DAWN: The Deployable Awning Water Network

Kayla Rafkin, Emily Sandler, Tuni Seneviratne, Ben Stettin, Theo Usher

The authors are with the Department of Mechanical Engineering, Columbia University, New York, NY (kdr2124@columbia.edu, ess2241@columbia.edu, cbs2181@columbia.edu, bas2262@columbia.edu, tsu2107@columbia.edu . This material is based upon work developed in the MECE E3420 / E3430 Engineering Design Courses

***Abstract*— Water scarcity is a pressing global issue affecting billions worldwide. This challenge is amplified for mobile and tiny home residents due to limited access to traditional water infrastructure. Current solutions such as rainwater collection systems are limited by installation complexity and water capture potential. To address these challenges, we introduce DAWN (The Deployable Awning Water Network), a novel system designed to capture and clean rainwater for mobile and tiny home residents. DAWN includes a deployable awning, collapsible rain barrel, and filtration system, offering ease of installation, portability, and stability. This report details the design and analysis of DAWN's key components, including the awning's structural integrity under wind and water loads and the barrel's structural integrity under water loads, validated through finite element analysis (FEA). Results demonstrate DAWN's viability as a consumer-grade solution, with discussions on potential optimizations for enhanced performance and affordability. The analysis reveals that DAWN meets or exceeds industry standards for structural stability, with factor of safety calculations indicating robustness against expected loads. Furthermore, stress distribution analysis shows that critical components such as the vertical support poles remain within acceptable limits, affirming the system's reliability in real-world applications. Analysis of the barrel reveals a large factor of safety, indicating further constraints could be made in future design development. Discussions on cost-effective design alternatives and material optimizations underscore DAWN's potential for widespread adoption as a sustainable water solution for mobile and tiny home dwellers, offering resilience against water scarcity challenges.**

I. INTRODUCTION

A. Motivation

Severe water scarcity affects approximately two thirds of the world's population [1]. These conditions especially affect residents of mobile and tiny homes because these homes often lack water infrastructure and city water connections [2]. Current solutions to this problem include capturing rainwater using pots, pans or portable water tanks. Water quantities are limited by lack of gutters and small capture area surfaces. Existing rainwater catchment systems require homes to have gutters and roofs with large surface areas to maximize water collection. Current awnings either only provide shade for consumers or simply direct water away from doors, but do not expand water catchment area. Additionally, according to customer reviews, existing collapsible rain barrels do not hold large enough quantities of water and are not structurally strong [3]. Furthermore, rainwater catchments systems require professional and permanent installation, making them inaccessible to mobile home residents.

B. Our Solution

DAWN, The Deployable Awning Water Network, is our solution. DAWN is a system comprising of a deployable awning, collapsible rain barrel, and an off-the-shelf pipe and filter, giving residents of mobile and tiny homes the ability to capture and clean rainwater to use for various purposes. The SolidWorks rendering and final design is shown in Fig. 1. The awning expands water catchment area, capturing rainwater and directing it through the filter and into the rain barrel where it can be stored for future use. When not in use, the awning can be retracted. Also, the entire system can be easily disassembled by hand if necessary.

Fig. 1. DAWN Solidworks Rendering

The awning is supported by a metal structure and anchors into the ground using ground screws. There are vertical support poles, linkage arms, a fabric roll, a track, and the awning fabric. The track is made of aluminum extrusion. A set of nuts, bolts, and washers connects the ends of the linkage arms to the track which allow these pieces to move together while deploying and retracting. The linkage arms are made of two hollow aluminum extrusions and one solid aluminum extrusion. These pieces are connected via two spring loaded to open hinges. This causes the linkage to naturally rest in the open configuration. The gearbox locks the assembly in the closed position when retracted. When deploying, the force from the spring loaded hinges pushes the arms and track outward. For the right linkage, the solid aluminum piece screws on the vertical poles and the bearing connection. The left linkage follows the same concept, except instead of the bearing there is a gearbox.

The fabric piece of the awning is made of coated canvas [4]. There is a drainage point at one of the bottom corners, where a hose can be screwed in and water can drain into the filter. The edges of the fabric have sewn in walls that guide the water to the bottom of the awning. It is slightly asymmetrical, with one side of the fabric longer than the other. This allows for all of the water to collect at the specific drainage point. The front wall of the awning fabric extends below the drainage point and has holes in it, which go over the pegs on the metal track, securing the fabric to the system. The back of the awning fabric is secured to the fabric roll with Velcro. The awning fabric has metal boning in the walls to ensure they stay upright and to provide structure. Due to the inability of bringing dirt into the MECE lab and design expo, the prototype screws into a metal bar and wooden base instead. This is seen in the physical prototype Fig. 2 below.

The collapsible rain barrel has a metal base and support poles, giving it a sturdy structure. The base has a gentle slope created by 3 stacked wooden pieces that helps to funnel the water toward the outlet point in the barrel bag. The barrel bag is a separate component which fits onto the base and stores the filtered water. It is made of a marine vinyl fabric with a nylon ripstop lining. Water flows in through a hole in the top, which is secured to the inlet pipe with a metal fastener. The user retrieves filtered water through a spigot in the bottom, which is an integrated component of the bag and

Fig. 2. DAWN Prototype

is held 6 inches above the ground by the metal base. The top of the barrel bag can open entirely for maintenance.

When all of the pieces are assembled and the tubing is connected, water flows from the awning into the pipe and filter, and then the cleaned water goes into the barrel for storage until use. Water can either be directly accessed from the spigot, or the spigot can be connected to a standard threaded hose for channeling to another location or into a separate water tank.

C. How DAWN Works: User Experience

DAWN can be easily installed by a consumer, is completely free-standing, and is easily collapsible. Additionally, customers that move can simply pack it up and reinstall the system at their next location. These qualities give it specific design constraints.

1) Awning User Experience: The construction and deconstruction of the awning is easily handled by one person. To enable this process, the entire awning is built on the ground and then simply lifted and locked in the upright position. To build the base of the awning, the user first screws the ground plates into the ground. The following screwed attachments are threaded ends connected to threaded holes. Next, users screw the support poles together and connect them to the ground plate via a locking hinge. The linkages are screwed on above the vertical poles. Then, above the left linkage arm, the gearbox is screwed into place. The bearing connection screws onto the right linkage. As previously described, a set of nuts, bolts, and washers are used to connect the linkages to the track. Similar to the vertical poles, the roll pole is constructed via two poles screwed together. Each end of the roll pole is then slotted into the gearbox and bearing.

User testing proved consumers preferred threaded connections because they are intuitive and require minimal instruction, so we incorporated threaded attachment points in as many locations as possible. The system is entirely mechanical to keep cost and weight low. To deploy and retract the awning users turn a gearbox using a hand crank that hooks onto it. The length of the hand crank is adjustable to make the awning accessible for various heights of users.

2) Barrel User Experience: The barrel base is built entirely with screws, which can all be attached by hand or with an Allen Key. The parts are symmetric and all use the same size 1/4-20 screws. The user connects the first aluminum base plate to the eight vertical support poles and uses the hole in the center to anchor it into the ground with a ground screw if desired. The second aluminum base plate and sloping wooden base are then secured, and the threaded steel support rods are screwed in by hand.

The barrel bag itself comes as one piece, with the outlet spigot already attached so that the user has to make as few watertight connections as possible. The user simply slides the bag onto the base structure using the sewn in vertical channels on the bag and attaches the tubing. The barrel's inlet pipe is attached by inserting the pipe through a hole in the barrel bag and then screwing a fastener on from the inside. The inlet and outlet pipes can be seen in Fig 3.

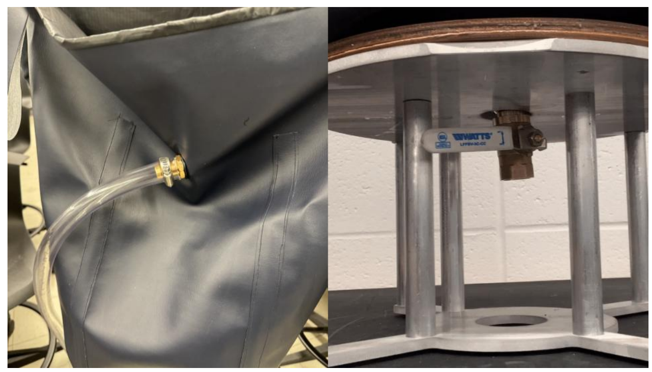

Fig. 3. L: Barrel Inlet, R: Barrel Outlet

The structure of the base is completely separate from the waterproof barrel bag, as can be seen in Fig 4. During disassembly, the product can be taken apart, and the bag can be rolled up. It takes up very little space, an important feature to prospective consumers.

Fig. 4. Barrel Assembly (L: Without Bag, R: With Bag)

D. Technical Design Constraints

1) Awning Technical Design Constraints: DAWN can be easily installed by a consumer, is completely free-standing, and is easily collapsible. Additionally, customers that move can simply pack it up and reinstall the system at their next location. These qualities give it specific design constraints. Because the awning catches rainwater, it needs to be able to withstand the load from the water it catches as well as the wind loads on the structure. Furthermore, the awning vertical support poles must be able to support the entire weight of the system because it is free standing.

2) Barrel Technical Design Constraints: The water collected by the rain barrel puts pressure on the lining of the barrel bag. Thus, the lining of the barrel bag must be strong enough to withstand this pressure. Furthermore, the weight of the water in the bag is significant, and the base of the barrel must be strong enough to hold the weight of a full barrel of water.

II. Methods

A. The Awning

The physical prototype for the awning required choosing a scaled-down model. The major concerns were the cost of components, manufacture-ability, and assemble-ability. In terms of physical quantitative constraints, the awning needed to be able to support all the loads. These loads come from three areas:

1) wind loading
2) water loading
3) individual part weights

Fig 5 shows the part of interest and loads well. Due to part availability issues and storage space, the scaled down model of awning was limited to 5 ft high, 4 ft wide and 3 ft in length.

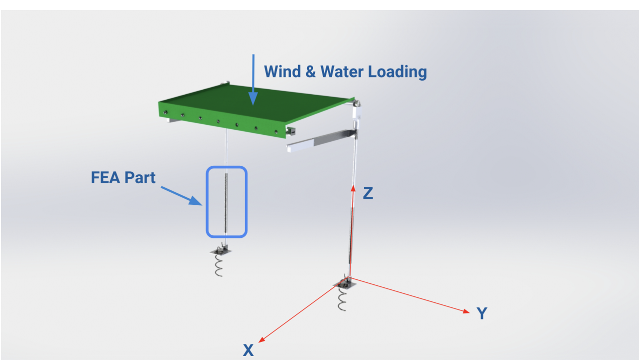

Fig. 5. DAWN Loading Conditions

The wind and water loads were determined through the use of equations. The part weights were determined using SolidWorks. The parts of concern are the bottom support poles as these are fixed into the ground. Once all the forces are known, the torques on the parts can be calculated using the equation for torque T, where F is the force and r is the perpendicular distance between distance location the force acts at and the point of interest as shown in Eq. 1. Once all the loads are known, a finite element analysis (FEA) simulation can be performed to ensure the part meets the loading requirements and will not fail in use. The FEA determines the stress and strains within a part to see whether it will fail under the loading conditions.

$$T = r * F \tag{1}$$

The wind loading is a key factor. Typically, when it rains, there are also gusts of wind. As a result, most municipalities have their own wind speed requirements. For example, Greenwood Village, Ohio requires awnings to be able to sustain wind speeds of more than 20 mph [5]. More generally, high grade awnings are tested at 25 mph wind speeds, so this wind speed was used to determine the minimum support requirements [6].

The pressure P can be related to the wind speed v in miles per hour via Eq. 2. This pressure is given in pounds per square foot. The force can be calculated by converting this value to Newtons per meter squared (which uses a factor of 4.8824). The overall force on the awning from the wind F_{wind} is given by rearranging the definition of pressure as seen in Eq. 3 where A is the surface area in contact with the pressure distribution.

$$P = 0.00256v^2 \tag{2}$$

$$F_{wind} = P * A \tag{3}$$

For the water loading F_{water}, a force estimation can be calculated by looking at the volume of water built up on the surface of the awning. This can be done by looking at the width w, length l, and thickness t (of the walls) of the awning in combination with the density of water ρ_w which is a constant $62.4\frac{lb}{ft^3}$ as seen in Eq. 4 [7]. The walls of the awning are .5in, the width of the awning is 3ft, and the length of the awning is 4ft.

$$F_{water} = \rho_w wlt \tag{4}$$

B. The Barrel

The barrel had several design constraints, the first being its scale. The consumer design is sized to be 3 ft in diameter and 3 ft in height to have a water capacity of 157 gallons, since that's the size of a typical large rain barrel [8]. Our prototype is scaled down due to part availability, to 2 feet high (1.5 ft of water storage and 6 inches for the base) with a 1x1 ft base.

Another major design constraint is water weight and pressure. The lining of the barrel has to be able to hold the water pressure calculated in Eq. 5, where P_{water} is water pressure in N/m^2, ρ is water's density (997 kg/m^3), g is gravity (9.81 m/s^2), and h is water depth or the barrel height.

$$P_{water} = \rho gh \tag{5}$$

The barrel's base also needs to be able to hold the weight of the entire barrel's worth of water. This was checked using a SolidWorks FEA. The mass of the water can be found using Eq. 6, where M_{water} = water's mass, ρ = water's density, r = the radius of the barrel, and h the height. The part of the barrel most likely to fail due to water weight is the .25" aluminum plate that the fabric barrel sits on. This plate holds the full weight of the water but is only supported by 8 1" columns from below. An FEA was run, with the mass of the water distributed over the top of the plate, while the areas in contact with the 1" columns from below were made into vertical fixtures.

$$M_{water} = \rho \pi r^2 h \tag{6}$$

III. Results

A. Awning FEA

Table I shows the calculated loads from the external loads on the base support. Since our awning is nearly symmetric, the forces for wind and water loads were divided by two. As mentioned previously, these values were calculated using equations 1, 2, 3, and 4. The values inside the moment arm column of Table I come directly from the one-third scale model of the awning.

TABLE I
FORCE AND TORQUE LOADS

Load Type	Force (N)	Distance (m)	Torque (Nm)	Axis
Wind	41.66	0.41	16.93	x
Water	61.68	0.41	25.07	x
Arm Weight	30.12	0.38	11.29	x
Pole Weight	5.74	0.00	0.00	-
Roll Weight	22.40	0.64	14.46	y
Connector Weight	5.333	0.00	0.00	-
Track Weight	4.59	0.64	2.96	y

The wind and water loads only exert torques in the X direction because the roll bar that runs between them prevents any flexing and bending inward (along the Y axis). The overall results for loading and direction are shown in the Table II below.

TABLE II
NET LOADS

Load Direction	Value	Unit
X-Torque	53.29	Nm
Y-Torque	17.42	Nm
-Z	171.52	N

The results of the awning FEA are shown in the subsequent figures. FEA results were run multiple times with different levels of mesh refinement until mesh convergence was achieved. Less than a 10% increase between stress and element number was an indication of convergence. As seen in Fig. 6, this was achieved.

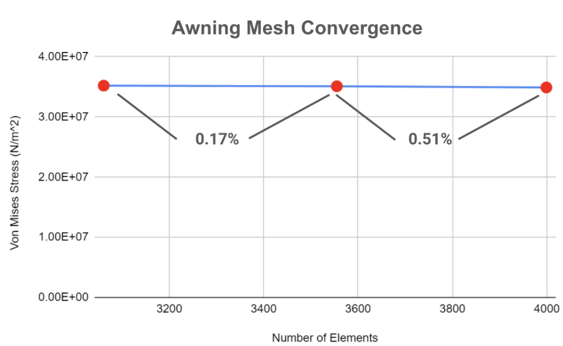

Fig. 6. DAWN Loading Conditions

Fig. 7 shows the factor of safety (FOS) of the awning. Only the smallest factor of safety value should be used since part failure will occur at this point.

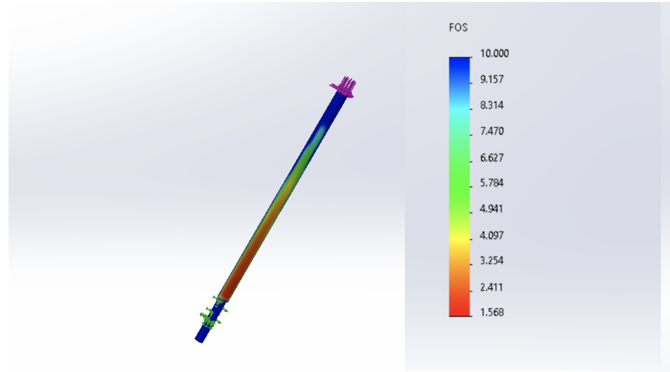

Fig. 7. Ground Pole Factor of Safety Plot

Fig. 8 shows stress throughout the part. The results are closer to red towards the base of the pole which is near the mounting (fixed) condition for the pole. The stress in the part is less than the yield strength of the material.

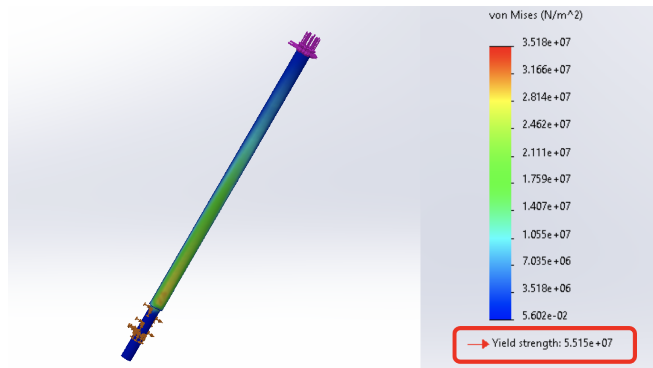

Fig. 8. Ground Pole Stress Results

B. Barrel Pressure

The maximum pressure on the side of the water barrel was found to be .65 psi (4471.6 N/m^2) by plugging the barrel height of 1.5 ft (.4572 m) into Eq. 5.

C. Barrel FEA

The barrel's FEA was run as described in the Methods section. The mass of the water in the barrel was calculated to be 301 lbs (136.5 kg) using Eq. 6 and the barrel dimensions. The FEA was run with this mass value, and achieved a 1% increase in max stress over much larger increases in mesh elements, as shown in Fig. 9. The FEA showed a minimum factor of safety of 5.829, as seen in Fig. 10. It also showed a max stress of $9.46 * 10^6 N/m^2$, compared to aluminum's yield strength of $5.515 * 10^7 N/m^2$, as seen in Fig. 11.

IV. Discussion & Conclusion

A. Awning FEA

The results for the awning in Fig. 6 show mesh convergence. Mesh convergence must be achieved before looking at the factor of safety plots and stress curves shown in Fig. 7 and 8.

From Fig. 7, the factor of safety of 1.57 seems fairly low for a consumer-grade product. However, it should be noted

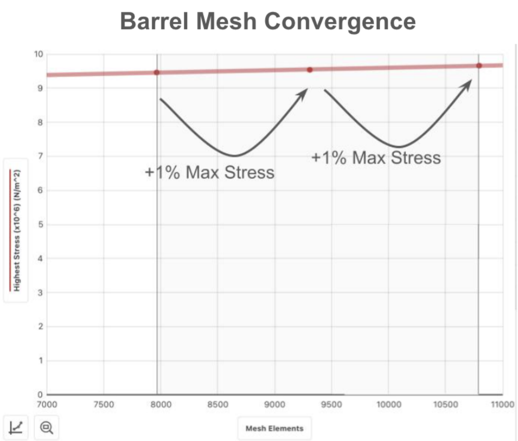

Fig. 9. Barrel FEA Stress Convergence

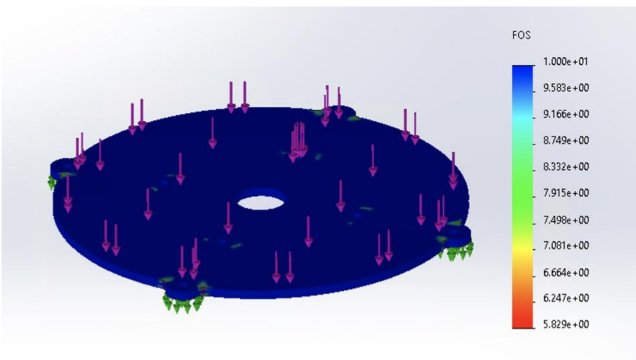

Fig. 10. Barrel FEA FOS

that the loads for FEA in Fig. 7 and 8 are overestimates. Initially, an FEA was performed using 2 inch diameter poles for all components. A factor of safety of more than 5 was achieved. Since 2 inch diameter poles were expensive for the lengths that we needed, we tried rerunning the simulations using 1 inch diameter poles which Fig. 6, 7 and 8 are for. The loads for the two cases remained the same. In reality, the 1 inch loads should have gone down since the size of components being supported would also go down (by a factor of 1/2). Furthermore, the linkage arms in the SolidWorks were solid. In our actual constructed model, these arms were hollow. As these components accounted for the most weight on the structure, we expect a more accurate simulation to have much lower torques and forces acting on the structure, which would lead to smaller stresses and a higher factor of safety.

From Fig. 8, we see that the stress within the pole is less than the yield strength of the material (Aluminum 6061). Thus, the FEA indicates that the part is strong enough to support the loads on it. Moreover, we see the highest stresses occur towards the bottom of the poll, close to the fixed geometry boundary condition which makes sense as these atoms are the most restricted from movement and so take most of the loading.

Based on the literature, Aluminum 6061 has a yield strength of 55 MPa, which generally agrees with the Solid-Works's value of 55.15 MPa used in the analysis [9].

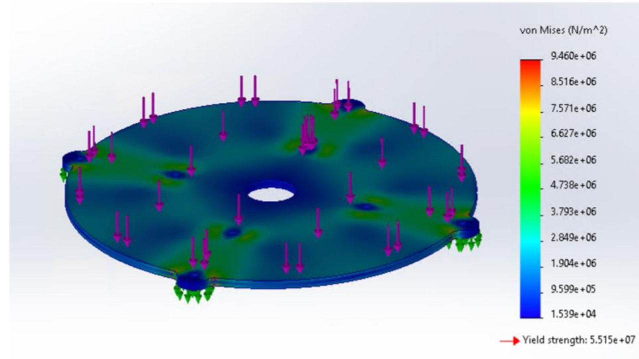

Fig. 11. Barrel FEA Stress

Moreover, the aluminum pole can be compared to the perpendicular loading of a cantilever beam since there is a torque is applied at one end with a fixed boundary condition at the other. Furthermore, the main stresses come from torque (as opposed to the parallel loading forces), further helping this comparison. As the literature suggests, stresses should be higher towards the fixed boundary conditions [10]. Indeed, our results in Fig 8 align with these results.

B. Barrel Material

The maximum barrel pressure was found to be 0.65 psi. The barrel's main material was chosen to be stronger than this pressure. The barrel is made of a double-layered fabric. The inner material is Nylon Ripstop, which can withstand up to can withstand up to 1.45psi, a FOS of more than 2 above what is necessary when the barrel is full [11]. The outer layer is Marine Vinyl, which can withstand 2000-3000 psi, far more than is necessary for this barrel [12]. This outer layer has the added benefit of protecting the barrel from scratches.

C. Barrel FEA

The barrel FEA showed that the factor of safety was extremely high at a minimum of 5.829. A thinner piece of aluminum could be used for the barrel plates, but 0.25" is a good, standard size, and a high FOS is useful for such a critical part. However, there was an error in the calculation of the mass of water in the barrel. 1 ft was used as the radius of the barrel in Eq. 6 instead of 0.50 ft. Therefore, the mass is 4 times higher than it should be, making the FOS even safer. While this is an error, it actually makes the product even better, as the height of the barrel could be quadrupled to 6 ft before the expected FOS of 5 is reached.

Based on the literature, Aluminum 6061 has a yield strength of 55 MPa which generally agrees with the Solid-Works's value of 55.15 MPa used in the analysis [9]. Furthermore, our FEA revealed that stresses increased near the holes in the aluminum plate, which is consistent with previously observed behavior of the material [13].

D. Non-Quantitative Results

1) Compliance with Drinking Water System Standards: The inlet attachment and outlet spigot of the barrel comply with ANSI 61 drinking water standards, which was our ultimate goal [14]. We also ensured that our inner fabric layer, Nylon Ripstop, would be considered food safe [15].

Another water safety standard is that the barrel must be cleanable [16]. We made the barrel as easy to clean as possible through a large opening in the top. This opening was inspired by a camper's dry bag, allowing the user easy access to the inside of the barrel but also closing in a watertight seal. This makes the barrel very easy to clean, which is a frequent issue with rainwater barrels [17].

2) Leak Proofing the Barrel: All components of the barrel should be fully watertight, especially at the inlet and outlet points. This was tested and confirmed by filling the barrel with water and ensuring it did not leak, even when shaken around and held upside down. However, this result is contingent on the user properly attaching the inlet pipe and correctly closing the dry-bag style opening. More work into ensuring that it's almost impossible to mess up these tasks would be useful.

E. Future Considerations

1) Awning Deployment System: Following construction of a scaled prototype, it was discovered that the spring loaded hinges were load bearing. Due to this oversight, we did not do an FEA analysis on these hinges, so the hinges that we used were not supportive of the weight of the linkages and track. For the prototype, we 3D printed conical supports that attached directly below the linkages and support the weight experienced by the hinges. For future prototypes, an FEA analysis on the loads experienced by the spring loaded hinges would be useful.

2) Barrel Fabric: ANSI 61 drinking water standards do not cover specific fabrics, so we were unable to acquire a material that fit the same standards as the rest of our components. Instead, we settled on using a food safe Nylon Ripstop. Since this standard is not backed by ANSI or FDA, it would be useful to test the Nylon Ripstop and other fabrics in the future to ensure drinking water safety. This test would involve a series of water quality tests at various points throughout the cycle of the DAWN system, including an analysis of any changes in water quality over a long period of time stagnant in the barrel.

F. Conclusion

Water scarcity is a major concern across the globe. Unfortunately, water scarcity especially impacts people who live in tiny and mobile homes due to a lack of water infrastructure. Current rainwater catchment systems are not fit for these homes because they require professional and permanent installation, large roof surface areas, and gutter systems. To solve this problem, we created DAWN - The Deployable Awning Water Network. DAWN is a system that captures and cleans rainwater for these residents to use. DAWN consists of a deployable awning, collapsible rain barrel, and filtration system. DAWN is portable, collapsible, and can be easily installed by a consumer.

This report shows the design and technical analysis of DAWN. It reveals how the key components were designed to ensure the awning could hold the the weight of the structure, water loads, and wind loads. Furthermore, it validates the barrel base's structural integrity under water loads. These design constraints were supported by finite element analysis (FEA).

The FEA proves that DAWN is a feasible consumer-grade product, although there are areas to improve and optimize the design. The analysis indicates that DAWN meets or exceeds industry standards for structural stability. The factor of safety calculations reveal it is secure against expected loads. Additionally, stress distribution analysis in the awning support poles remain within acceptable limits. This indicates the system would be reliable in real-world settings. The barrel has a large factor of safety, revealing even future iterations could have more design constraints.

With cost-effective design swaps and material optimizations, DAWN's has the potential for broad adoption as an eco-friendly water source for mobile and tiny home residents, helping them combat water scarcity.

References

[1] unicef, "Water scarcity: Addressing the growing lack of available water to meet children's needs.."

[2] G. Pierce, "Unreliable water access in u.s. mobile homes: Evidence from the american housing survey," 2015.

[3] Amazon, "Customer reviews: Vingli 100 gallon collapsible rain barrel."

[4] Amazon, "Waterproof canvas fabric 600d outdoor marine fabric 60" wx36" l."

[5] "Rules and guidelines for retractable awnings," 2012.

[6] A. Glover, "How much wind is too much for an awning?."

[7] W. S. School, "Water density."

[8] Amazon, "Amazon rain barrels results."

[9] AmesWeb, "Aluminium alloys - yield strength and tensile strength," 2007.

[10] T. E. ToolBox, "Cantilever beams - moments and deflections," 2013.

[11] Amazon, "9km dwlife nylon ripstop fabric, black 60x196 inch, 40d waterproof."

[12] Amazon, "Marine vinyl fabric - 54" - blue: Sold by the yard."

[13] NASA, "Stress concentration around an open circular hole in a plate subjected to bending normal to the plane of the plate," 2013.

[14] NSF, "Nsf/ansi 61: Drinking water system components – health effects," 2016.

[15] P. Industries, "Food grade plastic: Which plastics are safe for food storage," 2022.

[16] C. C. G. Association, "Disinfecting rain barrels to stay safe," 2020.

[17] F. S. Aquatics, "Your rain barrel, how to clean and maintain it," 2012.