

ORNL/TM-2020/1883
CRADA/NFE-17-06964

Feasibility of Using Additive Manufacturing to Produce Axial Flow Hydropower Turbine Housing, Runner, and Draft Tube



Phillip Chesser
Lonnie Love
Adam Witt
Paul Roos

January 25, 2021

Approved for Public Release.
Distribution is Unlimited.

CRADA FINAL REPORT
NFE-17-06964

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via US Department of Energy (DOE) SciTech Connect.

Website www.osti.gov

Reports produced before January 1, 1996, may be purchased by members of the public from the following source:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.gov
Website <http://classic.ntis.gov/>

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange representatives, and International Nuclear Information System representatives from the following source:

Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@osti.gov
Website <http://www.osti.gov/contact.html>

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**ORNL/TM-2020/1883
CRADA/NFE-17-06964**

Energy and Transportation Science Division
Advanced Manufacturing Office

**FEASIBILITY OF USING ADDITIVE MANUFACTURING TO PRODUCE AXIAL FLOW
HYDROPOWER TURBINE HOUSING, RUNNER, AND DRAFT TUBE**

Authors
Phillip Chesser
Lonnie Love
Adam Witt
Paul Roos

Date Published:
December 2020

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

Approved For Public Release

CONTENTS

	PAGE
CONTENTS	v
LIST OF FIGURES	vii
ACKNOWLEDGEMENTS	viii
ABSTRACT	1
1. FEASIBILITY OF USING ADDITIVE MANUFACTURING TO PRODUCE AXIAL FLOW HYDROPOWER TURBINE COMPONENTS	1
1.1 BACKGROUND	1
1.2 TECHNICAL RESULTS	1
1.3 IMPACTS	7
1.3.1 SUBJECT INVENTIONS	7
1.4 CONCLUSIONS	8
2. AMJET TURBINE SYSTEMS, LLC BACKGROUND	8

LIST OF FIGURES

Figure 1. Component CAD models (not to scale).....	2
Figure 2. Printed Stator Vane Body (L) and Rotor (R).....	3
Figure 3. Printed Draft Tube (L) and Bell Plug (R).....	3
Figure 4. Printed Stator Outer Housing	4
Figure 5. Assembled Unit for Pressure Test	5
Figure 6. 3DP Printed Stator Outer Housing	5
Figure 7. Vacuum Infusing Resin	6
Figure 8. Infused and Machined Stator Outer Housing	6
Figure 9. Assembly Rendering	7
Figure 10. Parts for Assembly and Testing.....	7

ACKNOWLEDGEMENTS

This CRADA NFE-17-06964 was conducted as a Technical Collaboration project within the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) sponsored by the US Department of Energy Advanced Manufacturing Office (CPS Agreement Number 24761). Opportunities for MDF technical collaborations are listed in the announcement “Manufacturing Demonstration Facility Technology Collaborations for US Manufacturers in Advanced Manufacturing and Materials Technologies” posted at <http://web.ornl.gov/sci/manufacturing/docs/FBO-ORNL-MDF-2013-2.pdf>. The goal of technical collaborations is to engage industry partners to participate in short-term, collaborative projects within the Manufacturing Demonstration Facility (MDF) to assess applicability and of new energy efficient manufacturing technologies. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

ABSTRACT

Oak Ridge National Laboratory (ORNL) worked with AMJET Turbine Systems, LLC (ATS), to demonstrate additive manufacturing of components for low head hydro turbine/generator applications. Several different types of additive manufacturing systems were used. Components were finished and assembled for testing in a turbine. However, one of the processes, Big Area Additive Manufacturing (BAAM), produced components that did not adequately perform due to persistent leaks that were caused by porosity in the parts produced. Therefore, the BAAM system was eliminated from contention. Vacuum infusion of resin into the parts eventually solved the porosity problem. Components were installed in an ATS-8 turbine to be tested on the Keokuk Dam for operationally testing the unit.

1. FEASIBILITY OF USING ADDITIVE MANUFACTURING TO PRODUCE AXIAL FLOW HYDROPOWER TURBINE COMPONENTS

This phase 1 technical collaboration project (MDF-TC-2017-132) began on October 17, 2017 and concluded on December 31, 2020. The collaboration partner AMJET Turbine Systems, LLC, is a small-medium business. The work done primarily used additive manufacturing (AM) to fabricate low head hydro components. Meeting the required specs with the processes available was found to be challenging, primarily because of porosity and low z-strength. However, these challenges were ultimately solved with resin infusion.

1.1 BACKGROUND

AMJET Turbine Systems, LLC (ATS) develops modules for the generation of low cost, low head hydropower turbines. The partner is evaluating manufacturing methods for components of their turbine technology. They wanted to investigate the use of AM for manufacturing five important turbine components. The ultimate goal of the partner was to lower the costs, the footprint, and the weight of their components to an attractive point for the market.

1.2 TECHNICAL RESULTS

Five different components were manufactured in this project. These components were the “stator vane body,” the “stator outer housing,” the “rotor,” the “bell plug” and the “draft tube.” Images of the CAD models are shown in Figure 1. These components are for an ATS-8 turbine unit, which produces 3 to 40 kW with up to 50 ft of head and 15 cfs flow.

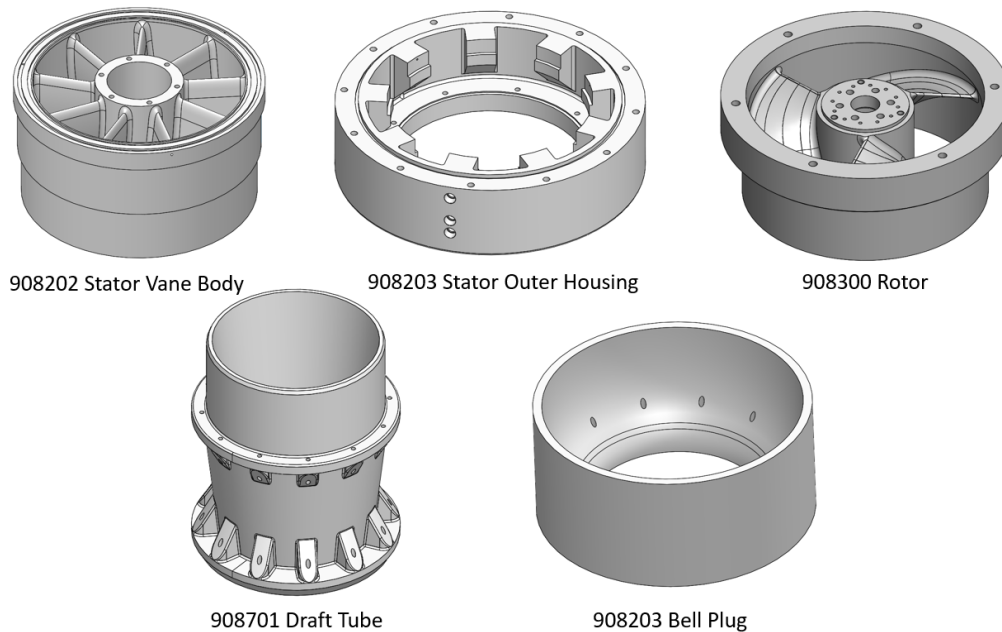


Figure 1. Component CAD models (not to scale)

Several different systems, with different scales, were compared for their ability to print these parts. For small-scale parts, the Stratasys Fortus 900mc was used. For medium-scale parts, a Cosine AM1 was used. For large-scale parts, a Cincinnati Big Area Additive Manufacturing (BAAM) system was used. Material cost and machine time are summarized in Table 1. Not every process was suitable for every part, so only appropriate processes for each part were investigated. While the rotor was printed, it was not included in this cost/time evaluation.

Part	Volume (cu in)	Fortus 900mc		AM1		BAAM	
		Print Time	Total Material Cost	Print Time	Material Cost	Print Time	Total Material Cost
908202 Stator Vane Body	106	39.5 hr	\$700				
908203 Stator Outer	267			1.5 hr	\$50	20 min	\$50
908203 Bell Plug	187	61 hr	\$1,300	3 hr	\$75	30 min	\$75
908701 Draft Tube	852			7.5 hr	\$200	1 hr 20 min	\$200

The stator vane body and rotor needed fine detail, so only the Fortus 900mc was appropriate and both these parts were printed on that system. The printed parts are shown in Figure 2.

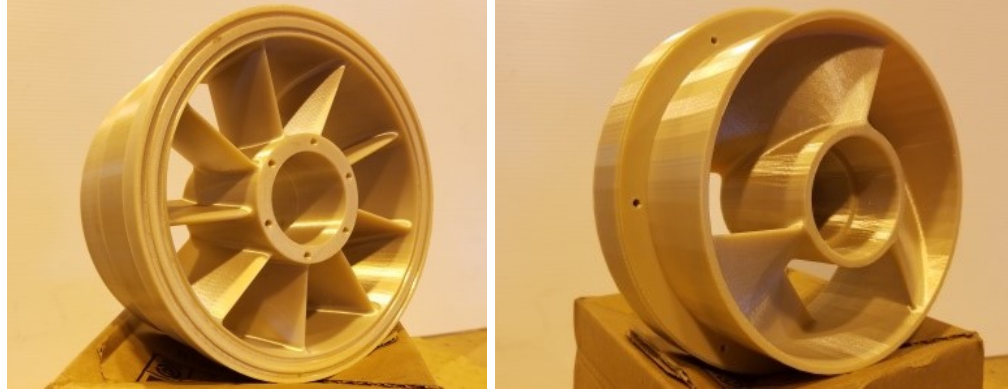


Figure 2. Printed Stator Vane Body (L) and Rotor (R)

The geometry for the other three parts was on a size scale that more suited the medium scale of the Cosine AM1. However, the AM1 system at ORNL was an early version and did not print reliably. Thus, the remaining three parts were printed on BAAM in ABS plastic and no tested parts were printed using the Cosine AM1.

BAAM is a large-scale, high throughput system, but it leaves a very rough surface finish on printed components. However, the draft tube and bell housing have internal flow passages that need to be smooth. To smooth the inner surfaces, a technician coated the inside of these components with an ABS and acetone slurry. This filled in the low places with ABS. Then, sanding was done to finish the surface. The technician spent approximately 2 days total on this process for these components. Figure 3 shows these components after the interior was finished by ORNL, and the outer surface was machined by ATS.



Figure 3. Printed Draft Tube (L) and Bell Plug (R)

The final component to be printed was the stator outer housing. This was also printed on BAAM. A picture of the printed component, after machining, is shown in Figure 4.



Figure 4. Printed Stator Outer Housing

ATS machined the BAAM parts for mounting holes and other similar geometries that could not be printed. They also applied a sealant. The stator outer housing had significant problems in the machining process because of voids. As can be seen in Figure 4, large voids were left between the beads of polymer. This is because BAAM lays down large beads of material and could not fill in all areas of a component this small.

Following machining, ATS applied a sealant to the components and did a leak test. Figure 5 shows the assembled unit for leak testing. The pressure test failed at 2 psi. This was due to the porosity and weakness between layers that is inherent in AM. Even the use of a sealant was not able to prevent leakage on BAAM parts. This suggests that the BAAM process produces parts that are too porous for this application. Additionally, the time-consuming surface-finishing was counter-productive. Furthermore, the BAAM parts suffer from low Z-strength. ATS had to use tie-rods to cancel the stress. The e-modulus was likewise low and made the components suffer from the “harmonica-effect” when compressed and tensioned. Ultimately, these issues show that BAAM is unsuitable for this application.



Figure 5. Assembled Unit for Pressure Test

After the manufacturing and testing discussed above, ORNL received a new medium-scale machine from 3DP: the 3DP Workbench 400 series. The size of this machine is better suited to the scale of parts used in this application. A second stator outer housing was printed with this machine, as shown in Figure 6. This part was printed in approximately 10 hrs, out of carbon fiber ABS. Because of the finer resolution of the 3DP, void space was reduced as compared to the BAAM printed part. However, there was still a prohibitive level of porosity. To address this, the part was vacuum infused with a low viscosity epoxy (Buehler EpoxiCure 2). Figure 7 shows an image of the vacuum infusing process and Figure 8 shows the part after vacuum infusing and post-machining. After infusing with resin, this part was pressure tested at ATS and was found to be leak-tight up to a pressure of 100psi.

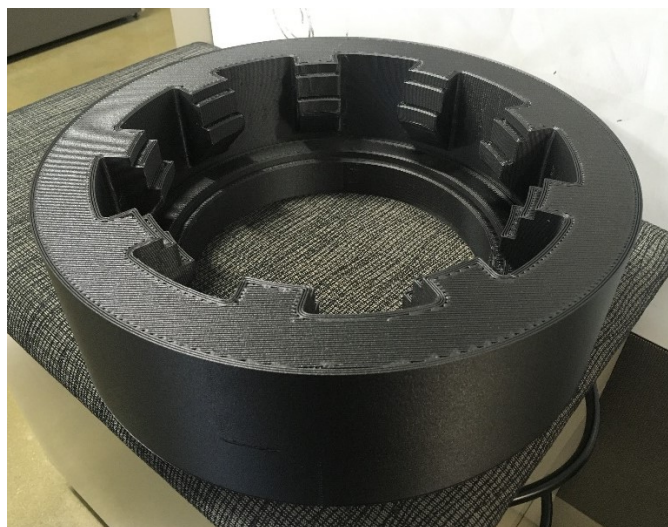


Figure 6. 3DP Printed Stator Outer Housing



Figure 7. Vacuum Infusing Resin



Figure 8. Infused and Machined Stator Outer Housing

The printed turbine components were assembled by ATS as illustrated in the rendering in Figure 9, while Figure 10 shows the actual components ready to be assembled. Future testing will involve testing on the Mississippi Dam in Keokuk IA.

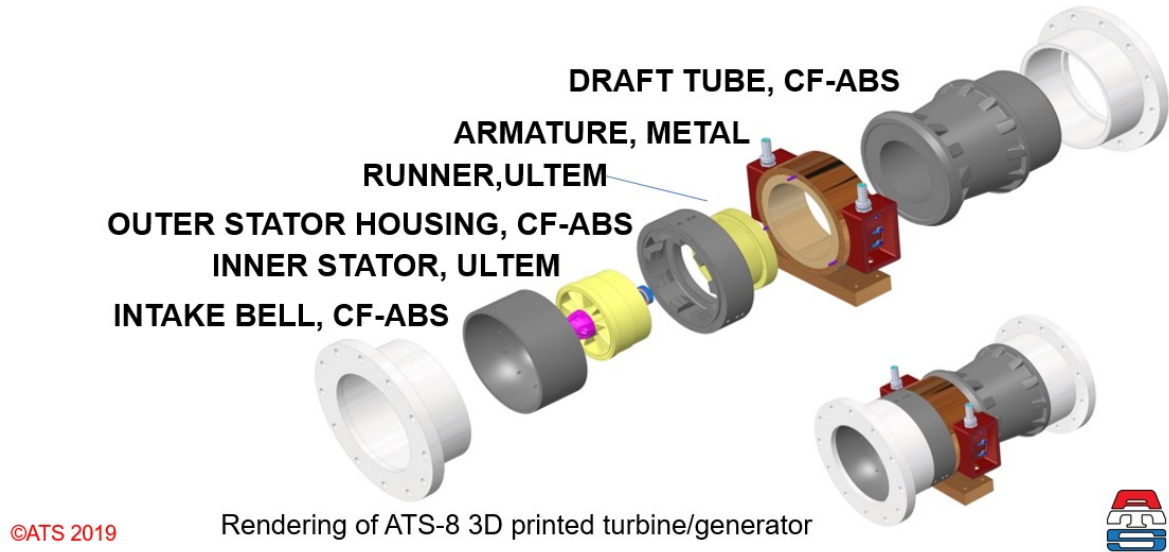


Figure 9. Assembly Rendering



Figure 10. Parts for Assembly and Testing

1.3 IMPACTS

This project highlighted the challenges that arise from producing parts with AM, when the parts must withstand pressure and not leak in a hydro application. While many of the parts produced in this project suffered severely from porosity and the resulting leaks under pressure, a solution was found. This solution involved printing components on a 3DP Workbench 400 series and vacuum infusing with epoxy to fill the voids. This resulted in a part that remained leak-free at pressure. This opens the door to hydro applications, such as the ATS-8 turbine system, for AM.

1.3.1 SUBJECT INVENTIONS

No Subject Inventions resulted from this collaboration.

1.4 CONCLUSIONS

The goal of the project was to enable additive manufacturing for the deployment of low head hydro power. While issues with voids and porosity dogged the project, a solution was ultimately found. The final conclusion of this project is that AM technologies, when used properly, can be used for certain low head hydro applications. Future testing by ATS will include testing in a dam. Further economic analysis that considers not only the printing cost, but also post-processing (including the vacuum infusing and the final machining), must be done to truly evaluate the feasibility of this approach.

2. AMJET TURBINE SYSTEMS, LLC BACKGROUND

AMJET Turbine Systems, LLC (ATS) has utilized composite marine water jet technology to create a new low head hydro turbine/generator. Low head hydropower (axial flow) is the inverse of a marine water jet. ATS has a sister company, American Hydro Jet Corporation (AHJ), that has designed and built water jets for large yachts. The flow direction and rotation are reversed but mechanical loads, stresses and hydrodynamics are similar and basic construction developed by AHJ is now used by ATS. Another major step was the integration of the turbine and generator components in one housing eliminating many drive components and introducing variable speed, eliminating flow controls, while reducing the total weight and footprint by up to 5x.