent proposal) from the small business concern. If "No", you must disclose any funding entities that have received overlapping or equivalent proposals and awards as required by this solicitation.	Y
5. A minimum of one-half of the research will be performed by this firm in Phase II.	Y
6. The primary employment of the Principal Investigator will be with this firm at the time of the award and will continue to be during the conduct of the research throughout the award period.	Y
7. It will permit the government to disclose the title and technical abstract page, plus the name, address and telephone number of a corporate official, if the proposal does not result in an award, to parties that may be interested in contacting the small business for further information or possible investment.	Y
8. It will comply with the provisions of the Civil Rights Act of 1964 (P.L. 88-352) and the regulations pursuant thereto.	Y
9. It has received Phase II SBIR or STTR awards from the Federal Government. If "Yes" provide a Company Commercialization History as described in the solicitation.	N
10. It is located in a Historically Underutilized Business Zone (HUBZone) as verified by the Small Business Administration (to verify HUBZone participation go to https://maps.certify.sba.gov/hubzone/map#center=39.828200,-98.579500&zoom=5).	Y
11. It agrees to abide by the terms of the solicitation as well as the award terms and conditions.	Y

Company Commercialization History

Data Not Available

Project Summary

Overview

Dynamic Locomotion (dba Dynaloco) is developing SailVane, a small, low-cost autonomous robotic sailboat for *in-situ* oceanic data collection. Though small, the vessel is robust enough for a harsh ocean environment, built to withstand unexpected collisions, capsizing, and biofouling. Its payload bay is large enough to carry a broad range of sensors, including water quality sensors, weather sensors, modems for data relay from underwater bioacoustics sensors, and fluorometry sensors for detecting hydrocarbons in the water. SailVane will use an innovative new fixed sail arrangement to navigate using minimal power. This innovation will allow SailVane to perform long-term navigation and stay in a user-defined location in the open ocean, making it suitable for oceanic research applications. Its small size enables mass production and low cost, as little as $5,000 each, opening up a myriad of station-keeping roles, long-term missions, and fleet applications that are cost-prohibitive with other Uncrewed Surface Vehicles (USVs) available today.

Key Words: Bioacoustics, climate change, marine life, meteorological data, navigation, ocean monitoring, path planning, robotics, autonomous surface vehicles

Subtopic Name: R3. Robotic Applications

Intellectual Merit

This Small Business Innovation Research Phase II project is focused on developing the SailVane, a 2-meter autonomous sailboat for *in-situ* data collection which is far less expensive than any existing technology. In Phase II, Dynaloco aims to prepare SailVane for commercialization by continuing to demonstrate the worth of this technology through a combination of field testing, computational modeling and simulation. Ocean-based testing will continue to demonstrate the robustness and effectiveness of SailVane. Additionally, the team will develop a novel multi-boat framework to support optimized multi-boat deployment missions. When deployed in a fleet, SailVanes can be used to create a network of sensors to enable large scale data collection on the ocean, providing spatial and temporal monitoring at a much lower cost than ever before. Objectives include: 1) designing for manufacturability and demonstrating navigation ability in harsh ocean environment with refined navigation algorithms 2) building out multi-boat software capabilities, and 3) developing optimization tool to calculate interplay between sensor use and operational lifetime. Ultimate customers of this technology include government agencies such as NOAA or the DoD, energy companies with a need for off-shore monitoring and oil spill detection capabilities, fishery monitoring organizations, as well as research institutions that use ocean data for studies of climate, weather prediction, pollution monitoring, and marine ecosystem health.

Broader Impacts

Dynaloco's compact, affordable, and low power solution to oceanic monitoring will reduce the cost of oceanic research. Oceanic data collection is pertinent to the operations of many of the sectors that comprise the ocean economy, including fisheries, national defense, offshore oil and gas, dredging, marine transportation, and research and education. Additionally, monitoring changes in the ocean is key to understanding the role of the ocean in the changing climate system. Rising ocean temperatures and current changes are bringing on new weather patterns, and SailVane will enhance understanding and ability to anticipate these new weather events through *in-situ* ocean measurements. Ocean monitoring and surveillance is also key to understanding ocean water quality, identifying contaminants, and devising strategies to prevent future contamination and pollution of the ocean's waters. SailVane will improve the health and welfare of Americans by tracking and helping clean up oil spills, monitoring and protecting fisheries, and performing research to help protect critical marine resources and preserve existing ecosystems.

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For font size and page formatting specifications, see PAPPG section II.B.2.

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Project Description

Part 1 Results of the Phase I Project

1.1 Overview

Dynaloco is developing SailVane, a small, low-cost autonomous robotic sailboat for *in-situ* oceanic data collection that will use an innovative new fixed sail arrangement to navigate using minimal power. This innovation will allow SailVane to perform long-term navigation and stay in a user-defined location in the open ocean, making it suitable for oceanic research applications. When deployed in a fleet, SailVanes can be used to create a network of sensors to enable large scale data collection on the ocean, providing spatial and temporal monitoring at a much lower cost than ever before. Ocean measurements are vital in climate modeling, weather predictions, oil spill monitoring, marine mammal tracking, and other research areas that will only become more vital as our climate changes.

Monitoring changes in the ocean is key to understanding the role of the ocean in the changing climate system. For instance, rising ocean temperatures and current changes are bringing on new weather patterns, yet our understanding and ability to anticipate these new weather events is limited by a lack of *in-situ* ocean measurements. USVs (Uncrewed Surface Vehicles) offer a revolution in ocean data collection, but existing USVs are relatively large and/or expensive compared to what we believe is possible. Just as the advent of small low-cost quadcopters led to a huge diversity of new applications for UAVs (unmanned aerial vehicles), small robotic sailboats (ASVs- Autonomous Surface Vehicles) have a wide range of new uses, from large fleets covering vast areas to specialized long-duration missions and new opportunities for STEM education.

While there are several modern remote sensing systems on the market today, these systems have limitations: satellites cannot sense many quantities of interest from orbit and can be blocked by clouds; freighters mostly travel on ocean highways thus limiting the scope of data collection; manned oceanographic vessels are costly to rent, on the order of tens or hundreds of thousands of dollars; tethered and untethered buoys are expensive to deploy and lack navigational control; and existing robotic Uncrewed Surface Vessels (USVs) cost upwards of $100,000 apiece. As a result, there is still an unmet need for technology to facilitate precise and affordable oceanic data. Our solution is SailVane, a 2-meter autonomous sailboat for *in-situ* data collection which is far less expensive than any existing technology. **SailVane has payload bay large enough to carry a broad range of sensors, including water quality sensors (such as temperature, conductivity, pH, chlorophyll concentration, and dissolved oxygen), weather sensors, modems for data relay from underwater bioacoustics sensors, and fluorometry sensors for detecting hydrocarbons in the water.** The vessel is small and robust, designed for the harsh ocean environment, built to withstand unexpected collisions, capsizing, and biofouling. Customers of this technology include governments, oil spill monitoring and cleanup organizations, fishery monitoring organizations, and research institutions that use ocean data for studies of climate, weather prediction, pollution monitoring, and marine ecosystem health, as well as for maritime domain awareness. In Phase I protypes of the corresponding SailVane hardware and software were tested.

1.2 PHASE I RESULTS: Design and build of an operational SailVane prototype

Prototype testing and construction:

1. **Indoor mini boat tests**. For hull shape design, we started with a fast-testing approach using 3D-printed and sealed boat hulls and keels, about 300 mm long. Then they were placed in a large water tank about 3 m long, 1 m wide, and 1 m deep.

Two types of testing were conducted:

1) A fan-generated wind was applied, and the speed of the boat and general boat performance were recorded. Performance quality included stability of motion and upwind effectiveness.
2) A test setup with precision low-friction pulleys, a fine string, and a falling weight was used to pull the mini boats across the top of the water surface at a constant force. The speed and general boat performance were recorded for the various hull and sail shapes.

2. **Full size quick mechanical prototype.** Next, we built a full-scale test version of SailVane, but only mechanical parts – no electrical steering control. Instead, the sail and air rudder were set

manually to various degrees, and then tested on a windy day in a local lake. Speed and upwind capability looked excellent, but the boat didn't yet have a wind sensor and GPS position/velocity data.

3. **First powered prototype.** Then motors, radio control, GPS, magnetometer, accelerometer, and weather sensors were added for control and data collection.

Figure 1. Initial SailVane prototype

Initial test of quick-constructed powered SailVane.

4. **Robust performance-test prototype.** A more robust, efficient, molded hull was used for an improved prototype SailVane, with better water protection and more reliable electrical wiring. The latest SailVane model has been tested in local lakes in a variety of conditions, from flat water and minimal wind to winds above 10 m/s and choppy lake waves. It is 1.5 meters long, 2.3 meters tall (including the keel and mast) and weighs 25 kg.

Materials: In Phase I, we sought to understand the best hull and sail materials for the proposed design. The initial concept involved HDPE molded shells for both hull and sail, with a thinner outer layer for the sail and a rigid closed-cell foam inside to increase strength and prevent buckling in high winds and large waves. Further effort suggested that the sail at least, and potentially the hull too, would be stronger and more reliable to manufacture using Surlyn ionomer ethylene sheet and foam. In either of these two material options, the goal is to take advantage of the mass production capabilities of a smaller boat with molded and formed plastics, instead of the expensive manual assembly techniques needed for large boats. Furthermore, these polymers in many cases are highly resistant to both weather and biological contamination, compared to most full-size boat materials. They also have extensive ocean testing in buoys and dock protective foam, giving us additional support that the hull and sail will survive well for many months of ocean missions.

1.3 PHASE I RESULTS: Development of client-side and server-side application interface for SailVane

To support communication to and from the SailVane we have completed significant work on the back and front end of the software to facilitate communication. A summary of developed features is below:

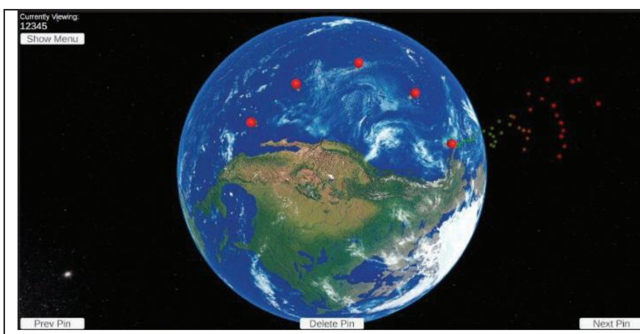

Figure 2. Full global view of the prior movement locations and requested waypoints for the future navigation path, for a particular SailVane (serial number shown) for a user. At least I think that's the display. If the user zooms in, the display will show many more details of the boat path and locations.

Client-side App: The client side application has been developed to an almost feature-complete degree, already in an MVP state. It is able to download the course data of a SailVane from our server based on the user ID to display on a 3D representation of the world. It can also be used to modify or plot new courses that are then uploaded to our server to adjust the control commands sent to the SailVane. Currently this app is designed for PC use, but can be deployed to support smartphones and other handheld devices as well.

Server-side App: On the server side, python was used to create the needed interactions with the client side app. The server stores the data of the SailVanes currently launched, and can relay the data with the PC and phone apps, while also allowing the client to save planned courses for the SailVanes for the server to handle controlling the boats.

Server code: Apart from simply allowing the client to download the SailVane information, the server also handles communication with the Iridium satellite network. Using HTTP Posts, it is able to both send and receive messages from any SailVanes currently deployed on the water. Data from the SailVanes is stored in an online database to keep track of their current location and status, while also saving the planned course for each SailVane. This allows control code to be easily inserted into the server, as it already has the ability to send messages to specific SailVanes.

Website: As part of the above system components, we also set up a web server to communicate between Dynaloco, Iridium satellite communications with the SailVane boats, and with users for navigation requests and received data for them from the boat sensors. The server will be able to host the navigation system that was designed as part of Phase I, the hosting connection will be finalized during Phase II.

1.4 PHASE I RESULTS: Development of a validated computational model which, given the angles of the sails and the current weather conditions, can predict SailVane's velocity.

Our computational model for the SailVane was developed in the Drake[1] simulation library, using the C++ API. Drake, though typically used for simulating rigid body dynamics with frictional contact, has extensively validated tools for numerical integration and optimizations that lend themselves well to efficient computation of controlled electromechanical systems with few degrees of freedom.

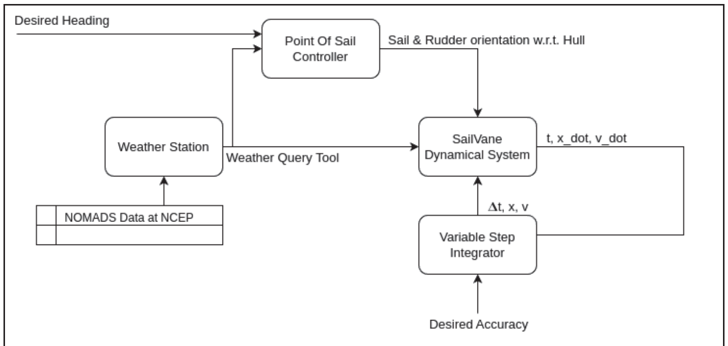

Figure 3. Overview of interconnected systems used with SailVane

The second order ordinary differential equation governing the motion of the sailboat is implemented as a Simulink[2]-like System within a Diagram of interconnected Systems forming the full model of weather, controller, boat, and integrator (below).

Using this framework, we simulated several runs for one week of virtual time or until landfall. A data point is plotted at the current coordinate of each boat for every hour of virtual time. For example, At latitudes 25°N,30°N, 35°N, 40°N each, 1000 starting points are uniformly distributed between longitudes 290°E and 340°E.

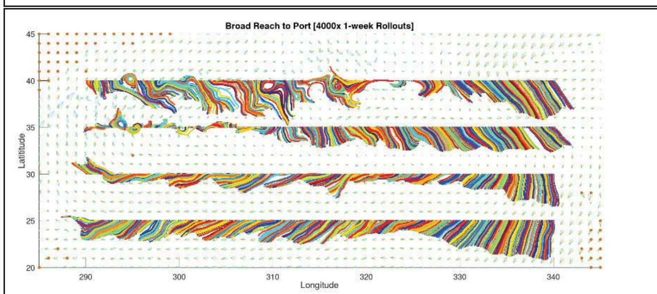

Figure 4. This plot of one-week rollouts shows us a stream plot of the SailVane's at sea trajectory with a fixed command. Plots such as this help us characterize the reachability of certain areas on the map and the complexity of various weather conditions which affects planning time and fidelity.

The SailVane's navigation system uses live weather data, to determine its passively-stable path between updates where it sets it sail and rudder angles. This dense weather data can be additionally augmented with wave and wind sheer data to further hone the dynamical model. From this simulation study we were able to determine following which will be used in future development efforts:

1. The second order ordinary differential equation governing the boat's motion behaved chaotically when operating in a system of ocean winds are currents. A predictive model of a passively-sailed buoy will not be sufficient to reach a destination over long time intervals. This is a statement that goes beyond the unpredictability of changing weather patterns, even under conditions of perfectly known weather, sailboats generally require feedback (and not a precomputed open-loop plan) to behave predictably.
2. More turbulent weather results in more computationally intensive simulation, as spatially noisy weather precludes taking long, low error integration steps.
3. We are ostensibly capable of accessing any coordinate in the addressed Atlantic region (over the July 10-17 study period), so long as it has either non-zero wind or non-zero current.

4. The maximum hull speed of the simulated 1.5 meter-long boat is, as predicted, approximately 1.5 m/s. This maximum hull speed, while not fast, also limits the effect of excessive winds on the boat and allows us to use a significantly smaller sail to propel the craft—reducing lift-induced and frictional drag on the production ASV. (Hull speed can be expressed as a simple mathematical formula 1.34 X the square root of the length of the waterline ($HS = 1.34 \times \sqrt{LWL}$). For instance, if a cruising sailboat has a waterline length of 36 feet, she should be able to sail 1.34 x 6, or approximately eight knots.)

1.5 PHASE I RESULTS: Simulation of SailVane's navigation. Predict the navigation performance metrics of the boat.

For navigation, we used an adaptation of the common trajectory optimization approach "Direct Transcription". We modified the approach to permit the number of integration steps between break points to be greater than one and the duration of each time segment is left open as a decision variable of the optimization problem. Direct Transcription[3] comes from the class of Multiple Shooting trajectory optimization problems. Multiple shooting is advantageous to our development because, as has already been demonstrated, we can evaluate the Direct Transcription constraint for each segment of the trajectory concurrently, as their evaluation is not coupled within one optimization update.

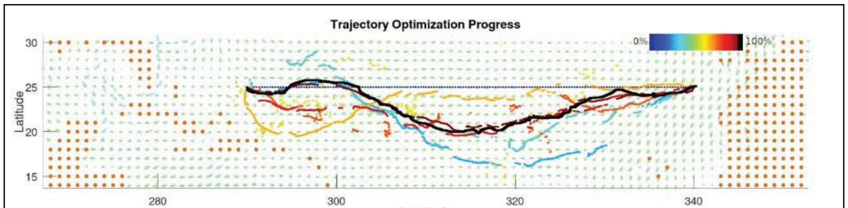

Figure 5. Illustration of wind and current streams overlayed on a map of the North Atlantic, near the east coast of the USA. (red) A target patrol zone. (yellow) Six autonomous SailVane drones at their most-recent GPS locations. (green) One-week rollout of planned heading via dynamic simulation (computable concurrently at approximately 2.5e5:1 real-time. These 6 1-week rollouts were computed concurrently on six threads in approximately 2.4 seconds).

Dynaloco's software makes use of the mathematical program solvers available through MIT's Drake[1] simulation library that implements its multiple shooting problems using the IPOPT[4] library. First, equally spaced (time and spatially) breaks are placed between the requested start and end coordinates, to create a seed *trajectory* of boat coordinates and commands, implemented as first order hold (linear function between time breaks) and zero-order hold (constant value between time breaks) trajectories. The decision variables at each break are: 1) the command that is held constant between breaks, the point of sail; 2) The duration of time until the next time break; 3) the location of the next break. These decision variables are modified through gradient descent until the constraint, the gap between the end of the previous segment--- calculated by simulating the SailVane for the segment duration--- and the start of the next, is reduced to zero. Once the constraint is zero, the resulting trajectory of commands describes the controls that can be used to follow the resulting trajectory of boat coordinates. Trajectory optimization is in Figure 5.

Figure 6. Tracking of SailVane deployment. A marker is shown at 2-second intervals, indicating the boat's coordinates, orientation, instantaneous velocity (yellow), hull orientation (gray), sail orientation (green), wind vane rudder orientation (red), keel orientation (blue). Picture of the SailVane.

1.5 PHASE I RESULTS: Demonstration of SailVane technology in a lake environment

In Phase I we were able to show that we were able to control the boat remotely and have it run autonomously during live deployments on a lake in relatively windy conditions (Figure 6). We were able to navigate the boat to a predetermined location using our navigation algorithms. Mapping against the deployment path also showed that we can successfully deploy and test our control surface designed (airfoil shapes) in simulation and expect our generated control strategies to map into the real platform. Testing in this area is ongoing and will be completed by the end of the project period.

Part 2 Phase II Technical Objectives, Approach and Work Plan

2.1 Objectives

Proposed Phase II technical objectives are as follows:

1. Optimize design of SailVane for manufacturability and robustness; demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data
2. Build out multi-boat software capabilities to manage optimized data collection coverage
3. Develop optimization tool to calculate interplay between sensor use and operational lifetime.

2.2 Objective 1: Optimize design of SailVane for manufacturability and robustness; demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data

Task 1.1: Design and fabricate SailVane for ocean testing based on Phase I learnings, conduct stress testing

Engineers at Dynaloco will use a sequence of ocean-grade prototypes for long-term ocean testing, extending the initial prototype testing of Phase I. Engineers at Dynaloco will design and fabricate two ocean-grade prototypes of SailVane over a period of 6 months. On a materials basis, we will upgrade components to be ocean grade and more robust to the external environment. With the new design, SailVane will have a thermoformed plastic hull and thermoformed plastic sails with a metal substructure for the mast, keel, keel bulb, and boom. The hull of SailVane will be made with ionomers, a class of material known for impact resistance and marine durability. It will have a deep keel (1 meter) with a heavy (≈2 kg) keel bulb, which will allow the boat to recover from capsizing. We will design the boat to specifications that will ensure that these prototypes can survive the forces associated with weather conditions of an 8 on the Beaufort scale. The boat is mechanically simple, with only two external moving parts: the mast rotates relative to the hull, and the air rudder rotates relative to the mast. Both parts will be sealed using twisting bellows or flexible covers, and will have an internal overload slipping clutch to prevent damage in overload situations, like being hit by a large wave. All design changes will also consider design for manufacturability principles. Several sets of testing will be implemented in parallel:

- **Step 1a:** Design and construct at minimum two SailVane prototypes over a period of 4 months, followed over the next 2 months by testing in local lakes and then in the Atlantic Ocean at Shoals Marine Laboratory (more details below). The goal is to measure SailVane performance and extended survival in a variety of weather and wave conditions, starting near a motorized support boat for a day, then if working well, extend up to one month of duration. One SailVane will be directed to a location and then maintain station-keeping mode, attempting to stay close to a single location while collecting weather data. A second SailVane will travel between a set of waypoints, checking its ongoing performance in a variety of weather and current conditions.
- **Step 1b:** Immediately begin long-term testing of biological fouling survival for all the SailVane exposed components, at the Shoals Marine Laboratory or a similar ocean dock facility. These include the ionomer polymer planned as hull and sail material, plus HDPE polyethylene alternative; several potential solar cell units; the keel materials and bulb weight; and a variety of sensor and antenna options.
- **Step 1c**: Also, immediately begin initial testing of mechanical design and manufacturing options for components and material samples, to help direct the prototype SailVanes.

After 6 months begins the second set of testing:

- **Step 2a**: Design and construct at minimum two new SailVane prototypes for another 4 months, then ocean tested for 2 months. The design intent for the second set has multiple goals: besides addressing issues identified in the first testing, we will be looking for best modularity and use of a wide variety of sensors, communications, water samples, and more, while also looking for lower cost manufacturing design.

- **Step 2b**: Continue testing of fouling options, and where necessary look for new parts and materials, and/or begin testing a variety of antifouling bio-simulated new coatings commonly employed in this space.[5]
- **Step 2c**: Continue mechanical and fatigue testing of the first prototype SailVane construction to help optimize the second prototype CAD effort, followed by testing of the second prototype components and full assembly. The goal is SailVane survival of impacts at a variety of angles in waves of increasing height. The simulation would likely be SailVanes dropped from increasing heights into a large water tank.

Stability Design Considerations: Initial simulations model the keel and sail with blade-element theory (the keel and sail were divided into a 2 or 3 independent pieces) and airfoil data (NACA0015) that included stall and post-stall conditions. The boat was as a rigid object, with resistance against vertical motion and pitching taken as a kinematic constraint (in other words, the water was calm with no waves). Yaw and roll, as well as two components of horizontal velocities and accelerations, were found with 3D dynamics. Forces and moments came from forces on the sail, air-rudder and keel as well as the gravitational righting from the ballast. The boat's design was improved based on this simulation. The resulting boat has a deep and narrow keel, a heavy ballast, and a short sail. This yields a boat that is unusually stable in roll. The simulations verify our hand calculations and intuitions that this design is directionally stable for headings of more than 45 degrees from the wind, and less than 150 degrees. For each of these allowed headings, there is an appropriate sail and air-rudder angles to maximize speed. Once these angles are set, the boat finds its correct heading, no matter what its initial orientation. When optimizing for maximum navigable wind speed, we may decrease the size of the sails.

Robustness Design considerations: The hull will be constructed out of ionomers, which is known for UV and chemical resistance, its ability to withstand impact, and overall durability. This is a major upgrade from our Phase I design which used fiberglass and foam. This material is commonly used by the Navy for the construction of ocean-going equipment. During the vessel construction phase, we will conduct a series of preliminary stress tests to preliminarily validate the seaworthiness of the hull, mast, and air rudder. Conducting these tests is standard in the ship manufacturing process, and is designed to assess a materials ability to withstand dynamic ocean forces. All tests conducted will follow guidelines published American Society for Testing and Materials (ASTM) or International Organization for Standardization (ISO) as relevant. Key tests of interest in include impact, tensile strength, and buoyancy.

Design for manufacturability:

- There are ways to manufacture a smaller boat under two meter that allow it to be mass produced
- Can use lighter less expensive and more flexible materials

Aside from durability benefits, the use of Ionomers will also streamline our manufacturing process as Ionomers can be easily molded and processed. This can be beneficial in creating hydrodynamic hull designs that improve the boat's performance in the water. The material is also significantly lighter and more flexible.

Task 1.2: Conduct performance testing on the Atlantic Ocean

In phase I, we were able to test our prototype vessel and software on a local lake where we demonstrated that our hardware is waterproof and that our models are accurate in moderate wind and low wave conditions. In Phase II, we aim to continue to show the robustness of our technology though ocean-based testing. Here, we will make two 1-week trips to the Shoals Marine Lab off the coast of Maine to test our prototypes in the Atlantic Ocean while also gathering additional data for our models. Specifically, we are interested in the temporal and spatial distributions of wind, current and waves.

Pilot tests and Data collection:

During these two weeks, we will test our computational models with the following general test procedure:

1. Record the current weather conditions with SailVane's instruments and off-board 'ground truth' instruments
2. Manually (using radio control or satellite communication) set the sails to the test angles

3. Begin continuously (>1 Hz) logging SailVane's position and heading for the duration of the test (>30 min)

This procedure will be done using a crewed chase boat (for early tests) or remotely from shore (for later tests). After each day of testing, we will collect and analyze the logged position data and use it to adjust the parameters of our 2D computational model of the boat so that our computational model matches our observed data.

Station-keeping mission: After these supervised tests at Shoals, to increase the range of weather we encounter during testing, we will use the navigation system to direct our two SailVane prototypes to conduct a 1-month long station-keeping mission. During this mission, the SailVanes will station-keep a safe distance from an existing NOAA weather buoy (#44073 – about 7.5 miles off the coast of Maine), which we will use to gather baseline data about the weather that the SailVanes are experiencing. The SailVanes will log their data, and we will set up a script which adjusts the parameters of 2D model based on the weather that the boats are experiencing and their performance in those conditions. After one month, we will instruct them to return to Shoals Marine Lab for pickup (either at a dock, on a sand beach, or by a crewed chase boat <500 feet from shore.)

The Station-keeping mission will be considered as success if the following milestones occur:

- Following a pre-determined error-bound (provided by e.g., the coverage area of the bathymetric scanner) return to the requested station (GPS coordinates) once every N (TBD) hours.
- We will consider success when there are no "two in a row" or greater missed visits over a one week mission. This can be readily tested in simulation for any number scenarios and will allow us to verify the capabilities of the station-keeping algorithm before any In Situ missions are deployed.

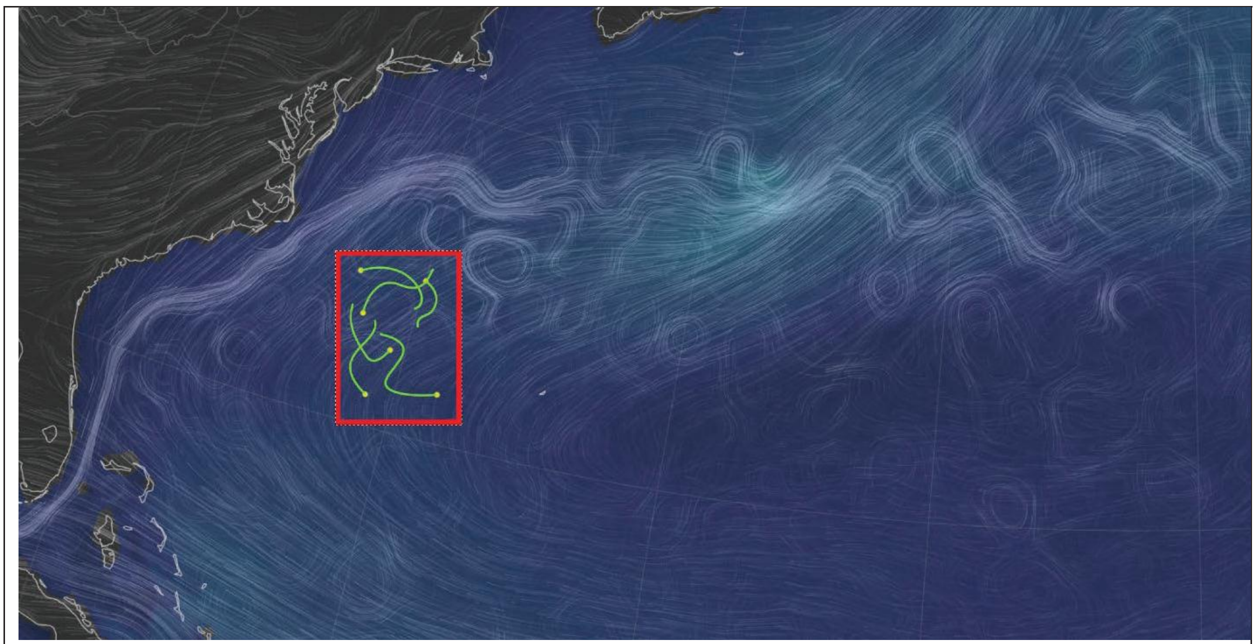

Figure 7. Station keeping zone GUI Example:
Illustration of wind and current streams overlayed on a map of the North Atlantic, near the east coast of the USA. (red) A target patrol zone. (yellow) Six autonomous SailVane drones at their most-recent GPS locations. (green) One-week rollout of planned heading via dynamic simulation (computable concurrently at approximately 2.5e5:1 real-time. These 6 1-week rollouts were computed concurrently on six threads in approximately 2.4 seconds).

Task 1.2: Use ocean deployment data to update navigational model

Given boat parameters, the wind, and a desired course, there is a best trim for the sail and air-rudder, thus yielding a 'polar' (possible speed as a function of direction). These were found by using the preliminary simulation in an optimization loop. In these simulations, which do not account for wash from waves, even a 1 m boat with a deep keel can still sail upwind in a mild hurricane, although not at a big angle nor a high upwind speed (the component of boat's velocity into the wind). Note that for common wind conditions of about 5 m/s or less, typical boat speeds are about 0.5 m/s with an upwind speed of about half of that.

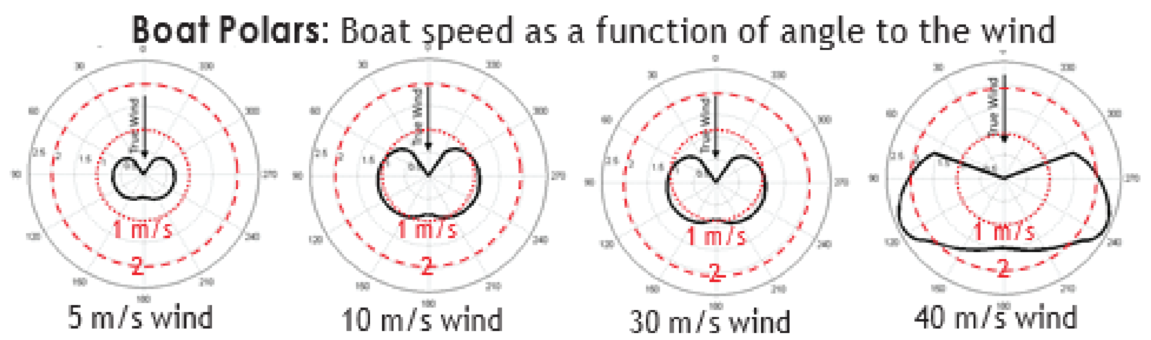

Figure 8. Polars at various wind speeds. Using a 2D quasistatic simulation of SailVane we calculate boat speed (radial component of plot) as a function of the boat's heading relative to the true wind. Each polar is for a different wind speed. According to these simulations, in flat water the boat can make progress into the wind even in a 40 m/s wind (winds of a mild hurricane). This calculation does not include the detrimental effects of surface spray and waves, which we will add to the simulation in Phase I of this project.

Our computational model of SailVane will be a 2D quasistatic model which, given the conditions the boat is experiencing, will calculate the set of all attainable velocities of the boat relative to the surrounding water. This set of velocities is known as a 'velocity polar', examples of which are shown in Figure 8. This 2D quasistatic computational model will be supplemented with a 3D dynamic numerical simulation of the boat, which uses airfoil "coordinates" (lift and drag coefficients at various angles of attack) for the sail, rudder, and keel control surfaces (e.g., UIUC Airfoil Data Site[6]) to generate a time-resolved dynamic simulation of the boat. The 3D dynamic model will incorporate the effect of waves, current, and weather, including the spatial gradients in wind and water speed near the water's surface. The 3D dynamic model will help us identify and avoid any dynamic instabilities or oscillations in the boat's motion. We will use computational fluid dynamics simulations, lift and drag style models, and real-world drag experiments to find the lift and drag coefficients of the keel, hull, sails, and any other components that are exposed to the wind and water. The time-averaged results of the 3D model should match the results of the 2D model. If the 2D quasistatic model does not match the time-averaged values of the 3D model, we will adjust the parameters of the 2D model until they do.

Objective 1 Milestones:

1. Complete fabrication of two identical SailVane prototypes designed for withstanding ocean environment

2. Demonstrate agreement between the 2D quasistatic model and time averages of the 3D dynamic models of at least +/- 20% in conditions up to an 8 on the Beaufort scale ("gale" conditions).

3. Have both SailVane prototypes survive in any conditions they experience during testing in the Atlantic Ocean (up to an 8 on the Beaufort scale).

4. Demonstrate that our model-generated polars are accurate within +/- 20% for more than 80% of the time duration of the tests.

5. Boat and all sensor components retain performance after station keeping mission and exposure to harsh ocean environment

2.3 Objective 2: Build out multi-boat software capabilities

As a small, low-cost vessel, SailVanes are well suited for multi-boat deployment missions, which will allow the user to capture data over a given region and time-frame. Akin to "drone swarm" technology, SailVane's multi-boat capability will unlock new potential for data collection in the ocean, by completing a variety of tasks in parallel without human intervention. Here, we propose to develop a novel multi-boat framework to support optimized multi-boat deployments for a given mission. Software capabilities will include calculating the number of boats needed to capture a desired temporal and spatial density for a given mission, optimizing based on weather conditions, and optimized reconfiguration in the event that a boat is lost or loses function.

Task 2.1 Develop optimized boat coverage model

When deploying SailVane in a fleet, it is important to ensure that a given area of interest has sufficient coverage during the data collection period. Given the chaotic nature of the ocean, and the several variables at play in ocean dynamics, there is significant risk of the SailVanes deployment path to be disrupted due to the effects of dispersion. To minimize data collection interruptions, we plan to develop an optimized boat coverage model to predict boat patterns and implement course corrections to maintain data coverage.

To accomplish this, we will leverage prior research on dispersion in the ocean,[7-9] and will adapt the finite-time Lyapunov exponent (FLTE) method for the SailVane use case. The FLTE method offers significant visualization capabilities which we can use to understand boat behavior and subsequently issue course corrections as needed. In practice, the model will be developed to provide a new input every six hours (minimizing on board power requirements), with each solution output providing a new set of headings designed to minimize the problem of uncovered area. Two methods will be tested for solving the coverage problem 1) a sampling-based strategy that involves choosing from a set of corrections until a minimum is determined, and 2) an evaluation of objective function and gradient descent subject to our decision variables of sail and rudder angle for each boat; methods will be evaluated for their computational intensity and accuracy.

The model will be built in Dynaloco's Simulink-like environment in C++; this graphical programming environment is well suited for modeling and simulating dynamic multidomain systems as well as supporting numerical integration. This is critical as it will enable high accuracy as we integrate the second order ordinary differential equations of the sailboat model over time and will enable fast simulations. Further, once the boat remains stable, we can take very large time steps using implicit integration tools and methods minimizing the computational load required. This is a major advantage over off the shelf methods such as explicit Euler integration software, which would preclude variable time steps requiring millions of computations per day of integration (versus just one with our proposed approach).

Task 2.2 Build reconfiguration optimization tool:

Building on the foundation of our optimized boat coverage model, we also seek to implement a boat reconfiguration optimization tool designed to mitigate the issue of a lost boat. In the event that a member of the fleet is lost, we need to be able to efficiently reconfigure the remaining group to maximize coverage for the mission. To build this capability, we propose to adapt existing swarm optimization techniques focused on coverage path planning[10] to the SailVane use case. While significant research on swarm optimization has been done in drones, the coverage problem in USV fleet deployments remains a key problem. These algorithms are focused on covering areas efficiently while also minimizing the time needed to get into the correct configuration. Here, we will test our algorithm performance in a simulated case when one boat's coverage area drops to zero. We aim to show that the coverage is maintained as a result of the model adjustments to the boat headings and that 50% confidence is maintained within the given area and that there are no gaps between passing boats. This will ensure that the tracts of the individual boats register amongst each other to enable full coverage. Ultimately, the degree of registration between boat sensor scans will affect the resolution of the output, with deeper sea features requiring higher levels of registration for acceptable levels of resolution.

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Task 2.3 Test software Capabilities in bathymetric scan simulation study

We will validate the proposed coverage and reconfiguration software via a simulated bathymetric scan study where we seek to demonstrate the algorithm's performance and also robustness to variable weather conditions and margins of error. Briefly, a one week mission will be simulated where, at regular intervals, a scan is made of the sea floor. This scan accounts for decreased resolution at steeper scanning angles (due to e.g., acoustic shadows).

At the conclusion of one week, we aim to show that 99% of the scanning area is covered once all scans are localized and registered with each other.

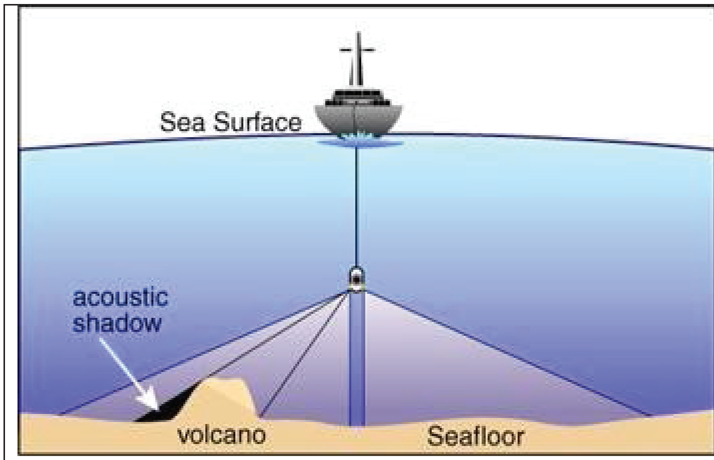

Figure 9. Bathymetric scan depiction showing acoustic shadow

After achieving this initial benchmark, we will perform an ablation study that focuses on evaluating algorithm performance when noise and uncertainty are introduced into scenario in the form of erroneous headings. We will start by testing the effects of introducing a heading that is off by, e.g., 5 degrees and will gradually increase it to see how corresponding accuracy drops. Our goal is to show that our algorithm's performance degrades gradually with input data quality. For example, adding white noise at 5% of the amplitude of the measured wind speed should not result in more than a 5% drop in algorithm performance--- which would demonstrate unstable effects of uncertainty on the algorithm.

Objective 2 Milestones:

- Build optimized boat coverage model and reconfigurations
- Demonstrate 99% scanning coverage in bathymetric scan simulation over a one week period
- Over the open-loop update interval time span (e.g., 6 hours between control updates), demonstrate an accumulated tracking error of no more than, e.g., 30% of the scanning radius.
- Show ability to direct an individual boat to a desired location while following a particular path, and the ability to return to that location at regular intervals as it patrols scan locations.

2.4 Objective 3: Develop optimization tool to calculate interplay between sensor use and operational lifetime.

Here, we aim to develop an optimization tool that allows us to take customer sensor requirements, as well as a planned route and corresponding weather conditions, and calculates out the operational lifetime of a vessel. Variables of interest include a given sensor's energy draw, the expected need for use given data density required (intermittent waking of device to collect data), the vessel's solar panel capacity in the context of other sensor needs (which may take up volume), and the predicted amount of solar energy available given historical and forecasted weather conditions of a given route. Combined these variables will be used in a mixed integer optimization algorithm, which will output a mission's operational lifetime given specific customer requirements.

Task 3.1 Construction of Optimization Tool

For our initial tool we will focus on inputting the power requirements for a total of 10 different sensors. These include our operationally required sensors (GPS, satellite, anemometer) as well as 7 additional sensors that were selected based on our customer discovery. Using these sensors and their corresponding power operational data, we will develop a mixed integer optimization algorithm that considers power draw, power capacity, and recharging rate, in the context of a given data collection mission (considering both density of needed data as well as locational weather patterns). In the context of electrical power production, this is referred to as a unit commitment problem. We will implement constraints of power balance, battery level dynamics, battery capacity, and device operation, with the objective of maximizing operational lifetime of given devices. We will solve the optimization problem using a mixed integer linear programming solver available from Gurobi (Gurobi Parallel Mixed Integer Programming solver). By accommodating both continuous and discrete decision variables, the solver is able to model practical and challenging problems, including resource allocation, scheduling, and network flow.

We will provide a 10% buffer to account for margins of error as well as unexpected weather patterns or other events that may affect input variables. The goals of the tool will be to 1) define operational capacity for a given scenario (this allows us to immediately know if a customer's request is feasible), and 2) optimize navigational routes and sensor use to maximize lifetime of battery and data coverage (to provide the best possible service for the customer).

Sensors of interest	
Sensor	Power draw
Anemometer	0.400 W
GPS	14.5 W
Satellite receiver	30 W
Deep Sea Sonar Detection	1000 W
Passive Acoustic	2.8 W
Active Acoustic	19.0 W
Camera and Wipers	8.0 W
Biological Oceanographic sensors	*16.8 W*
RADAR and LIDAR	*362.5 W*

Task 3.2 Validate optimization tool for an ocean floor mapping use case

To test the optimization model's performance, we will generate eight simulated weeklong ocean floor mapping missions that covers a predefined geographic space in the Atlantic Ocean. This type of mission has relatively high power requirements, allowing us to test the limits of deployment. To understand power availability, we will utilize NOAA's NOMADS historical data for cloud cover and UV intensity; this information will be used to estimate available wattage to power from the solar panel and calculate the available charge rate. We will randomly select eight separate periods of 7 days from 2022 of which to draw weather data from; allowing us to capture the variability of weather conditions. Each mission will have the same number of pulses (when the sensors are on and have a fixed power draw) and will be evaluated for its ability to complete the entire run without a power interruption. In the event that interruptions do occur, we will update our algorithm to account for a larger range of power variability.

As a follow-on to these studies, we also plan to perform ablation studies that will examine how other external factors such as biofouling will affect power requirements. This could be due to biofouling of solar panels (slower charging rate) or biofouling of sensors (greater energy requirement for coverage). We will simulate these changes in requirements and use the results to further refine our algorithms.

Objective 3 Milestones:

- Development of sensor optimization tool
- Validation of tool in 8 week long simulations, in each iteration the correct operational lifetime forecast is given
- Validation of tool in biofouling simulation, gather understanding of potential power use/availability buffers needed to be implemented into algorithm when biofouling is expected to occur.

2.6 Milestones and Deliverables

Performance Schedule								
Objective 1 Quarters	1	2	3	4	5	6	7	8
Task 1 – Fabricate new SailVane design + conduct performance Testing	x	x	x					
Task 2 – Atlantic Ocean testing at Shoals Marine Laboratory				x				
Objective 2								
Task 1 – Build boat coverage and reconfiguration models					x	x		
Task 2 – Test model performance in simulation study						x		
Objective 3								
Task 1 – Develop Sensor optimization Tool							x	x
Task 2 – Test tool in simulation study using historical weather data								x

Broader Impacts

Increasing the economic competitiveness of the United States.

SailVane will increase the economic competitiveness of the United States by providing a low-cost method to facilitate oceanic data collection, an activity that is pertinent to the operations of many of the sectors that comprise the ocean economy, including fisheries, national defense, offshore oil and gas, dredging, marine transportation, and research and education. In 2019, the ocean economy was responsible for generating $665.7 billion in sales, outpacing industries such as agriculture, data process and internet, and utilities.[11] **Critically, much of the economic activity that is derived from the marine environment would not be possible without the sustained collection of data and information.** For example, the US commercial fisheries and the seafood industry, valued at $5.5 billion, benefits from water quality ocean data, which is used to inform effective fisheries management techniques which greatly boosts economic output.[12] SailVane can be used to monitor water quality in fisheries and record the presence of fishing vessels to prevent overfishing and the destruction of marine ecosystems. When used as a weather station, SailVane can provide huge economic benefits. Between 2016 and 2020, NOAA has tracked 81 climate or weather disasters which have cost over $640 billion and claimed 3,969 lives. SailVane can be deployed as a low-cost weather station to track storms and gather atmospheric data which can be used to improve our climate models. These models can help save lives, mitigate disasters, and allow the US to make smarter decisions about weather adaptation and the climate. Similarly, other sectors are likely to benefit from improved access to ocean data which will provide a better understanding of the ocean and its resources, leading to improved safety, economic gains, and more effective regulations.[13] Ultimately, cost-effective oceanic data collection will help sustain and grow the ocean economy.

Advancing of the health and welfare of the American public.

The health of the ocean is directly related to human health. The ocean provides more than 50% of the oxygen we breathe and absorbs 50 times more carbon dioxide than our atmosphere. The ocean is also a source of drinking water and food. However, human activity (i.e., pollution, agricultural runoff), threatens to put ocean water and the marine ecosystems that inhabit it at risk for contamination. Such contaminants can result in waterborne infectious disease, contaminated seafood, toxic algal blooms, and other pollutants that threaten human health.[14] **Thus, to protect human health, ocean monitoring and surveillance (such as that enabled by the SailVane) is key to understanding ocean water quality, identifying contaminants, and devising strategies to prevent future contamination and pollution of the oceans waters.** SailVane can also advance the health and welfare of the American public by tracking and helping clean up oil spills, monitoring and protecting fisheries, and performing research to help us protect critical marine resources and preserve existing ecosystems.

Supporting the national defense of the United States.

USV's (and now ASVs) have been shown to excel at facilitating maritime domain awareness, and can be used to support the national defense of the United States by detecting illicit activities such as illegal fishing and piracy, as well as pollution, such as oil spills or ocean dumping of waste.[15] The US Department of Defense considers maritime domain awareness necessary for "facilitating effective action in the maritime domain and critical to its homeland defense mission."[16] Another possible defense-related use case for SailVane is for conducting surveillance on harbors and ports, which could be targets of attack to due to their economic value and importance to naval operations. SailVane can be used to detect vessels that have disabled AIS and may be conducting illegal activities or pose a threat, thus making it easier to put in place effective defense and policing policies.

Enhancing partnerships between academia and industry in the United States.

SailVane will reduce the cost of oceanic research, and will therefore open up a broad range of new research possibilities for nonprofit research institutions. SailVane will meet the academic need for lower-cost tools for gathering oceanic data and will help connect academia to industry by launching a new generation of low-cost ASVs. Reflecting our commitment to this cause, we plan to offer SailVane at discounted price to this customer segment and our focusing on this group for our early stage pilots in Phase II.

Part 4 Consultants and Subawards

Not applicable.

Part 5 Equivalent or Overlapping Proposals to Other Federal Agency

NONE

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5. Unmanned Surface Vehicle Market by Type (Remotely Operated, Autonomous), System (Propulsion, Payload, Component, Software, Chassis Material, Communication), Application, Hull Type, Endurance, Size, Cruising Speed, and Region - Global Forecast to 2026. Markets and Markets, 2021. (Accessed December 17, 2021, at https://www.marketsandmarkets.com/Market-Reports/unmanned-surface-vehicle-market-220162588.html.)

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Read more: https://www.digitaljournal.com/pr/unmanned-surface-vehicles-market-worth-1038-million-by-2026-at-a-cagr-of-11-0#ixzz7H7gz5iEx. Digital Journal, 2021. (Accessed January 5, 2022, at https://www.digitaljournal.com/pr/unmanned-surface-vehicles-market-worth-1038-million-by-2026-at-a-cagr-of-11-0.)
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9. Oceanographic Monitoring System Market. Straits Research, 2024 at https://straitsresearch.com/report/oceanographic-monitoring-system-market.)
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16. This Armada of Saildrones Could Conquer the Ocean. 2018. at https://www.bloomberg.com/news/features/2018-05-15/this-man-is-building-an-armada-of-saildrones-to-conquer-the-ocean.)
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SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION DYNAMIC LOCOMOTION, INC.	FOR NSF USE ONLY PROPOSAL NO. 2446383	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jason Cortell	AWARD NO.		

A. SENIOR/KEY PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior/Key Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jason Cortell - Principal Inv	3.0			35,000	
2. Andy Ruina	1.5			20,000	
3. Samuel Zapolsky	8.15			95,083	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.0			0	
7. (3) TOTAL SENIOR/KEY PERSONNEL (1 - 6)	12.65			150,083	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.0			0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	18.0			135,000	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				285,083	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				285,083	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Vacuum molding machine $ 25495					
TOTAL EQUIPMENT				25,495	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				3,983	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				39,508	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				50,000	
TOTAL OTHER DIRECT COSTS				89,508	
H. TOTAL DIRECT COSTS (A THROUGH G)				404,069	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) G&A (Rate: 50.0, Base:285083)					
TOTAL INDIRECT COSTS (F&A)				142,542	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				546,611	
K. FEE (FOR SBIR/STTR PROGRAMS: CONSULT SOLICITATION FOR GUIDANCE)				54,661	
L. TOTAL COST AND FEE (J + K)				601,272	

PI/PD NAME Jason Cortell	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Jason Cortell	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED ONLY FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION DYNAMIC LOCOMOTION, INC.				FOR NSF USE ONLY PROPOSAL NO. 2446383	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jason Cortell				AWARD NO.		
A. SENIOR/KEY PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior/Key Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Jason Cortell - Principal Inv	3.0			36,250		
2. Andy Ruina	1.5			20,750		
3. Samuel Zapolsky	8.1			97,875		
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.0			0		
7. (3) TOTAL SENIOR/KEY PERSONNEL (1 - 6)	12.6			154,875		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL SCHOLARS	0.0			0		
2. (4) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	24.0			190,000		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				344,875		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				344,875		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Vacuum molding machine $ 20900						
TOTAL EQUIPMENT				20,900		
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				7,863		
2. INTERNATIONAL				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
(0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				43,676		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				0		
TOTAL OTHER DIRECT COSTS				43,676		
H. TOTAL DIRECT COSTS (A THROUGH G)				417,314		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) G&A (Rate: 50.0, Base:344875)						
TOTAL INDIRECT COSTS (F&A)				172,438		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				589,752		
K. FEE (FOR SBIR/STTR PROGRAMS: CONSULT SOLICITATION FOR GUIDANCE)				58,975		
L. TOTAL COST AND FEE (J + K)				648,727		

PI/PD NAME Jason Cortell	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Jason Cortell	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED ONLY FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

	FOR NSF USE ONLY		
ORGANIZATION DYNAMIC LOCOMOTION, INC.	PROPOSAL NO. 2446383	DURATION (months) Proposed	 Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Jason Cortell	AWARD NO.		

A. SENIOR/KEY PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior/Key Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Jason Cortell - Principal Inv	6.0			71,250	
2. Andy Ruina	3.0			40,750	
3. Samuel Zapolsky	16.25			192,958	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)					
7. (3) TOTAL SENIOR/KEY PERSONNEL (1 - 6)	25.25			304,958	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.0			0	
2. (7) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	42.0			325,000	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				629,958	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				0	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				629,958	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				46,395	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				11,846	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
(0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				83,184	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				50,000	
TOTAL OTHER DIRECT COSTS				133,184	
H. TOTAL DIRECT COSTS (A THROUGH G)				821,383	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				314,980	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,136,363	
K. FEE (FOR SBIR/STTR PROGRAMS: CONSULT SOLICITATION FOR GUIDANCE)				113,636	
L. TOTAL COST AND FEE (J + K)				1,249,999	

	FOR NSF USE ONLY		
PI/PD NAME Jason Cortell	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Jason Cortell	Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED ONLY FOR REVISED BUDGET

DYNAMIC LOCOMOTION BUDGET JUSTIFICATION

A. SENIOR/KEY PERSON

(A.1.) Jason Cortell, Principal Investigator will manage and oversee the development during all tasks of the project. He will commit to 3 calendar months per year. $35,000 is requested in salary (annual salary $140,000/12 * 3 months) in year 1, and $36,250 is requested in salary (annual salary $145,000/12 * 3 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 11-9041.

(A.2.) Andy Ruina, Ph.D., Professor will commit to 1.5 calendar months per year. $20,000 is requested in salary (annual salary $160,000/12 * 1.5 months) in year 1, and $20,750 is requested in salary (annual salary $166,000/12 * 1.5 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 11-9041.

(A.3.) Sam Zapolsky, Ph.D., Senior Engineer will commit to 8.15 calendar months in year 1 and 8.1 calendar months in year 2. $95,083 is requested in salary (annual salary $140,000/12 * 8.15 months) in year 1, and $97,875 is requested in salary (annual salary $145,000/12 * 8.1 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 11-9041.

B. OTHER PERSONNEL

(B.2.) TBD, Mechanical Engineer, will commit to 6 calendar months per year. $45,000 is requested in salary (annual salary $90,000/12 * 6 months) in year 1, and $47,500 is requested in salary (annual salary $95,000/12 * 6 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 17-2141.

(B.2.) TBD, Electrical Engineer, will commit to 6 calendar months per year. $45,000 is requested in salary (annual salary $90,000/12 * 6 months) in year 1, and $47,500 is requested in salary (annual salary $95,000/12 * 6 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 17-2071.

(B.2.) TBD, Software Engineer, will commit to 6 calendar months per year. $45,000 is requested in salary (annual salary $90,000/12 * 6 months) in year 1, and $47,500 is requested in salary (annual salary $95,000/12 * 6 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 15-1252.

(B.2.) TBD, Manufacturing Engineer, will commit to 6 calendar months in year 2. $47,500 is requested in salary (annual salary $95,000/12 * 6 months) in year 2. This position falls under the Bureau of Labor Statistics occupational classification code 17-2141.

C. FRINGE BENEFITS

N/A.

D. EQUIPMENT

Year 1: $25,495 is requested for a Large CNC router machine. Pricing information is below.
Year 2: $20,900 is requested for a Vacuum molding machine. Pricing information is below.

E. TRAVEL

(E.1.) Year1: $3,983 is requested for the PI and one other personnel to travel to the NSF Phase II Grantee Meeting.

Year 2: $3,154 is requested per trip for two 5-day trips for two engineers to the Shoals Marine Lab in Maine to test and validate SailVane, per the R&D plan in the Project Description. The first trip will take place in the first week in May 2025, the second one the first full week in June 2025. The cost of each trip is broken down as follows:

Trip 1&2:

a. $800 for lodging and food at Shoals Marine Lab. Shoals charges a standard discounted rate of $100 per night per person for groups affiliated with Cornell.

b. $1320 for rental of the Research Vessel (R/V) Acipenser from Shoals for on-water testing. Shoals offers this service at a rate of $110 per hour for Cornell-affiliated groups. We will use 4 hours per day for 3 days.

c. $434 for travel to Shoals from Groton, NY. This amount is calculated at the standard reimbursement rate suggested by the IRS of 56 cents per mile. The pickup point for the Shoals ferry is 388 miles from Dynaloco's office in Groton, NY

d. $600 for miscellaneous costs and travel stipend, calculated at $30 per person per day of travel for 2 people and 5 days of travel.

Trip 3: $1,555 for a second, 2-day trip to Shoals Marine Lab in Maine at the completion of its 1-month mission to pick up the hardware and perform post-test data collection. The cost of the trip is as follows:

a. $400 for lodging and food. See Trip 1a, above, for justification.

b. $481 for one half-day boat rental of the R/V John B. Heiser to pick up SailVane on the ocean, in case SailVane has a failure and needs to be picked up within 20 miles of Shoals.

c. $434 for travel to Shoals from Groton. See 2c, above, for justification.

d. $240 for miscellaneous costs and travel stipend, calculated at $30 per person per day for 2 people and 2 days of travel.

F. <u>PARTICIPANT/TRAINEE SUPPORT COSTS</u>

N/A.

G. <u>OTHER DIRECT COSTS</u>

(G.1.) Materials and Supplies – In year 1, $39,508 is requested for the following materials and supplies:

Materials	Qty.	Unit Price	Total Price	Vendor
Iridium satellite monthly access fees	12	$150	$1,796	Ground Control
HDPE polyethylene sheet	10	$151.47	$1,515	US Plastic
Ionomer foam sheets	27	$55.62	$1,502	McMaster
TriSonica Mini anemometer/weather sensors	6	$1,720.00	$10,320	Licor
RockRemote Mini Iridium satellite modem	6	$1,496.00	$8,976	Ground control
Brushless gearmotors	16	$70.00	$1,120	Robot Shop
Batteries, microprocessors, GPS, solar panels	8	$500.00	$4,000	TBD
Printed circuit boards	8	$85.00	$680	TBD
Machined part sets - metal and polymers	8	$1,200.00	$9,600	TBD
TOTAL SUPPLIES			**$39,508**	

In year 2: $43,676 is requested for the following materials and supplies:

Materials	Qty.	Unit Price	Total Price	Vendor
Iridium satellite monthly access fees	12	$150	$1,800	Ground Control
HDPE polyethylene sheet	10	$151.47	$1,515	US Plastic
Ionomer foam sheets	27	$55.62	$1,502	McMaster
TriSonica Mini anemometer/weather sensors	6	$ 1,720.00	$10,320	Licor
RockRemote Mini Iridium satellite modem	6	$1,720.00	$10,320	Ground control
Brushless gearmotors	16	$ 70.00	$1,120	Robot Shop
Batteries, microprocessors, GPS, solar	8	$500.00	$4,000	TBD
Printed circuit boards	8	$85.00	$3,500	TBD
Machined part sets - metal and polymers	8	$1,200.00	$9,600	TBD
TOTAL SUPPLIES			**$43,676**	

(G.6.) Other Costs – A total of $50,000 is requested in year 1 for Optional TABA.

H. <u>DIRECT COSTS</u>

Year 1: $404,069
Year 2: $417,314

I. <u>INDIRECT COSTS</u>

The indirect cost rate is 50% and calculated on total direct labor. $142,542 is requested (0.5 * base of $285,083) in year 1. $172,438 is requested (0.5 * base of $344,875) in year 2.

J. <u>TOTAL DIRECT AND INDIRECT COSTS</u>

Year 1: $546,611
Year 2: $589,752

K. <u>FEE</u>

A fee of 10% of total direct and indirect costs is charged, $54,661 is requested in year 1, and $58,975 is requested in year 2.

L. <u>TOTAL COSTS AND FEE</u>

Year 1: $601,272

Year 2: $648,727

Equipment Pricing

RC SERIES CNC ROUTER

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STARTING AT $18,995.00

Note: shown with optional equipment.

DESCRIPTION

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	RC4	RC8
FOOTPRINT	79" X 88" X 69" (WITH TOOL CHANGER 78")	79" X 116" X 69" (WITH TOOL CHANGER 78")
CUT AREA	51" X 49"	51" X 97"
Z CLEARANCE	8"	8"
Z TRAVEL	9"	9"
RAPID SPEED	1500IPM STANDARD	1500IPM STANDARD
REPEATABILITY	+/-.002"	+/-.002"
DRIVE MOTORS	CLOSED LOOP MOTORS WITH PLANETARY GEARS	CLOSED LOOP MOTORS WITH PLANETARY GEARS
WELL EQUIPPED	$25,495.00	$27,995.00
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	Finance for as low as $481.48/month	Finance for as low as $506.71/month

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List Price $22,900.00
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4yr	$194/mo	$317/mo	$465/mo
3yr	$250/mo	$408/mo	$597/mo

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Model BV C-Class 48x96 (122 x 244cm) Heavy Guage Vacuum Former

Facilities, Equipment, and Other Resources

Dynamic Locomotion, Inc.

Engineering, fabrication, and lab testing of the sailboat prototypes and related hardware will largely be conducted in 1300 square meters of office, laboratory, and light manufacturing space at Dynamic Locomotion, Inc. The company has a machine shop and rapid prototype facility, including a commercial-grade 3D printer, laser cutter, and small CNC milling machine, with tooling and a full set of standard hand and portable power tools for assembly and basic machining and fabrication. Dynamic Locomotion is equipped to design, assemble, and test printed circuit boards, with a stereo microscope, soldering and reflow equipment, oscilloscope, voltmeters, power supplies, and other electronic test equipment. Computer workstations and related equipment are available for mechanical and electronic CAD design, data acquisition, simulation, and routine office tasks.

IDENTIFYING INFORMATION:

NAME: Cortell, Jason

POSITION TITLE: Lead Engineer/CEO

PRIMARY ORGANIZATION AND LOCATION: Dynamic Locomotion, Inc., Groton, New York, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Cornell University, Ithaca, New York, United States	Professional engineering license	05/2000	Mechanical Engineering
Cornell University, Ithaca, New York, United States	MENG	05/1997	Mechanical Engineering
Cornell University, Ithaca, New York, United States	BA	05/1990	College Scholar Program

Appointments and Positions

2018 - present Lead Engineer/CEO, Dynamic Locomotion, Inc., Groton, New York, United States
2018 - 2019 Senior Research Engineer, Beijing Institute of Technology, Beijing, Not Applicable, N/A, China
2013 - 2018 Research Engineer/Lab Manager, Cornell University, Ithaca, New York, United States
2012 - 2013 Mechanical Engineer, Aerovel Corporation, Husum, Washington, United States
2011 - 2012 Research Engineer, UC Santa Barbara, Santa Barbara, California, United States
2009 - 2012 Consulting Engineer, Phoenix Devices, Inc., Phoenix, California, United States
2005 - 2011 Research Engineer/Lab Manager, Cornell University, Ithaca, New York, United States
1998 - 2005 Project Engineer, Transonic Systems, Inc., Ithaca, New York, United States
1997 - 1998 Project Engineer, Intertek Testing Services, Cortland, New York, United States

Products

Products Most Closely Related to the Proposed Project

1. Bhounsule P, Cortell J, Grewal A, Hendriksen B, Karssen J, Paul C, Ruina A. Low-bandwidth reflex-based control for lower power walking: 65 km on a single battery charge. The International Journal of Robotics Research. 2014; 33(10):1305-1321. issn: 0278-3649
2. Bhounsule P, Cortell J, Ruina A. Adaptive Mobile Robotics. World Scientific; 2012. 441-448p.
3. Byl K, Byl M, Rutschmann M, Satzinger B, van Blarigan L, Piovan G, Cortell J. Series-elastic actuation prototype for rough terrain hopping. ; IEEE; c2012. isbn: 1467308560
4. Drumwright, E., Zapolsky, S., Schwandt, D., & Cortell, J. (2020). Robotic Manipulators, U.S. Patent Application No. 62/882,395. Washington, DC: U.S. Patent and Trademark Office. .

Other Significant Products, Whether or Not Related to the Proposed Project

1. Peele B, Li S, Larson C, Cortell J, Habtour E, Shepherd R. Untethered stretchable displays for

tactile interaction. Soft robotics. 2019; 6(1):142-149. issn: 2169-5172
2. Brunsden V, Cortell J, Holmes P. Power spectra of chaotic vibrations of a buckled beam. Journal of sound and vibration. 1989; 130(1):1-25. issn: 0022-460X
3. Van Fleet G, Cortell J, Lutkins K. Acoustically compatible insert for an ultrasonic probe. Google Patents; 2008.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Cortell, Jason in SciENcv on 2024-07-26 15:06:56

IDENTIFYING INFORMATION:

NAME: Ruina, Andy L.

POSITION TITLE: Professor, Mechanical & Aerospace Engineering

PRIMARY ORGANIZATION AND LOCATION: Cornell University, Ithaca, New York, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Brown University, Providence, Rhode Island, United States	PHD	05/1981	Engineering
Brown University, Providence, Rhode Island, United States	MS	05/1978	Engineering
Brown University, Providence, Rhode Island, United States	BS	05/1976	Engineering

Appointments and Positions

1999 - present Professor, Mechanical & Aerospace Engineering, Cornell University, Ithaca, New York, United States
1998 - 2009 Professor, Theoretical & Applied Mechanics, Cornell University, Ithaca, New York, United States
1981 - 1988 Assist. Prof., Theoretical & Applied Mechanics, Cornell University, Ithaca, New York, United States
1980 - 1981 Visiting Prof., Theoretical & Applied Mechanics, Cornell University, Ithaca, New York, United States
1979 - 1980 Geophysicist, US Geological Survey, Menlo Park, California, United States
1978 - 1998 Assoc. Prof., Theoretical & Applied Mechanics, Cornell University, Ithaca, New York, United States

Products

Products Most Closely Related to the Proposed Project

1. Baker R, Kambourian L, Hajarian S, Augenstein T, Harnett S, Lee G, Sudarshan M, Richter C, Trouillot C, Williamson P. Design and development of a self-stabilizing, autonomous sailboat with zero-net stored-energy use. ; Springer; c2016. isbn: 3319233343
2. Augenstein T, Singh A, Miller J, Pomerenk A, Dean A, Ruina A. Using a controlled sail and tail to steer an autonomous sailboat. ; Springer; c2017. isbn: 3319454528
3. Collins S, Wisse M, Ruina A. A three-dimensional passive-dynamic walking robot with two legs and knees. The International Journal of Robotics Research. 2001; 20(7):607-615. issn: 0278-3649
4. Collins S, Ruina A, Tedrake R, Wisse M. Efficient bipedal robots based on passive-dynamic walkers. Science. 2005; 307(5712):1082-1085. issn: 0036-8075
5. Srinivasan M, Ruina A. Computer optimization of a minimal biped model discovers walking

and running. Nature. 2006; 439(7072):72-75. issn: 0028-0836

Other Significant Products, Whether or Not Related to the Proposed Project

1. Ruina A. Slip instability and state variable friction laws. Journal of Geophysical Research: Solid Earth. 1983; 88(B12):10359-10370. issn: 0148-0227
2. Chatterjee A, Ruina A. A new algebraic rigid-body collision law based on impulse space considerations. 1998. issn: 0021-8936
3. Ruina A. Nonholonomic stability aspects of piecewise holonomic systems. Reports on mathematical physics. 1998; 42(1-2):91-100. issn: 0034-4877
4. Kooijman J, Meijaard J, Papadopoulos J, Ruina A, Schwab A. A bicycle can be self-stable without gyroscopic or caster effects. Science. 2011; 332(6027):339-342. issn: 0036-8075
5. Bhounsule P, Cortell J, Grewal A, Hendriksen B, Karssen J, Paul C, Ruina A. Low-bandwidth reflex-based control for lower power walking: 65 km on a single battery charge. The International Journal of Robotics Research. 2014; 33(10):1305-1321. issn: 0278-3649

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Certified by Ruina, Andy L. in SciENcv on 2024-07-26 15:36:04

IDENTIFYING INFORMATION:

NAME: Zapolsky, Samuel R.

POSITION TITLE: Senior Engineer

PRIMARY ORGANIZATION AND LOCATION: Dynamic Locomotion, Inc., Groton, New York, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
The George Washington University, School of Engineering and Applied Sciences, Washington, District of Columbia, United States	PHD	02/2017	Computer Science, Robotics and AI
The George Washington University, The Elliott School of International Affairs,, Washington, District of Columbia, United States	BS	05/2012	International Affairs, Economics, Computer Science

Appointments and Positions

2024 - present Senior Engineer, Dynamic Locomotion, Inc., Groton, New York, United States

2018 - 2019 Shared Autonomy Group Research Scientist, Toyota Research Institute, San Francisco, California, United States

2017 - 2018 Cloud Robotics Group Research Scientist, Toyota Research Institute, San Francisco, California, United States

2012 - 2017 Graduate Research Assistant, Positronics Lab, George Washington University, Washington, District of Columbia, United States

2012 - 2012 Research Assistant, Istituto Italiano di Tecnologia, Advanced Robotics, Genoa, Not Applicable, N/A, Italy

Products

Products Most Closely Related to the Proposed Project

1. Zapolsky S, Drumwright E. Inverse dynamics with rigid contact and friction. Autonomous Robots. 2017; 41:831-863. issn: 0929-5593
2. Zapolsky S, Drumwright E, Poursohi A. Systems and methods for persistent simulation. Google Patents; 2020.
3. Zapolsky S, Drumwright E. Environmental modification in autonomous simulation. Google Patents; 2019.
4. Thackston A, Zapolsky S, Bouma K, Stelzner L, Goldman R. Methods and systems for implementing customized motions based on individual profiles for identified users. Google Patents; 2022.
5. Thackston A, Zapolsky S, Miller K, Stelzner L, Goldman R. Intent based control of a robotic

device. Google Patents; 2022.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Zapolsky S, Drumwright E. System and/or method for grasping objects. Google Patents; 2024.
2. Zapolsky S. Systems and methods for simulation utilizing a segmentable monolithic mesh. Google Patents; 2021.
3. Thackston A, Zapolsky S, Miller K, Stelzner L, Goldman R. Selective arrival notification system. Google Patents; 2021.
4. Zapolsky S, Ahumada M, Poursohi A. Non-backdrivable passive balancing systems for single-axle dynamically-balanced robotic devices. Google Patents; 2020.
5. Zapolsky S, Stone K, Amacker M, Poursohi A. Robots with perception-based fiber-optic tactile sensing and methods for providing the same. Google Patents; 2020.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Zapolsky, Samuel R. in SciENcv on 2024-08-08 13:15:29

Other Personnel Biographical Information

Data Not Available

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Cortell, Jason

*POSITION TITLE: Lead Engineer/CEO

*ORGANIZATION AND LOCATION: Dynamic Locomotion, Inc., Groton, New York, United States

Proposals/Active Projects

***Proposal/Active Project Title:** SailVane: Low-Cost Autonomous Sailboats for Long-Term Ocean Missions

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Dynamic Locomotion, Inc.

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $1,250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	3
2026	3

***Overall Objectives:** 1. Optimize design of SailVane for manufacturability and robustness, demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data 2. Build out multi-boat software capabilities 3. Develop optimization tool to calculate interplay between sensor use and operational lifetime.

***Statement of Potential Overlap:** None

Certification:

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Cortell, Jason in SciENcv on 2024-08-14 09:57:40

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Ruina, Andy L.

*POSITION TITLE: Professor, Mechanical & Aerospace Engineering

*ORGANIZATION AND LOCATION: Cornell University, Ithaca, New York, United States

Proposals/Active Projects

***Proposal/Active Project Title:** SailVane: Low-Cost Autonomous Sailboats for Long-Term Ocean Missions

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Dynamic Locomotion, Inc.

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $1,250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1.5
2026	1.5

***Overall Objectives:** 1. Optimize design of SailVane for manufacturability and robustness, demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data 2. Build out multi-boat software capabilities 3. Develop optimization tool to calculate interplay between sensor use and operational lifetime.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Ruina, Andy in SciENcv on 2024-08-14 09:58:45

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Zapolsky, Samuel R.

*POSITION TITLE: Senior Engineer

*ORGANIZATION AND LOCATION: Dynamic Locomotion, Inc., Groton, New York, United States

Proposals/Active Projects

***Proposal/Active Project Title:** SailVane: Low-Cost Autonomous Sailboats for Long-Term Ocean Missions

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Dynamic Locomotion, Inc.

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $1,250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	8.15
2026	8.1

***Overall Objectives:** 1. Optimize design of SailVane for manufacturability and robustness, demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data 2. Build out multi-boat software capabilities 3. Develop optimization tool to calculate interplay between sensor use and operational lifetime.

***Statement of Potential Overlap:** None

Certification:

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Zapolsky, Samuel in SciENcv on 2024-08-14 09:56:26

Table 1

1	Your Name:	Your Organizational Affiliation(s), last 12 mo	Last Active Date
	Cortell, Jason B.	Dynamic Locomotion, Inc. (Founder/CEO)	
		Dextrous Robotics, Inc. (consultant)	
		Tsinghua University (consultant)	
		Cornell University (consultant)	

Table 2

2	Name:	Type of Relationship	Optional (email, Department)	Last Active Date
R	Andy Ruina	Business		
R	Evan Drumwright	Business		

Table 3

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)

Table 4

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active Date
A				

Table 5

5	Name:	Organizational Affiliation	Journal/Collection	Last Active Date

Table 1

1	Your Name:	Your Organizational Affiliation(s), last 12 mo	Last Active Date
	Ruina, Andy	Cornell University	
		Dextrous Robotics	
		Dynamic Locomotion	
		Weel Autonomy	

Table 2

2	Name:	Type of Relationship	Optional (email, Department)	Last Active Date
R	Cortell, Jason B.	Business		

Table 3

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G	Rice, James R.	Harvard University	
G	Dieterich, James	United States Geological Survey	
T	Goyal, Suresh	Alcatel-Lucent	
T	Chatterjee, Anindya	ITT Kanpur	
T	Coleman, Michael	U. of Vermont	
T	Garcia, Mariano	Borg-Warner	
T	Gomes, Mario	U. of Rochester	
T	Srinivasan, Manoj	Ohio State U.	
T	Walcott, Sam	UC Davis	
T	Cabrera, David	University of Illinois, Chicago	
T	Bhounsule, Pranav	U. of Texas, San Antonio	
T	Zaytsev, Petr	Postdoc with David Remy, U. of Michigan	
T	Grewal, Anoop	Arizona State at Tempe	
T	Chaudhry, Atif		
T	Stiesberg, Gregg		
T	Kelly, Matt	Boston Dynamics	
T	Sheen, Matt	Weel Autonomy	
T	Elandt, Ryan	Cornell U.; PhD expected 2022	

Table 4

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active Date
A	Autumn Pratt	Cornell University		

A	Karen Gellman	Maximum Horsepower Research		

Table 5

5	Name:	Organizational Affiliation	Journal/Collection	Last Active Date

Table 1

1	Your Name:	Your Organizational Affiliation(s), last 12 mo	Last Active Date
	Zapolsky, Samuel	Dynamic Locomotion, Inc	
		Dextrous Robotics	

Table 2

2	Name:	Type of Relationship	Optional (email, Department)	Last Active Date
R				

Table 3

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G	Drumwright, Evan	The George Washington University	

Table 4

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active Date
A	Thackston, Allison	Toyota Motor Corp		
A	Milller, Katarina	Toyota Motor Corp		
A	Stelzner, Laura	Toyota Motor Corp		
A	Goldman, Ron	Toyota Motor Corp		
A	Poursohi, Arshan	Toyota Motor Corp		
A	Amacker, Matthew	Toyota Motor Corp		
A	Stone, Kevin	Toyota Motor Corp		
C	Cortell, Jason B.	Dynamic Locomotion, Inc.		
C	Andy Ruina	Dynamic Locomotion, Inc.		

Table 5

5	Name:	Organizational Affiliation	Journal/Collection	Last Active Date

Jason Cortell founded Dynamic Locomotion, Inc., in 2018 to bring previously funded NSF technology to a commercially viable level, and advance robotic systems generally in the fields of assistive devices, environmental monitoring, agriculture, and logistics. Recent projects include a veterinary equine assist device, a high-performance bipedal robot, and a novel 10-axis mobile logistics robot.

Recently he also started GrotonWorks, a tech and manufacturing space adjacent to Groton High School. In addition to providing commerical co-working facilities, GrotonWorks expects to provide maker space and tech internship opportunities to members of the local rural community, including high school and community college students.

1. I have helped publicize our research for the general public through a press conference at AAAS, a talk at AAAS, two short made-for-TV science specials (one for international National Geographic), and various radio and newspaper interviews (e.g., NY Times, NPR and Science News).

2. I advise a student-competition robotic sailboat that uses and tests some of the ideas in this proposal as well as various other robotics-related undergraduate research projects.

3. I am energetically involved in issues related to the teaching of undergraduates (e.g., encouragement of computer use in the general curriculum, development of electronic course evaluation). I've received 3 teaching prizes from the dean of engineering.

4. With Rudra Pratap in Bangalore I am co-authoring a better Statics & Dynamics textbook for sophomore/junior engineering students. This book addresses many of the dissatisfactions that faculty, especially ourselves, have with the other available texts. The book continues to improve as we work on it for about 6 weeks per year (draft available online).

5. For 6 years I managed a community bicycle program, fixing bicycles and teaching bicycle repair: Recycle Ithaca's Bicycles (written up in the NY Times).

1. As CTO of Dextrous Robotics, I led technical efforts for developing robotics on a high speed, contact-based, bi-manual manipulation platform for logistics applications.

2. I previously worked at the Toyota Research Institute, and was the lead on hardware & controls team for developing an in-home mobile manipulator robot; I also contributed to the planning, controls & hardware for safe teleoperation of a mobile manipulator robot.

3. I have been named on several patents for my work at Toyota.

4. Prior to my graduate studies, I also spent time at the Italian Institute of Technology where I researched the simulation and physics of legged robots walking on low or variable friction surfaces at the Dynamic Legged Systems Lab. I additionally developed and deployed an inverse dynamics controller with contact-force prediction for the Hydraulic Quadruped robot.

Data Management Plan

All data generated in this SBIR Phase II project is considered proprietary.

Requested Payment Schedule

Select One Option:

(X) I request the standard payment schedule (see "Instructions" tab)

( ) I request a modified payment schedule (complete the below)

___ % Requested amount upon award

___ % Requested amount available upon approval of the first interim report (approx. 6 months into award)

___ % Requested amount available upon approval of the second interim report (approx. 12 months into award)

___ % Requested amount available upon approval of the third interim report (approx. 18 months into award)

___ % Requested amount available upon approval of the final report (end of project); cannot be less than $25,000

Justification for modified payment schedule:

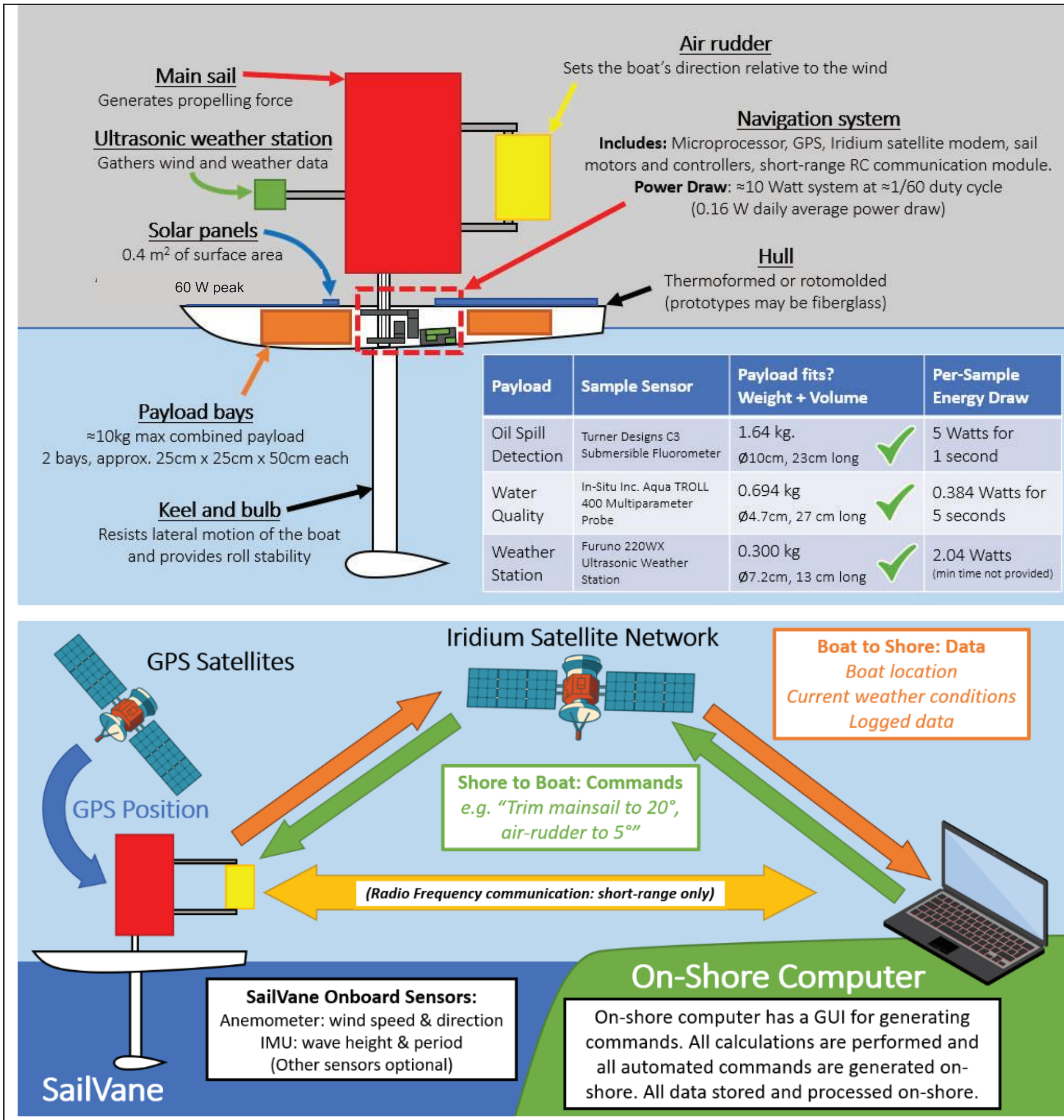
Projected Gantt Chart

	Months 0-6						Months 6-12						Months 12-18						Months 18-24					
Task 1: Design for manufacturing and boat deploymnet in the atlantic using refined navigational software																								
Jason Cortell	X	X						x																
Andy Ruina		x																						
Sam Zapolsky						x	x	x	x	x														
Task 2: Development of multi-boat optimization software																								
Jason Cortell														x		x								
Andy Ruina															x									
Sam Zapolsky										x	x	x	x	x							x	x		
Task 3: Descriptive title																								
Jason Cortell																				x				
Anyd Ruina												x							x					
Sam Zaplosky																					x	x	x	x

A. Market Opportunity

A.1 SailVane Technology

Dynaloco is developing SailVane, a small (2-meter), low-cost (<$5K bill of materials), autonomous robotic sailboat for *in-situ* oceanic data collection. The vessel uses an innovative new fixed sail arrangement and a "Weather Jiu-Jitsu" navigation system to overcome the key power and navigational challenges typically associated with small vessels.



Payload	Sample Sensor	Payload fits? Weight + Volume	Per-Sample Energy Draw
Oil Spill Detection	Turner Designs C3 Submersible Fluorometer	1.64 kg. Ø10cm, 23cm long ✓	5 Watts for 1 second
Water Quality	In-Situ Inc. Aqua TROLL 400 Multiparameter Probe	0.694 kg Ø4.7cm, 27 cm long ✓	0.384 Watts for 5 seconds
Weather Station	Furuno 220WX Ultrasonic Weather Station	0.300 kg Ø7.2cm, 13 cm long ✓	2.04 Watts (min time not provided)

Figure 1. Top- Schematic of SailVane, showing the parts of the boat and three useful sample payloads. Bottom – Overview of the SailVane control system design.

These innovations allow SailVane to perform long-term navigation and stay in a user-defined location in the open ocean, making it suitable for oceanic research applications. When deployed in a fleet, SailVanes can be used to create a network of sensors to enable large scale data collection on the ocean at a much lower cost than existing remote sensing solutions. SailVane has a payload bay large enough to carry a broad range of sensors, including water quality sensors (such as temperature, conductivity, pH, chlorophyll concentration, and dissolved oxygen), weather sensors, modems for data relay from underwater bioacoustics sensors, and fluorometry sensors for detecting hydrocarbons in the water. There are a broad range of applications for SailVane, including performing oceanic research, environmental impact studies, national security missions, assisting oil spill cleanups, monitoring fisheries, collecting weather data, and augmenting existing research tools and methods.

Two key innovations underlie the SailVane technology. The first innovation is a novel sail arrangement that makes the boat directionally stable relative to the wind without active electronic control; the vessel can maintain a navigational course without power for long periods of time, requiring only about 30 seconds of power every hour (averaging <1W power consumption). This eliminates the need for large solar panels or batteries, thus addressing the space constraints of smaller vessels. The second innovation is a novel "Weather Jiu-Jitsu" system that exploits the spatial and temporal variance in the weather and uses local weather data to direct the boats to "go with the flow", using currents and weather conditions to assist its navigation, rather than treating them as obstacles. For example, the Gulf Stream is the fastest surface ocean current in the world, traveling northeast at speeds as high as 2.5 m/s, faster than SailVane's 1 m/s typical speed. However, the Gulf Stream has local eddies in which some pockets of water that travel in the opposite direction of the main flow at speeds up to 0.25 m/s.[1] SailVane's "Weather Jiu-Jitsu" system will use the most up-to-date weather data and forecasts to optimize SailVane's trajectory and enable it to navigate between eddies, allowing progress in any direction.

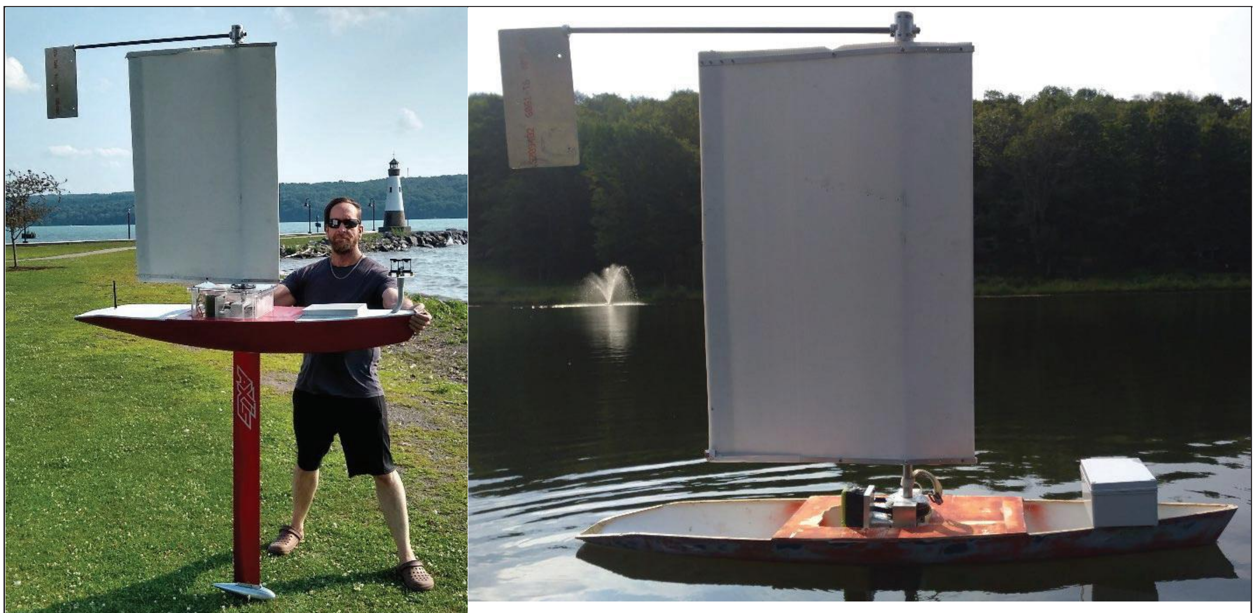


Figure 2. SailVane prototypes developed and deployed in Phase I

Our vessels are designed to be robust and marine-grade with just two exposed moving parts, each with overload protection clutches, and will be able to withstand being hit by large waves, capsizing, and salt water for months on end. Critically, SailVane's low cost makes it highly accessible: it can compete on cost with a small, instrumented buoy without the need for an expensive crewed mission for deployment and retrieval, and with average development costs of $5,000 it is significantly less expensive than existing robotic Uncrewed Surface Vessels (USVs), which cost upwards of $100,000 apiece. Notably, SailVane is autonomous, making it an ASV (Autonomous Surface Vessel). With SailVane, researchers will be able to deploy coordinated fleets, where before they were limited by cost to a few devices, allowing for more detailed data collection. This is advantageous over a single deployed buoy, as with a coordinated swarm approach each vessel will require shorter scan times for an area and a higher density of data will be able to be collected. In turn this will enable a faster response time to disasters (e.g., oil spill, tsunami, algae bloom) helping to mitigate negative effects of the potential threat.

Table 1. Sail Vane bill of materials. Price will vary based on sensor requirements, but on average we expect a cost of $5k.

SailVane Bill of Materials with basic sensor arrangement		
Part name	**Est. production costs (10 to 100)**	
Sail and vane drive motors	$	50.00
Belts and pulleys	$	45.00
Boat hull	$	500.00
Boat keel parts	$	300.00
Boat sail	$	250.00
Sail vane - air rudder	$	200.00
GPS	$	20.00
Iridium satellite modem	$	250.00
Machined parts for sail and rudder drive	$	500.00
Miniature weather station	$	1,500.00
Magnetometer	$	20.00
Accelerometer/IMU	$	20.00
Microcontroller boards and other misc. electronics	$	200.00
Paint, seals, floatation foam, and related materials	$	300.00
Shipping and transport case	$	300.00
Total COGS	**$**	**4,415.00**

** Note that the Iridium satellite modem can be upgraded to support higher data transmission rates, we will explore using an upgraded model in Phase II and evaluate its value in regard to the increased cost.

Prior Phase I work accomplished the design and testing of the prototype, demonstrating the feasibility of our approach. We integrated basic sensors and tested the autonomous navigation system in controlled environments, with initial applications for SailVane users to communicate their desired boat course to the navigation control server and the satellite communications.

Phase II will build on this foundation by refining the SailVane's technologies, integrating a broader range of sensors, and enhancing the autonomous navigation algorithms. By the end of Phase II, we expect to have a robust, commercially viable SailVane system ready for large-scale deployment. Our comprehensive field testing in various marine environments will validate the system's performance and reliability. This will position us to offer an unprecedented solution for oceanographic data collection, reducing costs and increasing accessibility for researchers, industry, and government agencies. Our innovative approach promises to transform how oceanographic data is gathered, significantly contributing to marine science, environmental monitoring, and resource management.

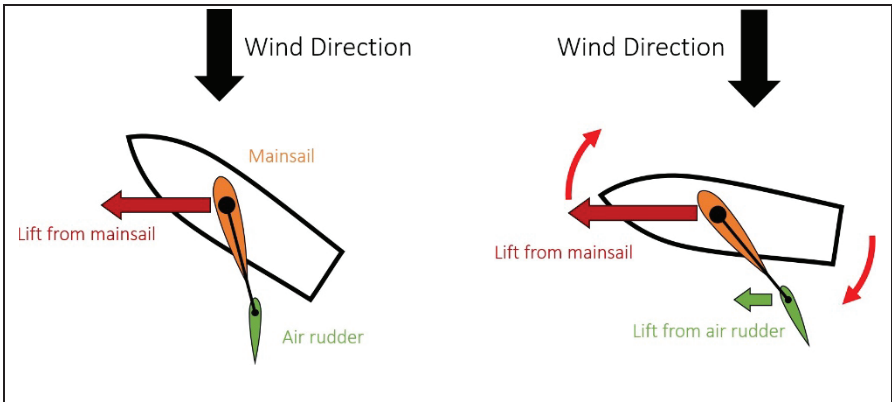


Figure 3. Directional stability. Between course corrections, the mainsail and air rudder remain at a fixed angle relative to the boat. The sail and keel centers of lift are approximately aligned with mast pivot point, and thus, lift from the main sail and keel do not tend to turn the boat. The only significant steering torque on the boat is from the air rudder which, like the tail of a wind vane, aligns the air rudder with the wind and steers the boat. **Left.** The boat in steady sailing. **Right.** The boat perturbed counter-clockwise from the desired heading. This perturbation gives the air rudder a non-zero angle of attack, and the resulting lift from the rudder applies a clockwise torque on the boat, whichrestores it to its desired orientation.

A.2 Customer

Customers of SailVane include government bodies, research institutions, and energy companies. These entities are seeking low cost data collection and monitoring solutions that can be operated in remote and hard-to-reach locations without the need for additional infrastructure for deployment and retrieval. Government agencies value ocean data for national security, environmental protection, and for facilitating economic activities like fishing and shipping in a safe and efficient manner. Collected data can also be used to support federal research and policy initiatives, especially around weather prediction, climate change, and sustainable development. Often, these activities require a whole-of-government approach resulting in interagency collaborations. For example, the Maritime Security and Fisheries Enforcement (SAFE) Act established the Interagency Working Group on Illegal, Unreported, and Unregulated Fishing, and is comprised of representatives from 21 different agencies.[2] Thus, our technology is of interest to several government agencies, ranging from NOAA to the DoD. Other customers include research institutions, such as Cornell Lab of Ornithology (see letter of support), Shoals Marine Lab (see letter of support), Woods Hole Oceanographic Institution, and Scripps Institution of Oceanography, which have a need for low cost tools to support extensive marine studies that require distant and long duration deployments. Finally, private sector companies, especially in offshore energy like Shell Oil (see letter of support) and BP, desire enhanced marine monitoring capabilities, ensuring regulatory compliance and optimizing resource extraction. For our early pilots we are targeting research entities with plans to expand into Oil & Gas after initial traction is demonstrated with an application focus on oil spill monitoring; we are currently in early conversations with Shell about this use case.

While there are several modern ocean remote sensing technologies on the market, they are limited in their capabilities and in most cases are cost prohibitive. For instance, satellite systems are expensive to launch, cannot sense many quantities of interest (such as many water quality metrics) from orbit, are affected by cloud cover and time of day, and are difficult to maintain. Furthermore, they are extremely expensive: NOAA's GOES-R series of four weather satellites had an estimated life cycle cost of $10.9 billion.[3] Other options include freighters, which mostly travel on ocean highways thus limiting the scope of data collection as well as manned oceanographic vessels, which are prohibitively expensive, costing up to tens of thousands of dollars a day. Smaller options include tethered and untethered buoys. While these are less expensive to purchase, they are expensive to deploy, especially in deep water or remote locations, because they require a crewed mission and expensive mooring; if the buoys are not moored they have positions and paths that are uncontrolled limiting their utility. Finally, there are competing ASV technologies on the market that address these issues, however they are extremely expensive. An overview of these close competitors is found in section C.3

Addressing these limitations, SailVane will enable our customers to collect data from virtually anywhere without excess deployment costs. We have validated these pain points from extensive customer discovery (see letters of support) and are confident that SailVane provides a much-needed solution in the ocean monitoring space. Our go-to-market strategy includes participating in industry conferences and trade shows (e.g., Offshore Technology Conference, Oceanology International, Unmanned Maritime Systems Technology USA, etc.) targeted digital marketing campaigns, and forming strategic partnerships with established marine research organizations and equipment distributors to build brand recognition and reach potential customers efficiently. Leveraging our existing relationships with key stakeholders like NOAA and prominent academic institutions will help gain early adopters and testimonials to drive further sales.

A.3 Business Model

Revenue Streams

Given the diversity of our customers, we plan to commercialize the SailVane through three different business models which offer varying tiers of service. This allows us to reach a broader range of end users and maintain our mission of improving the accessibility of ocean data collection technologies.

Our primary offering will be our "micro-boats as a service" (MBaaS) model, which provides use of the boat, data storage, and technical support/maintenance for a yearly fee of $25k. This is our most comprehensive service and geared towards customers with large operating budgets. In practice, a customer can lease one or more boats for the purpose of collecting data (from our provided suite of required and/or optional sensors) in a particular region, spatio-temporal density, and timespan. Sensors required for SailVane deployment include an anemometer that records barometric pressure and temperature, a magnetometer, GPS, and satellite. Additional sensors can be added to the payload bay at the customer's request, the primary limiting factor will be available wattage (current solar arrangement supports 60 watts of power, however only <1 watt of power is needed to navigate the boat). Collected data is then stored on Dynaloco's internal servers for the customer to download. The $25k price point was determined in consultation with prospective customers and an evaluation of market demand; this is likely to be the average annual price with the potential for fluctuation due to sensor requirements. In addition, we are also considering the potential for volume discounts for larger orders anticipated in the later stages of commercialization.

To ensure accessibility of our technology, we also plan to roll out a second MBaaS model designed for non-profit research institutions. This model will enable customers who qualify to lease our boats at cost, estimated to be around $10k year. In exchange for reduced pricing, customers will be asked to enter a “Friendly Pilot Agreement” with Dynaloco, which will 1) permit Dynaloco to test experimental software and collect data during deployments; 2) ask that the research partner credit Dynaloco in published work, helping to build brand recognition. These research-based customers will also serve as our early pilot customers of the technology.

Finally, in the long-term (i.e. year 5 and beyond of commercialization) we see potential to sell our SailVane technology to other entities in the marine monitoring space in the form of a strategic partnership. This would be a direct sales approach, where we would sell a complete boat with empty payload bay and a closed-source compiled API for controlling the boat remotely. The customer can then customize the sensor suite and data collection capabilities as required for their end users. This model will require minimum volume orders and will have an average price of $15,000/boat. An example of a strategic partner in this space would be Teledyne Marine, a marine equipment and technology solutions company.

Sales strategy

In the first year of commercialization, we will market SailVane through industry conferences and published works to build brand recognition. During this time, we will work on securing our first customers (planned for year 2) through our existing relationships within the industry; these efforts will be led by current personnel who have strong professional networks to leverage. For example, on the research side we have an existing relationship with the K. Lisa Yang Center for Conservation Bioacoustics (Yang Center) at the Cornell Lab of Ornithology at Cornell University. These early research tier customers will be used to generate data that can be used for broader marketing strategy in subsequent years. At the end of our second year of commercialization, we will hire our first two sales leads, with plans to scale the team alongside our operational growth.

Production Resources

All manufacturing of the SailVane can be conducted in Dynaloco’s existing facilities which include 1300 square meters of office, laboratory, and light manufacturing space. The company has a machine shop and rapid prototype facility, including a commercial-grade 3D printer, laser cutter, and small CNC milling machine, with tooling and a full set of standard hand and portable power tools for assembly and basic machining and fabrication. Dynamic Locomotion is equipped to design, assemble, and test printed circuit boards, with a stereo microscope, soldering and reflow equipment, oscilloscope, voltmeters, power supplies, and other electronic test equipment. Computer workstations and related equipment are available for mechanical and electronic CAD design, data acquisition, simulation, and routine office tasks. Note that we plan to implement facility and equipment upgrades in year 3 of commercialization to support more efficient manufacturing; these improvements will funded through a $3M seed round.

With these existing resources we estimate an annual production capacity of 10k SailVane’s per year. If demand exceeds this capacity, we will look to partner with a third party manufacturer.

Exit Strategy

Our exit strategy involves positioning the company for acquisition by a larger entity within the marine technology or environmental monitoring sectors. Potential acquirers include established companies such as Teledyne Marine, Ocean Infinity, and Kongsberg Maritime, known for acquiring innovative technologies to expand their product offerings. By demonstrating the commercial viability and scalability of the SailVane system, we aim to attract interest from these industry leaders. An acquisition would be an attractive strategy for both founders and investors to exit the investment.

Alternatively, we will consider strategic partnerships or joint ventures to provide additional resources and market access, accelerating growth through shared R&D initiatives, co-marketing agreements, or distribution collaborations. In the long term, we will also explore the possibility of an initial public offering (IPO) if market conditions are favorable, providing capital to scale operations, expand our product line, and invest in further technological advancements. This option will be evaluated based on the company's financial performance.

A.4 Market applications

SailVane is an Autonomous Uncrewed Surface Vehicle (ASV), a robot which travels on or near the surface of the ocean that can be equipped with sensors to enable continuous marine data collection in near-real time. There are a broad range of applications for SailVane, including performing oceanic research, conducting environmental impact studies, conducting national security missions, assisting oil spill cleanup, monitoring fisheries, collecting weather data, and augmenting existing research tools and methods.

Oceanic research. The ocean is an ecosystem that has been increasingly impacted by human activity. To better understand this impact, and inform mitigation and restoration efforts, continuous oceanic data monitoring is greatly needed. Insights derived from ocean monitoring data can provide a greater understanding of how human pressures, largely driven by industry (e.g., fishing, shipping, mining, coastal agriculture, tourism), are affecting ocean health.[2] For instance, data can be collected on marine wildlife, providing insights on species abundance, behavior, and geographic location. This type of work often includes sonar and acoustic monitors, among other sensors, which can be deployed by the SailVane. This data can also help identify instances of overfishing or ecosystem imbalance. Ocean research can also be used to better understand and quantify the impacts of climate change. A major outcome of increased greenhouse gas emissions has been rising sea surface temperatures, rising sea levels, and ocean acidification. These changes have brought about more severe weather, coastal flooding, and changes to marine habitat—all occurrences that threaten future prosperity. Ocean monitoring can help to track these changes by helping researchers better understand how to protect the marine environment.

Due to the company's academic connections, we have significant traction in this market application. For example, the Yang Center at the Cornell Lab of Ornithology is interested in using SailVanes to apply bioacoustic technologies across ecological systems at a scale. They envision using SailVane to facilitate real-time data transmission of their bottom-moored, autonomous passive acoustic recorders (by hovering SailVane directly above) as well as supporting the collection of environmental DNA.

Support for offshore energy operations. Energy companies have a critical need for in-situ metocean data for operational support and to support renewable energy developments. Use cases include risk management and operational efficiency, site assessment, environmental and compliance monitoring, as well as emergency detection and disaster response. For example, SailVane can be highly valuable for oil spill monitoring efforts due to its ability to autonomously navigate and collect data in hazardous or hard-to-reach areas in a quick and efficient manner. SailVanes can be equipped with a range of sensors, including fluoroscopes, cameras, sonar, and chemical detectors, allowing them to precisely detect and track the spread of oil. They can operate continuously over long periods, providing real-time data that is critical for assessing the extent of the spill and guiding cleanup operations. When deployed in a fleet, SailVanes can quickly map a detected oil spill, providing more granular details on its size and location. Additionally, SailVanes can safely operate in contaminated environments, reducing the risk to human responders and enabling faster, more efficient response efforts. The oil spill management market was valued at $125.6M in 2022.

Maritime surveillance. Real-time continuous monitoring of the ocean, and the millions of vessels that navigate its waters, is critical to safeguarding national security, detecting threats, and protecting the environment and its natural resources. SailVane can be used to detect illicit activities such as illegal fishing and piracy, as well as pollution such as oil spills or ocean dumping of waste.[3] A recent global law enforcement effort "Operation 30 Days at Sea 3.0" led by INTERPOL with cooperating agencies from 67 countries led to the detection of thousands of suspects and criminal networks engaging in maritime pollution, with activities such as illegal discharges of oils, plastics, and sewage, as well as waste trafficking. The effort also detected multiple vessels that had turned off their automatic identification system (AIS) systems to avoid detection. The large amount of illegal activity detected was, in part, attributed to a lack of maritime surveillance and criminals were taking advantage of vulnerabilities in the surveillance systems.[4] SailVane can be used to detect vessels that have disabled AIS, thus detecting vessels that may pose a threat, allowing for the earlier implementation of defensive measures. The US Department of Defense considers maritime domain awareness necessary for "facilitating effective action in the maritime domain and critical to its homeland defense mission."[5]

Broader Markets. Valued at $800M in 2023, the Global USV market is expected to grow at a CAGR of 10.3% to reach a market value of $1.2B by 2028.[4] Growth in this market is expected to be largely driven by the ability of USVs to continuously collect high quality data in real-time, serving critical applications such as water quality monitoring, ocean mapping, marine ecosystem monitoring, and notification of potentially catastrophic events such as earthquakes and tsunamis.[4-6] The first customer segments we plan to target in this broader market include research institutions followed by oil and gas.

Government organizations such as NOAA have made significant investments in USV technology, and private investment continues to grow.[7] Notably, a major constraint in this market is the high cost associated with manufacturing USVs[4] —a challenge that is addressed by SailVane, which is small enough to be manufactured using inexpensive materials and mass-manufacturing techniques like thermoforming and rotomolding. There is also expected growth in related adjacent markets: the global maritime surveillance market, valued at $24.7B in 2023 is expected to reach $40.3B by 2030 (CAGR 7.4%).[8] The increased deployment of autonomous marine devices is expected to be a major catalyst of this growth.[8]

Within these broader markets, the SailVane most closely aligns with the oceanic sensor buoy segment, which has recently undergone significant growth due to the shift towards automation, real-time data collection, and the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies in monitoring systems.[9] With respect to domestic market size, there is no single, definitive source that provides the exact total count of oceanic sensor buoys manufactured or used annually in the US. This information is often proprietary to the companies involved and not officially released, or in the case of military operations is kept confidential. Additionally, the number can oftentimes fluctuate year to year depending on research needs, funding, and technological advancements.

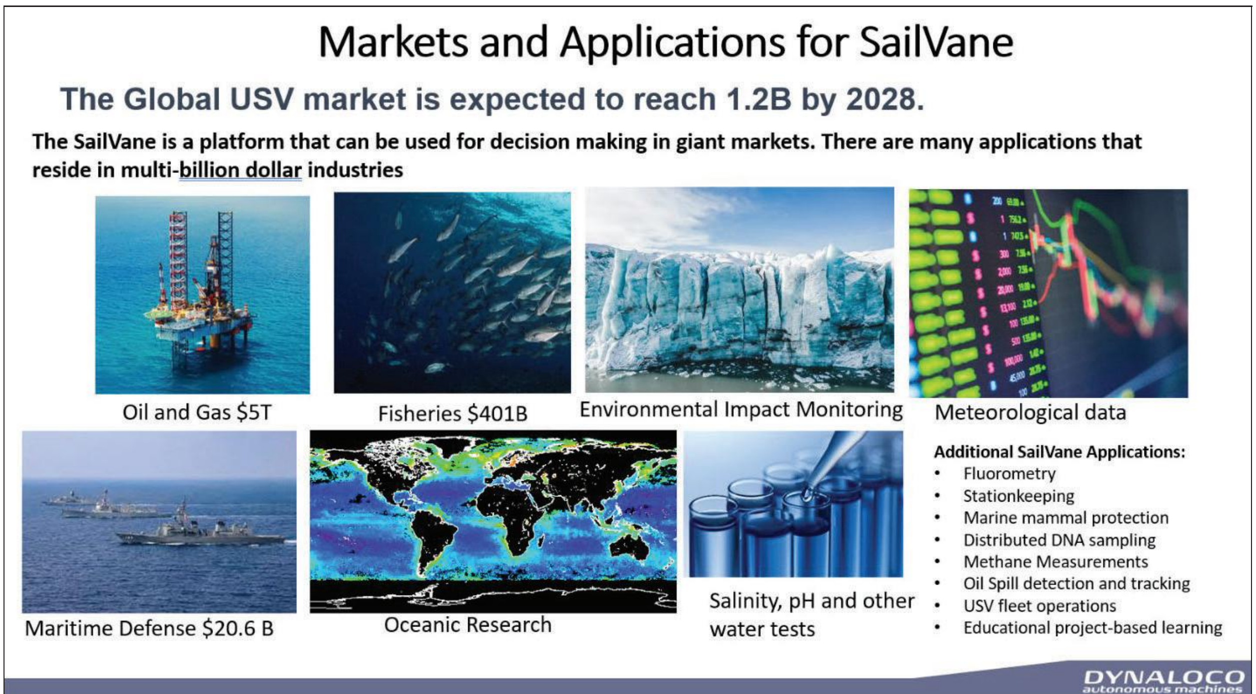


Figure 4. With capacity for custom sensor suites, SailVane has broad market applications. The three first markets we are targeting include research, oil and gas, and defense.

In general, the overall market trend is that advancements in technology (like that offered by SailVane) are leading to the development of smaller, more affordable buoys, which could potentially increase the number of buoys and research vessels deployed in the future. In the public domain, the use of buoys has specifically of been interest to NOAA, which operates the National Data Buoy Center (NDBC) among other initiatives, the Science Applications International Corporation (SAIC), which deploys thousands of buoys worldwide for tsunami detection and other oceanographic measurements, and the US Military which has noted use of sensor-equipped ocean buoys to support a variety of operations related to defense. On the private side, key players include energy companies with a need to monitor offshore operations, shipping companies with a need for condition monitoring and detection of adversaries, and fisheries with a need to monitor ocean conditions to optimize operations.

A.5 Milestones

The Phase II SBIR/STTR project will focus on refining and scaling our system, with objectives including enhanced sensor integration, improved autonomous navigation, and extensive field testing to ensure reliability and performance in diverse marine environments. By the end of Phase II, we expect to have a robust, commercially viable SailVane system ready for large-scale deployment. The resulting boat and software solution will have been validated pilot customer deployments that occur during year 2 of the phase II. Our comprehensive field testing in various marine environments will validate the system's performance and reliability. This will position us to offer an unprecedented solution for oceanographic data collection, reducing costs and increasing accessibility for researchers, industry, and government agencies. Our innovative approach promises to transform how oceanographic data is gathered, significantly contributing to marine science, environmental monitoring, and resource management.

Our key focuses of Phase II development seek to further define our key differentiators that will allow us to stand out in the market and outperform our competition:

- **Robust navigation in harsh environments.** The SailVane is designed to be exceptionally robust to collision damage, resistant to biofouling from long deployments at sea, and impervious to water intrusion. The tiny vessel will be shown to be robust to capsizing and able to self-right after such an event. In Phase II, we will verify the boat material resistance to marine organism contamination, with a variety of locations for testing of sample materials as well as conduct drop tests to demonstrate mechanical robustness.
- **Minimal maintenance.** The SailVane is autonomous and— due to its combination of sensors, battery, power generation and control system— can be deployed in the field for long intervals of time (on the order of several months to years) without need for maintenance or recall. The ship will also be designed to have minimal (one) or zero rotational connections exposure to the boat mechanical parts, to eliminate water leakage after rotational seal deterioration.
- **Low cost of manufacturing.** The SailVane is most importantly low-cost. This core tenet of providing a cheap sea-going vessel is the primary motivation for its small size. Additionally, it has been designed for mass manufacture, with a focus on making it easy to manufacture from affordable materials and accessible fabrication methods. Components we plan to implement in Phase II include a fully-molded and/or vacuum formed hull, sail, and air rudder. This will enable mechanical assembly time of only a few hours per boat.
- **Multi-boat (Swarm) Capabilities.** The SailVane's low cost of manufacture, ease of deployment, capability of serving long missions without intervention, and proprietary state-of-the-art control system permit the deployment of dozens to thousands of mini-boats that can station-keep in a grid for dense coverage of a section of ocean or autonomously navigate as a swarm to guarantee regular coverage of a large region of the ocean. Phase II will see the development of new software components designed to optimize coverage over the course of a mission. In particular, we will focus on automating boat repositioning in cases of dispersion or loss of a boat.

A.6 Societal Benefits

Our SailVane robotic sailboat has the potential to make a significant societal, educational, and scientific impact, aligning closely with NSF's mission. Societally, SailVane will revolutionize oceanographic data collection by providing an affordable, scalable solution for monitoring marine environments, crucial for climate change research, disaster response, and sustainable resource management. This technology will enable governments and organizations to make informed decisions based on real-time data, contributing to the protection and preservation of marine ecosystems.

Educationally, the low cost and accessibility of SailVane will democratize oceanographic research, allowing high schools, colleges, and universities to engage in hands-on marine science projects. Students will gain practical experience in deploying and managing autonomous systems, data collection, and analysis, fostering the next generation of marine scientists and engineers. Integrating SailVane into educational curricula can enhance STEM learning and inspire students to pursue careers in marine technology and environmental sciences.

Scientifically, SailVane will provide unprecedented opportunities for continuous, high-resolution oceanographic data collection, enhancing our understanding of ocean dynamics, marine biodiversity, and the impacts of climate change. Researchers will have access to comprehensive datasets, enabling groundbreaking studies and international collaborations. The innovative design of SailVane will push the boundaries of current marine research methodologies, driving scientific advancements.

In conclusion, the development and deployment of the SailVane robotic sailboat represent a transformative innovation in oceanographic research. By significantly reducing the cost and difficulty of data collection, SailVane will have far-reaching impacts across societal, educational, and scientific domains, embodying the NSF's mission and leading to a more sustainable and informed interaction with our ocean.

B. Company & Team

B.1 Company

Dynamic Locomotion, Inc. (d.b.a. Dynaloco) was founded in 2018 to develop advanced autonomous machines for environmental monitoring, agriculture, and other applications of energy-efficient robotic systems. Dynaloco currently operates as a robotics consultant and contractor, developing advanced robots for our customers. The company also performs internal R&D to develop robots for commercialization, such as SailVane. Our goal is to bring revolutionary dynamic, energy-efficient robots to our clients across a variety of industries and applications. Our headquarters is a 1300 square meter facility with office, lab and light manufacturing space. The company has grown steadily with the addition of new contracts and internal R&D projects and, in 2024, plans to hire additional engineers, technicians, sales leads, and operational support staff.

With SailVane, we aim to do for ocean monitoring what quadcopters have done for terrestrial observation. SailVane will enable small-budget survey projects, much as inexpensive UAVs (Uncrewed Aerial Vehicles) have created an accessible entry point for surveys on land. SailVane will enable even the most cost-conscious organizations to perform their own ocean research. Large-budget customers will be able to deploy coordinated fleets of hundreds of SailVanes, gathering data and samples from vast areas of the ocean. Over the next five years, we hope to bring SailVane and other innovative, high-impact robots to market, meeting critical needs within the market landscape.

B.2 Leadership Team

Jason Cortell, P.E, Dynaloco Co-founder and CEO, has spent 30 years in autonomous robot development, including system, mechanical, electrical, and embedded code design. He has focused on obtaining high performance from humanoid robots and other legged machines while maximizing battery life; the latter is particularly relevant to the current proposal. In addition, he has seven years' experience developing intraoperative and implantable medical devices for use in humans and animals. These environments show parallels to the chemically and biologically aggressive environment of the ocean, and his experience with materials selection and fabrication processes is a critical asset for this project.

Andy Ruina, Ph.D. Dynaloco Co-founder and Technical Lead, is an expert in dynamics, especially of locomotion, including analysis, simulation, control, and optimization of mechanical systems. He was previously the John F. Carr Professor of Mechanical Engineering at Cornell University. He is a life-long sailor and wrote one of the early papers on the theoretical limits of sailboat performance (the "downwind paradox"). Speaking to his expertise in robotic sailing, Dr. Ruina was selected to judge the World Robotic Sailing Championship (Finland, August 2015), and previously managed, for six semesters, a student team which designed and built small robotic sailboats. Technologies learned from his legged robots research (funded by NSF) overlap with those needed for robotic sailing, including dynamic simulation, structural calculations, microprocessors, communication networks, specialized electronics (GPS, IMU, rotary sensors), careful electrical power management, and reliable hardware development. He received his PhD in Mechanical Engineering from Brown University in 1981 and received the Presidential Young Investigator Award (National Science Foundation) in 1984.

Samuel R. Zapolsky Ph.D., Director of Engineering, is an expert in the development of software and hardware components for strong, precise, and fast-moving robots and, in particular, assembling such components into a robust and reactive robotic system. He specializes in research and development of software for high performance, contact-based manipulation and locomotion tasks, as well as leading a team of experts to do the same. Zapolsky was previously Co-founder and Chief Technology Officer at Silicon Valley-funded startup Dextrous Robotics, where he developed innovative robotics hardware and software for use in the logistics space, specifically for package handling. His team deployed robust software and hardware components to the field for strong, precise, and fast-moving robotic systems often only seen in advanced research labs. He holds a Ph.D. in Computer Science: Robotics and A.I. from The George Washington University.

B.3 Financial Performance

Dynaloco was initially funded through personal investments by its cofounders. Using these funds, Dynaloco has successfully grown its contract manufacturing and R&D business, generating approximately $966K in revenue as a result of contracting and consulting work in the past three years. The NSF Phase I award that precedes this application has allowed us to pursue developing SailVane, our first internally developed robot for commercialization.

C. Product/Technology & Competition

C.1 Customer Needs & Value Proposition

SailVane is a proposed marine-grade ASV designed to open a completely new market space in the world of ocean data collection and exploration. SailVane will be designed to cost an order of magnitude less than existing USVs for extended missions on the open ocean, creating new opportunities for:

- Operation of large USV fleets
- Fine temporal and spatial data resolution
- Cost-effective station-keeping (buoy replacement)
- Companies, researchers, and educators on tight budgets

Low cost will be achieved via small size and mass production. Small size can create energy and navigation challenges; solutions include a directionally stable steering system, intermittently powered sensors, controls, and communications, and satellite-linked navigation system optimized to take advantage of predicted weather and currents. Our technology can be deployed virtually anywhere in the ocean, is small (2 meters in length), 100% wind- and solar-powered, and nearly silent. SailVane can be outfitted with sensors to fit a variety of customer needs. Due to its innovative sail arrangement, SailVane can maintain a navigational course without power for long periods of time, requiring only about 30 seconds of power every hour (averaging <1W power consumption). As a result, SailVane does not need a lot of solar panels, which is why it can be such a small and inexpensive vessel. SailVane's low cost makes it highly accessible: it can compete on cost with a small, instrumented buoy without the need for an expensive crewed mission to deploy it, and SailVane can be navigated and automatically retrieved, unlike a buoy. With SailVane, researchers will be able to deploy coordinated fleets, where before they were limited by cost to a few devices, allowing for more detailed data collection. SailVane will be within the budget of even the most cost-conscious customers, making the purchase of fleets of vessels highly feasible and cost-effective.

C.2 Customer Demands & Costs

Our cost model ($25K/year) was determined based on the bill of materials, current market conditions, and the results of our customer discovery process. In general, customers are looking for less expensive solutions to collect data at scale. Typical sensor units used for data collection are referred to as "buoys", and so we use these as a basis for price comparison. Note that SailVane would be considered a "specialized buoy" as it can be autonomously controlled.

The cost of an oceanic monitoring buoy can vary widely based on its specifications, the type and number of sensors it includes, its construction, and additional features such as satellite communication. Below is an estimated cost range based on distinct types of buoys:

- "Basic Buoys" are simple buoys with basic sensors for parameters like temperature, salinity, and wave height with an estimated cost of $10,000 to $50,000.
- "Intermediate Buoys" are more advanced buoys equipped with additional sensors for parameters such as currents, dissolved oxygen, and pH levels with an estimated cost of $50,000 to $150,000.
- "Advanced Buoys" are high-end buoys with a full suite of sensors for comprehensive oceanographic monitoring, including meteorological sensors, carbon dioxide sensors, and more with an estimated cost of $150,000 to $500,000.
- "Specialized Buoys" are custom-built buoys for specific research needs or military applications, which might include advanced communication systems and autonomous capabilities with an estimated cost of $500,000 to over $1,000,000. While some of these costs can be attributed to expensive sensors onboard, a substantial portion of the high price tag is spent making a buoy controllable and robust at sea.

Our system, despite its low-cost of just $5K to produce with a basic sensor installation, can be categorized as a "specialized buoy" due to its autonomous capabilities and fitness for any ocean deployment. This high-performance to value ratio should make our product highly sought-after compared to other buoy types, as companies that historically rely on simple buoy deployments will now have enhanced data capabilities with lower operational costs. By fitting seamlessly into the existing industry structure and addressing key market needs with our SailVane system, we aim to significantly contribute to oceanographic research and monitoring, driving scientific and commercial advancements.

By offering our buoys at $25k/ year, we are able to cover the cost of materials, data collection, maintenance costs, potential for vessel loss, and overhead while still maintaining a healthy profit margin on average over the course of the boat's lifetime. We expect that with reasonable maintenance, an average boat life-span is around 5 years, with an estimated 10% failure rate due to boat loss or other issues.

C.3 Competition & Competitive Advantage

SailVane's competitive advantage comes from its low-cost, autonomous navigation capabilities, and swarm capabilities. No other technology on the market offers all three of these attributes, making SailVane a innovator in the space.

Technology	Vessel Type	Cost	Endurance	Self-deployed and retrieved	Remote navigation	Small footprint
DYNALOCO autonomous machines	**SailVane**	**$25k/ year**	**12 months**	**YES**	**YES**	**YES**
L3HARRIS™	Arabian Fox ASV	>$1M	<24 hours	YES	YES	NO
TELEDYNE MARINE Everywhereyoulook™	Slocum Sentinel Glider	$250k-350k	12 months	YES	YES	YES
NOAA	Atlas Buoys/ Argo Floats	$60k	variable	NO	NO	YES

SAILDRONE	Saildrone Explorer	$2.5k/day	12 months	YES	YES	NO
Offshore Sensing AS	Sailbuoy	$175k	6 months	NO	YES	YES

Among the available USVs, there is much variety in propulsion method, use cases, and technologies. A large portion of the market is currently occupied by large, expensive vessels, such as those produced by L3 Harris ASV, which use propeller engines, expensive and powerful electronics, and have highly limited endurance (<24 hours), making them unsuitable for long-term oceanic data collection. Boats like the Wave Glider.[11] Slocum Glider,[12] and Seaglider,[13] are examples of boats which use non-traditional propulsion methods and therefore can achieve longer endurance, but are all very expensive - the Wave Glider costs $250,000-$300,000 before adding sensors.[14] Buoys like Atlas buoys and Argo Floats cost on the order of $60,000 apiece and require a ship to deploy and retrieve them. Drifter buoys can cost on the order of $500, but since their position cannot be controlled, they have a limited usefulness and lifespan, and also require a ship to deploy. In comparison, SailVane is inexpensive to deploy and retrieve, and can be deployed from shore without any special equipment. There are some existing robotic sailboats in a range of design and commercialization stages. Notably, Saildrone[15] and Sailbuoy by Offshore Sensing[16] have logged thousands of hours of tests and are currently for sale to customers, but are extremely expensive: Saildrone rents its Explorer model for around $2,500 per day and carries over $100,000 worth of electronics alone,[17] while Sailbuoy costs around $175,000 per boat to purchase.[18] These autonomous robots cost less than renting and operating a crewed oceanic research vessel, but are still prohibitively expensive for smaller-budget research groups and organizations or for deployment in a fleet.

In contrast, due to its small and mass-producible nature, SailVane costs less than $5,000 per boat with basic sensors, and will be available for lease at $25k/year. At this time, no other companies have entered the small, mass-producible USV market. The combination of small size, low cost, and low power usage is not being publicly utilized by any of our competitors, and the possibilities for patentable technology emerging from our research is high. With a working, patented design, we anticipate a much larger market potential than exists for a more boutique USV, thanks to both the range of use cases and low cost. For the cost of a few days of renting and operating a crewed oceanic vessel, customers will be able to purchase and operate a small fleet of SailVanes for months or years at a time. For the first time, customers without large budgets will be able to conduct their own research using coordinated fleets of small sailboats, enabling new research, expanded environmental monitoring, and new discoveries about our climate and oceans. We aim to do for oceanic research what small quadcopters have done for aerial surveying and create an entirely new market for small, inexpensive ocean drones for both small- and large-scale survey missions.

C.5 Intellectual Property

SailVane's most valuable IP includes its autonomous navigation software as well as its swarm optimization algorithms. These technological aspects will be protected via trade secrets as is customary for algorithms. Any patentable IP generated as the result of this project will be protected to the full extent possible. Technology areas we anticipate being able to patent include the manufacturing process and any new hardware developed as part of the system. The protection of these assets will be critical to maintaining our competitive edge in the market.

D. Finance & Revenue Model

D.1 Finance Plan

Dynaloco plans to finance the R&D as well as the commercialization of the SailVane through a combination of non-dilutive funding and private investment. NSF funds will be used to continue to fund the technical development needed to de-risk the vessel for ocean missions. Private investment will support R&D as well as equipment upgrades for manufacturing and commercialization activities such as sales.

Funding Source	Type	Amount	Year
NSF SBIR Phase II	Cooperative Agreement	$1.25M	2025-2026
NSF Phase II B	Supplement	$500K	2027
Seed Round	Private Investment	$3M	2025

D.2 Access to Funding

We are currently in early discussions with potential investors around our SailVane technology. This effort is being spearheaded by Sam Zapolsky, who was previously involved in an 8 million raise for his prior startup. Raising outside capital will be critical to allowing us to expand our team and scale our operations to the level needed to sustainable on revenue alone. This capital will also allow us to pursue the Phase II B supplement offered through NSF, where will be able to do additional R&D on the SailVane technology.

D.3 Revenue

Our primary revenue stream will be an annual lease model for the SailVane, priced at $10K or $25K depending on the type of customer (non-profit research vs. commercial use). After several years of growing success with this model, we will then also explore a direct sales approach with marine monitoring companies for distribution (e.g., Teledyne). This would be a strategic partnership focused on increasing our distribution scale by allowing the partner to provide their own custom sensor suites for their customers.

We expect our first SailVane revenue to occur in Year 2 of the NSF Phase II, where we plan to pilot our technology with academic research partners. This will be critical to demonstrating the capabilities of the boat in a real-life use case, which in turn can be used to market our technology to larger commercial customers who are more willing to pay a premium for our service. Immediately following the conclusion of the Phase II project, we expect revenues from our first commercial entities which we expect will be from the Oil and Gas industry based on our current relationships in this market (E.g., Shell). With larger commercial customers, we expect that the average fleet size will be around 10 boats, which will enable taking advantage of our multi-boat and swarm data collection capabilities. On a year to year basis, we expect an 80% lease renewal rate and a technical labor force consisting of production and integration engineers that will grow to keep up with manufacturing and customer needs. In our operating costs we also account for 10% boat loss rate to build a buffer for the need for potential boat replacements (note that this is loss rate is higher than expected and was chosen as a buffer in case of unexpected issues). In preparation for scaling our operations to serve our higher paying customer segments, we expect to make infrastructure and manufacturing equipment upgrades at the end of the Phase II project. To cover these extra expenses, plus the lack of revenue in Year 1, we plan to raise a seed round of $3M. This raise will also allow us to access NSF Phase II B matching funds to support follow-on R&D. These assumptions are reflected in the pro forma below.

D.4 Pro Forma

Pro Forma Income Statement					
	Dynamic Locomotion - SailVane				
Pricing Projections	**Phase II (2025)**	**Phase II (2026)**	**2027**	**2028**	**2029**
Leasing-based revenue					
Academic/non-profit research customer annual lease cost (per baot)	$ 10,000.00	$ 10,000.00	$ 10,000.00	$ 10,000.00	$ 10,000.00
commerical customer annual lease cost	$ 25,000.00	$ 25,000.00	$ 25,000.00	$ 25,000.00	$ 25,000.00
Direct boat sales (strategic distribution partnerships in marine monitoring space)					15,000
Revenue					
Sales					
Early Pilots (academic research, nonprofit monitoring compnies)	-	5	10	20	30
Early Commerical Production Customers (Oil and Gas, Fisheries)		-	30	70	150
Late Commercial Production Customers (Defense and maritime surveillance)		-			100
Direct Sales	-	-	-		100
Revenue					
New leasing revenue	$ -	$ 50,000	$ 850,000	$ 1,950,000	$ 5,550,000
Recurring leasing revenue	$ -	$ 50,000	$ 890,000	$ 2,662,000	$ 7,679,600
Direct sales revenue	$ -	$ -	$ -	$ -	$ 1,500,000
Total Annual revenue	$ -	$ 100,000	$ 1,740,000	$ 4,612,000	$ 14,729,600
Total Production sales (Revenue)	**$ -**	**$ 100,000**	**$ 1,740,000**	**$ 4,612,000**	**$ 14,729,600**
SBIR/STTR Phase II + IIB	**$ 625,000**	**$ 625,000**	**$ 500,000**	**$ -**	**$ -**
Total Revenue	**$ 625,000**	**$ 725,000**	**$ 2,240,000**	**$ 4,612,000**	**$ 14,729,600**
Cost of Goods Sold (COGS)					
Boat retrofit equipment	-	25,000	200,000	450,000	1,900,000
Fixed install cost	-	3,750	30,000	67,500	285,000
Boat maintenance	$ -	$ 1,000	7,200.0	$ 21,600	$ 82,400
Technical Labor	$ -	$ 300,000	$ 600,000	$ 1,000,000	$ 3,000,000
Total direct cost			$ -	$ -	$ -
Total COGS	**$ -**	**$ 329,750**	**$ 837,200**	**$ 1,539,100**	**$ 5,267,400**
Gross Product Margins*					
Product Margin	$ -	$ (229,750)	$ 902,800	$ 3,072,900	$ 9,462,200
Product gross Margin %	**#DIV/0!**	**-230%**	**52%**	**67%**	**64%**
Operating Expenses					
				$ -	$ -
Sales staff	$ -	$ 180,000	$ 450,000	$ 500,000	$ 900,000
Administrative (G&A)	$ 87,000	$ 234,000	$ 600,000	$ 1,050,000	$ 3,000,000
R&D	$ 600,000	$ 800,000	$ 300,000	$ 300,000	$ 350,000
Legal	**$ 10,000**	$ 20,000	$ 30,000	$ 40,000	$ 800,000
10% Lost boat replacement	**$ -**	**$ 32,975**	**$ 83,720**	**$ 153,910**	**$ 526,740**
Facilities and Euipment	$ 30,000	$ 340,000	$ 40,000	$ 65,000	$ 100,000
Total Selling General and Administrative	**$ 727,000**	**$ 1,606,975**	**$ 1,503,720**	**$ 2,108,910**	**$ 5,676,740**
Total Operating Expenses	**$ 727,000**	**$ 1,606,975**	**$ 1,503,720**	**$ 2,108,910**	**$ 5,676,740**
EBITDA	$ (102,000)	$ (1,211,725)	$ (100,920)	$ 963,990	$ 3,785,460
EBITDA Margin % (operating margin)	**-16.3%**	**-167.1%**	**-4.5%**	**20.9%**	**25.7%**
Cash Proxy					
EBITDA	**$ (102,000)**	**$ (1,211,725)**	**$ (100,920)**	**$ 963,990**	**$ 3,785,460**
+ Investments (Paid in Capital)	$ 3,000,000				
Net Addition (Subtraction) from Cash	$ 2,898,000	$ (1,211,725)	$ (100,920)	$ 963,990	$ 3,785,460
Year-End Cash Proxy	**$ 2,898,000**	**$ 1,686,275**	**$ 1,585,355**	**$ 2,549,345**	**$ 6,334,805**

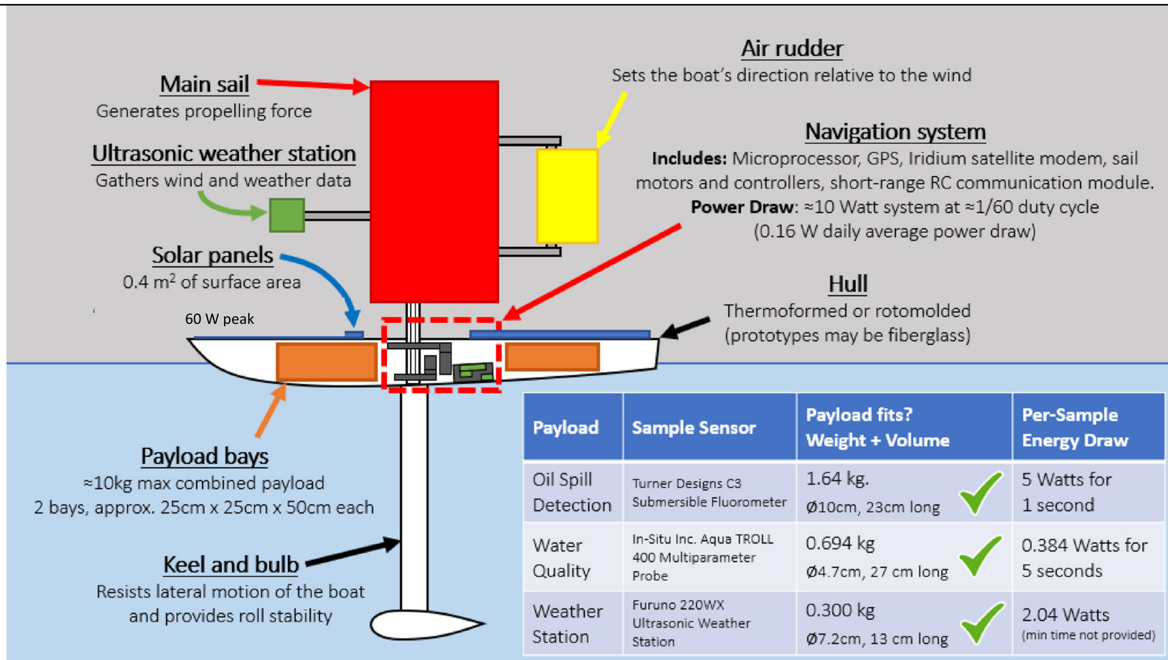
NSF SBIR Phase 1 Award # 2213250 – Final Project Report

Project Title: SBIR Phase I: Low-Cost Autonomous Sailboats for Long-Term Ocean Missions

SECTION 1: A SUMMARY OF THE RESEARCH, RESULTS AND THE ACTIVITIES

1.1 OVERVIEW

Dynaloco is developing SailVane, a small (2-meter), low-cost (<$5,000 bill of materials), autonomous robotic sailboat for *in-situ* oceanic data collection. The vessel uses an innovative new fixed sail arrangement and a "Weather Jiu-Jitsu" navigation system to overcome the key power and navigational challenges typically associated with small vessels.



Payload	Sample Sensor	Payload fits? Weight + Volume	Per-Sample Energy Draw
Oil Spill Detection	Turner Designs C3 Submersible Fluorometer	1.64 kg. Ø10cm, 23cm long ✓	5 Watts for 1 second
Water Quality	In-Situ Inc. Aqua TROLL 400 Multiparameter Probe	0.694 kg Ø4.7cm, 27 cm long ✓	0.384 Watts for 5 seconds
Weather Station	Furuno 220WX Ultrasonic Weather Station	0.300 kg Ø7.2cm, 13 cm long ✓	2.04 Watts (min time not provided)

Figure 1. Overview of the SailVane

These innovations allow SailVane to perform long-term navigation and stay in a user-defined location in the open ocean, making it suitable for oceanic research applications. When deployed in a fleet, SailVanes can be used to create a network of sensors to enable large scale data collection on the ocean at a much lower cost than existing remote sensing solutions. SailVane has a payload bay large enough to carry a broad range of sensors, including water quality sensors (such as temperature, conductivity, pH, chlorophyll concentration, and dissolved oxygen), weather sensors, modems for data relay from underwater bioacoustics sensors, and fluorometry sensors for detecting hydrocarbons in the water. There are a broad range of applications for SailVane, including performing oceanic research, environmental impact studies, national security missions, assisting oil spill cleanups, monitoring fisheries, collecting weather data, and augmenting existing research tools and methods.

Phase I work so far has accomplished the design and testing of the prototype, demonstrating the feasibility of our approach. We integrated basic sensors and tested the autonomous navigation system in a lake setting with winds from under 2.5 to over 10 m/s. In parallel to our hardware effort, we made significant progress on the software side of the technology, building a user interface for global SailVane waypoint entries and data reporting through satellite communications, as well as developing navigation and trajectory optimization algorithms. Phase II will build on this foundation by improving the SailVane boat design (with a focus on manufacturability and robustness), integrating a broader range of sensors, and building out our swarm optimization technology for fleet deployment. To validate these improved versions of SailVane, we aim to enter several research pilots during the Phase II project; this will allow us to conduct a more realistic test of the boat's operation in preparation for our higher-paying commercial customers. By the end of Phase

II, we expect to have a robust, commercially viable SailVane system ready for commercial deployment. Our comprehensive field testing in various marine environments will validate the system's performance and reliability. This will position us to offer an unprecedented solution for oceanographic data collection, reducing costs and increasing accessibility for researchers, industry, and government agencies. Our innovative approach promises to transform how oceanographic data is gathered, significantly contributing to marine science, environmental monitoring, and resource management.

1.2 SailVane

Two key innovations underlie the SailVane technology. The first innovation is a novel sail arrangement that makes the boat directionally stable relative to the wind without active electronic control; the vessel can maintain a navigational course without power for long periods of time, requiring only about 1 minute of power every hour (averaging <1W power consumption). This eliminates the need for large solar panels or batteries, thus addressing the space constraints of smaller vessels. The second innovation is a novel "Weather Jiu-Jitsu" system that exploits the spatial and temporal variance in the weather and uses local weather data to direct the boats to "go with the flow", using currents and weather conditions to assist its navigation, rather than treating them as obstacles. For example, the Gulf Stream is the fastest surface ocean current in the world, traveling northeast at speeds as high as 2.5 m/s, faster than SailVane's 1 m/s typical speed. However, the Gulf Stream has local eddies in which some pockets of water that travel in the opposite direction of the main flow at speeds up to 0.25 m/s.[1] SailVane's "Weather Jiu-Jitsu" system will use the most up-to-date weather data and forecasts to optimize SailVane's trajectory and enable it to navigate between eddies, allowing progress in any direction.

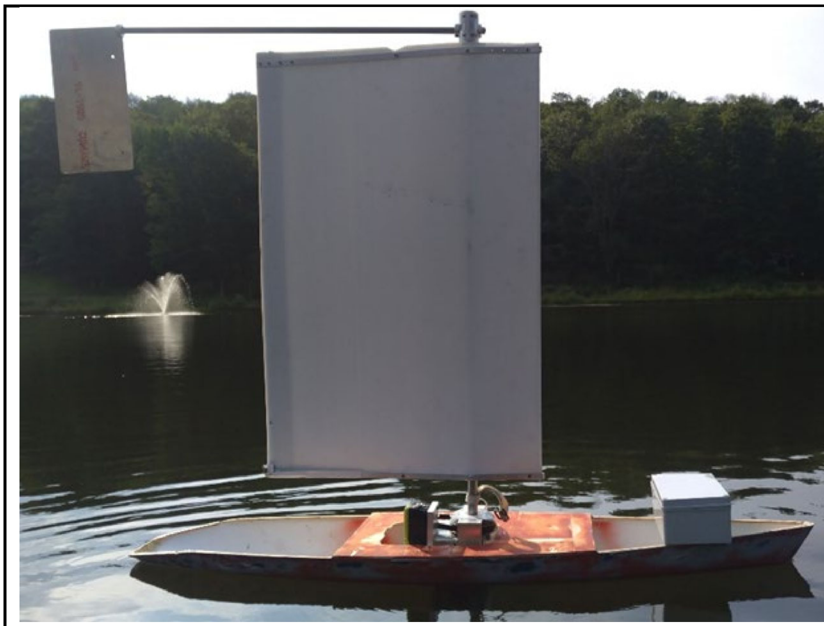


Figure 2. SailVane prototype developed and deployed in Phase I

Our vessels are designed to be robust and marine-grade with just two exposed moving parts, each with overload protection clutches, and will be able to withstand being hit by large waves, capsizing, and salt water for months on end. Critically, SailVane's low cost makes it highly accessible: it can compete on cost with a small, instrumented buoy without the need for an expensive crewed mission for deployment and retrieval, and with average development costs of $5,000 it is significantly less expensive than existing robotic Uncrewed Surface Vessels (USVs), which cost upwards of $100,000 apiece. Notably, SailVane is autonomous, making it an ASV (Autonomous Surface Vessel). With SailVane, researchers will be able to deploy coordinated fleets, where before they were limited by cost to a few devices, allowing for more detailed data collection. SailVane will be within the budget of even the most cost-conscious customers, making the purchase of fleets of vessels highly feasible and cost-effective.

1.3 PHASE I RESULTS: Design and build of an operational SailVane prototype

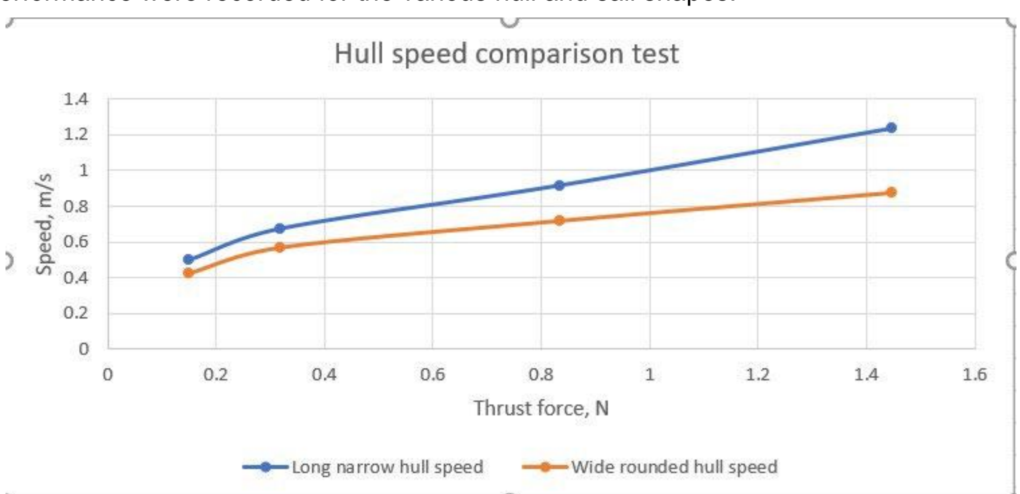
In Phase I, we sought to understand the best hull and sail shapes and materials for a more advanced design.

Prototype testing and construction:

1. **Indoor mini boat tests**. For hull shape design, we started with a fast-testing approach using 3D-printed and sealed boat hulls and keels, about 300 mm long. Then they were placed in a large water tank about 3 m long, 1 m wide, and 1 m deep.

Two types of testing were conducted:

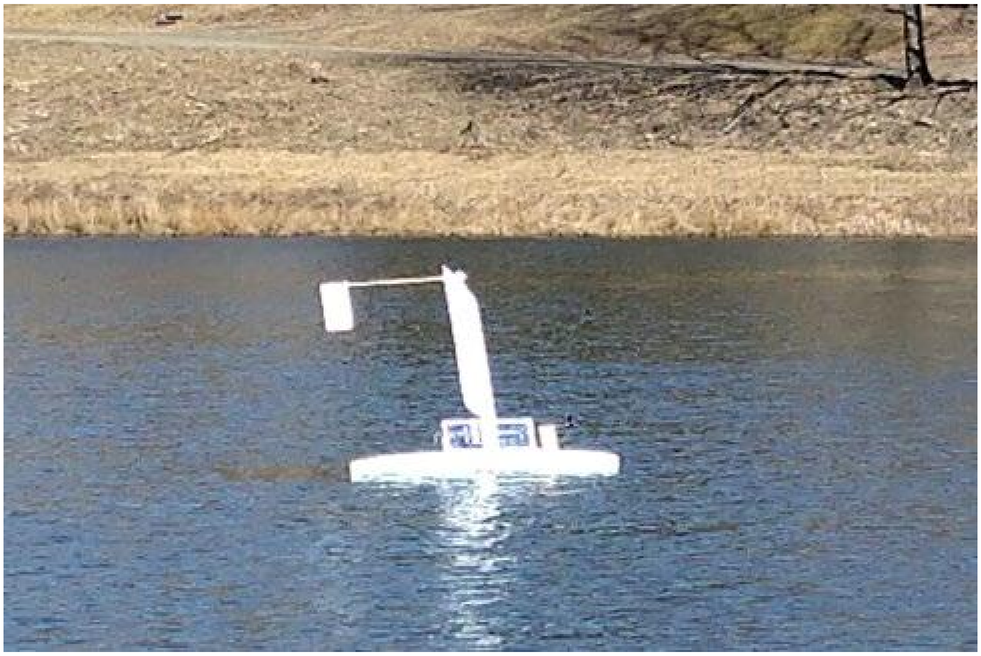
a) A fan-generated wind was applied, and the speed of the boat and general boat performance were recorded. Performance quality included stability of motion and upwind effectiveness.
b) A test setup with precision low-friction pulleys, a fine string, and a falling weight was used to pull the mini boats across the top of the water surface at a constant force. The speed and general boat performance were recorded for the various hull and sail shapes.



2. **Full size quick mechanical prototype.** Next, we built a full-scale test version of SailVane, but only mechanical parts – no electrical steering control. Instead, the sail and air rudder were set manually to various degrees, and then tested on a windy day in a local lake. Speed and upwind

capability looked excellent, but the boat didn't yet have a wind sensor and GPS position/velocity data.

3. **First powered prototype.** Then motors, radio control, GPS, magnetometer, accelerometer, and weather sensors were added for control and data collection.



Initial test of quick-constructed powered SailVane.

4. **Robust performance-test prototype.** A more robust, efficient, molded hull was used for an improved prototype SailVane, with better water protection and more reliable electrical wiring. The latest SailVane model has been tested in local lakes in a variety of conditions, from flat water and minimal wind to winds above 10 m/s and choppy lake waves. It is 1.5 meters long, 2.3 meters tall (including the keel and mast) and weighs 25 kg.

Materials: In Phase I, we sought to understand the best hull and sail materials for the proposed design. The initial concept involved HDPE molded shells for both hull and sail, with a thinner outer layer for the sail and a rigid closed-cell foam inside to increase strength and prevent buckling in high winds and large waves. Further effort suggested that the sail at least, and potentially the hull too, would be stronger and more reliable to manufacture using Surlyn ionomer ethylene sheet and foam. In either of these two material options, the goal is to take advantage of the mass production capabilities of a smaller boat with molded and formed plastics, instead of the expensive manual assembly techniques needed for large boats. Furthermore, these polymers in many cases are highly resistant to both weather and biological contamination, compared to most full-size boat materials. They also have extensive ocean testing in buoys and dock protective foam, giving us additional support that the hull and sail will survive well for many months of ocean missions.

1.4 PHASE I RESULTS: Development of client-side and server-side application interface for SailVane

To support communication to and from the SailVane we have completed significant work on the back and front end of the software and servers. A summary of developed features is below:

Client-side app: The client side application has been developed to an almost feature-complete degree, already in an MVP state. It is able to download the course data of a SailVane from our server based on the user ID to display on a 3D representation of the world. It can also be used to modify or plot new courses that are then uploaded to our server to adjust the control commands sent to the SailVane. Currently this app is designed for PC use, but can be deployed to support smartphones and other handheld devices as well.

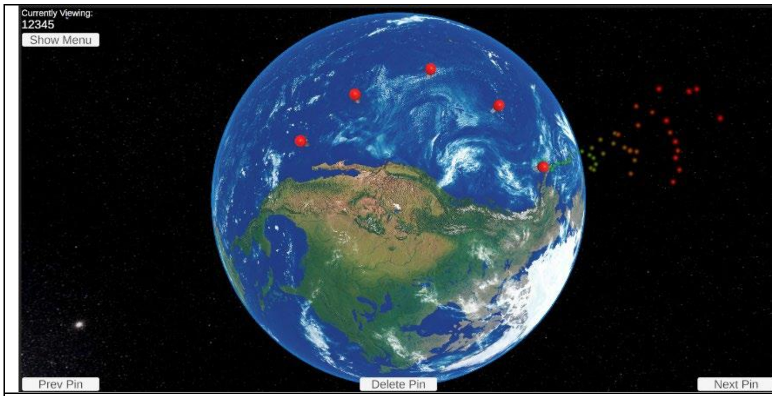


Figure 3. Full global view of prior course path and locations, and requested waypoints for the future navigation path, for a particular SailVane (serial number shown) for a particular user. If the user zooms in, the display will show many more details of the boat path and locations.

Server-side app: On the server side, python was used to create the needed interactions with the client-side app. The server stores incoming Iridium incoming data of the SailVanes currently at sea, and then relay the data to the PC and phone apps, while also allowing the client to save planned SailVane waypoints in the server to update navigation goals.

Server code: Apart from simply allowing the client to download the SailVane information, the server also handles communication with the Iridium satellite network. Using HTTP Posts, it is able to both send and receive messages from any SailVanes currently deployed on the water. Data from the SailVanes is stored into an online database to keep track of their current location and status, while also saving the planned course for each SailVane. This allows control code to be easily inserted into the server, as it already has the ability to send messages to specific SailVanes.

Website: As part of the above system components, we also set up a web server to communicate between Dynaloco, Iridium satellite communications with the SailVane boats, and with users for navigation requests and received data for them from the boat sensors. The server is able to host the navigation system that was designed as part as Phase I; the hosting connection will be finalized during Phase II.

1.5 PHASE I RESULTS: Development a validated computational model which, given the angles of the sails and the current weather conditions, can predict SailVane's velocity.

Our computational model for the SailVane was developed in the Drake[1] simulation library, using the C++ API. Drake, though typically used for simulating rigid body dynamics with frictional contact, has extensively validated tools for numerical integration and optimizations that lend themselves well to efficient computation of controlled electromechanical systems with few degrees of freedom.

The second order ordinary differential equation governing the motion of the sailboat is implemented as a Simulink[2]-like System within a Diagram of interconnected Systems forming the full model of weather, controller, boat, and integrator (below).

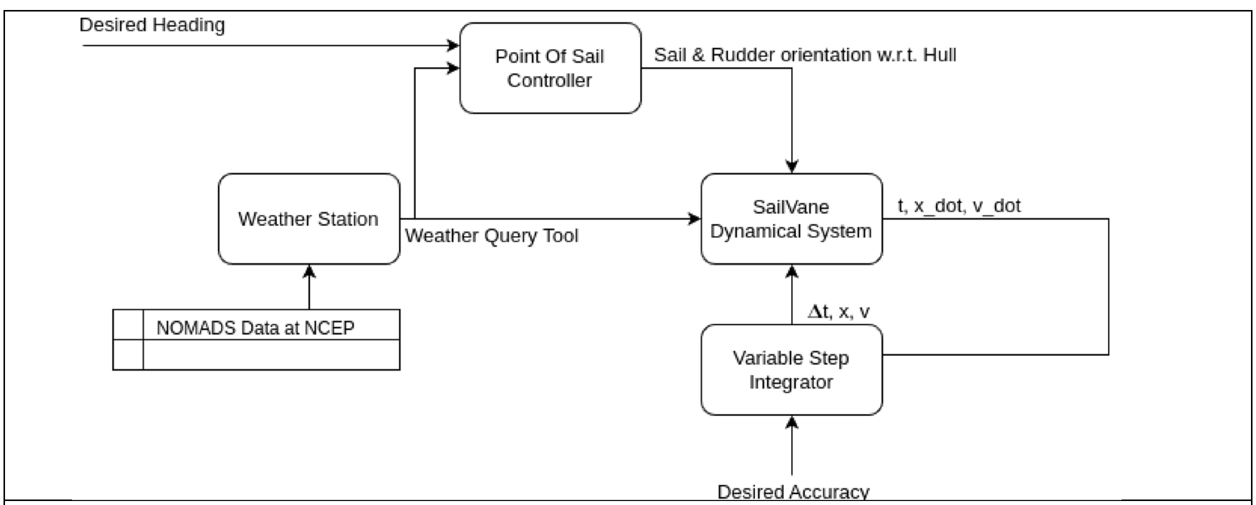


Figure 4. Overview of interconnected systems used with SailVane

Using this framework, we simulated several runs for one week of virtual time or until landfall. A data point is plotted at the current coordinate of each boat for every hour of virtual time. For example, at latitudes 25°N,30°N, 35°N, 40°N each, 1000 starting points are uniformly distributed between longitudes 290°E and 340°E (Figure 5)

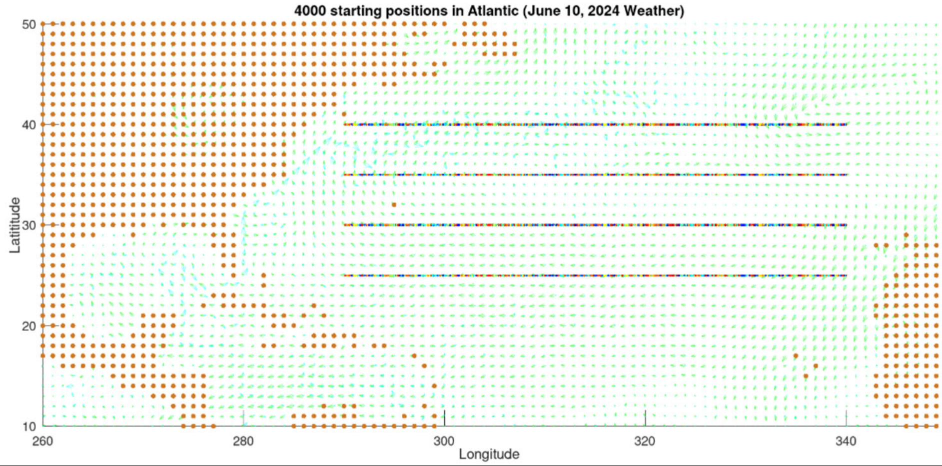


Figure 5. Simulation results. 1000 boat runs from four different latitudes.

Weather conditions (wind and ocean currents) are shown as a normalized quiver plot, in the following illustration (Figure 6). Where green shows surface wind velocity, cyan shows ocean currents (right), a lone brown dot (land) in the referenced figure is Bermuda. The SailVane's navigation system uses live weather data, like the one presented here to determine its passively-stable path between updates where it sets it sail and rudder angles. This dense weather data can be additionally augmented with wave and wind shear data to further hone the dynamical model.

Latitude	Simulation duration (wall time) for 1 week of virtual time (1000 traces on 64 cores)
40°N	5.0 min 30.844 s
35°N	10.0 min 29.940 s
30°N	1.0 min 35.565 s
25°N	0.0 min 50.412 s
Total	18.0 min 26.760 s (real-time rate per core: 3.415×10^4:1)

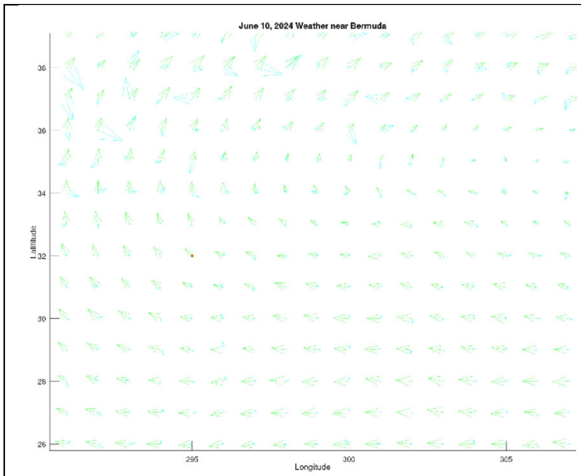


Figure 6. Simulated weather condition quiver plot.

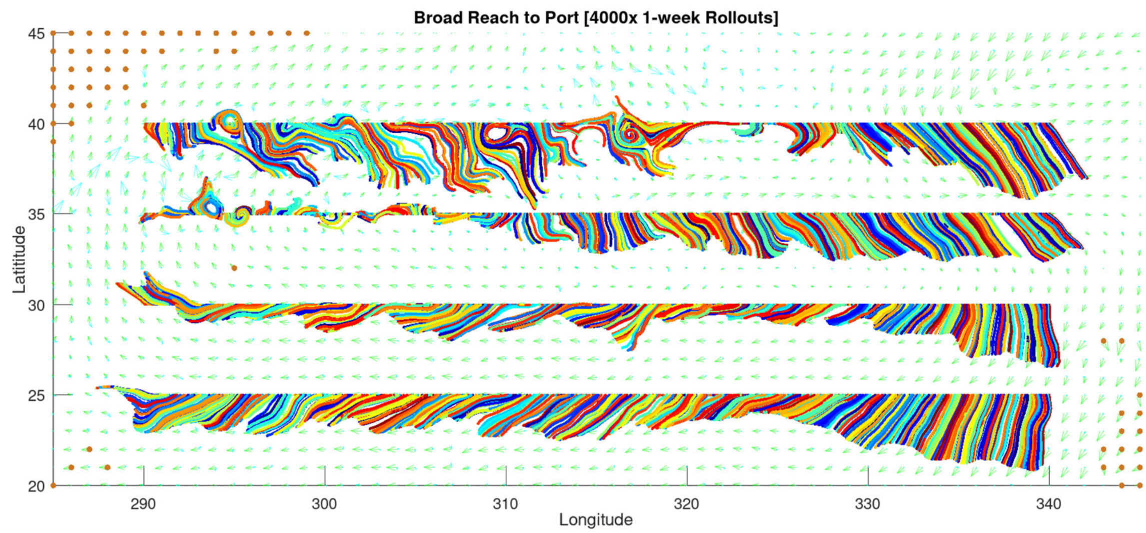


Figure 7. This plot of one-week rollouts shows us a stream plot of the SailVane’s at sea trajectory with a fixed command. Plots such as this help us characterize the reachability of certain areas on the map and the complexity of various weather conditions which affects planning time and fidelity.

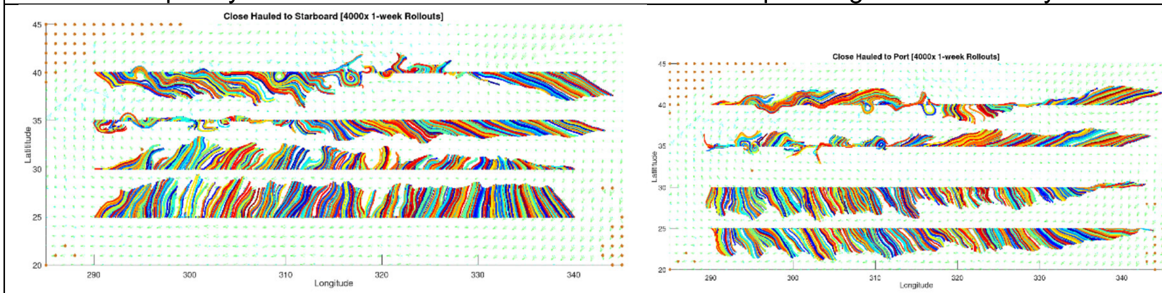


Figure 8. Representative Closed Haul to Starboard and Closed Haul to Port one week sea trajectories

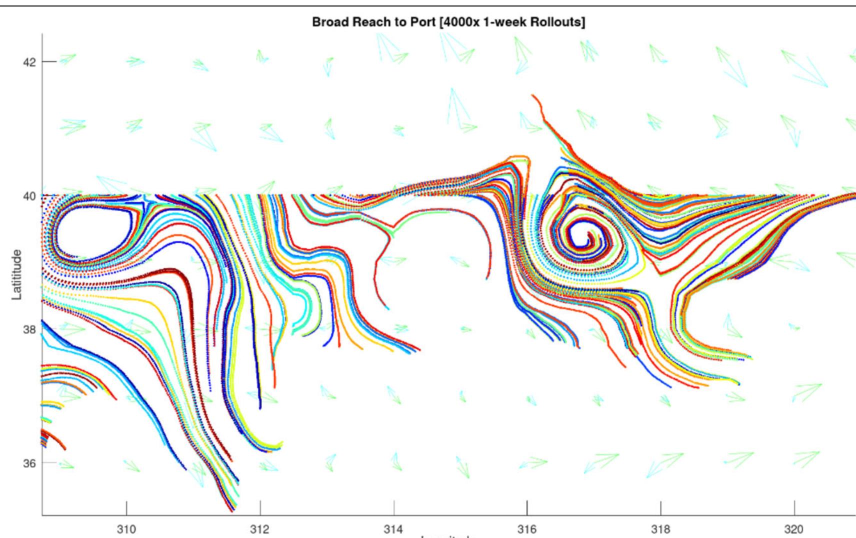


Figure 9. This figure focuses on a particularly complex weather pattern where an eddy current and strong winds interact. The resulting paths of boats under the same command with different initial conditions demonstrates the chaotic behavior of accurately observed weather patterns on a sailboat, motivating a need for controllable buoys for ocean monitoring.

From this simulation study we were able to determine following which will be used in future development efforts:

1. The second order ordinary differential equation governing the boat's motion behaved chaotically when operating in a system of ocean winds are currents. A predictive model of a passively-sailed buoy will not be sufficient to reach a destination over long time intervals. This is a statement that goes beyond the unpredictability of changing weather patterns, even under conditions of perfectly known weather, sailboats generally require feedback (and not a precomputed open-loop plan) to behave predictably.
2. More turbulent weather results in more computationally intensive simulation, as spatially noisy weather precludes taking long, low error integration steps.
3. We are ostensibly capable of accessing any coordinate in the addressed Atlantic region (over the July 10-17 study period), so long as it has either non-zero wind or non-zero current.
4. The maximum hull speed of the simulated 1.5 meter-long boat is, as predicted, approximately 1.5 m/s. This maximum hull speed, while not fast, also limits the effect of excessive winds on the boat and allows us to use a significantly smaller sail to propel the craft—reducing lift-induced and frictional drag on the production ASV. (Hull speed can be expressed as a simple mathematical formula 1.34 X the square root of the length of the waterline (HS = 1.34 x √LWL). For instance, if a cruising sailboat has a waterline length of 36 feet, she should be able to sail 1.34 x 6, or approximately eight knots.)

1.6 PHASE I RESULTS: Simulate SailVane's navigation. Predict the navigation performance metrics of the boat.

For navigation, we used an adaptation of the common trajectory optimization approach "Direct Transcription". We modified the approach to permit the number of integration steps between break points to be greater than one and the duration of each time segment is left open as a decision variable of the optimization problem. Direct Transcription[3] comes from the class of Multiple Shooting trajectory optimization problems. Multiple shooting is advantageous to our development because, as has already been demonstrated, we can evaluate the Direct Transcription constraint for each segment of the trajectory concurrently, as their evaluation is not coupled within one optimization update.

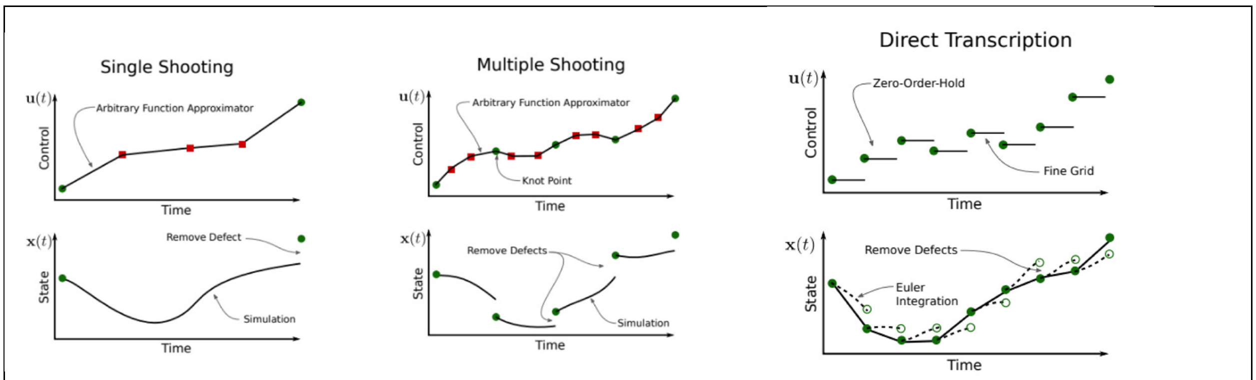


Figure 10. Trajectory Optimization Problems Credit: Matthew P. Kelly, Cornell University[3]

Dynaloco's software makes use of the mathematical program solvers available through MIT's Drake[1] simulation library that implements its multiple shooting problems using the IPOPT[4] library.

A brief outline of the method.

First, equally spaced (time and spatially) breaks are placed between the requested start and end coordinates, to create a seed *trajectory* of boat coordinates and commands, implemented as first order hold (linear function between time breaks) and zero-order hold (constant value between time breaks) trajectories. The decision variables at each break are: 1) the command that is held constant between breaks, the point of sail; 2) The duration of time until the next time break; 3) the location of the next break.

These decision variables are modified through gradient descent until the constraint, the gap between the end of the previous segment--- calculated by simulating the SailVane for the segment duration--- and the start of the next, is reduced to zero. Once the constraint is zero, the resulting trajectory of commands describes the controls that can be used to follow the resulting trajectory of boat coordinates. Graphical illustrations of our trajectory optimization progress included below:

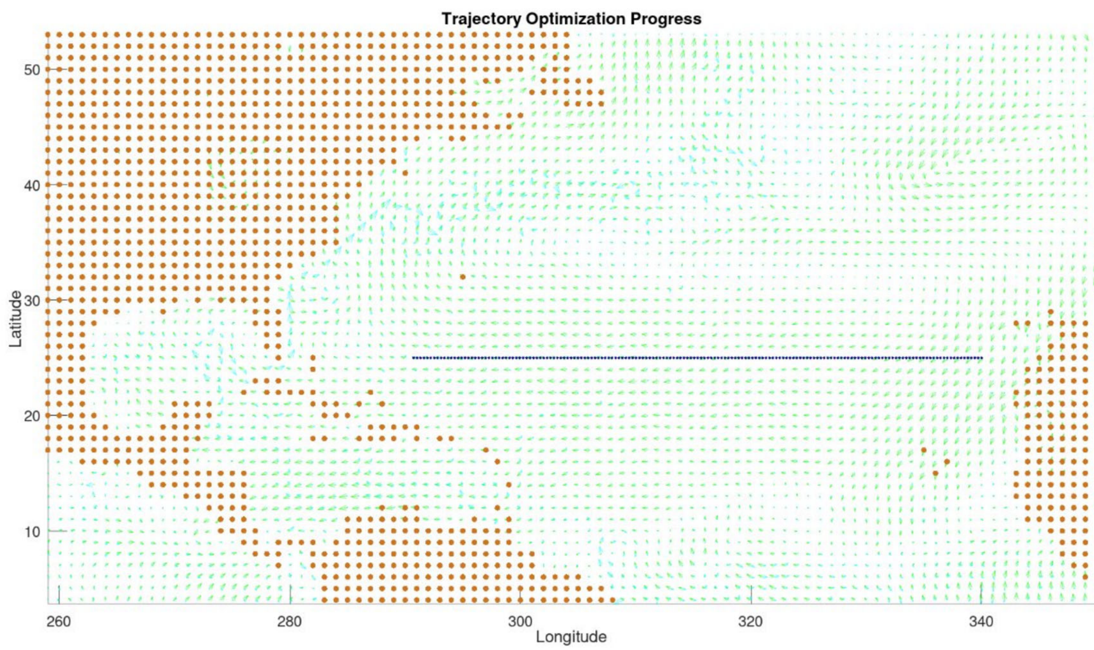


Figure 12. A plot of the seed trajectory provided to the trajectory optimization, the boat is initially commanded to follow a straight path from start to end points and follows a gradient descent approach to join the trajectory segments by changing rudder and sail commands and waypoint positions while following the physical constraints imposed by the dynamics of the system (e.g., cannot travel directly upwind, maximum speed of the boat).

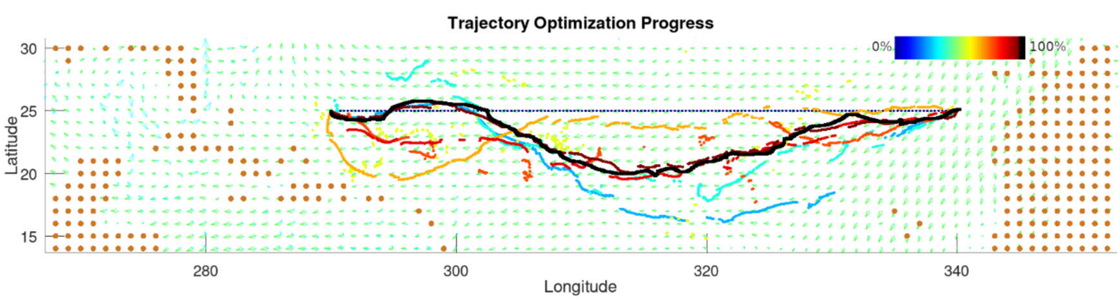


Figure 13. Illustration of wind and current streams overlayed on a map of the North Atlantic, near the east coast of the USA. (red) A target patrol zone. (yellow) Six autonomous SailVane drones at their most-recent GPS locations. (green) One-week rollout of planned heading via dynamic simulation (computable concurrently at approximately 2.5e5:1 real-time. These 6 1-week rollouts were computed concurrently on six threads in approximately 2.4 seconds).

1.7 PHASE I RESULTS: Live deployments of the SailVane.

In Phase I we were able to show that we were able to control the boat remotely and have it run during live deployments on a lake in relatively windy conditions. We were able to navigate the boat to a predetermined location using our navigation algorithms.

In the following section we show data from two live deployments of SailVane prototypes. Both deployments were on Cayuga Lake near Dynaloco's offices in Groton, NY

Figure 14. The deployment location (red) on Cayuga Lake near Dynamic Locomotion's offices in Groton, NY (green); Ithaca, NY also pictured (blue). The SailVane prototype before deployment.

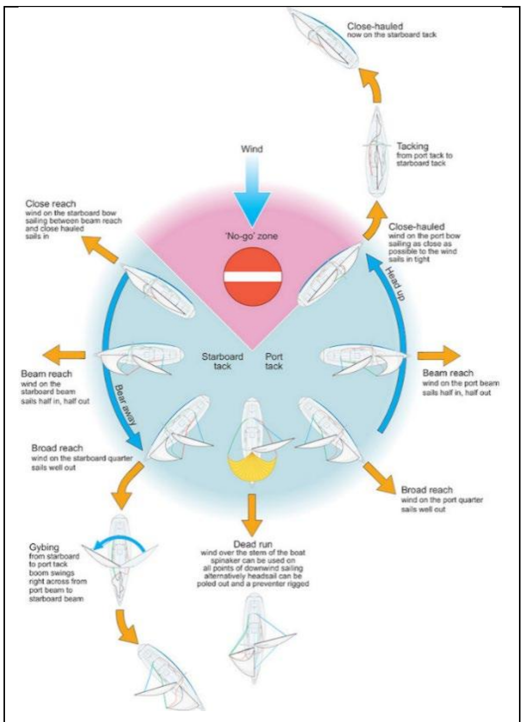


Figure 14. An illustration of the named "points of sail", which is shorthand for the boat's heading relative to the wind. These terms are used throughout the

During the deployment, telemetry data from round-hulled SailVane starting in the top left and following the "sail point" directives:

A. Dead Run
B. Broad Reach to Starboard
C. Close Haul to Port
D. Broad Reach to Starboard
E. Beam Reach to Port
F. Broad Reach to Starboard

In the is deployment, there were weather conditions of approximately 10 m/s (noon-3pm):

The boat's position was plotted during the deployment, and all velocity data was transmitted back to shore for analysis (Figure 15).

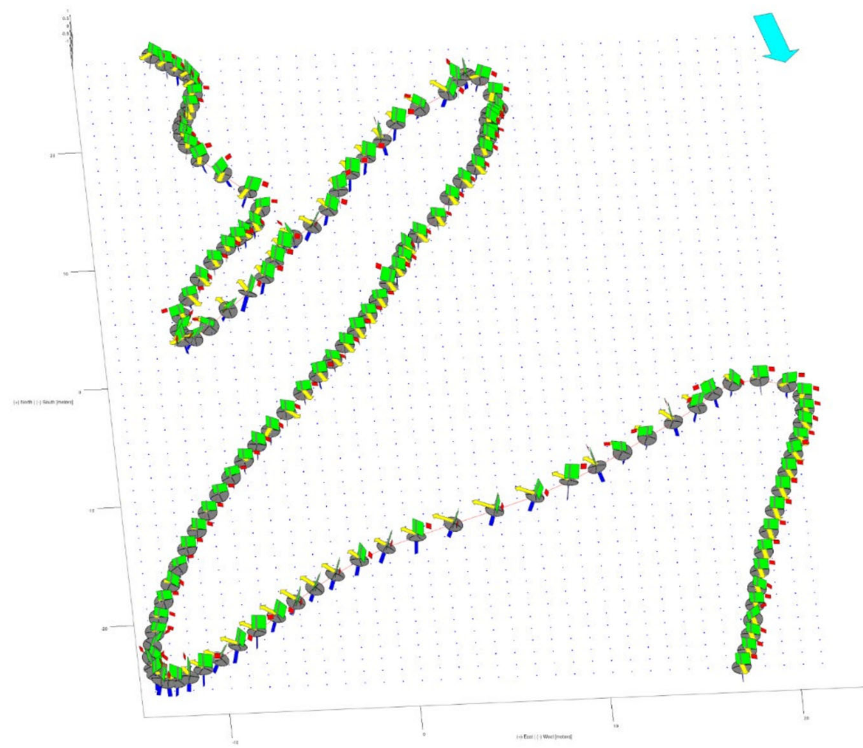


Figure 15. A marker is shown at 2-second intervals, indicating the boat's coordinates, orientation, instantaneous velocity (yellow), hull orientation (gray), sail orientation (green), wind vane rudder orientation (red), keel orientation (blue).

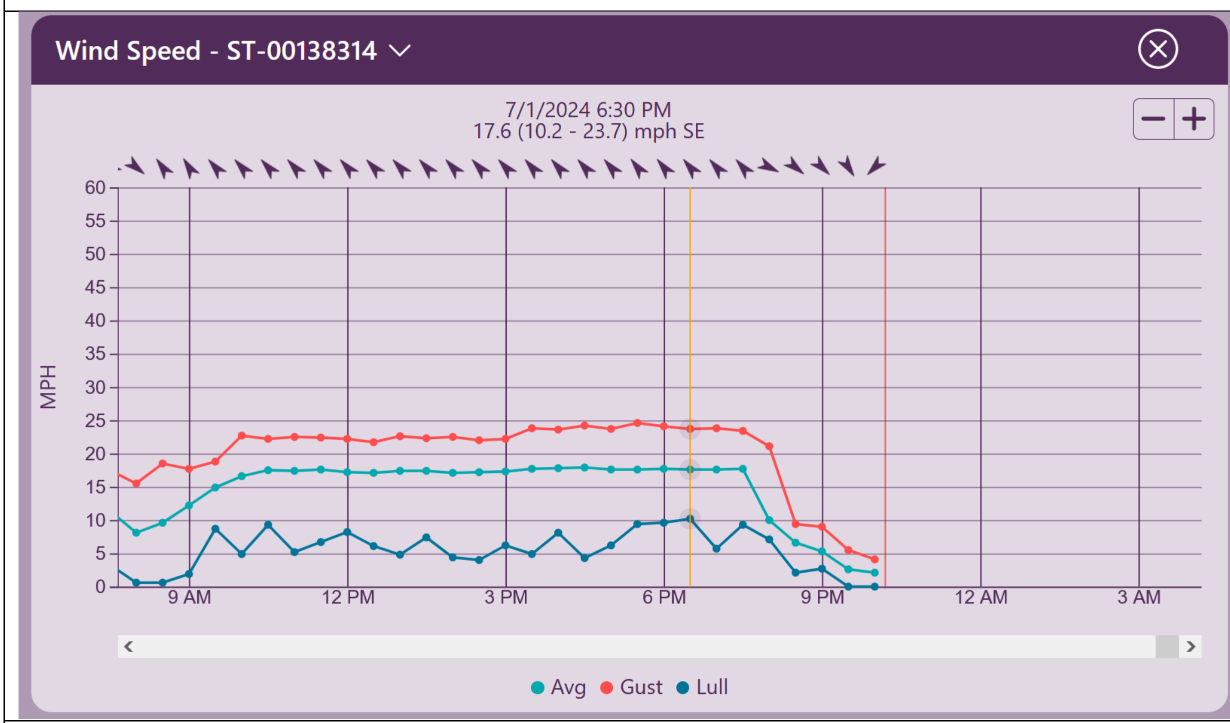


Figure 16. Wind conditions of deployment

Optimal control surface orientations for this test were determined via simulation of 100,000 boats (plotted below).

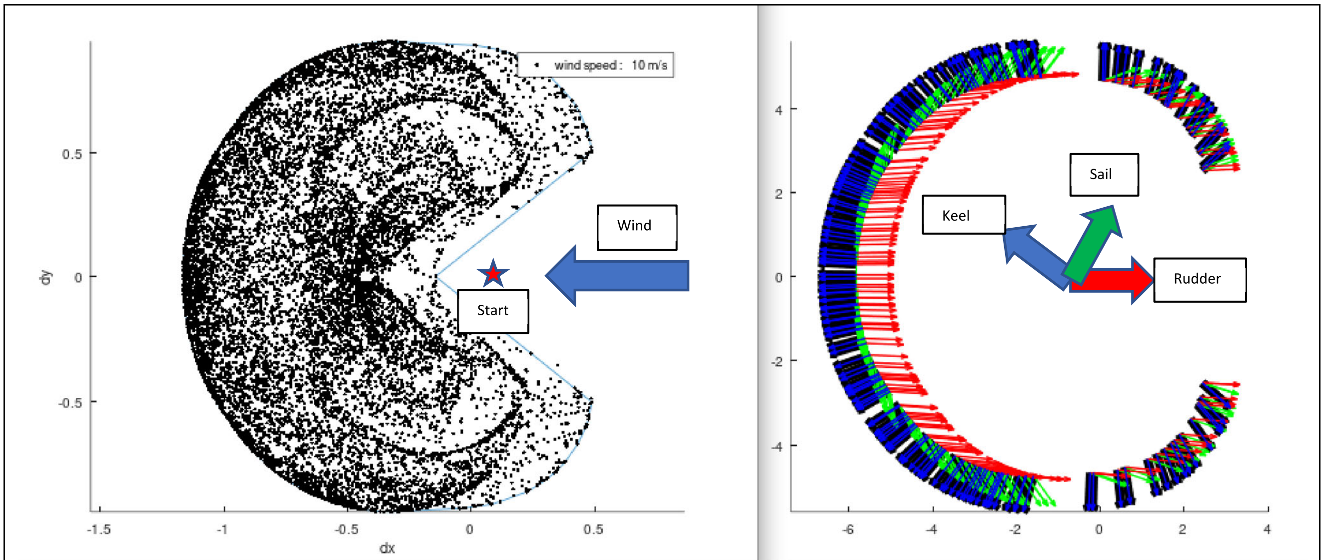


Figure 17. Control Surface orientation simulations

For the following points of sail control surface orientations, angles are reported relative to the sail's forward edge pointing to the bow of the ship (0°), with the rudder (wind vane) trailing behind it toward the stern with its front edge pointing to the bow, also at 0°. These zero positions are depicted in figure 2.

Point of Sail	Rudder angle to Keel	Sail angle to Rudder
Close Hauled	39.64°	12.86°
Beam reach	85.85°	14.27°
Broad reach	127.75°	53.40°
Dead Run	180°	90°

This result indicates that we can successfully deploy and test our control surface designed (airfoil shapes) in simulation and expect our generated control strategies to map into the real platform.

SECTION 2: PROBLEMS ENCOUNTERED AND METHODS OF RESOLUTION

We knew that the sail size would need to be small for survival in very high winds, but we were surprised that a large sail also had no apparent benefit, and in fact resulted in less efficient performance, even at modest wind speeds like 5 to 10 m/s. Small boat designs have a low hull speed, and thus they reach their maximum speed in their desired heading with very little lift force from the sail. Early on in our development we were under the impression that the sail we used would scale similarly to the hull of a larger vessel, but instead we found that the sail could be much smaller than predicted, as a larger sail contributes more drag downwind than lift it provides for sailing upwind. In response, we have designed more recent sailboats with better-scaled sails to the size of the vessel that account for this asymmetric scaling issue, and our ocean-ready boats will have even smaller sails, though with some minor boat speed reduction in very low wind speeds.

SECTION 3: PROBLEMS REMAINING / UNFILLED RESEARCH OBJECTIVES

In the remaining time of our project period, we plan to continue making progress on all aspects of the technology. Priorities are to:

- Continue to hone computational model within situ testing.
- Improve hull and sail design to maximize upwind performance and improve navigation at sea with high winds.
- Minimize leeward motion during excessive gale-force winds and storms.
- Determine the boat can reliably self-right after capsizing due to wind or waves.
- Improve the reliability of the electric controls. Maintaining reliable boat operations, solar power reception, and sensor performance and accuracy in marine environments is an ongoing and important objective for ASVs.
- Demonstrate SailVane data collection capabilities in an extended mission.

SECTION 4: CONCLUSIONS OF PHASE 1 FINDINGS AND SUPPORT FOR PHASE II PROPOSAL

4.1 READINESS FOR PHASE II

After completing phase I research objectives, we will have completed the development of a small, low-cost sailboat that is mass-producible, controllable via satellite communication and well-modeled by our navigation software. The passive stability of the heading of the SailVane w.r.t. wind direction enables extensive use of autonomous navigation software at low frequency, mitigating excessive control and planning computation, high-accuracy prediction of the boat's movement and low power needs at sea. These facets of the boat and how it interacts with our planning systems combine into a unique product whose cost is similar to a buoy to build and upkeep, but can perform many of the same jobs as a larger, manned sailing ship when at sea.

This combination of long run time, controllability at sea, and low cost give us an immediate entry into an under-served market, including non-profit research organizations, as a low-cost ASV. Soon after we plan a much larger scale with for-profit organizations, as swarms of ASVs for large data collection missions.

4.2 COMMERCIALIZATION TRACTION

We have been building relationships in our two early target markets of research and Oil and Gas. We plan to have our first research pilot customers during the second year of our Phase II and Oil and Gas customers in year three of commercialization.

Existing relationships we would like to highlight include:

- Shell Energy- Need for in-situ metocean data for operational support and renewable energy developments.
- Shoals Marine Lab – Need for affordable research tools to implement data collection at scale.
- Cornell Lab of Ornithology- Need for affordable research tools to help augment existing data collection efforts.

We have included letters of support for all three of these entities in our application.

4.3 PHASE II PLANS

In Phase II, we plan to prepare for the commercial launch of our boat by making upgrades to both the boat design and corresponding software components. This will be accomplished through the following technical objectives.

1. Optimize design of SailVane for manufacturability and robustness; demonstrate navigation ability in harsh ocean environment; refine software algorithms based on collected data.
2. Build out multi-boat software capabilities that will enable optimized data collection coverage.

3. Develop optimization tool to calculate interplay between sensor use and operational lifetime. This work will help us understand potential mission lengths in the context of a customer's sensor requirements.

Successful completion of this work will allow us to capture our first pilot customers in year 2 of the project. This will be critical for demonstrating the SailVane's mission readiness as we look to expand into our more profitable commercial markets.

1. Drake by MIT

2. Simulink by Mathworks

3. Kelly MP. Transcription methods for trajectory optimization. Tutorial, Cornell University, Feb 2015:21.

4. Interior Point Optimizer found at GitHub

Shell Exploration and Production Company
150 North Dairy Ashford
Houston, TX 77079
United States of America
pak.leung@shell.com

August 12th, 2024

Subject: Letter of Support Dynaloco's Sailvane for NSF STTR Phase II Application

Dear Madam or Sir,

I am writing to recommend Dynaloco for the NSF STTR Phase II funding opportunity. My program has been following the development of Dynaloco's SailVane technology over the years, and I am impressed with their progress and the potential impact of their innovative approach.

The SailVane's unique sail and rudder configuration addresses critical power and navigational challenges that small vessels typically face. These innovations allow SailVane to perform long-term navigation and maintain a user-defined position in the open ocean, making it an ideal platform for extended ocean monitoring and observation campaigns.

Shell has a strong history of supporting innovative technologies that improve marine monitoring and offshore safety. Small, low-cost autonomous sailboats like SailVane are valuable, especially as the offshore industry increasingly relies on in-situ metocean data for operational support and renewable energy developments. SailVane's ability to collect accurate data affordably makes it a significant asset.

I enthusiastically support the further development of SailVane for open ocean use. Its low cost, small footprint, and versatile sensor payload fill a critical market gap. Funding this proposal will help prepare SailVane to advance its technology readiness for commercialization, including scaling up manufacturing and developing software for multi-boat deployments. Your support is crucial in developing a potential solution that may meet market needs effectively.

I look forward to following SailVane's progress and would be happy to provide guidance and input during its development. I am eager to see SailVane in action on the ocean soon.

Sincerely,

Pak Leung, PhD, CSci, MBA
Marine Renewable Program Manager

The Cornell Lab of Ornithology

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August 3rd, 2024

Jason Cortell, CEO
Dynamic Locomotion Incorporated
107 Corona Ave, Groton, NY 13073

Re: Letter of support for NSF Phase II SBIR SailVane proposal

Dear Mr. Cortell:

I am writing this letter in strong support of your NSF Phase II SBIR proposal to develop the SailVane passively stable environmental monitoring sailboat.

I am the director of the K. Lisa Yang Center for Conservation Bioacoustics (Yang Center) at the Cornell Lab of Ornithology, Cornell University. The Yang Center's mission is to collect and interpret sounds in nature by developing and applying innovative bioacoustic technologies across ecologically relevant scales to inspire and inform the conservation of marine and terrestrial wildlife and habitats. My background is in developing hardware and software tools to monitor marine mammals at large spatiotemporal scales around the globe. Many of my projects are funded by US federal agencies, including the Office of Naval Research (ONR), the Bureau of Ocean Energy Management (BOEM), and the National Oceanic and Atmospheric Administration (NOAA). Our research projects are applied, and outcomes often have regulatory implications (e.g., for the siting and construction of offshore wind farms).

I am very excited about the proposed SailVane technology and would like to discuss two important applications that have the potential to transform my field of research:

(1) Real-time data transmission
My group has been developing bottom-moored, autonomous passive acoustic recorders for decades. Typically we deploy these instruments for many months in the ocean. During a deployment, the instruments sit on the seafloor and continuously record the underwater soundscape. After retrieval of the instrument, the data is analyzed in the lab for acoustic signals of interest (e.g., vocalizations of marine mammals). While this is a very effective way to monitor the occurrence patterns of marine mammals, we are currently lacking the ability to provide (near) real-time data on the presence of marine mammals. This is crucial for time-critical applications, for example, to minimize the risk of whales being struck and killed by large vessels. While mooring-based solutions exist, these are only viable in shallower water. In addition, mooring-based solutions are logistically challenging and expensive.

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As an alternative, the SailVane could be used to hover above a deployed bottom-moored instrument and function as a data relay. Our units are capable of running detection and classification algorithms on board. When signals of interest are detected, the unit could establish a communication link (via an underwater modem) with the SailVane at the surface, and the information could be relayed to shore in (near) real-time. There are many valuable applications for this type of technology, including the mitigation of potential negative impacts of anthropogenic activities on endangered and threatened marine mammal species.

(2) Collection of environmental DNA (eDNA)

While passive-acoustic technology is a powerful tool to monitor the occurrence patterns of marine mammals, two main challenges remain. Firstly, the vocal behavior of marine mammals is highly variable and if no calls are being detected, that does not necessarily confirm that no animals are in the area. Secondly, some signals we record cannot be classified to the species level. To overcome these challenges, we have been working on environmental DNA (eDNA) monitoring technologies. The basic idea is to collect water samples at the ocean surface and to analyze them for the presence of marine mammal DNA (sloughed skin, feces, mucus, etc.). Recent advances in DNA analysis technologies (e.g., next-generation sequencing) allow researchers to detect tiny amounts (molecules) of DNA in the collected samples and have made eDNA a viable tool to monitor species diversity in a variety of environments non-invasively.

However, we rely on expensive research vessels to go out and collect the water samples for us. Alternatively, SailVanes could be equipped with existing autonomous eDNA water samplers to cost-effectively collect samples at large spatiotemporal scales to improve our understanding of shifts in marine mammal occurrence patterns.

In summary, the SailVane is an exciting new technology with the potential to transform the field of marine mammal monitoring. If your proposal is selected for funding, I will support your project to the best of my abilities.

Sincerely,

Dr. Holger Klinck

John W. Fitzpatrick Director
k. Lisa Yang Center for Conservation Bioacoustics

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SHOALS Marine Laboratory

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August 6, 2024

Mr. Jason Cortell, P.E.
CEO, Dynamic Locomotion, Inc.
107 Corona Avenue
Groton, NY 13073

Dear Jason:

I am pleased to provide a letter of support for your upcoming Phase II project focused on the development of the SailVane. The proposed autonomous robotic sailboat technology would offer many unique and innovative opportunities for oceanic research and commercial applications. In my capacity as the director of Shoals Marine Laboratory (SML)—a marine science institution that is jointly run by the University of New Hampshire and Cornell University—we work with a broad range of scientists who study the ocean and the environment for which your vessel represents transformative technology that, if successful, would significantly improve access to ocean data for a greater diversity of users.

Understanding the oceans is of paramount importance for climate research, naval operations, commerce (e.g. the blue economy), protecting endangered species, and much more. As you may know, gathering data *in situ* is an important part of conducting thorough oceanic studies, and many quantities of interest must be measured *in situ*, as opposed to using satellites. However, *in-situ* data is currently expensive, often requiring expensive missions and personnel to collect data or distribute buoys. The technology represented by SailVane is an affordable alternative, made even more accessible as it can be deployed without special equipment and is easily tailored to meet specific data needs. I anticipate that its low cost will open a broad range of new research possibilities and help us study the oceans like never before. Making ocean data collection accessible to a wider array of users will increase equity in marine science and enhance the array of applications and uses. Considering that roughly 30% of Americans live in coastal counties and the blue economy is worth almost $400 billion, the need is great and growing.

At SML alone, we work with a broad range of researchers who currently collect data on the weather, oceanography, protected and endangered marine species, water quality, climate change, and changes to the flora and fauna over time; and I anticipate that many of these researchers will be very interested in employing SailVanes in their research. SML works with dozens of labs across the east coast and we are building networks from the grassroots such as the Northeast Coastal Station Alliance that would benefit greatly from affordable oceanographic data that would fill gaps in the current NOAA buoy systems, which are widely scattered and insufficient for building models across a variety of spatial scales.

At SML, we look forward to future opportunities to collaborate with Dynamic Locomotion and utilize your SailVane technology. Please let us know how we can assist with the testing and validation of your technology.

Sincerely,

Sara R Morris

Sara Morris
John M. Kingsbury Executive Director
Shoals Marine Laboratory

Cornell University

University of New Hampshire

Potential Impacts on Tribal Nations

Data Not Available

Other Supplementary Documents

Data Not Available

List of Suggested Reviewers

Data Not Available

List of Reviewers Not to Include

Data Not Available