AAE 418 Eyewash Redesign Project

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REDESIGN OF NASA 0g EMERGENCY EYEWASH SYSTEM



REPORT

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Overview and Objectives

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Figure 1: Original Emergency Eyewash System

The Spring 2026 Purdue 0g Eyewash team continued the redesign of the dated Russian zero-gravity astronaut eyewash device, pictured in Figure 1, to eventually deliver a 1-g prototype of an improved system to NASA. Starting with only NASA's deliverables and a photo of the old system, the team designed fully independent, Purdue-specific design concepts informed by research, industry engagement, and systems-engineering work. The purpose of this document is to outline what the group has completed and what possible improvements could be made to the system for 0g optimization. Within the report below, the team will outline the preliminary research, design processes, and outcomes from the Spring 2026 semester.

Requirements

Table 1 outlines the level 1 requirements for the Purdue 0g eyewash system. These requirements outline a success criterion for the system, informing design decisions, system trades, and future work. Along with the requirements, flow down verification activities for each requirement are specified along with an indication of whether the requirement is mission critical. The team defined mission critical requirements as requirements that risk total system failure if they are not met and verified properly.

ID	Mission Critical	Level	Requirement Summary	Verification Activity
1.1	☑	1	The system shall clean an astronaut's eye to a neutral pH as directed by ANSI/OSHA standards or an experimentally proven condition.	pH Testing and standards analysis
1.2	☑	1	The system shall be operable by either a single user or with the help of one additional user.	System testing and demonstration
1.3	☑	1	The system shall prevent cross-contamination between eyes.	Contamination testing
1.4	☐	1	The system shall prevent backflow of contaminated water into the water supply.	Reservoir testing
1.5	☐	1	The system shall be operable for continuous use for at least 15 minutes.	System testing and demonstration
1.6	☐	1	The system shall not require any specialty tools to operate or maintain.	System testing and demonstration
1.7	☑	1	The system shall be operable hands free after it has been activated.	Test and demonstration
1.8	☑	1	The system shall be operable with <1% of volumetric leakage throughout the system operation.	Volumetric flow testing

Table 1: L1 Requirements and Verification Matrix

Schedule

Date	Goal
October 9th, 2025	Requirements and System Definition Review (SDR)
December 15th, 2025	Preliminary Design Review (PDR)
February 11th, 2026	Critical Design Review (CDR)
March 11th, 2026	Progress Checkpoint Review
April 27th, 2026	Project Completion and Evaluation by NASA

Table 2: Finalized General Schedule

Table 2 displays the finalized presentation schedule. The listed design reviews allowed the team to stay on track and gather valuable feedback from NASA.

Date	Goal
November 7th, 2025	Completed Initial Fit and Function Test
November 14th, 2025	Completed Initial Dye Flow Test
March 20th, 2026	Leakage Test without Custom Seal
April 10th, 2026	Flow Rate Test
April 17th, 2026	Custom Seal Leakage Test
April 20th, 2026	Honey Contaminant Test

Table 3: Finalized Testing Schedule

Table 3 outlines the completed testing schedule. These tests took place to verify the system was meeting all requirements and allow the design team to conclude what improvements still had to be made during the prototyping and design process.

Prototyping and Assembly

Goggle Selection

The initial design concepts drew inspiration from the existing ISS design, which has an input and output tube fitted into each eye segment, shown in **Figure 1**. To improve the existing design, the team formed a new design that incorporates a larger, SCUBA-like mask. This design is pictured in **Figure 3**; it's focus was to mitigate recirculation of cleaning fluid within the system to stop recontamination. The other preliminary design included a swim style goggle, as seen in **Figure 2**. These designs were not aimed to be a final product, but to deliver preliminary testing results.



Figure 2: Swim Goggle CAD Model **Figure 3: Scuba Goggle CAD Model**

The initial testing plan focused on meeting Level 1 requirements, namely that the system would effectively clean the eye and properly seal the water into the system while preventing backflow and cross-contamination. The team also hopes to demonstrate that the system could effectively clean the eye quicker than the ANSI standard of 15 minutes of continuous washing, ultimately reducing the water requirements for the system.

For the testing setup, the group purchased a mannequin head and built a rotational test stand that allowed six different planar orientations as well as full 360-degree rotations. For the prototypes, the team purchased sets of SCUBA goggles and swimming goggles, as well as a submersible pump to input water from the reservoir. Liquid food dyes were also ordered to act as contaminants on the eye.

For the prototype assemblies, the team opted to drill water inlets into the outer sides of the goggles, positioned roughly parallel to the eye. This was recommended to the team by a Purdue eyewash expert to maximize the effectiveness of eye coverage and washing. Similarly, the water

outlets were located close to the nose piece to create smooth, one-dimensional flow out of the goggles. To initiate water input, rigid plastic tubes were run from the submersible pump to the inlet holes, and a second pair from the goggle outlets leading into the sink. This setup is presented in Figure 5**.** For these prototypes, the team decided against using a vacuum and to have one input and output tube per eye segment, differing slightly from the heritage ISS design mentioned above.

The SCUBA goggles were difficult to drill into and only one input/output configuration could be drilled, shown in **Figure 4**. The swim goggles were easier, and the team drilled an A and B configuration, shown in **Figure 5**. With the A configuration, the team hoped to promote a surface-parallel flow by draining liquid sideways, while the B configuration is similar to the NASA configuration for reference.

To further prepare for prototyping, the team created CAD models to evaluate frame designs that would fit the dummy head and remain secure in various orientations (upside down, left, right, etc.). Two CAD models were finalized: one based on SCUBA goggles in **Figure 4**, and one on swimming goggles in **Figure 5**. The team estimated and marked rough hole locations in the models, then attached tubes and diffuser components, some at specific angles. This process provided valuable insight into suitable hole and tube placements for the physical prototype assembly.



Figure 4: Scuba Goggle Design

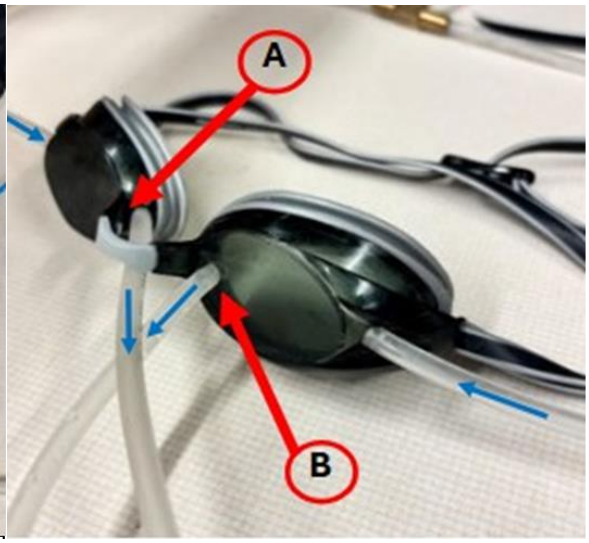


Figure 5: Preliminary Goggle Design

The team quickly realized that, compared to swim goggles, SCUBA goggles did not have separated eye chambers, which drastically increases the risk of cross contamination between the eyes. Avoiding cross contamination is a Level 1 Requirement and therefore the team decided to discard the idea of using SCUBA goggles and pursue swim goggles to mitigate the possibility of cross contamination.

Testing Stand



Figure 6: Updated Test Stand

Originally, the team manufactured a temporary frame for the mannequin head made out of wood, as seen on the right in **Figure 6**. This stand was used for preliminary testing; however, the structural integrity of the stand was compromised when testing in various orientations. To improve this, the team elected to solidify the frame by changing to a more rigid aluminum bar and base plate. This new frame supported tests of the system in all orientations. Furthermore, the newly manufactured test stand condensed all tubing and the diaphragm pump to the system. This prevented any sloppiness and confusion within the system and allowed for easier testing setup and demonstration.

Custom Seal Development

A large part of our prototyping time was spent designing a custom seal for our goggles. The seal on the stock goggle was ineffective at preventing water from escaping since it was designed to keep water out. Therefore, the team sought to create a seal that had a concave internal design to have the water press the seal down rather than push under it as pressure increased. The team created the seal in Siemens NX and used it to make our mold, pictured in **Figure 7**. Subtracting the seal from a mold block, adding inlet holes, breathing holes, and alignment pins, created a suitable mold to pour silicon into. This mold is seen below in **Figure 8** and **Figure 9**.

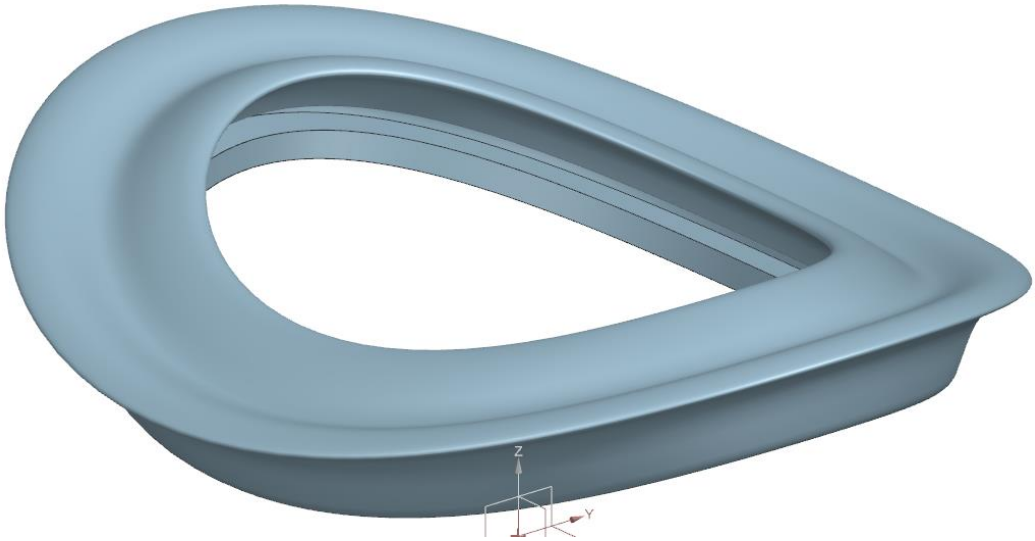


Figure 7: Custom Goggle Seal Design

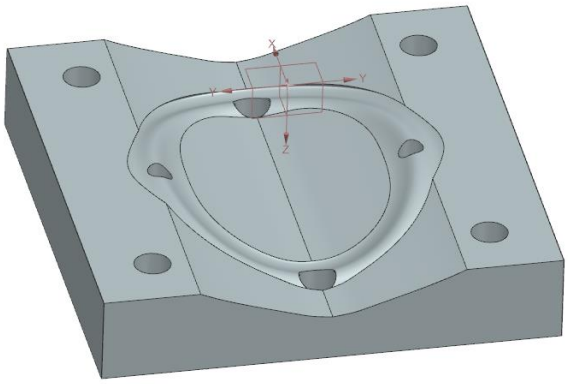


Figure 8: Top Mold Piece

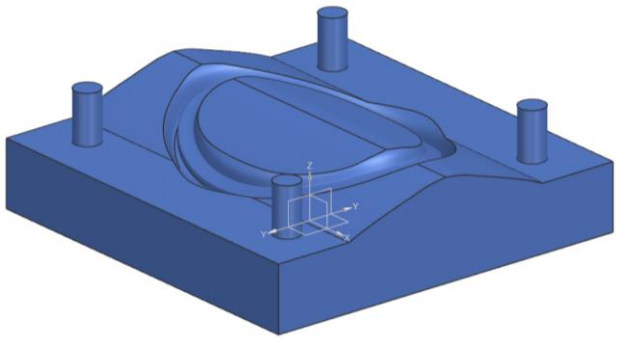


Figure 9: Bottom Mold Piece

This was then 3D printed and the afternoon team began to mix, pour, and let cure new silicon custom seals in our molds. Every new batch of goggles had flaws or things to improve on so with each test ran changes were made to our process. The team made updates to the seal design making it thicker and less wide which improved the fit on the goggles. Additionally, the team began to vacuum the silicon after mixing, this drew out bubbles and made the end silicon product

more consistent. With the finished seals used in the final prototype, the seals prevented any leakage while running.

Diffuser Development

The team concluded that a turbulent flow would more efficiently clean the eye. The team evaluated two different methods to achieve this. First, a pump with a larger flow rate was attached to the system to increase the flow velocity. However, based on the viscous flow analysis, this approach caused significant head loss, making it ineffective for the system.

The second method was to introduce a diffuser. The team attached a diffuser to the end of the delivery tube. The team constructed the diffuser using a plastic tube fitting and a 0.02-inch mesh. The plastic tube fitting was cut down so it could fit into the goggle cavity better. Then, the mesh was cut out to fit the square area of the tube fitting where it was attached using gorilla glue. The finalized diffuser is shown in **Figure 10**. One-inch holes were drilled into the side of the goggles to allow the tube fitting to sit in the goggles as seen in **Figure 11** and **Figure 12**. As the liquid hits the mesh, it the flow is disturbed and disperses into a turbulent flow. This grants full coverage of the eye.

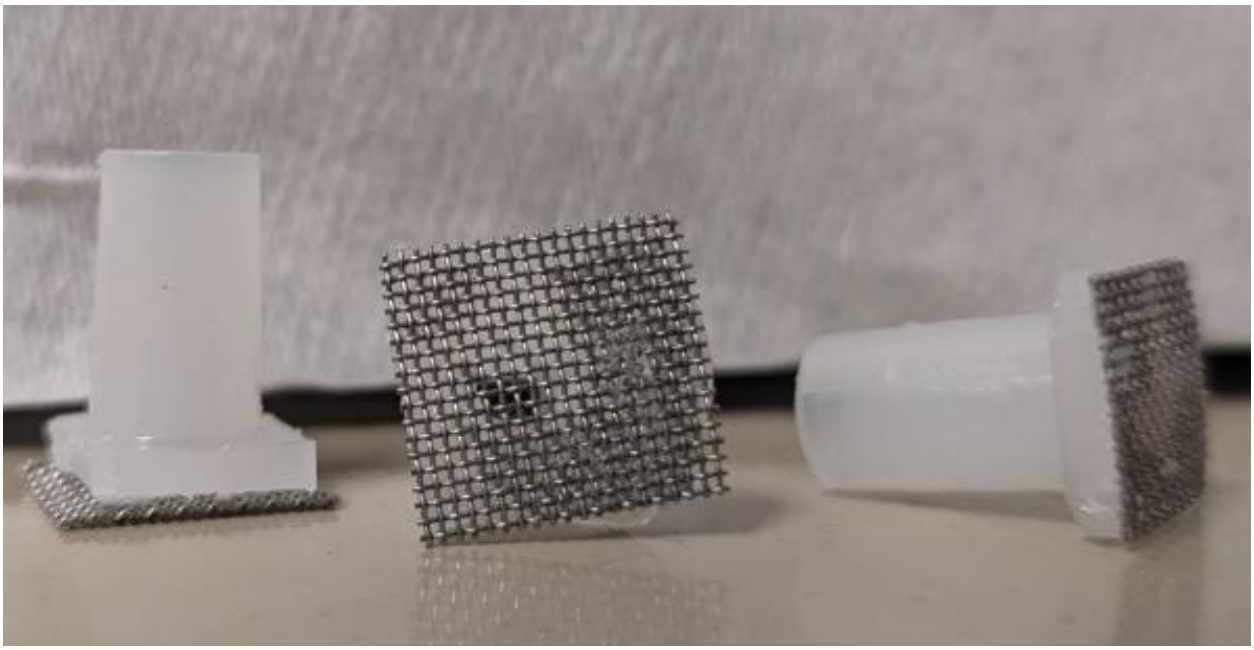


Figure 10: Finalized Diffuser Design



Figure 11: Diffuser Implemented in Goggle



Figure 12: Diffuser Goggle Interface

Diaphragm Outlet Pump

Figure or Table containing sensitive information, or possible unauthorized copyright information has been removed.

Figure 13: Diaphragm Pump

The team noticed early on that the system struggled with draining water out of the system as fast and efficiently as pumping water into the system. To mitigate this, the diaphragm pump

seen in **Figure 13** was implemented to promote flow out of the system. This pump also functions to prevent backflow and recontamination of the reservoir in addition to promoting system drainage.

Experimental Results and Analysis

Preliminary Leakage Testing

The team conducted leakage testing to understand whether the new pump and mannequin head that were purchased at the beginning of the Spring 2026 semester reduced leakage from the goggles. The team began by measuring the mass flow rate at the goggle inlets. For each eye, the team first measured how much water flowed from the inlet tube into a container in 10 seconds. Then, the team weighed the water in the container. The team conducted three trials for each eye. After calculating the mass flow rate at the inlets, the team measured the mass flow rate at the goggle outlets. Again, for each eye, the team measured how much water flowed from the outlet tube into a container in 10 seconds. The team then weighed the water in the container. **Table 4** shows the average mass flow rates for the inlet and outlet of each eye, as well as the average loss for each eye. The team was satisfied with these results, as 3-9% leakage from the goggles is a decrease from the 45.81% leakage that the eyewash had at the end of the Fall 2025 semester. Additionally, the leakage testing was conducted without the seals, which further reduced the leakage from the goggles. The impact of the new seals on further reducing the leakage in the goggles will be discussed later in this report.

	Left Eye	Right Eye
Mass Flow Rate (Inlet) (kg/s)	0.015331	0.014851
Mass Flow Rate (Outlet) (kg/s)	0.014776	0.013593
Average Loss (%)	3.617678	8.470048

Table 4: Leakage Testing Results

Flow Rate Test

In addition to leakage testing, the team conducted a flow rate test on the eyewash with the exception of the seals because they were not yet manufactured. The team began by measuring how much water flowed from the outlet tube into a container in 10 seconds. The team then weighed the water in the container and calculated the mass flow rate through the eyewash. The team conducted five trials for the flow rate test, and the results are shown in the table below. The average mass flow rate through the eyewash was 1414.39 mL/min. **Table 5** includes the results of the flow rate test for each of the five trials, as well as the average mass flow rate through the eyewash.

Trial	Time (s)	Mass (g)	Mass (kg)	Mass Flow Rate (kg/s)	Mass Flow Rate (mL/min)
1	10.53	247.3	0.2473	0.023485	
2	11.56	272.2	0.2722	0.023547	
3	10.56	244.6	0.2446	0.023163	
4	10.26	245.9	0.2459	0.023967	
5	10.8	256	0.256	0.023704	
Average				0.023573	1414.39

Table 5: Flow Rate Test Results

Contaminant Clearing Test

The contaminant clearing test measures how long it takes contaminants to clear the eye. The team used honey as the contaminant. The team placed the honey in three different locations in the eye as seen in **Figure 14**: the inner corner of the eye, the outer corner of the eye, and the middle of the eye. The test was conducted to determine the effectiveness of the diffuser.

Then, they measured how long it took the honey to clear the eye in seconds. Furthermore, they tested this with and without the diffuser in order to the measure the effectiveness of the diffuser within the system in clearing contaminants. The results of this test can be seen in **Table 6.**

There was an average of 5.24 seconds reduction in time when using the diffuser across all locations.

Some things to note:

1. The angle at which the diffuser is placed in the goggle is important. The hole has to be drilled at an angle, so the flat part of the diffuser sits flush against the inner wall of the goggle. If the hole is drilled straight in, the diffuser does not sit properly, and the flow is not across the entire eye.
2. The current system (with the diffuser) does not fully clean the outer corner of the eye. With or without the diffuser, there is still some honey in the outer corner of the eye. Additionally, without the diffuser, there is a small amount of honey in the inner corner of the eye. However, with the diffuser, the inner corner is fully cleaned.

The results concluded that the diffuser had a significant impact in reducing the time it takes to clear contaminants. This proved that there is improved flow distribution that covers the whole eye with a diffuser.

Note, these results are not for the final system but act as more of a guide as to incorporate the diffuser in the final design. Furthermore, these tests were done before the seals were attached.

Location	With Diffuser (seconds)	Without Diffuser (seconds)
Inner Corner of Eye	10.35	16.7
Outer Corner of Eye	7.67	9.37
Middle of Eye	9.99	12.37
Whole Eye	22.03	32.55

Table 6: Contaminant Clearing Test Results



Figure 14: Contaminant Test Setup

Viscous Flow Analysis

The team performed system-wide head loss calculations using viscous pipe loss theory. Using the experimental mass flow rates from the leakage test, the team performed the analysis assuming: no leakage vs experimentally measured leakage, and laminar flow.

The system was split into different sections highlighted in **Figure 15**. **Equation 1** was used to find the head loss of each individual section.

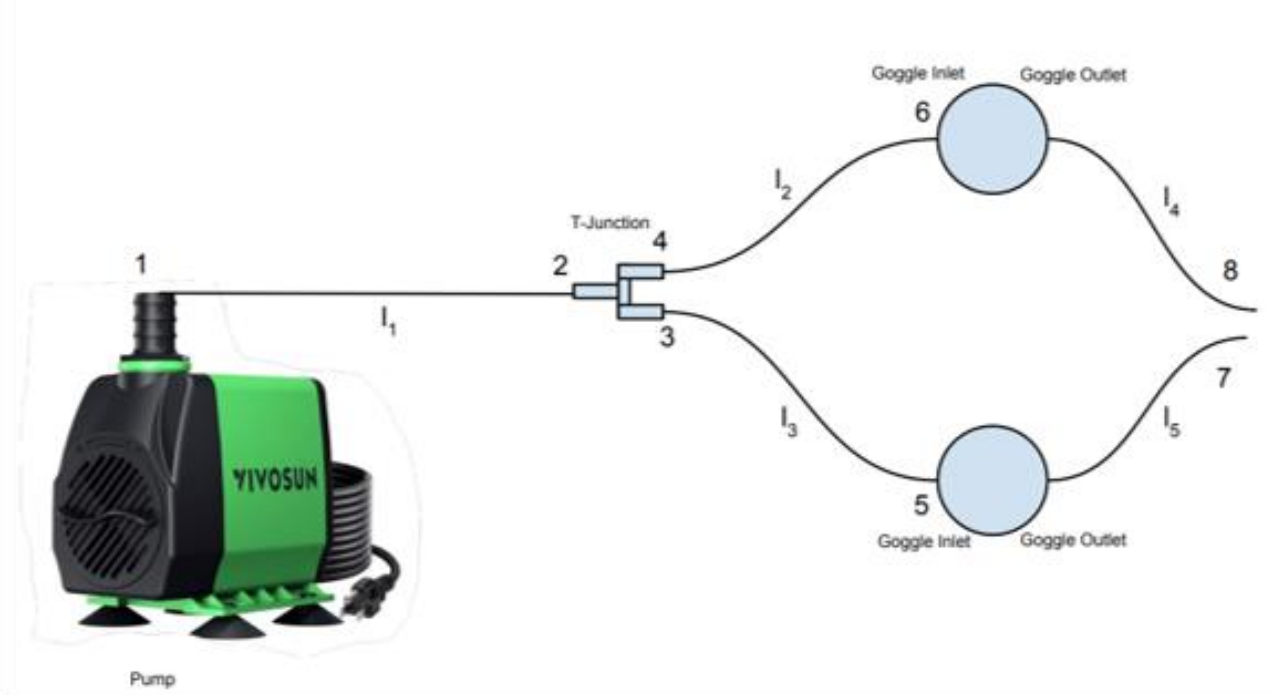


Figure 15: Head Loss System Diagram

$$h = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$ (**Equation 1**)

The friction factor, f, was calculated in two different ways: For the laminar case, the approximation $f = \frac{64}{Re}$ was used. For the turbulent case, the Moody Diagram in **Figure 16** was used to estimate f for our given material. L and D are the length and diameter of each section. Velocity was found using mass flow rates measured in the leakage tests (refer to section 1). Each section was calculated individually, and the total head loss is the sum of all sections. The results of the head loss estimates for each case are tabulated in **Table 7**.



Figure 16: Friction factor for fully developed flow in circular pipes

It is unlikely that the tubing used in this analysis will be used for the final product. Different tubing means a different value of f, making the current estimates obsolete. However, the purpose of this analysis was not to find exact head loss measurements but both to see the impact that assumptions on the flow state makes and understand the impact of leakage. One lesson learned is that laminar flow is not a valid assumption for this system. While the velocity is low, the pipe diameter is small enough that the flow must be assumed turbulent. Another lesson learned is about the impact of leakage. A larger head loss in a system without leakage must be overcome by a greater pressure output from the pump. If the difference between the cases of leakage and no leakage were significant enough, the current pump may not provide enough pressure to overcome this difference and deliver the required flow rate. However, the impact of leakage showed only minor differences in head loss, so there is no significant increase in pressure demanded from the pump for a system without leakage. Knowing this, *the team can be confident that the pump that satisfied flow rate requirements in a system where leakage is present can still be used in a system with no leakage.*

Estimated Head Loss [m]		
	Laminar	**Turbulent**
With Leakage	0.536	1.035
Without Leakage	0.396	1.062

Table 7: Estimated head loss results

Final Design

Mass Volume Analysis

A mass-volume analysis of the current system was performed. The results of this can be seen in **Table 8.**

The pumps account for 89% of the mass and 94.9% of the volume. The other items, individually, account for less than 5% of the total mass and the 2.5% of the total volume.

Item	Mass (kg)	Volume (cm^3)
Blue Input Pump	0.301	335.600
Orange Output Pump	0.5986	1157.0000
Goggles	0.035	38.000
Tubing	0.045	23.039
Seal	0.009	2.0739
Valves	0.015	8.295768
Diffusers	0.003	8.295768
Total	1.0066	1572.3

Table 8: Mass Volume Analysis for Finalized system

Fill Fraction Analysis

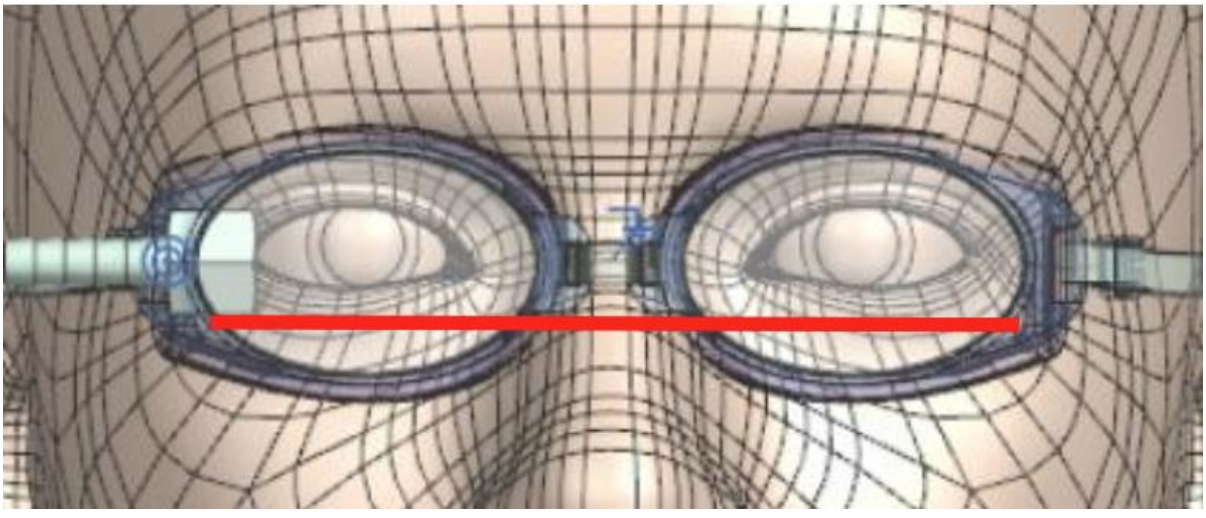


Figure 17: Optimized Fill Fraction

The objective of a set fill fraction was to ensure adequate clearance between the eye opening and the settled water level to prevent recontamination of the users eye. The total internal lens volume of each goggle was measured at 15 mL, however the effective usable volume decreases when the goggles are worn. To account for this, a 1g safety line, shown as the red line in **Figure 17**, was defined 7 mm from the bottom of the goggle, and a target fill fraction of 1:3, water to air was selected to keep the settled water level below this threshold during use. This safety margin was chosen to prevent water pooling near the eye and corresponds to a clearance within two standard deviations of the median eye size.

Overview

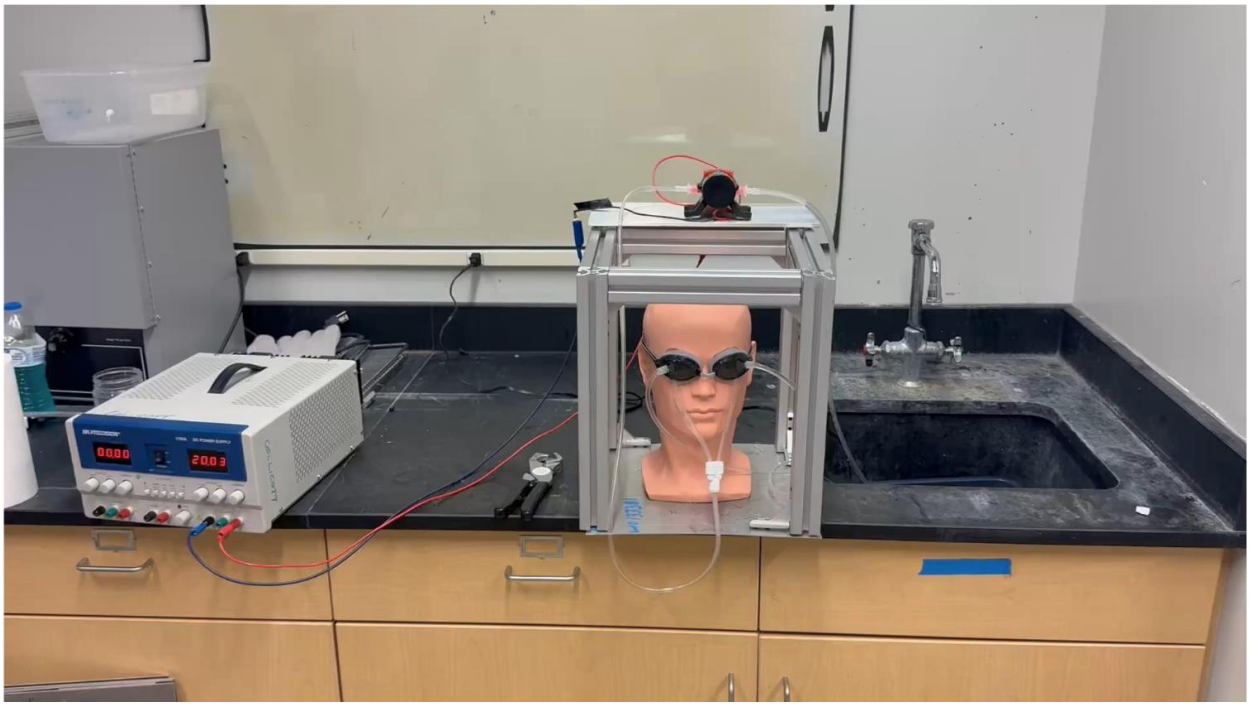


Figure 18: Full System

The fully assembled system is shown in **Figure 18**. The water reservoir is the blue bucket on the right side of the figure. The goggles equipped with the custom seals and diffuser discussed above are tightly strapped to the mannequin head. The diaphragm pump is attached to the aluminum frame to aid in promoting flow out of the system, powered by the variable power source seen in the left of the figure. The outlet tube from the diaphragm pump is seen going back into the original water source.

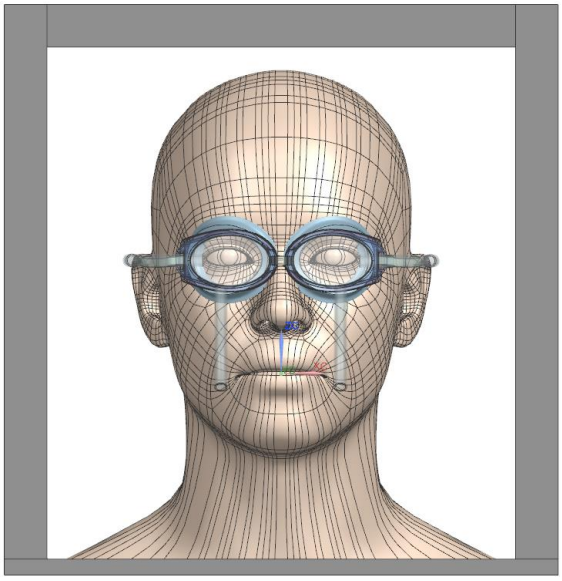


Figure 19: Goggle CAD

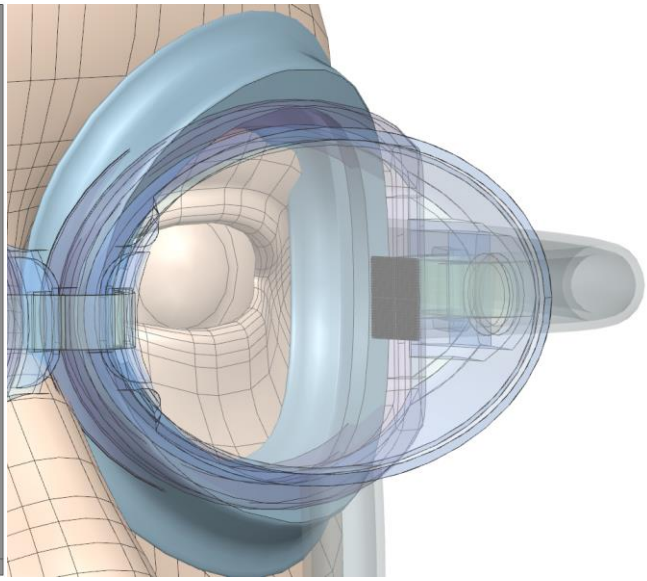


Figure 20: Goggle Inlet

Shown above, **Figure 19** and **Figure 20** illustrate the finalized CAD for the system. In the CAD assembly, the custom seal and diffuser are present, as well as an accurate scale testing stand in the left image. Additionally, the attached tubes are at the correct locations and are the proper size. The CAD gave the team a good understanding of the amount of room between the eye and the diffuser before putting it on the dummy head.

Flow Diagram



Figure 21: Flow Diagram

The final flow path in of the system shown in **Figure 21** shows water from the reservoir being pulled through a submersible pump (in sink) into tubing which then connects to a T-junction, splitting the flow into two separate tubes. These streams are directed into each lens, where the water is evenly dispersed across the eye surface, providing effective cleaning. After passing over the lenses, the water exits through outlet tubes connected to each lens. Outlet flow is then combined back to one tube via a T-junction. Outlet flow is then driven by a diaphragm pump, which is powered by an external power supply. This pump pulls the contaminated water from the lenses and directs it into the sink, which serves as the system's wastewater disposal path.

System Effectiveness

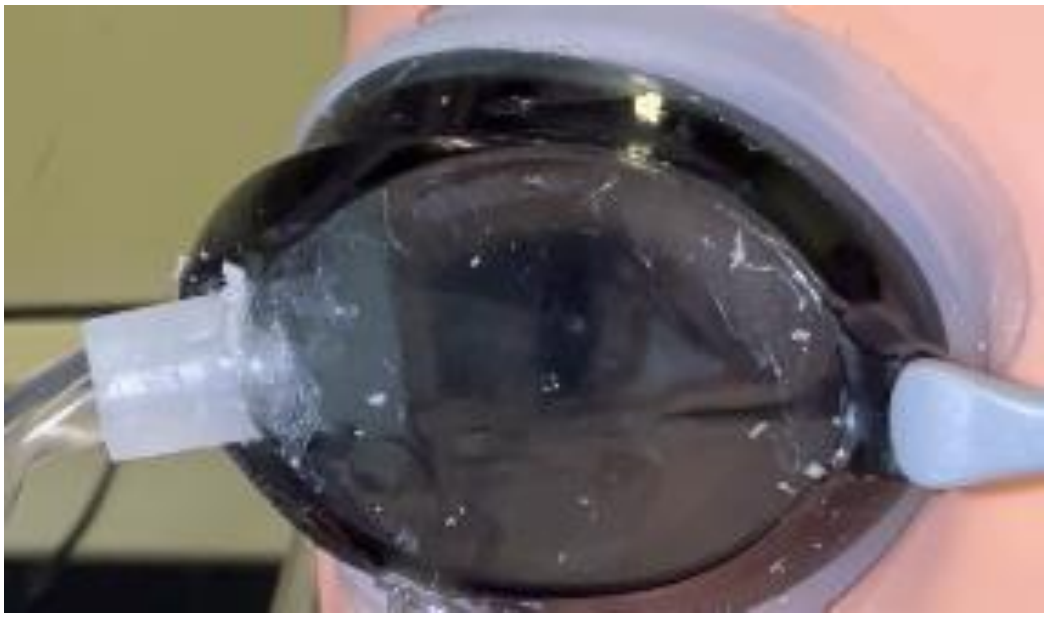


Figure 22: Prototype in Action

The system effectiveness is demonstrated in **Figure 22**. The incoming flow can be seen entering the diffuser, making contact with the eye, and successfully draining out of the system with little to no leakage. Prior to running the final contaminant testing, the team wanted to ensure the system was running properly. Within this validation process, the system was running up to the team's level 1 requirements. 0% leakage was observed in the system with a 1:3 water to air ratio. With the combination of the new diffuser implementation, the insertion of the new diaphragm pump, and insertion of the team's new goggle seal, the system functioned properly and met desired specification.

Final System Honey Test

Following the final prototype manufacturing process, the team needed to complete a final contaminant test to verify that the system is adequately removing contaminants from the system. In order to do this, honey was chosen as a contaminant to remove due to its high viscosity. The team chose to conduct three trials, observing whether all of the honey would be removed following a 2-minute system run time. The team also needed to ensure that the system was not leaking during this final test.



Figure 23: Honey Placement in Eyes



Figure 24: Cleaned Eyes After Running Eyewash

The honey test results are depicted above in **Figure 23** and **Figure 24**. Before the system was used, the honey was applied to the eyes. After two minutes of runtime, the photo in **Figure 24** was taken. All honey was successfully removed from the eyes with no leakage observed during all system runs, as shown in **Table 9.** These trials demonstrated the system's ability to decontaminate a viscous substance from the user. Possible future work should involve maximizing the system's efficiency to minimize the amount of water usage. This further testing and optimization are critical to ensure that sparse resources are preserved.

Test Specifications	Trial 1	Trial 2	Trial 3
Run Time [min]	2	2	2
Leakage [%]	0	0	0
Contaminant Removal [%]	100	100	100

Table 9: Honey Contaminant Removal Data

Future Work

Future efforts should focus on more expansive contaminant testing, reusability, reducing the required water, and 0g optimization. Contaminant testing may involve selecting a wide range of contaminants, running the system, and narrowing down when the contaminant is removed. Moving beyond the usage of pH strips towards a more rigorous contaminant measurement method would also be useful.

The future plan for enhancing reusability generated by the team focused on developing a cap that fits over the goggles. This cap would allow the eyewash system to be flushed with water for an extended period of time without requiring a human user. With this flushing cycle, the team anticipates that the system will be fully reusable. Future efforts on water reduction will require the reusability and contaminant measurement methods to be well-established and documented. Testing will need to be done to determine when the flushing cycle and initial eyewash phase are successful. After this, the total run time can be reduced based on an arbitrary factor of safety.

While the system was tested in multiple orientations to ensure no leakage was detected, this is not a substitute for a fully 0g test. 0g will likely have effects on the flow rate and power requirements, as well as how the water enters the system, hits the eye surface, and drains. Tests in low-earth orbit would be ideal, but a suborbital flight may allow for enough testing time to fully assess the system. Computational studies could also serve as a possible testing avenue.

Acknowledgments

The design team acknowledges Professor Steven Collicott and graduate teaching assistant Don-Terry Veal for key contributions and guidance during the design process. With their help along with the execution of the undergraduate design team, this project has fulfilled all deliverables.

References

Cover Page:

1. *ChatGPT*. (2026, April 27). *Purdue-themed cover page featuring redesigned NASA 0g emergency eyewash system* [AI-generated image]. OpenAI. https://openai.com/
2. International Safety Equipment Association. *"ANSI/ISEA Z358.1 Standard for Emergency Eyewash and Shower Equipment."* ISEA, https://safetyequipment.org/standards/isea-z358-1/.
3. Occupational Safety and Health Administration. *"Medical Services and First Aid (Standard Number 1910.151)."* U.S. Department of Labor, https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.151.

Figure 1:

Photo from Daily Mail article, original 0-g eyewash system (2014, April 10). *Daily Mail.*

https://i.dailymail.co.uk/i/pix/2014/04/10/article-2601454-1CFDE4F700000578-971_634x475.jpg

Figure 12:

Photo from Amazon, diaphragm pump (2026). *Media-Amazon.com*. https://m.media-amazon.com/images/I/71IRXSjl5GL._AC_SL1500_.jpg