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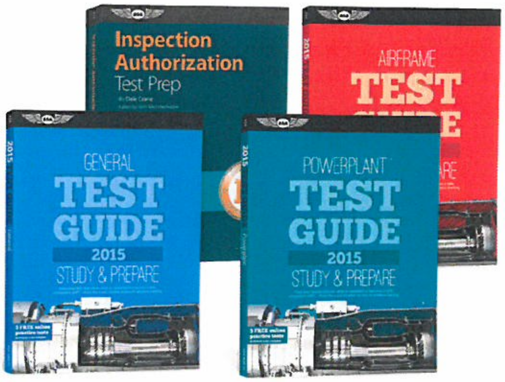

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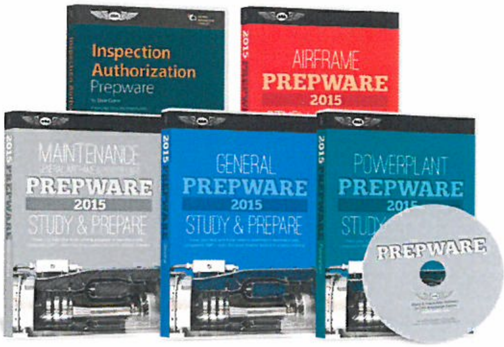

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Incorporating 3D Printing as an Introduction to Digital Manufacturing in an Aeronautical Engineering Technology Curriculum

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ABSTRACT

Fluency in application of digital manufacturing practices like 'additive' 3D printing is key for engineering and technology graduates entering the next generation aerospace workforce. Research faculty and students at Purdue University's Hangar of the Future Research Laboratory teamed with the Dept. of Aviation Technology's Aeronautical Engineering Technology Powerplant Lab to design, 3D print, install and operationally test a 3D printed prototype part on a turbine engine. The component was a bellmouth inlet manufactured using rigid plastic prototyping material. This design project was developed to evaluate ease of integration of advanced manufacturing practices into existing aeronautical engineering technology laboratory learning projects. In addition, the component was successfully tested on the department's outdoor engine test cell and is one of a series of advanced aerospace manufacturing design projects being integrated into Aviation Technology research and curriculum laboratories at Purdue.

INTRODUCTION

Advances in computing power, automation and the network enabled workspace have allowed aerospace manufacturers to rapidly evolve and integrate digital manufacturing practices like 3D printing directly into production operations at the point of manufacture or maintenance. These advances are rapidly changing how we view lifecycle management of today's 'smart' sensor driven air vehicles and their powerplants. 3D printing in particular has been coined by some as the 'standard bearer of the next industrial revolution' (Koten, 2013) as the art and science of today's 3D printing capabilities continues to allow for faster and more cost effective printing applications (Brewster, 2014).

As advanced manufacturing practices are being rapidly integrated along all parts of aerospace manufacturing processes, the demand for graduates with these skill sets has increased as well. In fact, a recent study in September 2014 indicated that in addition to core technical background, global demand for 3D printing and other additive manufacturing skills in the last year was the highest across high technology manufacturing industries including aeronautical (Columbus, 2014) where job ads requiring workforce knowledge and skills in 3D printing alone increased over 103% since 2013. It is therefore essential that graduates in aerospace manufacturing and air vehicle maintenance programs have more than just cursory knowledge of this important technology.

BACKGROUND

The aerospace landscape engineering and technology graduates enter today is characterized by rapid virtual collaboration capabilities, multi-sourced data acquisition, sensing and computer assisted visualization technologies, rapid prototyping and computer assisted problem solving. All of these which were once accessible only in the remote domain of an Information Technology or Engineering department, are now part of front line operations daily tool kit required at the point of manufacture or maintenance. They are now useful portals or reference points for self directed teams working at all stages of the aircraft or engine's lifecycle, aptly referred to as the 'Digital Thread' (NIST, 2014). These critical networked information portals form the basis by which the U.S. government has defined advanced manufacturing (U.S. NNMI, 2014) used by many high technology industries including aerospace, as U.S. manufacturing is becoming revitalized at a rapid rate.

To produce successful gradates with the requisite knowledge, skills and abilities for working with this 'digital thread', the modern aviation engineering technology curriculum must do more than just discuss this rapidly evolving digital workspace. Curriculum applications must immerse the learner in direct, experiential learning applications within a realistic setting.

Integration of advanced manufacturing principles, (like adding 3D print design solutions to existing methodologies for air vehicle and engine component fabrication and repair descried here) has been reported to facilitate transfer of basic passive textbook knowledge into deeper active learning and knowledge transfer. This approach, enhanced by access to more powerful design software and more affordable and user friendly 3D printing technology, is believed to result in deeper engagement, optimizing knowledge transfer similar to previous studies when using computer enhanced, self-directed learning platforms (Johnson, Adams, & Haywood, 2011; Ropp, et.al, 2012).

Research shows increased achievement levels and understanding when classroom material is augmented with the tools of advanced manufacturing like networked computing (computer based tools and projects), as demonstrated by tests of technical content mastery by Greaves et.al., (2010) in a study on the impact of technology transformed schools. Adding the additional project attribute of the learner's direct involvement in the component design (including direct involvement in planning, generating and producing a solution part with the options for creative re-design), not just mastering the installation process, adds synthesis, evaluation and assessment opportunities to the learning process, which are the preferred domains of higher level learning taxonomies (Bloom, 1956; Krathwohl, 2002).

PROJECT DESIGN AND TEST METHODOLOGY

This design-build-test project involved CAD modeling a component for a jet engine powerplant simulating a common removal, repair or replacement process. An Allison 250 gas turbine engine was selected as a test platform from the department's powerplant laboratory. This particular powerplant was selected for its compact size, accessibility and robust operating performance reliability making it easy to work with and very mobile.

A component routinely inspected, removed and reinstalled during test cell runs is a bellmouth inlet surrounding the intake (Figure 1) which was selected as the design test piece.

Figure 1. Engine inlet bellmouth - Original component

The turbine engine test cell bellmouth is used to simulate an actual aircraft intake system and offered enough complex geometry for a low to moderate level of design challenge for this project. It must be able to streamline the airflow into the intake of the engine, allowing the engine to receive a smooth distortion-free supply of air as on an actual aircraft. The bellmouth is also utilized as an attach point for static temperature, pressure and other test probes.

3D engine component modeling and configuration process

The part was dimensioned and modeled using CATIA, a commercial three dimensional computer aided design (CAD) software application (Figures 2 and 3) in approximately 4 hours by the research student with basic CATIA skills from AET curriculum courses. This software was selected because of its original design for use in aircraft manufacturing and its continued common use in the aerospace industry. Other CAD software has been used successfully in 3D printing as well, provided file formats are compatible with the 3D print system being utilized. The most common file format for many consumer level 3D printers is Standard Tessellation Language (STL). STL was the file language used for this print as it proved to be the easiest format to work with and recognized by the model printer used for this experiment, a Makerbot 5th generation 3D print system.

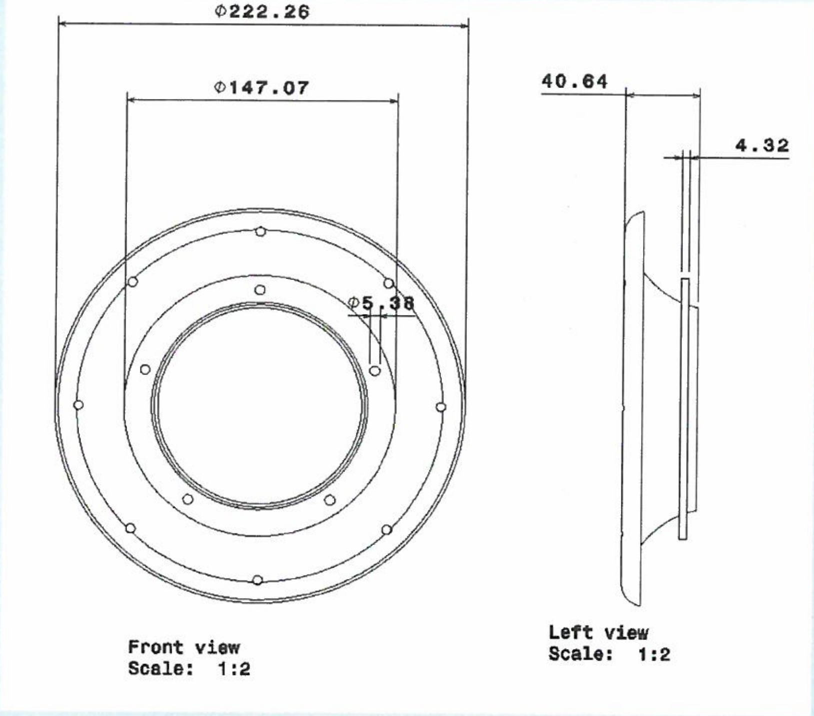

Figure 2. Inlet Dimensions (in mm).

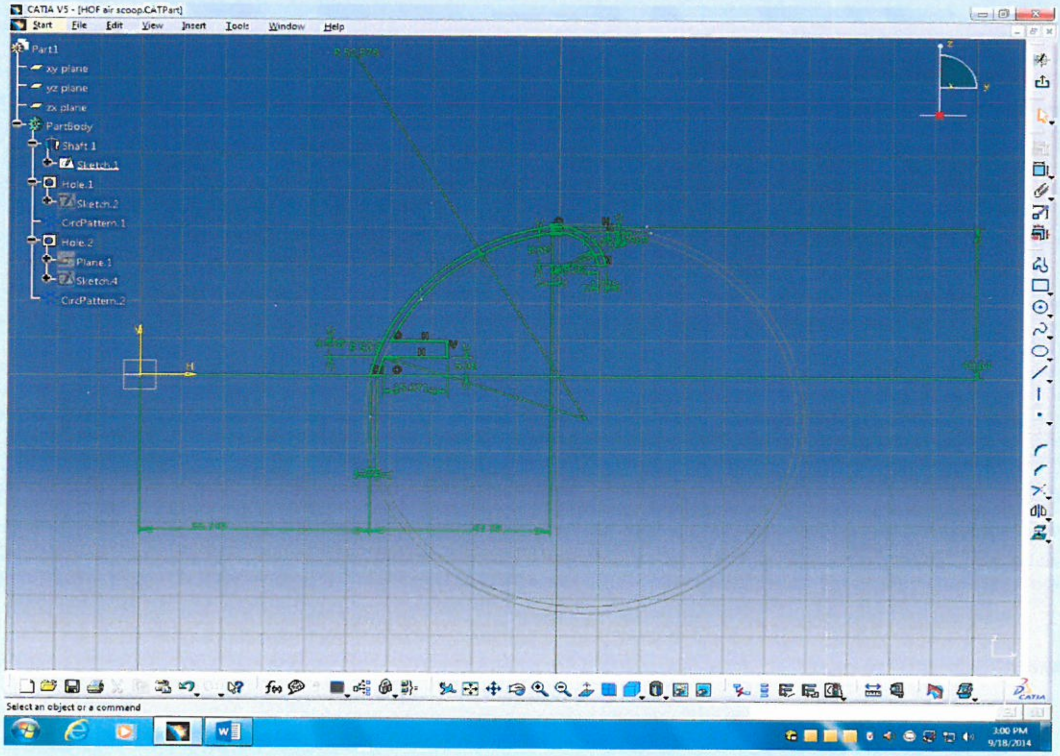

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Figure 3. Sketch of the inlet cross-section with dimensions (in mm).

Because 3D printers create three dimensional parts in x, y and z axis, the inlet component presented constraint challenges of staying within the print build volume limit of the printer's design plate. Print build plate limits were 9.9" L (251.46 mm) x 7.8" W (198.12 mm) x 5.9 H (149.86 mm). Because the diameter of the part (222.26 mm) was larger than the width of the plate, the final installation part had to be 3D printed in two separate halves (Figure 4) which were then attached together after manufacture to form the finished inlet piece.

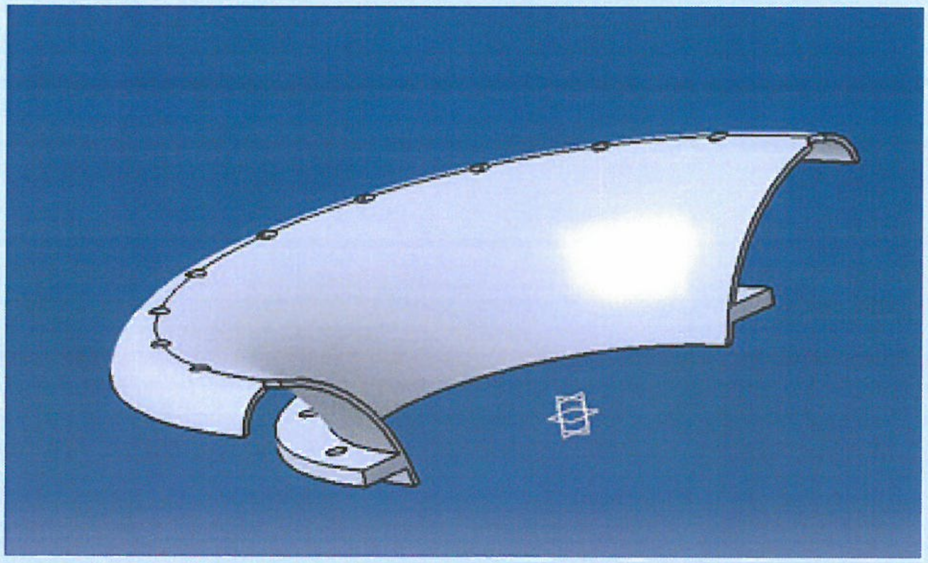


Figure 4. CATIA modeled bellmouth inlet half. Courtesy: A. Anne

The full part model configured into the printer's virtual build plate interface is shown for reference (Figure 5). This view enables pre-print orientation of the part on the build area.

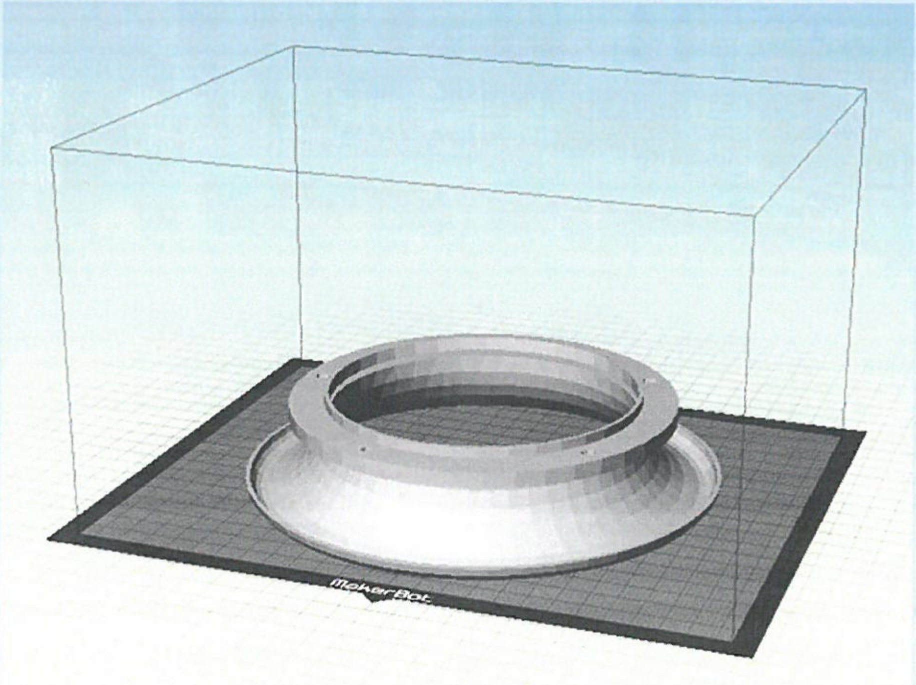


Figure 5. CATIA modeled bellmouth full inlet on virtual build plate.

3D engine component print process

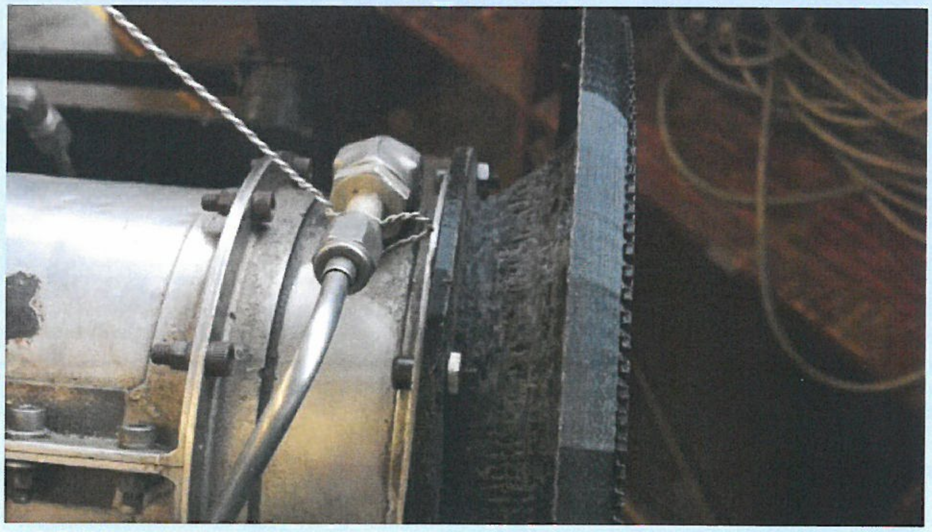
The print was accomplished using the department's current 3D printer, a Generation 5 Makerbot Replicator. When the print file is loaded into the printer CPU, the printer uses a process known as fused deposition modeling. This essentially involves numerous passes of the print head extruder, which additively layers melted prototype material, building the part in successive passes of the print extruder head.

In this test case a polylactic acid (PLA) rigid plastic prototyping test material of 1.75 mm diameter was utilized. This material was deemed rigid enough to approximate the original strength and structural fit requirements of the original inlet for fit and low power engine test runs.

Printed Engine component installation and test

The 3D printed inlet (shown in black, Figure 6) had concentric alignment of fastener holes, however some excess material from printing had to be removed from the holes. Excess material was minimal however, and a sander was used to easily remove excess material from planar areas taking about 15 minutes. All fastener holes were able to receive the original engine component fasteners during installation.

Figure 6. 3D printed bellmouth inlet installation.



A low power test run protocol was used to evaluate overall part integrity and fastener fit. As this part was not designed or intended for high power structural testing, only low power engine settings were used.

After installation, the engine was secured at an external engine test run up stand (Figure 7).

The test run duration was five minutes evaluating the part's fit, hardware fastener security and overall structural integrity at 50% rpm.

Figure 7. Turbine engine test run with 3D printed inlet installed.

DISCUSSION

It must be re-emphasized that the printed part was a rigid plastic filament prototype material, not intended for large force or structural load testing. It is recognized that 3D parts as produced in the aerospace industry utilize advanced metal or composite print processes and have manufacturing and airworthiness capabilities and approvals for their design and installed use.

The thrust of this project was 1) to evaluate overall manufacturability and efficiency of a 3D printed design, build and installation task and 2) demonstrate the ability to incorporate 3D printing as part of a deeper, immersive learning process within an existing Aeronautical Engineering Technology Part 147 curriculum. As such, the goals for this phase of the 3D printing research described in this report were to demonstrate the 'art of the possible' by blending existing curriculum with next generation, digital advanced manufacturing principles that closely approximate current industry standard processes. This design project was therefore considered a success.

CONCLUSION

3D printing within an active learning context notably engaged multiple learner competencies simultaneously. These included: problem identification, technical and contextual repair design, transfer of ideas and creations from virtual to the material world, installation methods, testing and assessment. These skills included Computer Aided Design (CAD) for 3D modeling, hands-on dimensioning, understanding the mission profile of the powerplant and use case of the part, as well as understanding the potential benefits and applications of the additive manufacturing process of 3D printing itself.

Major engine manufacturers are already employing advanced metal or other aerospace grade materials in 3D printers to produce aircraft engine fuel nozzles and ducting. This immersive learning project applied skill sets resulting in deeper learning with notable tendencies by learners to seek similar novel assembly and maintenance solutions for other air vehicle airframe and engines. Future advanced manufacturing projects will incorporate productivity comparisons (time to print versus traditional subtractive manufacturing or composite layups) and material cost comparisons. The primary benefit noted for applying 3D printing into an AET project was the ability to rapidly reproduce a part to test fit, form and function in a matter of hours that would otherwise take weeks or months to produce. The student designer was also able to produce and experiment with customized design variations in a relatively short amount time while extending learning transfer of core aerospace design and repair skills into the realm of advanced manufacturing.

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