Monterey Bay Aquarium Research Institute

Coastal Profiling Float Drop Weight

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ABSTRACT

A design for a drop weight to be used on the Coastal Profiling Float observation platform is described and tested. The design is informed by requirements including use conditions, target mass, independent operation, multiple triggers, reliability, manufacturability, and time constraints. Several concepts for the drop weight and its subsystems are considered, prototyped, and compared. A preliminary version of the drop weight was constructed and tested in both dry and underwater conditions.

INTRODUCTION

Existing ocean profiling floats in use at global scale are adept at acquiring quantitative seawater observations in the open ocean. Such profiling floats are ill-suited for use in the coastal environment due to their inability to precisely control their path of travel to prevent beaching or moving too far offshore. Because of this, an observation gap in coastal areas currently exists. Coastal areas are hugely influential in determining ocean health. The Coastal Profiling Float (CPF) addresses this problem through its ability to land on the seafloor for extended periods of time, arresting its lateral movement between vertical profiles. This ability requires a higher amount of battery power devoted to buoyancy change, increasing the platform's power draw and necessitating frequent recoveries to replace batteries in order to maintain an acceptable lifetime.

In the event that the float's buoyancy engine is unable to return it to the surface, the only existing solution is an ROV recovery. While feasible, this solution is expensive in time and effort, and puts expensive equipment at risk. Equipping the float with a drop weight would enable it to return to the surface in such a situation and be recovered normally.

The objective of this project is to design a drop weight for the CPF to act as a recovery failsafe mechanism. This drop weight must be able to operate in the conditions that the CPF is expected to encounter, comprise a mass sufficient to overcome the platform's negative buoyancy, actuate in response to several independent triggers, and maximize reliability, manufacturability, ease of use, and reusability. This drop weight was designed, prototyped, and tested in both laboratory and indoor tank conditions. It is now at a preliminary stage of development could be made deployable at scale.

MATERIALS AND METHODS

DESIGN REQUIREMENTS

The first step in undertaking this project was to determine the requirements that the drop weight had to meet. These were set based on prior experience of deploying the CPF. It is known that the CPF rests on the seafloor when it is not profiling in the water column or transmitting at the surface. Therefore, the weight must be able to release when the float is resting on the bottom. Based on the range of displacements that the buoyancy engine can produce, it was determined that the weight should have a mass of four kilograms. This would allow dropping the weight to more than overcome any negative buoyancy set by the float itself. Since a failure of the CPF batteries could be the cause of a buoyancy engine failure, the drop weight was not allowed to rely on the platform's batteries to operate as this would represent a common failure mode. Its power supply must be self-contained and independent of the CPF. The drop weight was also required to actuate in response to several independent triggers. In the event of an overpressure event, indicating that the platform had exceeded its rated depth, the weight should release to send the float back to the surface. After a specified deployment time, the weight should also release. In addition to the pressure and time triggers, the CPF controller must be able to release the weight electronically. Lastly, the weight should also release in response to interrogation from an acoustic modem to allow it to be dropped manually from the surface.

DESIGN GOALS

The above requirements were considered testable necessities of the drop weight design, but did not encompass the system's entire design philosophy. This device's objective was to maximize reliability to consistently enable emergency recoveries. It was also supposed to maximize manufacturability, which would in turn reduce the drop weight's cost and permit the broadest possible use of the system. Using and resetting the weight should also be as simple as possible to simplify deployment in the field. Open volumes and horizontal surfaces where mud could collect and impede the weight's function were to be minimized.

DESIGN CONCEPTS

The design of the drop weight was divided into two main subsystems: the release mechanism and the weight itself. Two concepts were considered for each subsystem. For the weight, a lead- and oil-filled plastic tube was compared against a rolled stainless steel bar. The release mechanism concepts were a wet external burn wire and a sealed pin puller.

Several factors drove the mounting location and overall shape of the drop weight. Attaching it as low as possible would help stabilize the float, since it would act as a pendulum when attached to the CPF. Since the external bellows of the buoyancy engine occupy the central space at the extreme lower end of the CPF, this area was considered off-limits for weight attachment. Placing the weight at the extreme end of the CPF would also risk mud accumulation and downward force exerted by the platform interfering with the weight's deployment. For these reasons, a ring-shaped weight was conceptualized that would avoid interfering with the external bellows while mounting as low as possible on the CPF.

With the location and shape determined, the weight's precise form and material had to be set. The initial weight concept was a flexible PVC tube containing ¼" wires of pure lead. To prevent tube deformation due to pressure at depth, the remaining internal volume would be filled with oil. At each end of the tube, a barbed fitting would be installed to seal the oil and lead inside while also providing a location for a connection to the release mechanism. When installed, this tube would be fastened around the external bellows bucket in a discontinuous ring with tension applied to the tube ends to secure it in place like a SCUBA weight belt. To drop the weight, the tension would be released and the plastic tube's stress would cause it to straighten and fall off of the bucket. This concept was prototyped and found to be workable on the bench, but concerns remained with its long-term reliability. Although the weight opened as expected when placed under tension for a few minutes or hours, it was not clear if this behavior would be preserved if the plastic were kept deformed for months or years during a real CPF deployment. If the material crept into position during this time, it could fail to open once the release mechanism actuated and prevent the CPF from ascending. To address the plastic tube's unknown long-term reliability, the rolled stainless steel bar was considered. Its form would be almost identical to the lead-filled tube, as shown in Figure 1, but it could be relied on to maintain its spring force for extended periods of time without creep due to its material properties.

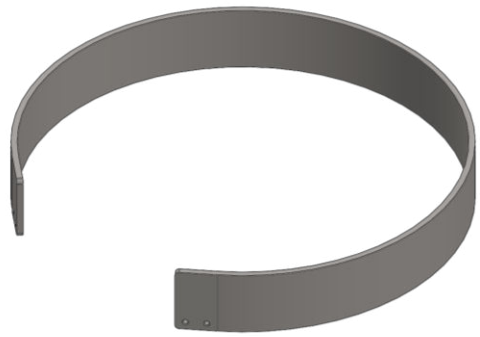


Figure 1: Isometric view of rolled stainless steel bar weight CAD model

The first concept considered for the drop weight release mechanism was an external burn wire that would act on a synthetic rope applying tension to the discontinuous ring-shaped weight. A burn wire is a length of thin electrically conductive material that is heated by electrical resistance as current passes through it. When the sufficiently heated wire is applied to synthetic rope of a compatible material, the rope melts and is eventually severed without requiring a large cutting force. Using this mechanism would be very simple, since it includes no moving parts. However, designing a housing that could consistently seal the penetrations required for the small-diameter wires was determined to be difficult. In addition, the exposed burn wire could be damaged by external interference and prevent it from conducting electricity when needed. Maintaining tension on the burn wire outside of a pressure housing would also be complex. Prior burn wire examples in the literature were designed for use in spacecraft where vacuum would prevent convective heat loss to the surroundings, while exposing the wire to the surrounding seawater would require it to dissipate much more heat than these preexisting designs in order to reach the same operating temperature [1] [2] [3].

Before proceeding with the external burn wire design, using a pin puller was also considered. A pin puller is a resettable one-way linear actuator that applies a force to a rod that can be used to lock components in place. Once the pin is pulled, the components are freed to move. Rather than securing the weight with a rope alone, the rope could be looped around such a pin to maintain tension. Actuating the pin puller would remove tension from the rope and release the weight. This concept had multiple advantages over the external burn wire. The release mechanism which would be protected inside a pressure housing, isolating it from seawater and externally applied forces. This would prevent corrosion and damage to delicate components.

Both a burn wire- and shape memory alloy-actuated pin puller were compared. Constructing a shape memory alloy actuator that could apply a consistent force was considered to be outside the scope of the project, but such devices are commercially available from reputable manufacturers. A quote from one such manufacturer was obtained and was determined to be infeasible due to economic and timeline issues. Building a burn wire-actuated pin puller with sufficient pull force and displacement was determined to be realistic on the internship timeline and project budget. Compared to the external burn wire, this concept would also insulate the heated wire from convective cooling induced by contact with seawater, lowering the required heat dissipation. The burn wire-actuated pin puller was considered to be the most viable release mechanism and the project proceeded from the concept to the preliminary design stage.

PRELIMINARY DESIGN

The preliminary drop weight design incorporated the rolled stainless steel weight and burn wire-actuated pin puller concepts that were identified previously. These subsystems had to be detailed and integrated both with each other and the CPF external bellows bucket. The modeled preliminary design is shown in Figure 2.

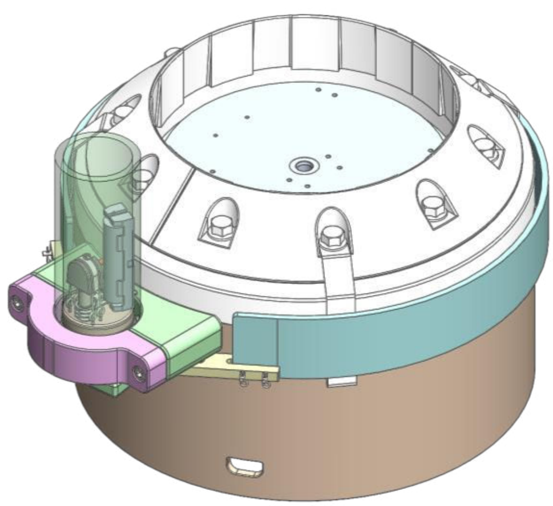


Figure 2: Isometric view of CPF external bellows bucket with drop weight mechanism attached

To secure the rolled bar weight onto the bucket, sheet metal ramps were designed. They would provide an angled section on which the secured weight could rest. Since they were somewhat flexible, they could also be manually tuned to act as springs that would apply additional outward force to the weight, increasing the tension applied to it and pushing it outward once released. These ramps are shown in red in Figure 3.

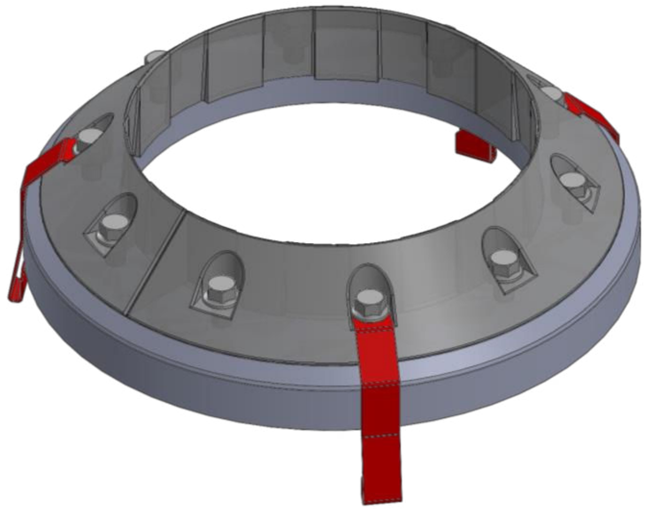


Figure 3: Isometric view of external bucket bellows top ring with sheet metal ramps highlighted in red

Securing the weight to the release pin was originally accomplished using two machined stainless steel “rod end” components. These parts had half slots cut into them where they fit around the weight bar and attached to it using stock clevis and cotter pins as shown in Figure 2 and Figure 4. They each had a hole to mate with the release pin with enough clearance to fit a low-friction Rulon sleeve. Both parts were identical to reduce system complexity and mated with the weight bar in opposite orientations.

Figure 4: Top view of weight rod end showing release pin hole and half-slot

The design of the pin puller comprised a significant portion of the design effort for this project. Titanium was selected as the release pin material due to its strength and high resistance to saltwater corrosion. The pin was concentric with a steel stacked disk wave spring that generated the force to pull the pin. To arm the pin puller, the pin was pushed down to compress the spring and a loop of 300 pound synthetic Spectra line was passed over a 3D printed “mushroom head” that threaded onto the end of the pin. This component also guided the line four anchoring eyelets screwed into the end cap. The burn wire was attached to a small sheet metal bracket that provided holes to mount two electrically insulating ceramic spacers. Electricity was supplied by attaching insulated wires to ring terminals screwed to the same spacers. Figure 5 shows this assembly armed with the pin extended, spring compressed, and the Spectra line and burn wire in place.

Figure 5: Assembled pin puller end cap

The pin puller housing was made out of clear Schedule 80 PVC pipe to allow the internal mechanism to be inspected and observed in operation without opening the housing. One radial static O-ring sealed the housing around the SLA 3D-printed end cap, and another O-ring fit into a gland around the release pin to form a dynamic seal as seen in Figure 6. The housing contained sufficient volume to contain the pin, burn wire subassembly, an 18650 lithium-ion battery, and a small electronics package. This assembly was secured to the outside of the bellows bucket using 3D-printed clamping components that were themselves screwed to Helicoils installed in the bucket.

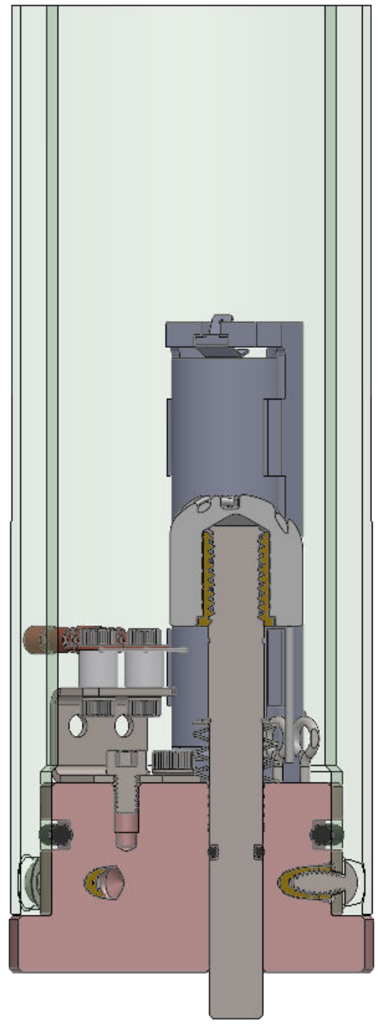


Figure 6: Section view of burn wire-actuated pin puller

For testing purposes, the top of the housing tube was left open. The tube was left long enough for the open end to reach above the water's surface during tank tests as shown on the fully assembled and armed system in Figure 7.

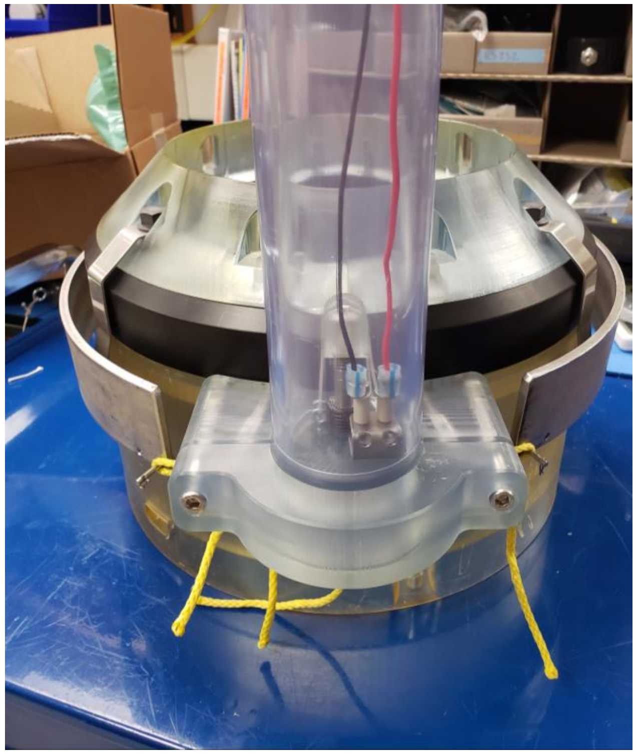


Figure 7: Assembled and armed drop weight prototype on the bench

RESULTS

UNIT TESTING

Following design and fabrication, the system was first tested as individual subsystems, with the weight and release operated separately. The pin puller was actuated manually by tensioning a nichrome wire against the Spectra line using alligator clips attached to a variable DC power supply as shown in Figure 8. This test showed that the pin could be successfully pulled using the burn wire and spring.

(a) (b)

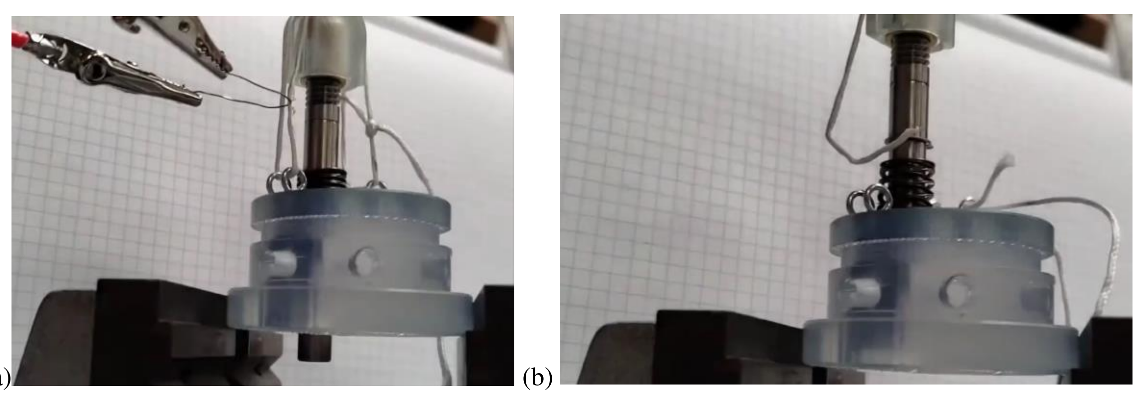
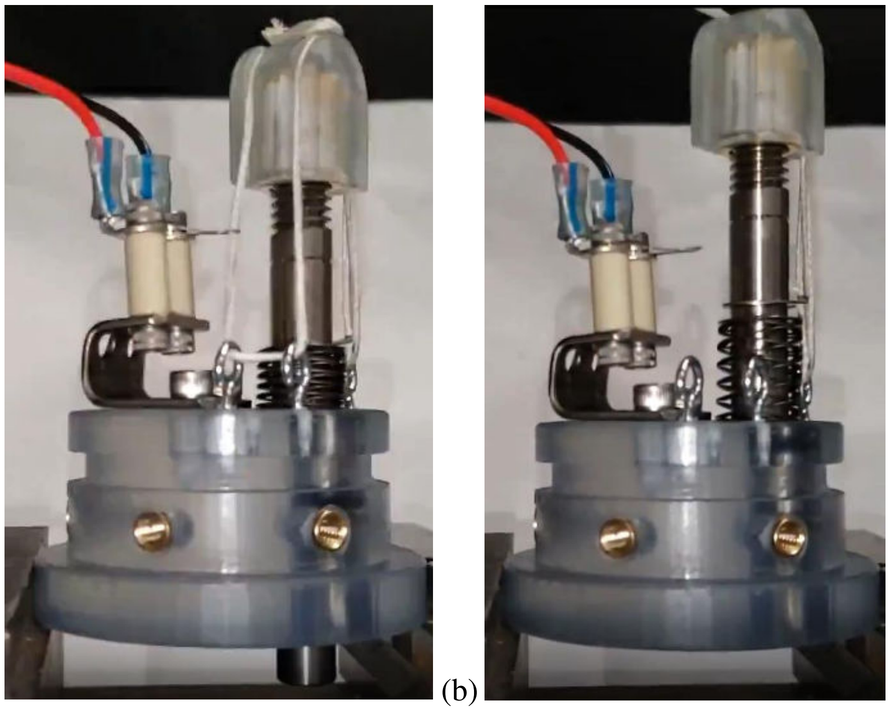


Figure 8: Manual test of the pin puller with (a) pin extended and (b) pin pulled

The burn wire mount was then incorporated to show that the pin puller would actuate upon activation without manual wire tensioning. Figure 9 shows the successful result of this test.



(a) (b)

Figure 9: Pin puller tested with burn wire showing pin (a) extended and (b) pulled

The weight was also tested as its own unit. It was compressed onto the bellows bucket using a bar clamp to deform it as a spring and then released using the clamp's trigger. This test revealed that the stainless steel rod ends posed a problem as they caught onto the pin puller mount as the weight was released, preventing it from dropping completely as shown in Figure 10.

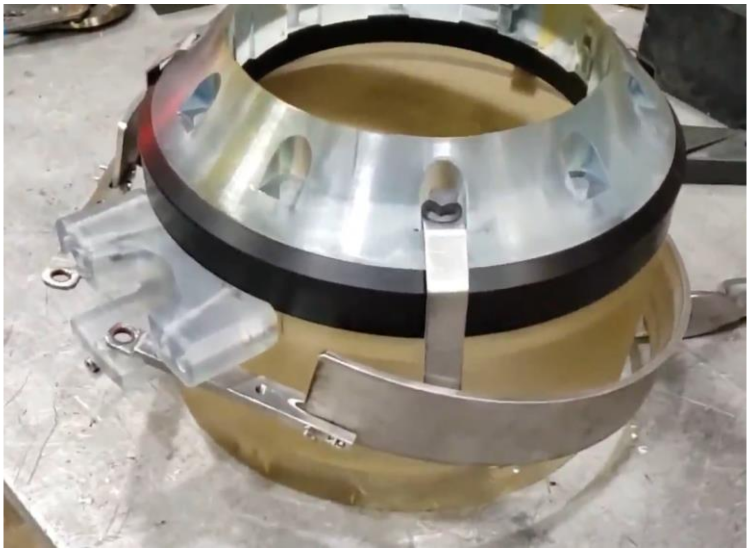


Figure 10: Unsuccessful unit test of weight release showing rod end stuck in pin puller clamp

When tested using a pin through the rod ends manually as shown in Figure 11, tension exerted by the weight generated too much friction for the pin to be pulled back out, again preventing the weight from dropping. Problems with these rod ends presented themselves again in later testing.

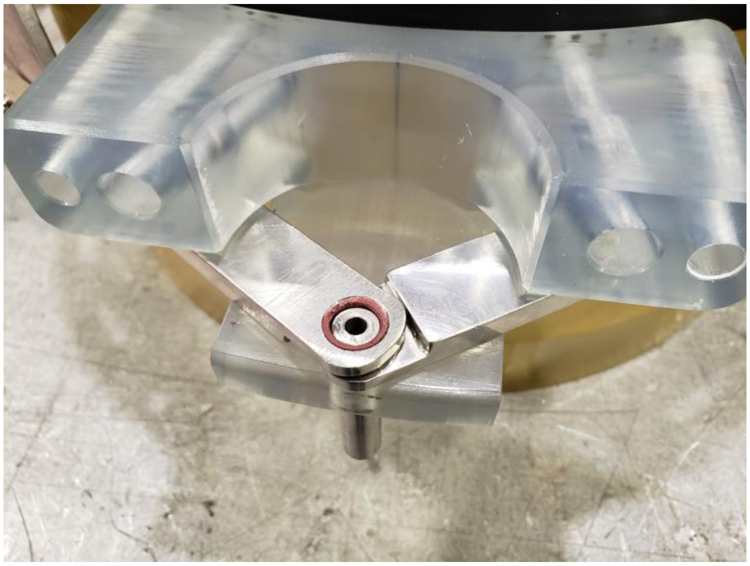


Figure 11: Pin held in place by friction during unit testing

SYSTEM-LEVEL TESTING

With the pin puller and weight tested independently, they were then tested as a complete system where the pin puller was fully responsible for releasing the weight. The problems posed by the rod ends proved to be insurmountable, as the friction they exerted on the pin was too great for the pin puller's spring to overcome when released in testing. Instead of using the rod ends, they were removed and replaced by a length of Kevlar rope that looped around both around the release pin and the clevis pins in the weight bar. This change allowed the tensioning and positioning of the weight bar to be made more flexible. Instead of tightly fastening the weight bar around the external bellows bucket, the bar and ramps could be bent manually so that the bar was fastened more loosely, reducing the tension on the rope and bringing the force requirement within the capability of the spring. Once these adjustments were made, the pin puller was able to actuate successfully with the weight loaded onto the bucket in dry conditions. Figure 12 shows the result of this dry test.

(a) (b)

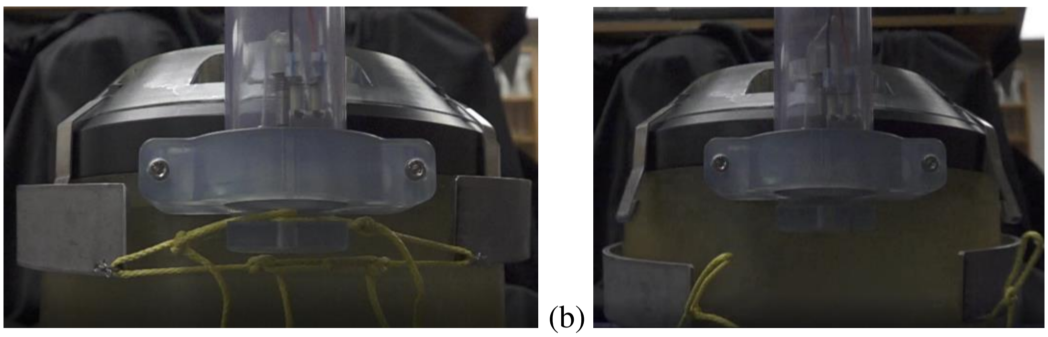


Figure 12: Successful dry system-level test showing the weight bar (a) attached and (b) released (Images: Todd Walsh)

Following the successful dry test, the drop weight was also operated in the test tank to demonstrate its function underwater. Once again, the weight was able to deploy successfully as shown in Figure 13.

(a) (b)

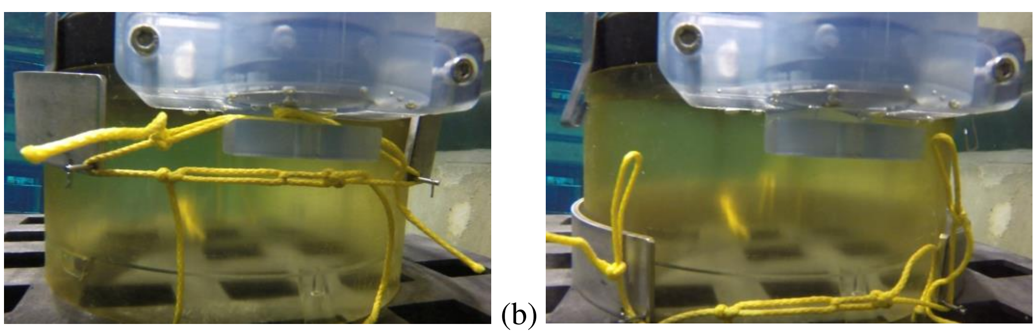


Figure 13: Successful wet system-level test in the tank with the weight (a) attached and (b) dropped

DISCUSSION

The successful demonstration of the drop weight's function in both dry and wet conditions confirms the value of this design as the basis for a deployable recovery failsafe. However, even these successful tests come with caveats.

One of the biggest drawbacks of the design as it currently stands is the low force that the spring exerts on the pin when compressed. This spring was selected for expedience based on the size of the pin, the estimated necessary pin displacement, and an estimate of the required force at this displacement. Both the pin displacement and force were found to be sufficient for overcoming the friction exerted by the dynamic O-ring seal, but not enough for pulling against the friction exerted by the weight bar when fastened tightly. Replacing the spring with a stiffer one would enable it to overcome more friction and allow the weight to be fastened more securely.

Another limitation of the tests is that the weight and ramps had to be adjusted such that the weight was just barely resting in its mounting position when the system was armed. This was done to lower the force exerted on the pin and enable the existing spring to overcome the reduced friction force. While acceptable in a test scenario, a deployable system must retain the weight more securely. This would allow low tension to be applied to the weight bar without risking it releasing from the CPF unintentionally. Increasing the length of the sheet metal ramps would place their angled sections in a more advantageous location, allowing them to retain the weight at a lower tension. Applying a material with a high coefficient of friction to the ramps or the weight bar, such as strips of durable rubber, would also improve the weight retention.

The mate between the rope and the release pin could also be improved by reducing the friction on these surfaces. Using a rope thimble inside loops tied at the ends of the rope instead of using the rope bare would result in a lower contact area of metal-on-metal at this mate. This should result in a lower coefficient of friction and easier actuation of the pin puller.

During all tests, the burn wire was energized using an external power supply. Although the housing was designed to accommodate the battery and electronics necessary to perform this function, they were not ready for any of the tests. The electronics would need to be developed and integrated to produce a deployable system. The additional triggers, namely the corrosive link and burst disk, also remain unincorporated, but could be attached to the rope tensioning the weight onto the bucket.

Lastly the housing was designed to allow more than enough space to fit all of the required components. This means that it could be greatly reduced in size without negatively impacting the release's function. It could also be changed in form to be more easily manufacturable without 3D printing.

CONCLUSIONS/RECOMMENDATIONS

The drop weight mechanism presented here for use on the CPF proved itself to be a viable candidate for eventual deployment. With proper adjustment, it could operate successfully in both dry and wet conditions. Continued development following the suggestions made in the Discussion section are likely to yield a deployable system that will make the Coastal Profiling Float easier to recover in an emergency.

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