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RAPID PROTOTYPING USING DIGITAL ADDITIVE MANUFACTURING AT SOLAR® TURBINES

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ABSTRACT

In a world of rapidly evolving technology, there are growing demands for faster results as well as a reduction of cost for gas turbine development cycles. The time for prototype trials that often require several iterations between engineering, manufacturing, and assembly are being reduced. The lean solution of Additive Manufacturing (AM) Rapid Prototyping allows you to decrease the development cycle by accelerating design iterations, providing rapid learning to find the best solution quickly.

Historically, the time it takes to go from idea generation to concept design and testing/validation can take years before a part is ready for production implementation. The Additive Manufacturing organization at Solar Turbines has been focusing on combustion system components that would traditionally be made from complex castings and assemblies that require special molds, fixtures, and elaborate tooling. All of these steps add to the initial cost and lead time required to evaluate if an idea is even feasible. A traditional fuel nozzle development project can take between one to three years and includes multiple separate design iterations that each need to be designed, built and rig tested. With the use of AM Rapid Prototyping fuel nozzles development projects have been completed and tested in a matter of months.

Solar learned the advantages of designing for AM and the benefits of rapid prototyping on the first attempt at producing an AM combustion component. Solar acquired its first 3D printer in 2014 with a goal to reduce production costs. The targeted combustor components were already designed and modeled for additive manufacturing. However, the team realized that with additive manufacturing and using an iterative design process with rapid prototyping the part could be optimized for lower cost and improved performance. When adjusting an existing model to the additive process, numerous obstacles are present that need to be resolved while staying within the original design requirements. Some of the lessons learned with the first AM component pointed out that designing for additive manufacturing must be embraced and be flexible enough to change designs through initial trials of AM. With AM Rapid Prototyping it is easy to print a wide range of product variations that can assist in developing a new product to solve a problem in an iterative design and manufacturing process rather than being given a design solution and figuring out how to make it.

By embracing the design for additive thinking, all the engineering groups working for each project open numerous routes for making use of AM Rapid prototyping. Additive manufacturing inherently drives an iterative design process to quickly develop parts. Plastic prints can be used as visual aids, they are often used for fit-up checks, or even flow analysis. Metal prints can be produced, and finish machined for rig or engine tests. One build plate can be printed with an entire Design of Experiment (DOE) array of parts that can be used to determine specific build parameters and model geometries that will result in the desired outcome. Even if the ultimate plan is to return to a cast part for production, metal prototypes are low-cost alternatives to making multiple casting changes. Often, it has been found that additive manufacturing of a complex single part is the more cost-effective alternative compared to traditional complex assemblies of multiple pieces.

As part of the rapid prototyping in Solar, process Flow Mapping has allowed the Additive Manufacturing Organization to create a detailed flowchart for each project that has a clear path towards production implementation. The AM Team got together with representatives from

Design and Materials engineering groups at Solar to put together the typical milestones that must be addressed on the path to developing a new part. There are built in decision points in the process flow that drive communication between the AM engineers and the Design engineers to ensure models are printable and manufacturable.

Keeping track of models and changes is of the utmost importance with rapid prototyping of AM parts. Solar has created a tracking system that provides a central location to keep track of MBD (Model Based Definitions) along with blueprints, build files, and print parameters. After input from Manufacturing Engineering, the design department models the final product that is the preferred solution, and documents to the part number in the system. The Manufacturing department can then create manufacturing copies of the model to assist in model and geometry compensation for development of a design that accurately generates the desired physical part. If a part is destined to remain an AM part into production, Design engineers can then document the compensated model in the system, associated with the part number. Process engineering would also document the build file and parameters in the system, associated with the part number. Without a standard practice for organization, it would be easy to lose track of what was printed when and with what type of geometry compensations or build parameters.

Having a plan and flowchart are essential to maintain a standard process, however in order to keep all the different stages of the process on track, Solar improved the organizational structure. To ensure that AM Rapid Prototyping projects stay on track it has become standard to designate one individual as a project manager who helps maintain velocity and throughput. One key tool that the project managers have at their disposal is the Lean AGILE methodology, utilizing Azure DevOps with daily sprint meetings that makes it easier to stay on track and get support when needed.

Three examples where AM rapid prototyping was used to accelerate the development process are listed next. First, AM turbine torch tubes are a direct replacement for an existing part and are required to have printed holes that meet existing cast hole geometry. A DOE was created and multiple compensated geometry models were printed on one plate. Trial parts were used to determine that for these specific holes the horizontal diameter needed to be oversized by .005" and the top of the hole needed to be elongated by .014" to compensate for the sag in the unsupported region of the hole.

Secondly, combustor air tubes went through a redesign to address several manufacturing and overhaul issues to increase robustness and ease installation during liner assembly.

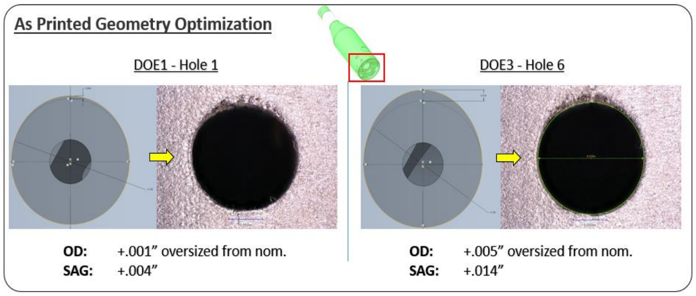

Figure 1. Torch tube hole geometry and sizing to achieve as printed holes that meet drawing requirement

The previous design consisted of sheet metal and tube components that were difficult to install, requiring extensive assembly experience to meet drawing requirements. In addition, the air tubes historically did not meet life requirements and needed to be replaced at each engine overhaul. The AM air tube had to fit into the existing assembly without requiring new or extra tools, be easier to install, and robust enough to potentially last more than one engine overhaul cycle. The model went through nine iteration cycles, consisting of iterative design changes and print trials to develop a model that was printable and accurate that were subsequently analysed and tested to achieve a design that would meet thermal needs.

Finally, a Titan 250 special segmented preswirler was developed using AM Rapid Prototyping. This effort started with a model geometry that was expected to be printable based on experience of past prints. A metal part was printed to confirm that the designed model was in fact printable. The part was flow checked to get a baseline effective area to compare to analysis. From the baseline several plastic parts were printed: one the same as the baseline to check the compensation correlation and then others with differing throat sizes to find a geometry that would result in the desired flow. Once a geometry was down selected based on flow results, the full set for an engine test were printed.

In conclusion, Solar has implemented an AM Rapid Prototyping process. This process is unlocking the potential for departments across the business to try new concepts for product improvements that were previously not feasible because of the initial cost and time commitment for development.