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Big Area Additive Manufacturing Engineering Development, Process Trials, and Composite Core Fabrication

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy & Transportation Science Division
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ABSTRACT

Oak Ridge National Laboratory (ORNL) has worked with Raytheon to develop and test the materials necessary to produce a moderately sized boat using Big Area Additive Manufacturing (BAAM). This Phase 2 project focused on printing and testing the components of the boat designed by Raytheon. This involved collaborating on boat design, printing the boat, testing surface coatings, and assembling the boat.

1. RAYTHEON PHASE 2 REPORT

This Phase 2 technical collaboration project (MDF-TC-2017-123) began on September 29, 2017 and completed on September 29, 2019. The collaboration partner Raytheon is a large business. The results of this Phase 2 project include successful printing of a 40ft Unmanned Surface Vehicle (USV) and complete assembly of the 3D printed boat.

1.1 BACKGROUND

Raytheon is a defense contractor for the United States that employs over 50,000 people worldwide. Integrated Defense Systems, one of Raytheon's businesses, makes sea-based radar systems and missile launchers. This invokes a need for boats and other watercrafts to operate these systems. The traditional method to prototype and produce these boats involves tedious hand-made molds with fiberglass layup or welding and assembly of heavy metal plates. Currently, there is no efficient way to directly manufacture the boat.

Using BAAM, large objects such as wind blade molds, cars, and boat hulls can be quickly produced using high-strength thermoplastics reinforced with carbon fiber. BAAM allows for accelerated prototyping and development of new applications, such as boat building. Raytheon partnered with ORNL and set out to rapidly build an entire boat using the BAAM process and test its load carrying capabilities. With BAAM, Raytheon and ORNL hope to directly manufacture a USV and skip the entire molding process.

During Phase 1, ORNL printed test sandwich composite panels using BAAM, and Raytheon then tested the panels. Testing included tensile strength (ASTM C297), compressive properties (ASTM C365), flexural and shear stiffness (ASTM D7250), and core shear by beam flexure (ASTM C393). The results of the Phase 1 work were used to influence the boat design for Phase 2.

1.2 TECHNICAL RESULTS

In Phase 2, Raytheon worked closely with ORNL to develop a printable design for a 40ft long USV. This meant hosting a design review for the Raytheon engineers (Task 2.1), printing the hull and deck plates (Task 2.2), conducting materials and coatings tests (Task 2.3), and assembling the boat (Task 2.4).

1.2.1 Design Review

The first task of the Phase 2 was to host a design review with Raytheon. This was accomplished through an ORNL-hosted workshop in October 2017, during which the Raytheon engineers visited ORNL's Manufacturing Demonstration Facility (MDF). During the workshop, the engineers were able to get hands-on experience with BAAM and see how to design parts for the process. The boat geometry was discussed, and a small nose piece was printed as a test (Figure 1). The test allowed for the engineers to see how BAAM performed and understand how to design and print the boat components. Following the design review, a plan was made for the boat that minimized material while maximizing strength.

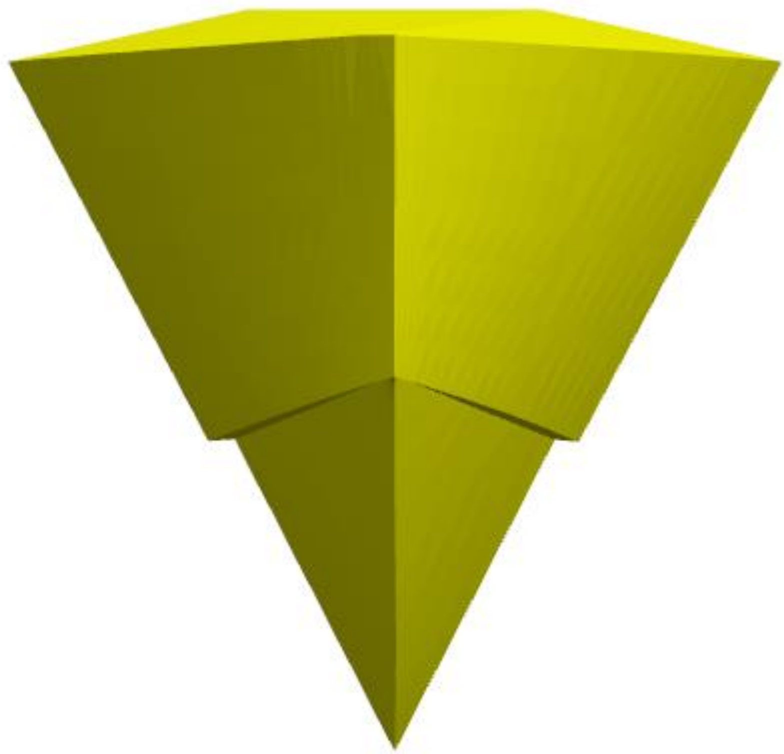

Figure 1: Nose test print from the design review

1.2.2 Hull Manufacturing

Following the design review, Raytheon engineers worked with ORNL engineers to establish a final printable design for the boat. The 40ft boat was to be printed in eight separate 5ft sections. Each section design was based on a two-bead thick wall to maximize strength while saving weight. Atop each hull was a specially designed deck plate to help spread the deck load across the hull.

Once the final design was established, Raytheon began delivering stereolithography (STL) files to ORNL for printing, beginning with the aft. Based on the testing from Phase 1, Carbon Fiber Acrylonitrile Butadiene Styrene (CF-ABS) was selected as the printing material. Each of the four aft hull sections weighed more than 1400lbs and took approximately twenty-four hours to print. Atop each aft hull piece was a deck plate. Like the hull, these were designed with two bead walls to help save weight. The deck plates weighed an average of 450lbs and took about eight hours each to print.

Four sections went together to form the bow of the boat. These pieces varied in weight from 1400lbs to 500lbs with the tip of the bow being the lightest. The tip of the bow was also the fastest print, at approximately eight hours. Pictures of the printed parts for the boat are considered business sensitive. Therefore, they are not included with this report.

1.2.3 Coatings Testing

To test coatings, ORNL printed small test panels out of CF-ABS. The tests panels for cold spray were 24in x 24in and the layup samples were 1.36in x 30in x 24in XYZ and 1.36in x 12in x 30in XYZ. The panels were machined by ORNL to give a flat, smooth surface for testing; then, they were shipped to Raytheon. Testing included thermal management, electromagnetic (EMI) shielding, and thermal heat shielding.

1.2.4 USV Assembly

ORNL printed all eight sections of the hull and the corresponding deck plates and shipped the pieces to Raytheon. Once Raytheon received all the final pieces, the assembly process began. Raytheon made a special steel carriage to support the individual hull pieces and assembled them together. This allowed for easy and quick alignment of the printed parts. It also allowed for the fully assembled boat to be wheeled around. The steel carriage is reusable for assembly of additional boats.

1.3 IMPACTS

Phase 2 was successful in proving the feasibility of directly printing a boat hull mold. The total print time was nine days six hours, and the total material weight was approximately 12,900lbs. The material for the printed components of the boat cost approximately $67,695. Traditional boat panels are made by casting billets then machining them to shape and size. This is not only wasteful, but it's very energy intensive. BAAM has helped improve the effectiveness and efficiency of prototyping large boats.

This project demonstrated a significant savings in time, cost, and energy and a new means to directly manufacture a boat. BAAM enables rapid prototyping of new boat cores and structural composites with 3D shapes. Traditionally, sandwich panels are only flat planar surfaces, but BAAM enables more complex shapes and geometry not previously possible. This gives engineers more design freedom when developing complex structures and geometries, and it eliminated the need for tooling. Traditional tooling is slow, expensive, and prohibitive to rapid prototyping, but BAAM enables engineers to make quick iterations and continue development.

1.4 CONCLUSIONS

The production of a 40ft long boat was successful. ORNL printed all eight hull sections and corresponding deck plates with the BAAM system and shipped the components to Raytheon for assembly. Raytheon assembled the full boat and used it for fit-checks and prototyping of the defense components to be installed on the boat. Through this collaboration, ORNL has proven the feasibility and efficiency of using BAAM for prototyping large boat components and has transitioned the technology to Raytheon for further testing and development. Future research will involve applying this technology to more than just boats, such as ground vehicles as well as structures and ground-based facilities.

2. PARTNER BACKGROUND

Raytheon is an international aerospace and defense company headquartered in Waltham, Massachusetts. Their four businesses work together to craft solutions for a wide variety of government and commercial customers. Integrated Defense Systems specializes in air and missile defense, large land- and sea-based radars, and systems for managing command, control, communications, computers, cyber, intelligence, surveillance, and reconnaissance. It also produces sonars, torpedoes, and electronic systems for ships. The project will help reduce manufacturing costs and lead time, enabling more rapid response to military needs.