

# Development of a New Autonomous Underwater Moored Mobile Profiler

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***Abstract***—Observation of the ocean environment is key to attaining the knowledge and understanding required to predict its evolving state and to respond to its condition. However, manned observation and collection of high resolution oceanographic data over long periods of time is both expensive and hazardous. Various autonomous profiling platforms have been developed to address the issue but there still exists the opportunity to develop efficient, robust, and reliable, low cost platforms to provide the data. In this paper we present the development of a new autonomous profiling system for areas along the continental shelf. The proposed design is a moored vehicle that will profile the water column by controlling the predetermined ascent/descent routine of an instrumentation payload through the use of a buoyancy engine. One of its unique features is the use of a subsea mooring to secure the profiler while still providing the ability to profile the entire water column and make a telemetry link. The profiler has two modes of dynamic behavior during its profile. One mode is similar to that of a profiler which follows a mooring line, while the other mode is similar to a winched profiler.

## I. INTRODUCTION

The ocean is a very dynamic system both physically and biologically. The global scale poses a sampling challenge that is compounded because of the short dynamical scales in the ocean, tens of kilometers or less. In order to develop a thorough understanding of the ocean and its effects we need high temporal and spatial resolution oceanographic data. While remote sensing provides good spatial coverage of surface features at high-resolution, subsurface observations are more difficult to obtain. New developments in autonomous vehicles offer the capability to sample the ocean but the need for time series at high vertical resolution remains. This paper reports on the development of a reliable, robust and efficient autonomous underwater profiling system to collect oceanographic data at fixed locations on the continental.

## II. BACKGROUND

Mobile profiling platforms such as the ARGO floats [1] or autonomous gliders are now being used on a global scale to collect profile data in the open ocean and on the continental shelf. The ARGO floats are capable of operating in the ocean for up to five years, sampling down to two kilometres depth, but only profiling every 10 days. The ARGO float is a true Lagrangian profiler, its ever changing geographic location is determined by the ocean current. Gliders perform profiles at a frequency in the order of hours, however their mission duration is generally limited to weeks or months. Due to their limited speed (tens of cm/s), gliders are also restricted to operate in favorable current regimes.

Fixed depth moored profilers [2] are essentially a suite of sensors mounted at fixed depth intervals along a surface or subsurface mooring. In order to obtain adequate vertical resolution, many instruments need to be deployed on the mooring, substantially raising the cost of the mooring deployment.

Autonomous moored profilers were developed to provide high resolution spatial and temporal data by periodically travelling through the water column at a fixed location. The two most common systems are those with a sensor package that either follows a fixed cable, or is attached to a moving cable. Winched systems such as the MINI AMP [3] and VPS [4] profile by paying in/out a cable. The sensor payload of these systems have a large positive buoyancy in order to allow them to reach the surface. As a result, they require a lot of power when working against the buoyancy. These systems have also been challenged by fouling of the cable which must be repeatedly spooled and unspooled neatly. Profilers that follow a fixed mooring line are designed to have neutral buoyancy which significantly minimizes the power required to move them. However, they are not ideal for

reaching the surface unless deployed in area where benign conditions are expected and a surface mooring can be used over the more conventional subsurface mooring. The most prominent line crawler is the McLane profiler [5] which uses a traction wheel to move up and down the mooring line. The SeaTramp [6] utilizes a buoyancy engine while the SeaHorse [7] employs a wave powered ratcheting system.

### III. NEW PROFILER DESIGN PARAMETER

We are proposing to develop a new approach to the vertical profiler, focusing on an application for the continental shelf rather than the open ocean. We begin by considering the characteristics that we would like for the profiler.

#### A. Physical Operational Requirements

The new autonomous moored profiler will be designed to meet the following operational requirements.

1. Operate to depths of 200 m
2. Operate in currents up to 1 m/s
3. Operate in waves up to 5 meters
4. Profile to the surface
5. Profiles 5 times every 24 hours
6. Profile at a speed of  $0.3 \text{ m/s} \pm 0.1 \text{ m/s}$
7. Regular communication/data transmission
8. Operate continuously for 365 days

#### B. Sensor Payload

The profiler will be outfitted with necessary sensors to measure and record at least the following properties.

1. Salinity
2. Temperature
3. Depth
4. Dissolved Oxygen
5. Current Velocity
6. Chlorophyll

Aside from ensuring the sensors have excellent performance specifications such as accuracy, range and resolution; other parameters to consider are the power consumption, the ability to mitigate biofouling effects, and endurance.

#### C. Data Collection and Management

The system is designed to store the collected data in memory until it is able to communicate with a base station and transmit the data. The system will be designed to abort the profile and not surface when the surface waves exceed five meters in height. Thus there will be times when it will be unable to upload the collected data from one or more

partial profiles. The system will also be designed to self-monitor its health and to respond accordingly to the potential issues it detected. Ideally the system will surface and transmit a distress signal if it is unable to resolve the issue.

### IV. DESIGN CONCEPT

Fig. 1 shows a design schematic of the new profiler with the sensor payload float in the retracted position. The design is made up of four main components; a basic subsea mooring, a sensor payload float, a passive float, and the main body. The basic purpose of the design is to move the sensor payload float from the bottom of the ocean to the surface during which time it will measure and record water parameters from the onboard sensors. Once at the surface it will transmit the data via a satellite telemetry link. After the data is successfully uploaded, the profiler will then return to its resting position on the bottom where it will hibernate to conserve energy until the next profile is required. The intended method to provide propulsion of the profiler is by altering the buoyancy of the main body using a buoyancy engine.

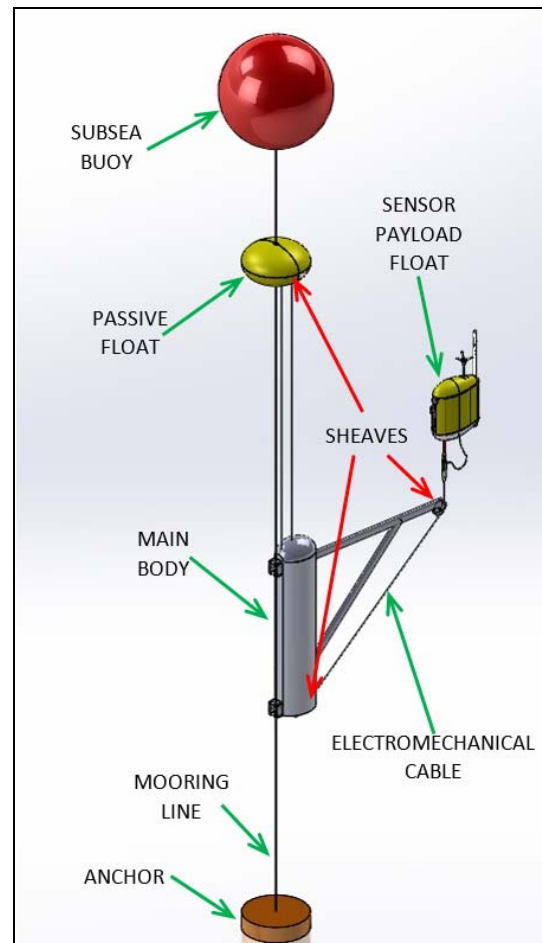


Fig. 1. Profiler Concept Schematic. A not to scale, typical arrangement of the major components that make up the profiler. The subsea buoy is 10 m below the surface and the main body/passive float/sensor payload moves up and down the ~200 m mooring line via a buoyancy engine.

The subsea mooring consists of a buoy, polypropylene jacketed steel mooring line, and an anchor. The mooring line provides a means for securing the profiler at a fixed geographic location and to guide it up and down through the majority of the water column. The subsea buoy will be positioned at a minimum of ten meters below the surface to provide protection from the dynamic sea state, impact from ship hulls, vandalism, and biofouling [8]. The passive float and main body of the profiler are secured to the mooring line by low friction cable guides. The sensor payload float, passive float and main body are connected together by a four conductor electromechanical cable. Two conductors are to route power and the other two are for communication. One end of the cable is terminated at the sensor payload float while the other end terminates at the main body. The cable passes through a series of sheaves located on the main body and the passive float.

Fig. 2 shows a stepwise progression of the profiler's ascent through the water column. The system has two modes of dynamic behaviour during its operation which is dependent on its position along the mooring line. The first mode which occurs for the majority of the profile is when the passive float is not in contact with the subsea buoy (Position A). The second mode is when the passive float is in contact with the subsea buoy (Positions B –D). On an upwards profile with the profiler starting its ascent from the bottom of the mooring line the equilibrium arrangement of the profiler is such that the sensor payload float is in the retracted position against the extended arm of the main body; and the passive float is at its maximum extension from the main body (Position A). The retraction of the sensor payload float is due to the buoyancy of the passive float creating more tension in the cable than the buoyancy of the sensor float. The full retraction of the sensor float is critical to ensure it will not become

entangled around the mooring line. Propulsion towards the surface is achieved by adjustment of the buoyancy of the main body such that the overall buoyancy of the entire profiler system (sensor payload float, passive float, and main body) is positive. When the passive float contacts the subsurface buoy it no longer has the ability to produce tension in the cable to keep the payload sensor retracted (Position B). As a result the payload sensor float is now capable of continuing the profile all the way to the surface (Position C and D). Model testing in the deep water tank at Memorial Universities Faculty of Engineering and Applied Science was conducted to verify the dynamic behavior of the system.

The key design features that allow for the sensor payload float to reach the surface while in the second mode of operation is the set buoyancy of the three main components (sensor payload float, passive float, and main body) along with the sheave and electromechanical cable arrangement. The buoyancy of the sensor float is designed to have a fixed positive buoyancy of 100 N. The passive float is designed with a fixed positive buoyancy of 220 N. The main body is designed to have variable buoyancy, and in the case of ascent its buoyancy is set to negative 280 N. The result is a net positive buoyancy and hence upward motion. When the passive float contacts the subsea buoy there is a perceived loss of +200 N of buoyancy and in order to continue the profile, the +100 N sensor float must move up against the negative buoyancy of the -280 N main body. This is achieved through the sheave and electromechanical cable arrangement. With one of the sheaves attached to the main body and the other one attached to the passive float the sensor payload is given a mechanical advantage of three to one. As a result, the +100 N sensor float is able to lift the -280 N main body.

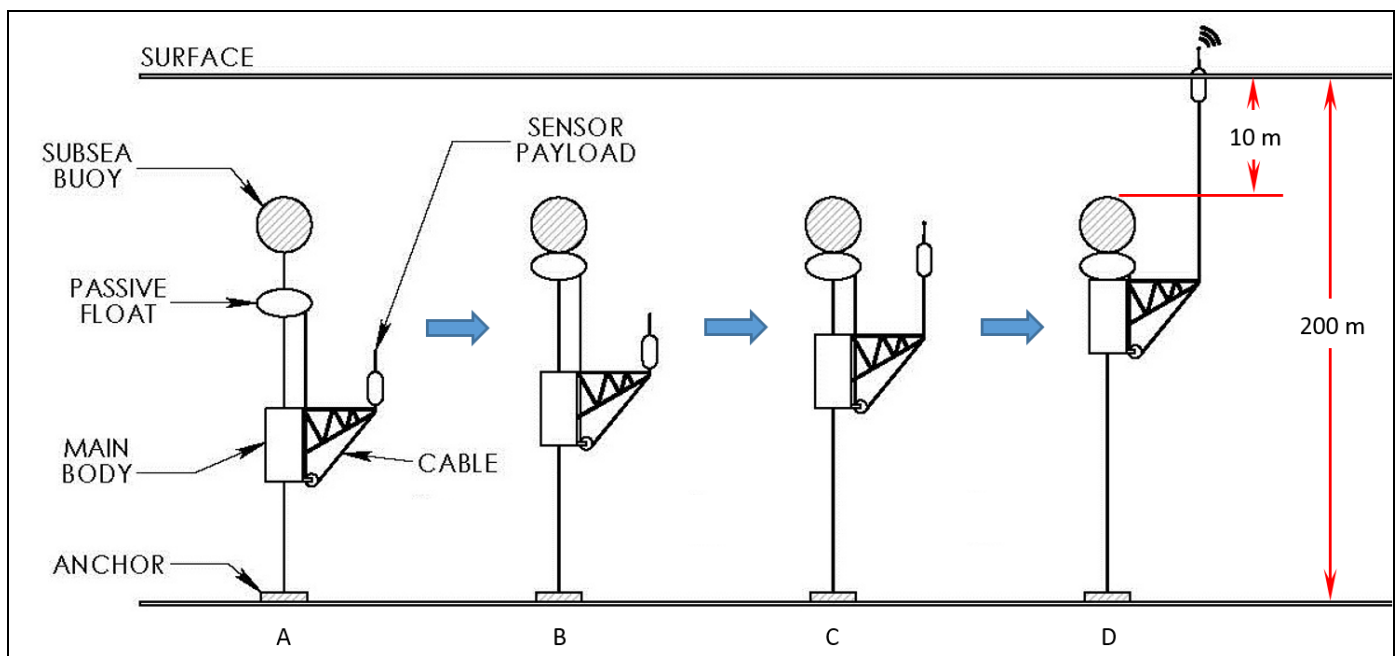


Fig. 2. Stepwise Ascent Progression of Profiler. There are two modes of dynamic behaviour; Mode 1: Position A; Mode 2: Positions B, C, and D.

The 3:1 mechanical advantage also results in the distance traveled by the sensor float being three times the distance traveled by the main body. This is also advantageous to the design of the system. With the subsea buoy set at 10 meters below the surface, if a cable length is selected such that it provides 6 meters of separation between the main body and passive float when the sensor float is in the retracted position (first mode) then 12 meters of cable will have been deployed once the main body has reached the passive float/subsea float (second mode). In a current, the drag on the sensor float and attached cable results in a horizontal excursion of the float. Therefore, in order to reach the surface the amount of deployed cable needs to be greater than the undeployed submerged depth. Based on the drag, buoyancy, and depth, the calculated deployed length of the cable must be at least 10.5 meters for the sensor float to reach the surface in a 1 m/s current.

Deploying the sensor from the main body while only at the top of the subsea mooring reduces the possibility of entanglement in the mooring line. The critical point during the release of the sensor payload is when the sensor float is at the same depth as the subsea buoy (Position C). Ocean currents creating drag on the sensor float develop a horizontal displacement. In the unlikely event the displacement is directed towards the mooring line there could be a possibility of entanglement. To mitigate this issue the extension arm of the main body is long enough such that the calculated horizontal excursion developed by a 1 m/s current is not sufficient enough to allow contact between the sensor float and the mooring. Preliminary design calculations result in an arm length of 1.25 meters.

To retract the sensor payload and descend the profiler to the ocean floor, the buoyancy of the main body is adjusted to negative 330 N which results in a net negative buoyancy of the system. The sequence of operation is opposite to the ascent. First the sensor payload will fully retract back to the arm and then the entire system will proceed to descend.

## V. PROFILER COMPONENT DETAILS

### A. Sensor Payload Float

The sensor payload float shown in Fig. 3 has been design to carry the main oceanographic sensors, data logger, controller and telemetry system. To perform under the operating conditions specified it has been designed to provide upright stability, low drag, dynamic loading, and positive buoyancy.

The suite of sensors that will initially be deployed on the sensor float are listed below. Additional or different sensor can be included with minimal design changes to midsection of the sensor float.

1. A Seabird GPCTD w/DO to measure conductivity, temperature, pressure, and dissolved oxygen.
2. A Nortek Vector Velocimeter to measure current velocity.

3. A WET Labs FLS Fluorometer to measure chlorophyll.
4. A Tritech LRPA200 Altimeter to measure altitude.
5. An inertia measurement and GPS unit to measure the motion and position of the sensor float.

Data logging and control of the sensors will be carried out using a PC104 embedded computer system. At the time of this paper development of the system has just begun. The telemetry system will use the iridium satellite system. Aside from the antenna, the data logging, controller and telemetry components will be located in an enclosure inside the sensor float.

The sensor float is designed with a symmetric airfoil shape to provide low drag. The cord length is 500 mm, with a thickness of 200 mm, and a length of 550 mm. A computational fluid dynamics analysis was done through SolidWorks (solid modeling computer aided design software) which determined the sensor float will experience a drag force of 13 N when subjected to a 1m/s current. The low drag of the sensor float coupled with its +100N of buoyancy ensures that the horizontal excursion is within the limits to allow the sensor float to breach the surface with the available cable length when deployed from 10m below the surface. To provide upright stability which is required to ensure the antenna can breach the surface, the relative positions between the center of gravity and center of buoyancy of the float is such that the metacentre is above the center of gravity.

In wave heights of 6 meters with a 5 second period the maximum vertical velocity that could be experienced by the 24 kg sensor float while at the surface is approximately 2.6 m/s (using deep water wave approximation). In the event that

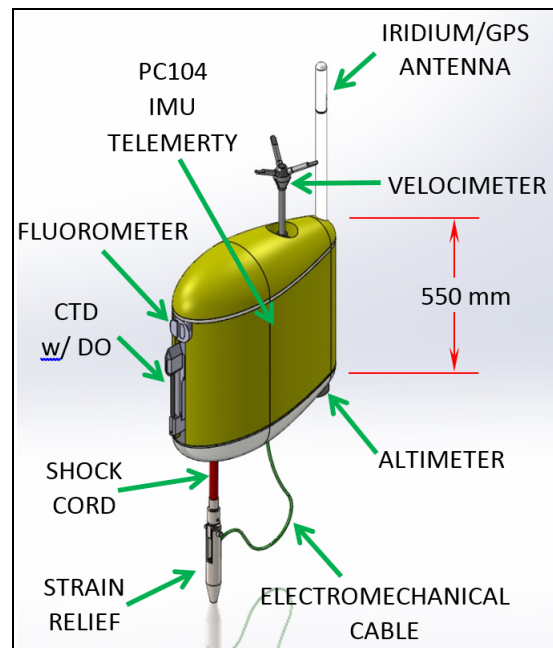


Fig. 3. Sensor Payload Float. Position and location of the sensors and components that make up the sensor payload float. It has a symmetric airfoil shape with a chord length of 500 mm, thickness of 220 mm and length of 550 mm.

the cable is pulled tight at this speed, 81 J of kinetic energy will be generated by the motion of the sensor float in the generated wave field. The electromechanical cable attached to the sensor float has an aramid fiber reinforcement with a breaking strength of 5350 N and a manufacturer's recommendation to not exceed 20% of the breaking strength which is 1070 N. To limit the potential load on the cable to 1000 N, the energy is dampened by an Ø19 mm x 120 mm long natural rubber shock cord which is attached to the cables strain relief termination. The natural rubber shock cord is able to withstand up to  $5 \times 10^6$  cycles before failure. Natural rubber is also able to endure long term submerged exposure in a salt water environment [9].

The attachment point of the shock cord is near the front end of the float. This is to ensure that the float will orientate in the current with the front forward. This is the optimal position for the sensors since they will be exposed to an undisturbed parcel of water. Water that has been disturbed by the body of the float can introduce errors in the measurements.

The buoyancy and shape is provided by an internal structure machined from a low density cross linked polymer closed cell foam that has an operational depth specification of 300 m. The internal foam structure will be protected by either fiber glass or a thermoformed polycarbonate shell.

### B. Passive Float

The main purpose of the passive float shown in Fig. 4 is to provide a set amount of buoyancy and to house a sheave. Its shape is that of a 2:1 oblate spheroid with a 600 mm diameter. Its orientation is not affected by the current due to the symmetry of its shape. In the event that the current direction was different from the cable orientation it could cause the cable to wrap around the mooring line if the passive float was subjected to current orientation. The placement of the sheave inside the body of the float also eliminates it from acting like a fin and driving the orientation into the direction of the current.

In order to reduce tilting of the float due to tension in the cable, the half opposite the sheave is only a vented shell providing zero buoyancy while the half with the sheave has a foam core to provide the required buoyancy. The location of

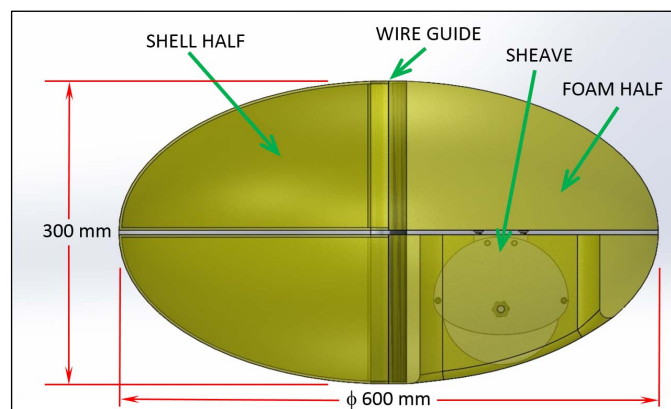


Fig. 4. Passive Float. Transparent side view of the passive float to illustrate the sheave location.

the sheave with respect to the center of buoyancy results in a zero moment about the center wire guide. Tilting of the float will impose an unwanted lift force on the float which can affect the statics and dynamics of the system

### C. Main Body

The main body of the profiler shown in Fig. 1, the components are still in the preliminary design phase. The main body will house the buoyancy engine and its control system, in addition to the power supply for the sensor payload and buoyancy engine. It will be shaped to minimize drag, however due to the extension arm its orientation will be forced by the current. As with the passive float care will be taken to ensure the loading creates zero momentum about the wire guides.

### D. Buoyancy Engine

At the time of this paper the design of the buoyancy engine is the significant work currently ongoing for this project. The underlying principle of the buoyancy engine is quite simple. To add positive buoyancy to the system, fluid is pumped from a fixed displacement internal reservoir to a variable displacement external bladder. The weight of the system does not change, however the displaced volume increases. The result is the addition of positive buoyancy. Pumping the fluid from the bladder back into the reservoir has the opposite effect. A buoyancy engine was chosen for the profiler due to its relative simplicity, efficiency, and robustness. Most components such as the motor and pump are protected from the harsh saltwater environment by locating them inside an enclosure. Only a small amount of tubing and the bladder need to be exposed.

Based on preliminary estimations, a five liter (~50 N) buoyancy engine will be sufficient to propel the profiler. The hydraulic fluid will be pumped with a small axial piston pump. Axial piston pumps have the capability of operating at a high efficiency (~90%). At the 200 m operating depth the pump must work against a pressure of approximately 20 Bar to inflate the bladder. Unfortunately this is not the optimal pressure for most axial piston pumps. The pumps are generally designed to operate most efficiently in the range of 150 to 300 Bar. To have the pump operate at its best efficiency we will be assessing the implementation of a hydraulic circuit that works to reduce the pressure delivered to the bladder with minimal loss of efficiency. A high pressure, low volume hydraulic cylinder can be used to drive a low pressure, high volume hydraulic cylinder, Fig. 5. The work done on or by a hydraulic cylinder is the pressure multiplied by the volume; to get 5 liters at 20 Bar from one cylinder it will need to be driven by a 0.5 liter cylinder at 200 Bar with the same stroke. This arrangement would allow the pump to operate at its maximum efficiency while delivering the required pressure and volume to the bladder. A 90% efficient pump coupled to two 95% efficient cylinders gives an overall efficiency of ~81%, whereas, with only the pump working at the non-optimal pressure of 20 Bars its efficiency would be ~60%.

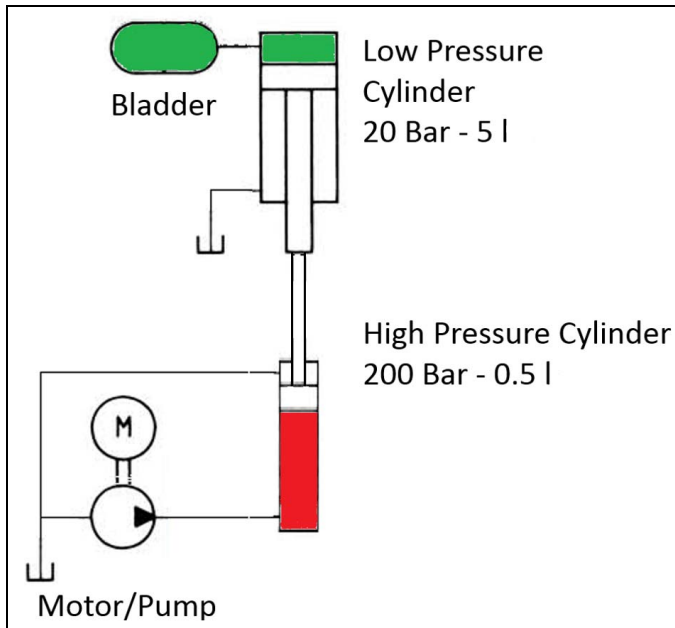


Fig. 5. High pressure 0.5 liter cylinder driving a low pressure 5 liter cylinder to fill the external bladder.

## VI. ONGOING AND FUTURE WORK

Once the buoyancy system is finalized and its space and power requirements are determined the main body can be designed. With a fully defined system, a more thorough analysis can be carried out on its overall operation. In parallel with the development of the buoyancy engine the data logging, control and telemetry systems are being developed. As well, a full-scale prototype of the sensor float is being fabricated to conduct tank testing. The testing will be to assess drag effect, stability, and overall reaction to waves and current. Test facilities are available that can produce 1 m/s currents and 1 meter wave heights. Eventually when all the system components have been successfully designed, fabricated and tank tested, initial field tests would be at a shallow water site where the system can be visually monitored and accessed.

## VII. SUMMARY

There is great demand for efficient and effective profilers of the physical and biological characteristics of the ocean. We are designing a system that takes advantage of the reliability

and power efficiency of buoyancy engines linked to the simplicity of the single point subsurface mooring. The “in progress” design of a new and unique autonomous moored profiler has been presented. The design objectives are to provide a reliable, robust and efficient long-term profiling system for the entire water column along areas within the continental shelf. The system is designed to measure, collect and transmit high-resolution spatial and temporal oceanographic data.

## ACKNOWLEDGMENT

This research is supported by the National Centers of Excellence program, Marine Environmental Observation Prediction and Response Network (MEOPAR).

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