SAVISARR: Surface Autonomous Vehicle for Initial Search and Rescue Response

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The National Aeronautics and Space Administration (NASA) launched their Artemis Program in 2017. Similar to its twin program, Apollo, the end goal of Artemis is to establish a presence on the Moon as preparation for future missions to Mars. Astronauts will be transported to the Moon via Spaceship Orion. In the event of a spaceship malfunction on take-off, ensuring the safety of the crew members is a priority. If crew members are separated from the capsule upon landing in water they need to be quickly recovered. The Ohio State University Micro-g team designed an autonomous rescue boat for the sole purpose of rescuing stranded crewmembers fitted with a 121.5 MHz beacon. This paper details the challenge that NASA presented and the team's attempts at manufacturing, building, and testing the device that was designed.

Nomenclature

DOA = Direction of Arrival
Micro-g NExT= Microgravity Neutral Buoyancy Experiment Design Teams
NASA = National Aeronautics and Space Administration
NBL = Neutral Buoyancy Laboratory
SAVER = Surface Autonomous Vehicle for Emergency Response
SAVISARR = Surface Autonomous Vehicle for Initial Search and Rescue Response
SDR = Software Defined Radio
STEM = Science, Technology, Engineering, and Mathematics

I. Introduction

Every year the Micro-g NExT program challenges teams of undergraduate college students to design a tool or device for a space exploration challenge. The Micro-g NExT administration selects then selects a few teams who are invited to build their prototype and test it at the National Buoyancy Laboratory in Houston with professional divers. Through the development process, Micro-g NExT provides support to teams in the form of mentorship, stipends, and focus sessions leading up to the tests in person. Buckeyes of The Galaxy submitted a proposal for the Surface Autonomous Vehicle for Emergency Response (SAVER) challenge and was accepted for phase II which led to the creation of SAVISARR.

SAVISARR is the device the Ohio State University team built to locate and provide aid to a waterborne astronaut. It was shipped to the NBL for testing but was not operated as the device did not fulfil the requirements presented by Micro-g Next. This paper outlines what the device can currently do and how it's constructed. Additionally, it details outreach that the team conducted to fulfill NASA requirements and further STEM education in the Columbus community. The final conclusion section is an example of "failing forward" as suggestions are

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given for future Micro-g NExT teams from our university and beyond.

II. Challenge Overview

Each challenge that Micro-g NExT put forth in the 2020-2021 school year comes with its own set of requirements. Below is a table of requirements for the Surface Autonomous Vehicle for Emergency Response and the device compares.

Table 1: NASA Design Requirements

Requirements	Compliance
1. The vehicle shall be capable of being dropped from a 10-15 foot height into the maritime environment.	Drop test simulations indicate that the boat can be dropped into the water without significant structural damage.
2. The vehicle shall be capable of being carried on a Group 1 (small) or Group 2 (medium), Close-range UAV.	The device weighs around 40 lbs and can be carried on a Group 2 drone.
3. The vehicle shall be capable of transporting (carrying or towing), at a minimum, the following items to the victim: a. Water (1 liter - 2.5 Liters per HSI Standard) b. Medical kit (Orion 0.6 lb kit) c. Spare Life Preserver Unit (LPU) d. Contingency/Spare 406 MHz Second-Generation Beacon (ANGEL) e. Survival Radio f. Inflatable life raft	The cargo bay in the front of the device has ample space to store all items including the optional inflatable life raft. A cargo net will be used and tightened to ensure all items are secured and held in their stable position. The hull is rated for loads up to 130 lbs which is more than enough for our needs.
4. The vehicle shall be capable of using existing equipment to detect the ANGEL beacon 121.5 MHz homing signal in order to guide the vehicle toward the beacon.	Radio system can track signal with manual operation.
5. The vehicle shall be capable of traveling to the person in distress via the most direct route in an autonomous manner, including: a. Unmanned operation (no local or remote human intervention) b. Programmed with mission profiles to address specifics of rescue scenario	Boat does not function autonomously.
6. The vehicle shall include protections in software/hardware to ensure no harm to the crew upon arrival in their vicinity.	No protections are included..
7. Pneumatic Power Requirements	Not Applicable.
8. Electrical Power Requirements	The power tether is a copper 100 foot 12 AWG wire with banana connectors on each end and is sufficient in handling 12 volts, 25 amps. Our testing configuration for our device doesn’t use batteries. All electrical components are housed inside the device away from any water.
9. Labels	The device has passive indicators in the form of labels and stickers.

The device meets 6 out of 9 requirements. It critically failed to meet the autonomous requirement which disqualified it from testing at the NBL.

Figure 1 shows the completed device floating in a lake.

Figure 1. Device fully deployed.

III. Technical Design

A. Materials

The device hull and propulsion housing is made out of high-density polyethylene (HDPE). We chose HDPE due to its beneficial material properties; it is extremely lightweight, weather-resistant, durable, impact-resistant, shatterproof, and malleable. The propulsion housing is made of plastic welded HDPE sheets with steel wire mesh reinforcements embedded into the HDPE. Additionally, we epoxied the joints of the propulsion housing to add another layer of reinforcement.

The antenna tower is made out of a 3D printed 60% carbon fiber and 40% acrylonitrile butadiene styrene polymer(ABS). We chose this polymer as it provides additional strength and stiffness at a lower weight compared to traditional ABS printing. The antenna tower is deployed by a 6061T6 aluminum flat bar and a stainless steel torsion spring. We chose aluminum due to its corrosion resistance and reduced weight. We chose steel due to its high strength, corrosion resistance, and high yield strength. The antenna arms are made of PLA plastic due to its reduced weight, high strength, and reduced manufacturing resources.

B. Hull/Cargo

The cargo bay lies in the forward section of the hull. A cargo net latches to three points on the hull and can be easily removed by the user. Additionally, the cargo net is adjustable to allow for various pieces of supplies and equipment to be loaded. The cargo net attached to the hull is pictured below in Figure 2.

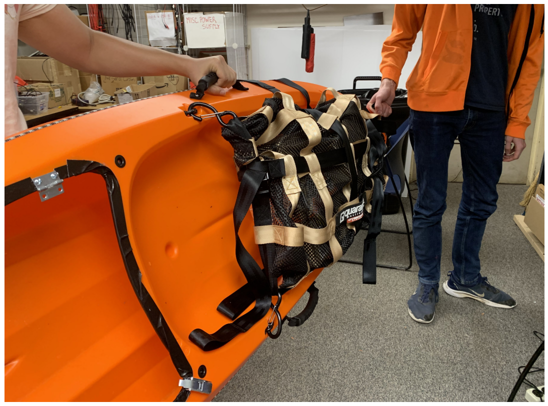


Figure 2. Cargo net secured to hull.

C. Antenna Tower

The radio tower is a 2 foot tall tower mounted to the top of the hull using a 3D printed ABS base and an aluminum pipe. The deployment system consists of a fabricated aluminum bar welded on an aluminum pipe, a stainless steel torsion spring, and a 3D printed ABS base. When deployed the spring will push and lock the tower in the upright position. Figures 3 and 4 below show the antenna tower in both configurations. The space between each antenna and the center of the array in the deployed position is 0.5 meters.

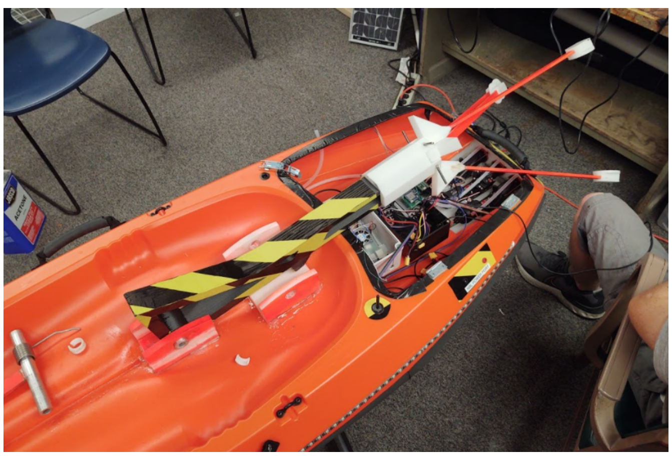
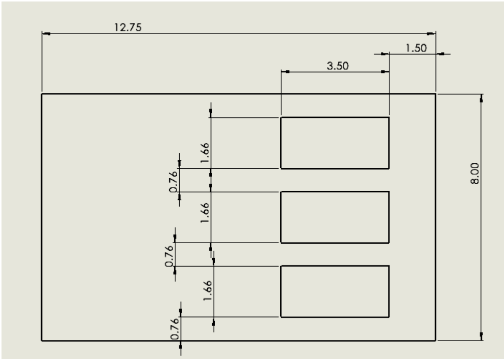


Figure 3. Antenna in the stowage position.

Figure 4. Antenna in the upright position.

D. Propulsion

The propulsion system is composed of three 300 gram water jet thrusters(jet drives) mounted to the back of the hull of an orange Lifetime Wave Youth Kayak. The hull's original shape did not allow space for the jet drives so a hole approximately 8 inches wide by 12.75 inches long was cut out of the back portion of the hull. In its place a series of ⅛ inch high-density polyethylene plastic welded sheets were used to create a box with the appropriate slope. The resulting box was epoxied to the end of the hull and has a flat bottom that is submerged in the water at a 90 degree angle to the back plate. The bottom plate contains three equally spaced 3.5 inch long by 1.66 inch wide holes in which the water jet thruster intakes are mounted (Figure 1). The back plate contains three equally spaced 1.38 inch circular holes for the water exhaust. This is the deepest component of the device and sits 4 inches below the waterline. The side and front plates ensure that the propulsion area is waterproof.



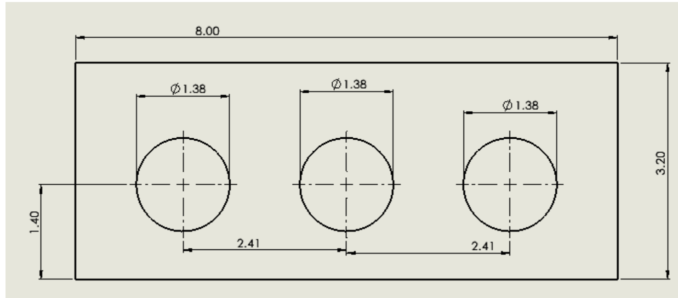
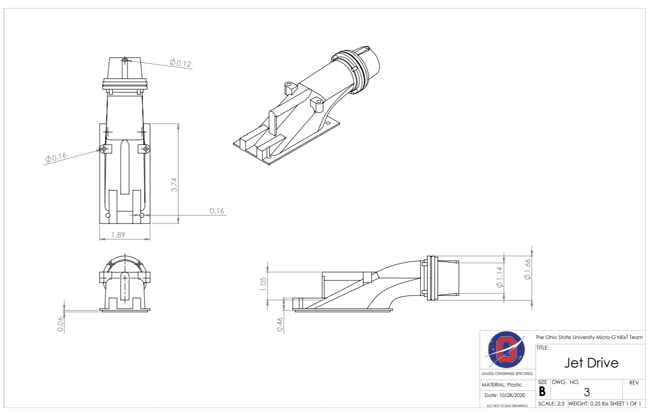


Figure 5. Bottom plate of propulsion house. **Figure 6. Back plate of propulsion house.**

The jet drives are made out of nylon for the body and nozzle and aluminum for the propellers and shaft. Refer to Figure 3 for the jet drive CAD model. The bearings are lubricated with Red n Tacky lithium grease to ensure smooth operation and a watertight seal. A 6 kg servo accompanies each jet drive for steering control. They are mounted via a 3D printed PLA mount. Powering each jet drive is a brushless 3660 motor (36mm diameter by 60 mm long) with a max speed of 19440 RPM at 12 volts on testing voltage and a max speed of 68040 RPM at 42 volts on battery power. The motors are cooled during operation from water pulled in at the jet thruster water exhaust. It's then ejected on the rear right of the hull. While tending to the user, the watercooling exhaust is not ejected. Additionally, the water jet thrusters do not have any exposed moving parts and the intake grating will protect a user from accidental injuries. Refer to Figure 4. For battery operations, the high powered motor controller will be cooled in series with the motors.



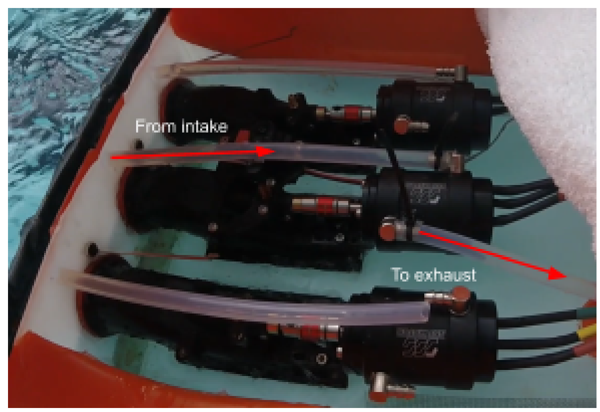


Figure 7. Jet Drive CAD. **Figure 8. Testing Water Cooling Setup.**

E. External Indicators

The device will have active and passive indicators. Passive indicators will consist of markings and stickers. There is caution tape around the water cooling exhaust line. While the device won't expel water while the user is in close range, it will still notify them that it is an area of caution. Additionally, there is caution tape around the water jet thruster outlets. The outlets don't pose any significant thermal or physical danger. Our active indicators consist of an external LED system that notify the user when it is safe to approach the device. Different color and light pattern indicators relay information to the user and/or operators. Refer to Figure 9.

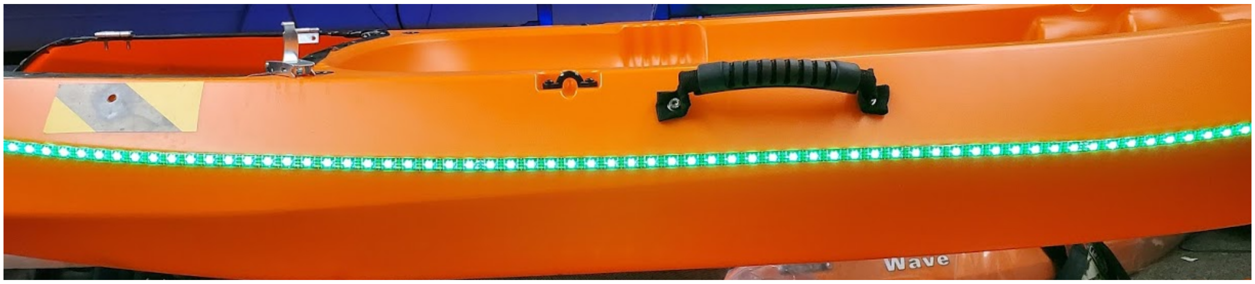


Figure 9. External LED system showing safe to approach.

Table 2. LED state indicator chart.

State	Color	Notes
Neutral	Blue	Sine Wave
LND	Red	Sine Wave
SND	Blue	Fast Sine Wave
TRK	White	Flashes
SCH	White	Ping pong
DEP	Green	Solid

IV. Electronic Design

Table 3: Current consumption of electronics.

Component	Current Draw (A)
Teensy	.33
Steering Servo	1
Kerberos/Raspberry Pi	2
Brushless Motor	14
External Indicators	2

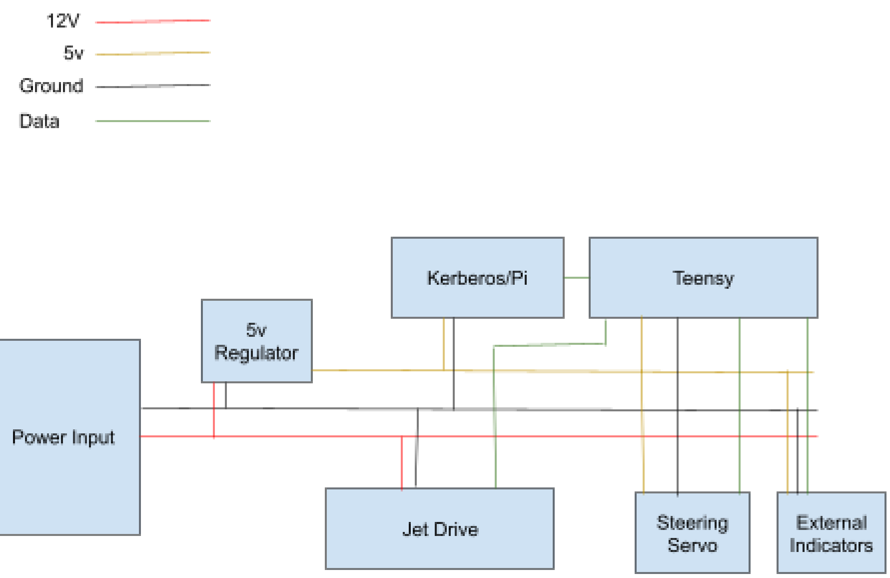


Figure 10. Power diagram.

A. Radio Systems Design

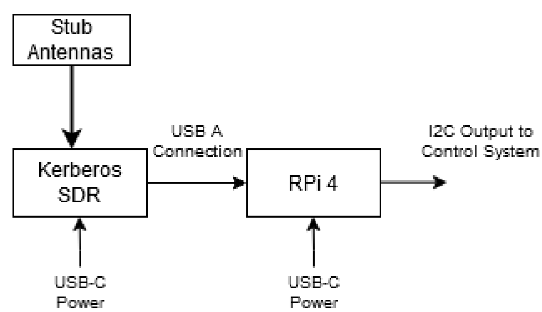


Figure 11. Radio tracking system diagram.

The Raspberry Pi 4 runs a modified Kerberos SDR image. On boot, a supplementary Python script callibrates the stub antennas and autofills values into the Kerberos settings (Helwa, KerberosSDR-Automation 2020). The incoming signal is processed using the MUSIC algorithm and outputs the direction of arrival (DOA), confidence, and power of the signal. The python script then finds this data in memory and then outputs data on its GPIO pins acting as an I2C slave to the controls system.

Because the controls system does not run, the radio tracking data must be accessed through the server the KerbersSDR creates on boot. Instructions to connect to the tracking system are at http://www.rtl-sdr.com/ksdr/.

V. Design Fabrication

The radio tower was fabricated using additive manufacturing of carbon fibre and Acrylonitrile Butadiene Styrene plastic. Additionally, the radio tower bases, radio tower arms, radio tower arm mount, and servo mounts were printed using additive manufacturing of Acrylonitrile Butadiene Styrene plastic. The bases were then glued to the hull using industrial adhesive. The radio tower deployer was machined in house using aluminum stock. Components such as the propulsion bay were custom made in house using plastic welding and adhesives.

A. Design Validation

Before the propulsion bay was manufactured, different design iterations and plastic welding techniques were tested to determine the best technique that will ensure strength of the bay. We determined that plastic welding with embedded metal mesh on the interior accompanied by epoxy was the best technique to ensure strength. One successful test showed resistance to more than 30 pounds. After the propulsion bay was manufactured and attached, various stress tests were conducted. Weights of up to 60 pounds were being pressed on the propulsion bay and showed no signs of compromised integrity. Additionally drop tests into a solid surface were conducted and heights of up to 6 inches showed no signs of compromised integrity. The tests were inconclusive to determine water resistance, however we calculated 12 in^3/22 minutes of leakage in the propulsion bay. This leakage is not significant to the overall volume. The addition of more seals or a water pump will eliminate the problem completely.

Table 4. Bill of material.

Subteam	Subtotal
Hardware and Hull	$850
Electronics, Radio Tracking, and Support	$1,400
Shipping	$600

VI. Results

No results exist for the entirety of the device as it was not complete in time for testing. There are qualitative results pertaining to the design process and project management.

The team created a GANTT chart in January to organize deadlines. Most subteams did not finish their sections by the deadlines they set for themselves. The first Complete Systems Test scheduled for April 4, 2021 was never conducted.

A. Lessons Learned

Better communication between the team and the university shipping and receiving department will help ordered parts arrive on time.

Team leaders need to hold subteams accountable so that deadlines are met

The team would benefit from having more members from mechanical and electrical engineering backgrounds.

The team can implement effective communication strategies to improve efficiency and avoid errors due to communication mishaps.

VII. Outreach

The Ohio State University Micro-g NExT Team ran two outreach events during the Spring 2021 semester. The outreach mission statement in the team's original proposal is, "To cater knowledge and spread awareness of NASA and STEM to various communities." Both outreach events followed the 5-E Model of Instruction (check to see if need ref) with segments meant to engage, explore, explain, elaborate, and evaluate.

On March 15, 2021, the team virtually presented a 36-page slide show to a class of 20 8th graders at Dublin Middle School. This presentation shared information about ongoing and future NASA missions, women in NASA, the Micro-g NExT challenge, the OSU team's use of the engineering design process throughout it, and the importance of technical writing in STEM fields. After sharing how OSU's team used Gantt charts to stay organized and meet deadlines throughout the Micro-G NExT challenge, two activities were done with the participants. These two activities were designing a space station for the moon and prototyping model rockets. Both activities encouraged students to do research, brainstorm solutions, constructively critique and build off of each other's ideas.

For the second outreach event, students included information on their OSU activities, roles within the Micro-g NExT project, and their own backgrounds. Previous NASA projects were discussed, including the Perseverance rover, highlights of some women of NASA's contributions, and a look forward to future endeavors. The Engineering design process was gone over in detail, and specifics of the Micro-g NExT project were elaborated on before students were invited to participate in related activities.

VIII. Conclusion

The team will continue to work on the device in the space between the Spring 2021 semester and the Fall 2021 semester. There are no plans to do more outreach or submit for publication.

The device as designed has the potential to be a useful tool for search and rescue missions. Characteristics of the device's subsections can be adapted to fit existing technology. The radio tracking system as designed is accurate, ranged, and rugged. The jet drive installation as designed provides speed and maneuverability to the device. The team hopes that these subsystems can be studied and implemented in different projects in the future.

Acknowledgments

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The OSU Center for Design and Manufacturing Excellence for 3D fabrication.

OSU Innovation Studio for assistance in fabrication of propulsion bay parts.

The Electronics Club at Ohio State for workspace usage and equipment usage.

The Amateur Radio and RF Club for technical expertise and equipment usage.

The Ohio State Aquatics Center for a testing location.

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