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# Wide and High Additive Manufacturing (WHAM)



Lonnie J. Love  
Brian Post  
Alex Roschli

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Energy and Transportation Sciences Division  
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**Wide and High Area Additive Manufacturing (WHAAM)**

Authors  
Lonnie J. Love, Ph.D.  
Brian Post, Ph.D.  
Alex Roschli

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OAK RIDGE NATIONAL LABORATORY  
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## **ABSTRACT**

The goal of this project is to develop and demonstrate the enabling technologies for Wide and High Additive Manufacturing (WHAM). WHAM will open up new areas of U.S. manufacturing for very large tooling in support of the transportation and energy industries, significantly reducing cost and lead time. As with Big Area Additive Manufacturing (BAAM), the initial focus is on the deposition of composite materials.

### **1. WIDE AND HIGH ADDITIVE MANUFACTURING**

This phase 1 technical collaboration project (MDF-TC-2017-167) was begun on August 2016 and was completed on March 2017. The collaboration partner Ingersoll Machine Tools is a small business. One sentence to summarize results.

#### **1.1 BACKGROUND**

Ingersoll Machine Tool is a small U.S. machine tool manufacturer located in Rockford, Illinois that produces large scale machine tools for use in metal cutting and automated fiber placement. The company was founded in 1891 by Winthrop Ingersoll when he moved W.R. Eynon & Co. from Cleveland, Ohio to Rockford. Originally, Ingersoll Machine Tools focused almost entirely on milling machinery and processes for metal removal. It acquired contracts from General Electric and, by 1917, was closely involved with wartime production and had a workforce of 600. It went on to produce customized machines for industries such as airplane and auto manufacturing. In the period from the 1960s to the 1980s, the company employed around 2,000 people at its plant, also developing CNC technologies to introduce automation into its manufacturing processes. Today, Ingersoll is a global leader in the development of advanced machine tools for the world's aerospace, transportation, energy, and other heavy industries. Products range from general purpose machines that bring greater flexibility and productive to a wide variety of parts, to special purpose, one-of-a-kind machines delivering unique solutions. For the aerospace industry, Ingersoll excels in building machines to produce component parts and large structures made of aluminum, hard metals and composite materials. In addition, Ingersoll provides a unique contract manufacturing resource for prototype machining and production runs, from small engine parts to locomotive diesel blocks and windmill hubs.

The goal of this project is to develop and demonstrate the enabling technologies for Wide and High Additive Manufacturing (WHAM). WHAM will open up new areas of U.S. manufacturing for very large tooling in support of the transportation and energy industries, significantly reducing cost and lead time. As with Big Area Additive Manufacturing (BAAM), the initial focus is on the deposition of composite materials. This effort compliments Ingersoll's expertise in the composites industry where they are a world leader in tape layup technology. The systems they typically develop are extremely large (exceeding 100 ft) for the wind, rail, shipping and aerospace industry. WHAM will enable Ingersoll to rapidly manufacture large tooling to help accelerate U.S. manufacturing in the area of large scale components (major dimensions exceeding 20 ft). The primary technical challenge is controlling part distortion and delamination due to the very large part sizes. The approach the team is exploring is to use two complimentary technologies. First, prior experience shows that layer adhesion is a function of the layer temperature during deposition. A typical layer could exceed 1000 square feet with a bead thickness of 0.1" which is equivalent to 500 lbs of material. This will require

approximately five hours to print with current BAAM technologies. Current efforts show that ideal layer times need to be less than 30 minutes for good adhesion. Therefore, an extruder with approximately 1000 lb/hr is needed for WHAM. The second technology is localized heating to eliminate the need for a heated bed. Ingersoll has extensive experience in the area of IR heating for composites and leveraged this experience to address initial layer adhesion. The goal of the first phase is to install a current 100 lb/hr extruder on an Ingersoll system and demonstrate the ability to control and deposit material with localized heating.

## 1.2 TECHNICAL RESULTS

The goal of the project is to manufacture a large scale composite additive manufacturing system. Figure 1 and Figure 2 are a conceptual design of the WHAM. The system will be based on an existing Ingersoll gantry design. The system is large enough that the 1000 lb/hr extruder can be directly mounted on the gantry as well as multiple 1000 lb hoppers for drying the material. Four 1000 lb hoppers will provide 4 hours of residence time for the material to dry when operating at 1000 lb/hr. When one hopper is emptied, the system can automatically switch to a different hopper and park in a corner to quickly replenish the empty hopper. As with other Ingersoll gantry systems, multiple tools can be changed to enable additive, subtractive, pick and place as well as tape placement. The development of new materials such as foams and long fiber reinforcement will enable direct structural part production.



Figure 1: WHAM front view

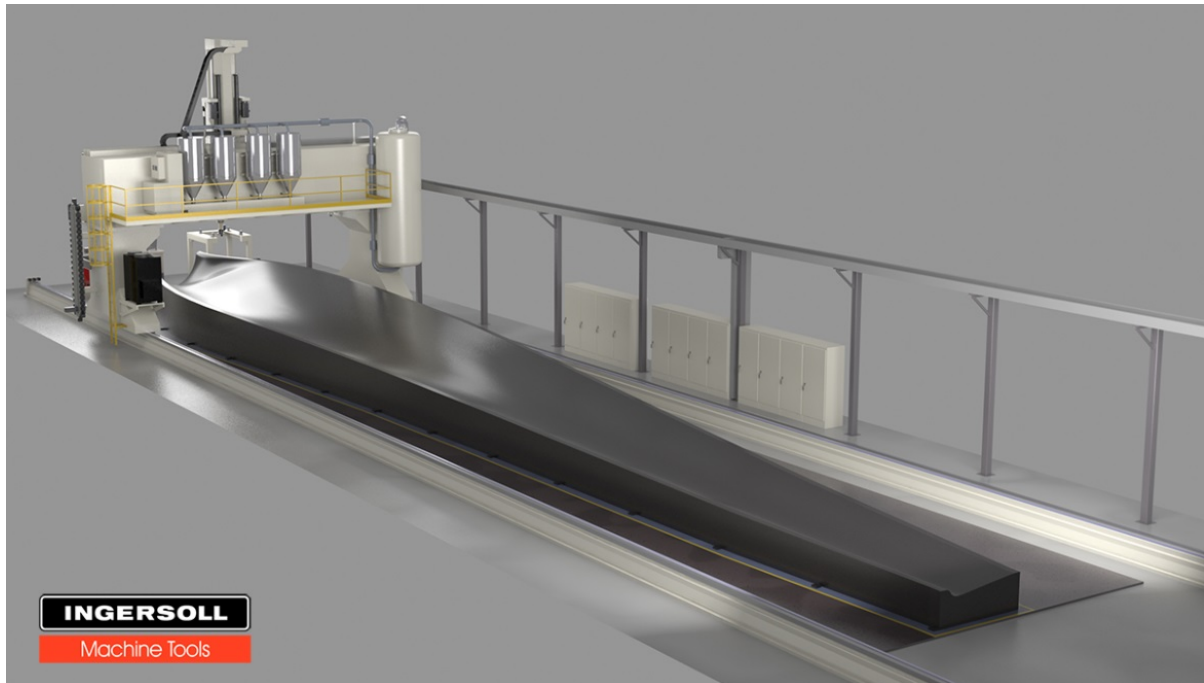


Figure 2: WHAM back view

### 1.2.1 Extruder

In order to accelerate the project, ORNL leveraged a current technical collaboration with Strangpresse. Under this technical collaboration, Strangpresse had developed a new 150 lb/hr extruder (see Figure 3). Ingersoll installed the extruder on a testbed at their Rockford facility and integrated all controls. ORNL visited the facility and installed the ORNL slicer and developed both a translator for the g-code for the robot and identified all of the required processing parameters. The system is completely operational (see Figure 4).



Figure 3: Strangpresse extruder

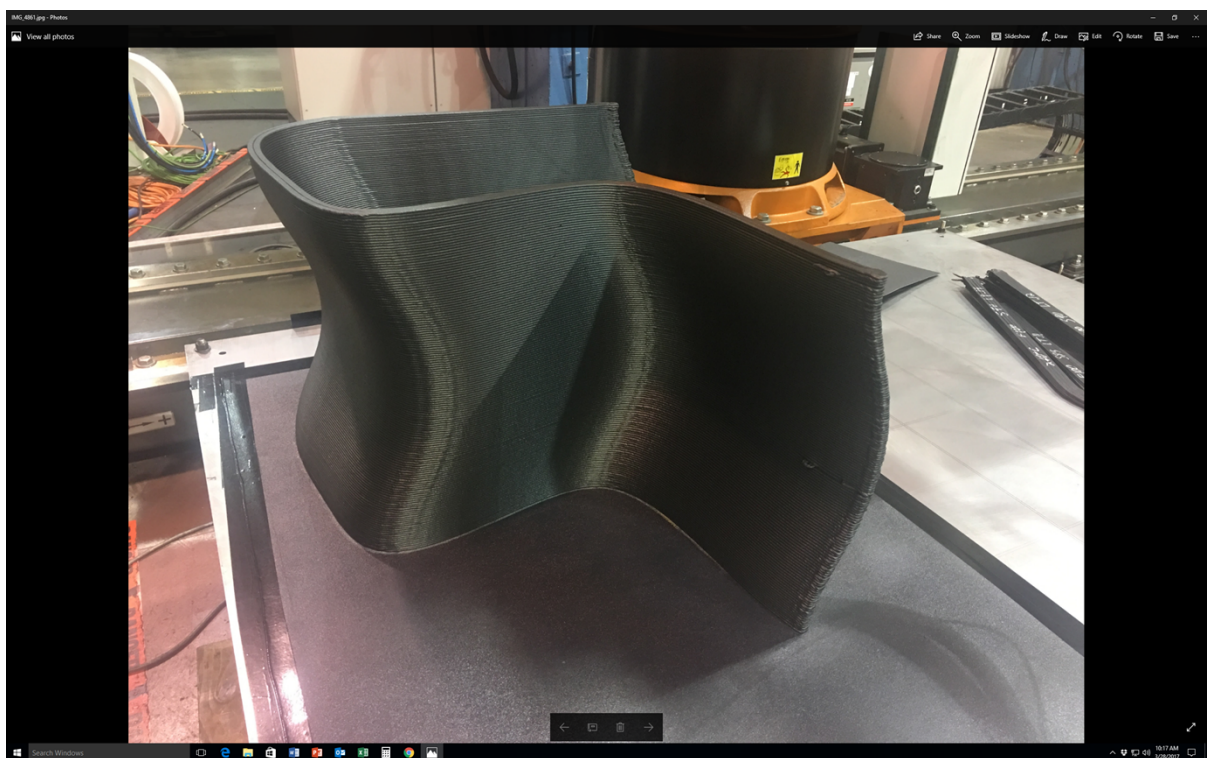


Figure 4: Printed chair

Figure 5 and Table 1 provide the resultant flow rate characteristics of the extruder.

Table 1: Flow calibration data

RPM	lb of material	lb/min	lb/hour
200	0.25	0.25	15
500	0.6875	0.6875	41.25
800	1.0625	1.0625	63.75
2500	2.5	2.5	150

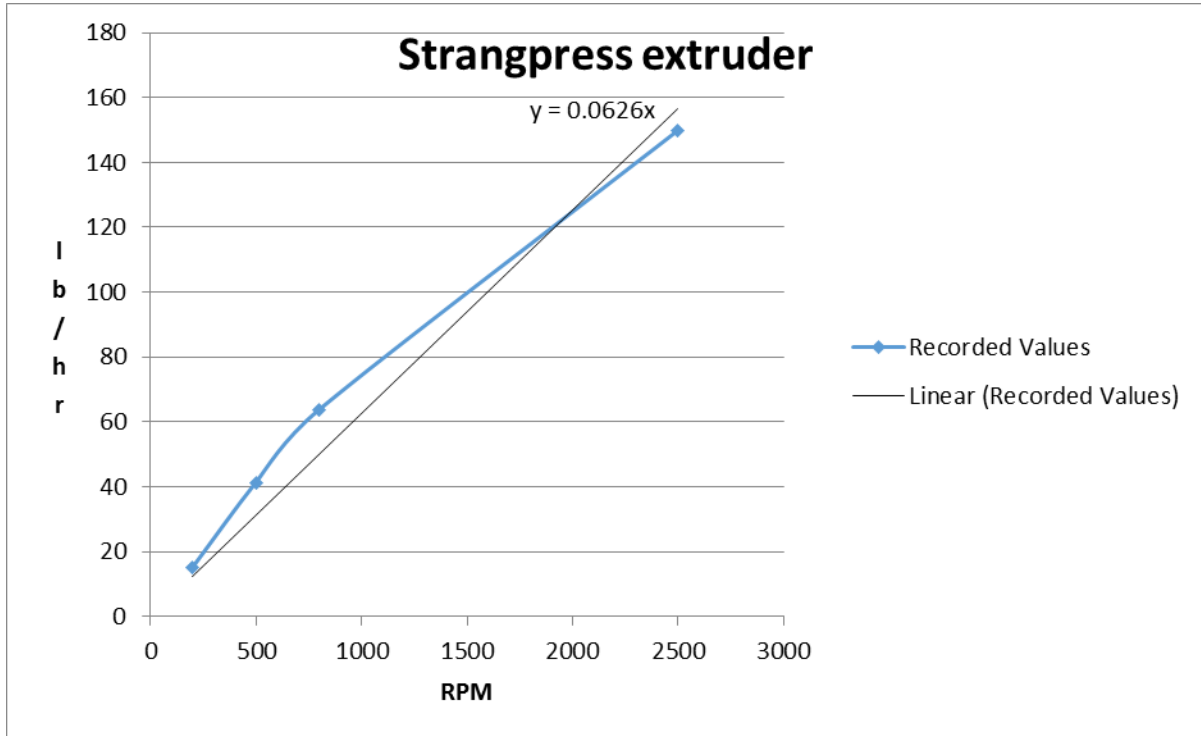


Figure 5: Flow rate

Figure 6 and Figure 7 show the resulting mechanical properties of the parts manufactured on the WHAM at Rockford.

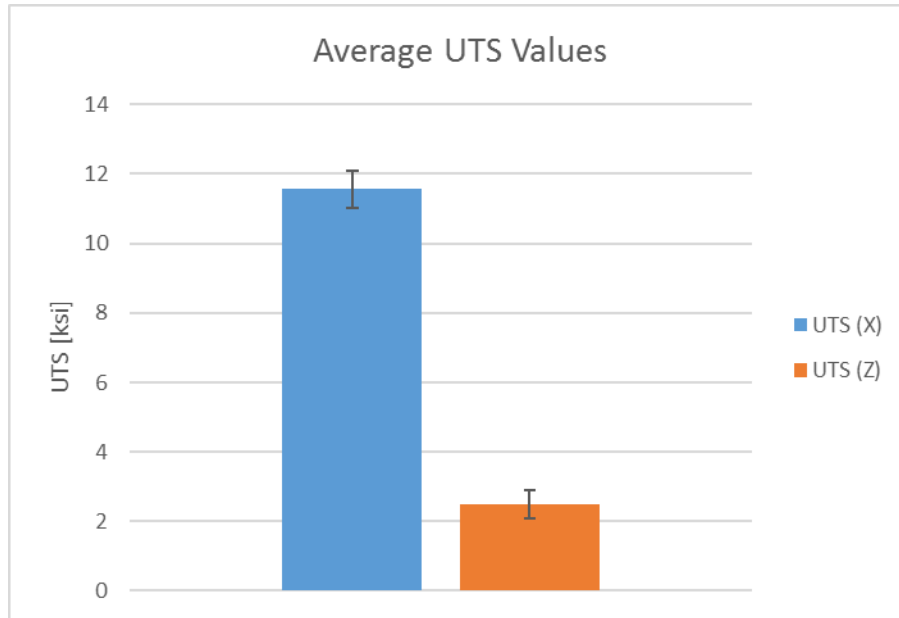


Figure 6: Tensile strength of CF ABS

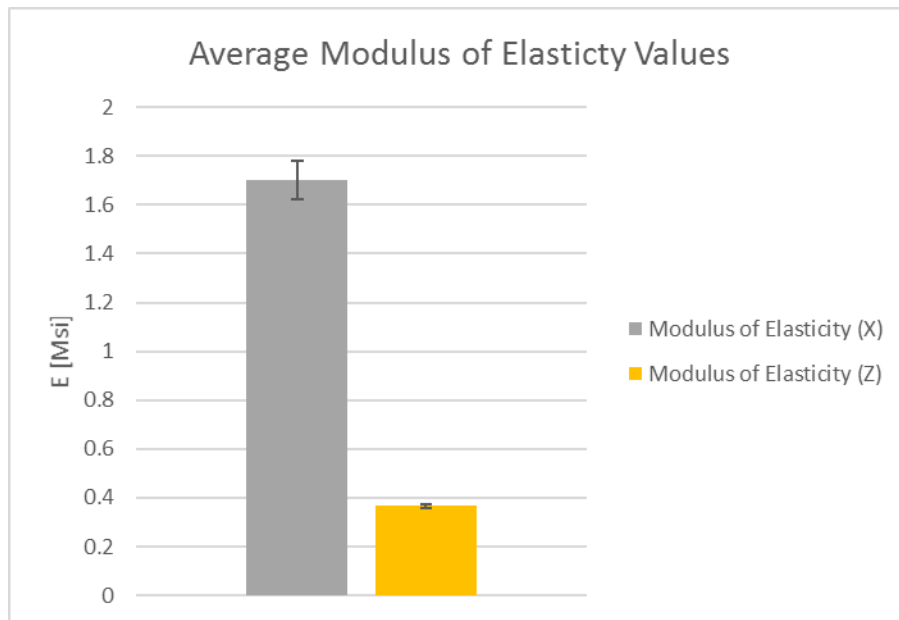


Figure 7: Modulus of CF ABS

### 1.3 IMPACTS

The development of WHAM will enable greater innovation in the areas of U.S. large scale manufacturing which includes marine, rail, trucks, aerospace and energy (wind, hydro, solar). The technology is scalable to allow rapid manufacture of very large structures at a relatively fast rate and low cost.

## 1.4 CONCLUSIONS

The goal of this project was to identify the system requirements, design an extruder, design a heated platform and develop the interfaces between the extruder and Ingersoll gantry system. The team successfully identified the system requirements by specifying the need for a 1000 lb/hr extruder. The team originally designed a series of extruders (ten 100 lb/hr extruders) but elected to go with a single large 1000 lb/hr extruder. Furthermore, the team successfully evaluated an existing 150 lb/hr extruder from Strangpresse on an Ingersoll testbed. The results provide the team confidence that Strangpresse can design and manufacture the final 1000 lb/hr extruder. ORNL developed the processing parameters and slicing software successfully demonstrating pellet to part manufacturing on an Ingersoll testbed. Ingersoll installed a bank of infrared heaters and used that to locally heat the start sheet rather than designing a full heated table. Test pieces were manufactured and evaluated successfully.

This provides the team with confidence that Phase 2 efforts can likewise be based on aligning both Ingersoll and Strangpresse. We propose to align the second phase of both projects. Strangpresse will design and fabricate the extruder with ORNL working with Ingersoll on the integration and control of the extruder on an Ingersoll gantry. This will also foster commercialization of Strangpresse and Ingersoll within the same project.

## **2. PARTNER BACKGROUND**

Ingersoll Machine Tool is a U.S. manufacturer located in Rockford, Illinois that produces large scale machine tools for use in metal cutting and automated fiber placement. The company was founded in 1891 by Winthrop Ingersoll when he moved W.R. Eynon & Co. from Cleveland, Ohio to Rockford. Originally, Ingersoll Machine Tools focused almost entirely on milling machinery and processes for metal removal. It acquired contracts from General Electric and, by 1917, was closely involved with wartime production and had a workforce of 600. It went on to produce customized machines for industries such as airplane and auto manufacturing. In the period from the 1960s to the 1980s, the company employed around 2,000 people at its plant, also developing CNC technologies to introduce automation into its manufacturing processes. Today, Ingersoll is a global leader in the development of advanced machine tools for the world's aerospace, transportation, energy, and other heavy industries. Products range from general purpose machines that bring greater flexibility and productive to a wide variety of parts, to special purpose, one-of-a-kind machines delivering unique solutions. For the aerospace industry, Ingersoll excels in building machines to produce component parts and large structures made of aluminum, hard metals and composite materials. In addition, Ingersoll provides a unique contract manufacturing resource for prototype machining and production runs, from small engine parts to locomotive diesel blocks and windmill hubs.