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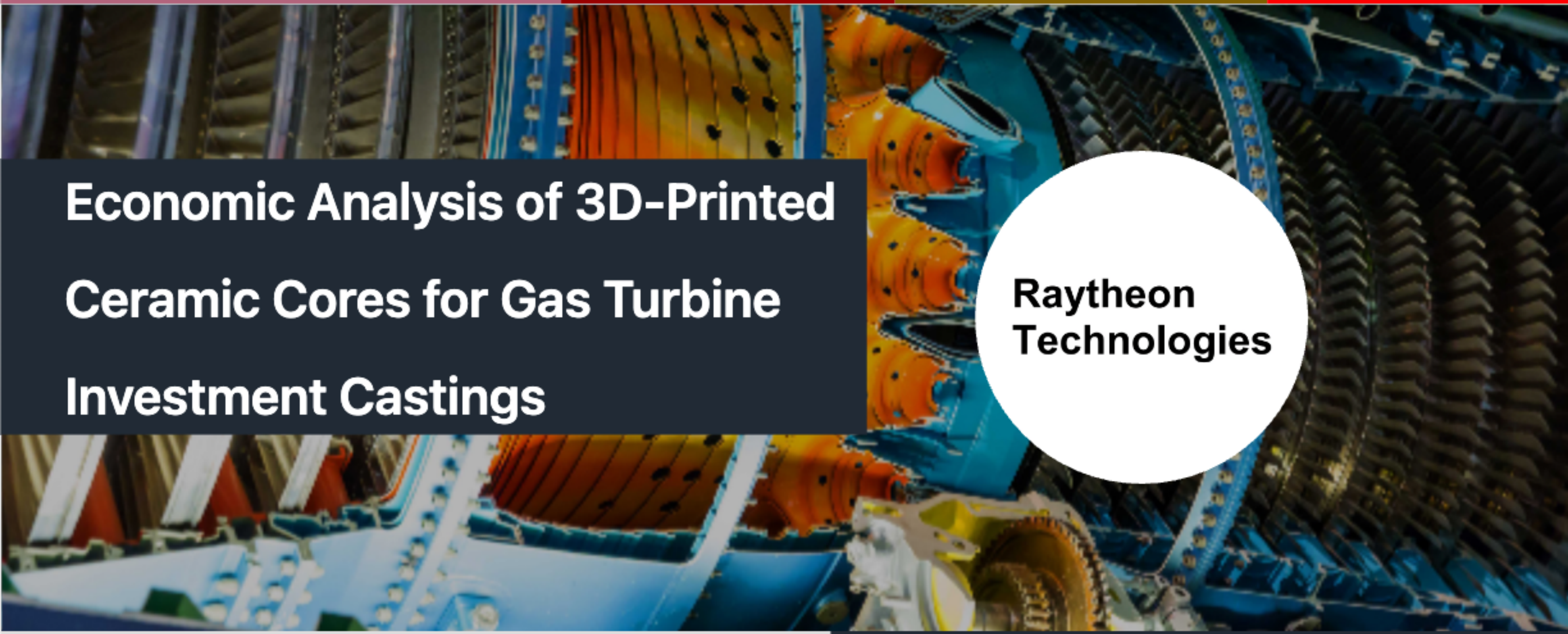


Economic Analysis of 3D-Printed Ceramic Cores for Gas Turbine Investment Castings

Raytheon Technologies

BUSINESS PROBLEM

When manufacturing blades and vanes for gas turbine engines, internal cooling channels are formed by investment casting with sacrificial ceramic cores. The hot injection and pressing techniques traditionally used to manufacture ceramic cores have long lead times and high up-front costs, motivating an interest to form cores via additive manufacturing. While industrial additive manufacturing technologies enable a faster and more iterative ceramic core manufacturing process, this efficiency comes with high per unit manufacturing costs of additive methods.

APPROACH

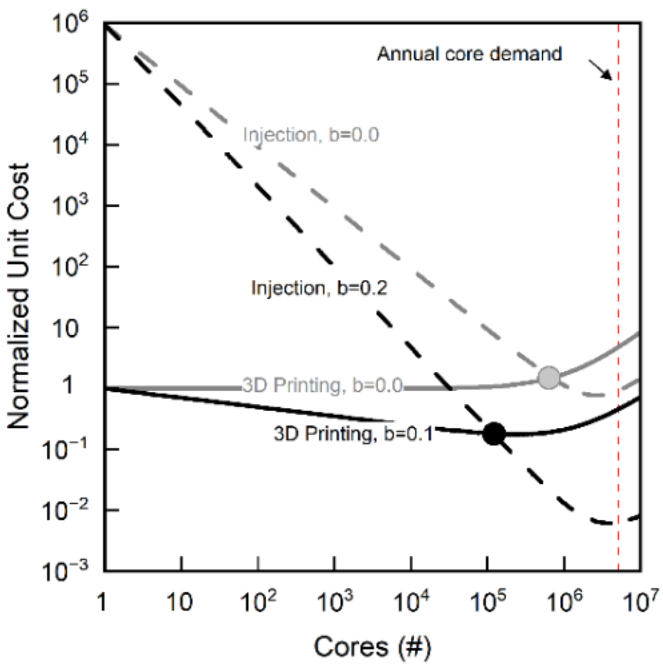
To determine the quantities for which additive manufacturing is more economical than traditional hot injection and pressing methods, an economic analysis of the aircraft engine and investment casting markets was conducted. To determine the technical feasibility of using additive manufacturing, current technical capabilities of several additive methods for forming ceramic cores were compared.

DATA SOURCES

Publicly available financial data from aircraft engine OEMs and casting companies, metal commodities prices, aircraft fleet sizes, industry reports, and aircraft MRO information.

Data Types and Format

Financial statements, industry reports, fleet size data.



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IMPACT

The economic advantage of using viable additive manufacturing methods was assessed using publicly available financial, maintenance, and aircraft fleet size data in a manufacturing cost model. When considering user experience curve effects, the model shows that for a single core design, additive manufacturing is economical at quantities below 1,900 cores, or about 16 high pressure turbine stage sets. When considering multiple core designs needed to satisfy demand across all commercial aircraft in use, the model shows that additive manufacturing is economical at quantities below 720,000 cores, or 14% of the total core market demand in 2019. This motivates the use of additive manufacturing for new core design development and testing as well as the maintenance of older engine designs while reaffirming the use hot injection and pressing techniques for production level manufacturing and maintenance.

DRIVERS

The lack of competitive pressures in the casting industry, the high cost of developing and manufacturing the steel dies, and low yields of intricate, hot pressed ceramic cores motivates the use of alternate manufacturing processes. Traditional subtractive machining processes are not suitable given their incompatibility with ceramic materials traditionally used for cores, making AM a promising approach.

BARRIERS

The fact that the airfoil casting industry is essentially a triopoly also means that a lot of their actual manufacturing costs and airfoil pricing structure is obscured to outsiders, and potentially, to their customers. This lack of transparency makes it particularly challenging to extract the true manufacturing cost of the actual ceramic cores, since they are essentially a sacrificial tool in the process of manufacturing airfoils.

ENABLERS

Speaking with several airfoil casting experts at Pratt & Whitney allowed me to focus on the right data in order to be able to extract a cost estimate for ceramic cores. Along the same lines, speaking to additive manufacturing experts at Pratt & Whitney allowed me to focus on the right additive processes.

ACTIONS

The original plan for this internship was to either commission ceramic AM test articles or print parts in-house in order to verify the three ceramic core requirements. Four suppliers were selected based on their availability of ceramic printing materials that would have a high likelihood of being easily leachable. Quotes were obtained from all four suppliers, but unfortunately no parts were able to be delivered before the end of my internship.

INNOVATION

The model developed found that AM is most economically advantageous at low, pre-production quantities. This is in line with most other uses of AM as prototyping method rather than a mass production one. However, the rapid fabrication times for additive manufactured cores presents a great opportunity to utilize AM in the development of new HPT blade and vane designs, without having to commission prohibitively expensive and long lead time dies.

IMPROVEMENT

As AM technologies keep improving, the cost of printers and print material goes down, and the size and print speed of printers goes up, the model developed for this research can be utilized to find the most up-to-date break-even point of switching to AM. This would allow aircraft engine OEMs and MRO providers to continuously reassess the scale of their use of AM to manufacture ceramic cores.

BEST PRACTICES

The model presented in this report can be extended to analyze costs and demands for any given year, regardless of extraneous market conditions. Anyone trying to replicate the results just needs to make sure that their data and assumptions are in line with industry knowledge and best practices.

OTHER APPLICATIONS

Another area of consideration would be to assess the ability of aircraft engine OEMs to rent printing capacity—by ordering printed parts from a third party—rather than purchasing printers outright. The inputs of the model could be modified to remove this consideration and instead adjust the material and overhead costs to reflect the higher costs associated with contracting out to a third party with existing printing capabilities.