

Introduction to Innovation Management (ACPA7005) – Assessment B -

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1. General Electric: Jet engine Kings

General Electric (GE) has been a leader in pushing aviation for over a hundred years. They have claimed several world-first titles in the jet propulsion industry, including the first jet engine in America, the first turbojet engines to allow flight at 2 or 3 times the speed of sound, and the first high bypass turbofan engine (GE Aerospace, no date a). GE has been a constant source of innovation and a key contributor to the evolution of jet engine technology over the past century and is still making strides even within the last decade, as will be covered in this report.

But how does a company continue to innovate on a product that has been in development for a century? What factors can contribute to these innovations, and how significant are they in a business's performance? This report will look at GE's recent steps in improving the designs of their jet engines through the investment in Additive Manufacturing, the opportunity that was utilised and how this was implemented and maintained even when faced with significant risks.

2. Additive Manufacturing in the Aerospace industry

The aerospace industry is primarily driven by a significant design factor when it comes to progress and improvement, mass. Keeping the mass of your aircraft as low as possible leads to substantial benefits in efficiency, and every step towards lighter equipment is welcomed (Mohd Yusuf, Cutler and Gao, 2019). As long as the engines have mass to be removed, optimisations can be made, and the designs are not complete.

Additive manufacturing (AM) is a term used to refer to a group of processes that produce 3D geometry through the deposition of successive layers. These processes can vary in deposition method, material and application and are relatively new additions to the manufacturing industry with no standout application. However, when used successfully, AM processes can manufacture components that are simply impossible otherwise (Blakey-Milner *et al.*, 2021).

Due to the digital nature of the input files and the capabilities of manufacturing, AM processes are able to manufacture products with a number of advantages over traditional methods. Component consolidation and significant material reductions are two notable advantages that are achievable due to the advanced abilities of computer-aided design, generative design and layer-by-layer manufacture (Blakey-Milner *et al.*, 2021). Both of these concepts have been implemented into the design of several components within GE's GE9X, GEnx and GE90 jet engines (General Electric, 2022).

The GE9X jet engine, built upon the GE90 model, isn't being used within commercial flights as of January 2023. However, the engine will be used within all Boeing 777X series aircraft (Boeing, no date). The Boeing 777X is described by Boeing as "the world's largest and most efficient twin-engine jet, unmatched in every aspect of performance", and similarly, GE describes the engine as "the most powerful commercial aircraft engine ever built" and "the most fuel-efficient engine in its class" (Boeing, no date; GE Aerospace, no date b). These titles are rewards for the significant technological and economic investment GE has made in both its Aerospace and Additive departments.

3. 3D printed parts in high spec functions

As noted in the previous section, AM uniquely allows for some significant design benefits. This potential design was not ignored by GE as, in 2016, they became the majority stakeholders of two additive companies Arcam AB in Sweden and Concept Laser GmbH in Germany (GE Additive, 2016b). Since 2016, GE has continued to commit to product and process innovation by developing these companies and the technology they manufacture with continuous releases of new machines, improvements upon existing processes and research into the various materials and applications. (GE Additive, 2016a, 2017). Two machines manufacturing additive components within the GE9X engine are Aracam EBM A2X and the Concept Laser M2. Both of these are metal additive manufacturing processes which utilise the fusion of metallic powder to form individual layers of the components (GE Additive, no date a, no date c). The primary difference in these machines is the fusion process and materials used. Both of these processes are commonly associated with internal defects within their products due to issues with energy distribution and printing parameters. Significant inconsistencies in part performance and reliability are often highlighted when discussing the application of parts manufactured by laser powder bed fusion processes. (Mukherjee and DebRoy, 2018).

GE has managed to develop its additive capabilities and successfully apply the products of this within its GE9X engine. One example of the 6 different components additively manufactured are the 28 “Fuel Nozzle Tips” manufactured using the Concept Laser M2 using carbon fibre composites. This part combines 20 components in a “5X more durable” consolidated assembly, something possible only due to the application of AM processes (General Electric, 2020; GE Additive, no date b). This may seem to be one of many significant innovations in the component design of these engines, but this did not come about without considerable business and engineering risks and barriers.

4. The Risks laid out

The outcomes of component failure in any vehicle can vary between disastrous and almost unnoticeable depending on the component that failed. When it comes to aeroplane engines and GE, any component failure, regardless of how small, could lead to significant outcomes, both in terms of company image and the health of the airline customers. GE has a notable reputation in the aerospace industry, as was described in section 1, and any failure of its engines within flight could significantly damage this image, putting numerous people’s lives at risk. If GE’s additive division were to fail in its anticipated value generation, the scale of its investment loss would be genuinely significant to the company’s future. For GE to implement parts made using these processes, appropriate levels of development, research, and testing are crucial.

GE knew for this to be a successful endeavour, they had to have the entire business behind the investment into AM. A long-term investment plan and commitment to the development of the technology and materials were required, and that is what GE has showcased since making obvious and distinct business decisions favouring AM (GE Additive, 2016c). GE was aware that this was not an instance of “technology shock” where the benefits would be instantly felt, this innovation was to be incremental and gradual with the long-term objectives for the investments being planned out years prior.

5. Approaching these risks

In terms of AM, confidently utilising additively manufactured parts in significant quantities for these high-stress applications shows great faith in the research and development of GE's additive division, the machines designed by the Arcam AB and Concept Laser companies, and the quality of their materials. These applications have not been without significant periods of testing as the engine is nearing 7 years since its first test, 5 years since its maiden flight and has undergone "the most rigorous testing program of any of GE commercial aircraft engines", allowing it to meet numerous certifications so far. (Daugherty, 2016; GE Aerospace, 2021). It is clear that GE is taking the most appropriate and thorough testing scheme for this engine and that this introduction of AM into the development stream of its engines has been an innovation plan in the works for over a decade.

This implementation approach is reminiscent of the innovation-focused company culture Rajesh K. Chandy described in "Organising for Radical Product Innovation", an article published in 1998 by Sage Publications, Inc. In this article and in Chandy's later publications, he notes that successful implementation of innovation must include the involvement of those in prominent decision-making positions and has to consider future factors to minimise the risks associated with the innovation implementation process (Chandy and Tellis, 1998). This methodology has been vital to minimising risks when it comes to working with AM, as many of the factors surrounding the success of its implementation in high-stress environments are still being researched due to the processes and materials being relatively new.

Even with this long and thorough approach, jet engines have hundreds of components and thousands of points of potential failure. In October 2022, a GE9X failed during a test flight in the US due to an undisclosed issue, which has potentially delayed the progress of the GE9X testing program (Aerotime, 2022). The true success of this innovation process can only be measured once the engine has been in public service for enough time to gauge metrics such as payback upon the long-term investments, opening new ground for further innovation and reliability of AM components in applications such as jet engines.

6. Looking generally at General Electric

In a 2015 article by Danielle Merfeld, the current Vice President and Chief Technology Officer at GE Renewable Energy, titled "*GE Is in a Startup State of Mind*", GE is described as changing its business operations towards a more "nimble" or agile state through company streamlining (Merfeld, 2015). Two internal initiatives that have been designed to achieve this are "Simplification" and "Fast works" which have been developed alongside the trends that we now know have developed significantly nearly 10 years on, Advanced Manufacturing and Industrial Internet.

The article describes some of the vital appealing factors of these initiatives and trends that GE has aimed to move towards to "reinvent" itself. It notes the key benefits of extensive data analysis and management that we now refer to as fundamental in Industry 4.0 implementation and how these can be used to improve efficiency, customer service, and achieve a more controlled product lifecycle. Merfeld explains how advanced manufacturing techniques, such as the use of additive manufacturing in conjunction with industrial data collection, are allowing for more complex component design, even touching on the fuel nozzle that this report detailed in section 3, and how this movement is allowing for more agile manufacturing centres. GE also utilised innovation challenges to solve specific problems by letting people from over the world suggest their solutions, leading to a part redesign achieving 85% mass reduction.

Fast Works is GE’s model for approaching customer problem statements most effectively and efficiently by using strategies such as “minimum viable product” for gauging real, significant customer feedback through the development process. It is a metric and quantifiable data-driven process that allows pivoting throughout the problem-solving process so the best solution can be found and developed.

If we take these concepts and place them into Greg Satell’s Innovation Matrix, as described in his book “*Mapping Innovation*”, we can gauge the intent of each (Satell, 2017). The matrix is shown below in Figure 1.

Problem Definition	Well Defined	Breakthrough Innovation • Fast Works	Sustaining Innovation • Advanced Manufacturing • Additive Manufacturing • Industrial Internet
	Not Well Defined	Basic Research • Innovation Challenges	Disruptive Innovation • Simplification • Reinvention
		Not Well Defined	Well Defined
		Domain Definition	

Figure 1: GE’s 2014 Reinvention plan, Satell Matrix (Satell, 2017).

Breakthrough Innovation: Fast works. This concept not only aims to implement a structured response to customer problems but also to improve the solution development process and encourage customer-to-employee conversation where feedback can be utilised in real-time. This is changing the customer relationship in a significant way through a relatively fast implementation process with the intent of forming substantial change.

Sustaining Innovation: Advanced manufacturing and Industrial Internet are both innovative “new” concepts that reshape and provide avenues for significant development within many areas of the business. For the reasons that were noted above, these concepts have been introduced to significantly alter the business model and processes over a long introduction period. The implementation process dictates its inclusion within this quadrant as it is likely to occur in numerous more minor changes to the existing systems over time to ensure successful management.

Disruptive innovation: Simplification and Reinvention are two concepts that encompass the whole innovation direction described within this article. Changing the position GE takes within the many markets it has businesses in allows it to shift markets entirely and generate momentum if done

correctly. Since GE is such a prominent player in many markets and industries, it can quite comfortably disrupt those around it through such significant reinvention.

Basic Research: Innovation challenges are not a new concept and have been performed by companies such as Amazon in the past to achieve similar goals (Wurman and Romano, 2015). It has proven to be an effective method of solving problems through the amassing of numerous sources of concepts and thought processes. This functions as a critical source of finding the initial steps of new innovation processes, products and business models. The basic research before full innovation implementation.

7. Touching on Best Practice

In this report, GE's innovation implementation process has been considered through several established lenses. Rajesh K. Chandy's interpretation of correct innovation implementation notes a consideration for the future and minimisation of risks through accurate innovation planning and management conducted by those in decision-making positions, a concept that GE has showcased confidently.

Satell's method of categorising innovation concepts and events into the four quadrants can help map and understand the implementation process. In terms of GE's approach, not only can its specific focus on Additive Manufacturing be categorised into sustaining innovation, but also the broader strategy of the implementation of Advanced Manufacturing. Through the matrix, it is clear that GE is considering several innovation avenues and that its continued development of these strategies is critical to the implementation process of its companywide innovation movement and the "smaller" scale innovation events.

8. Critique and Concluding remarks

General Electric's Additive Manufacturing innovation implementation strategy is a prime example of successful innovation management. The scale of GE's general innovation and reinvention scheme is significant, holistic, and companywide, but this does not take away from the specific approach taken in GE's additive business. GE Additive has demonstrated the successful implementation of additively manufactured components within high-stress environments despite recent research dictating considerable difficulties with material properties. Alongside the other significant developments in jet engine design and research, the addition of additive components has aided in creating the most powerful and efficient jet engine in aviation history.

This success has not come without extensive planning, notable investment, and risk management. If the release of the GE9X engine is used as a milestone for the completion of this innovation event, then the operation has been in process for over a decade and is yet to be completed. GE Additive is taking the appropriate approach to ensuring all potential barriers, determinants, and the future of the business and its customers are being entirely considered following similar thought processes to that of Rajesh K. Chandy as a method for minimising business and engineering risks. Risk minimisation is vital for successfully implementing innovative business models and technological advancement and is amplified by the nature of the aviation industry.

As for GE as a whole, this innovation event, plus the "reinvention" of the business model, has been able to be implemented so successfully due to a combination of; thorough planning and management by the people in senior positions, a holistic culture throughout all areas of the company aiming towards the future with modern concepts, and an excellent foundation providing

the resources that would allow for significant pieces to be put into place, the purchase of Arcam AB and Concept Laser companies. Overall, GE's innovation journey so far has been full of small integral steps that could make for innovation analysis reports on their own. However, it has not come without its setbacks and issues, but these act as proof of success for the solidity of its plan and risk minimisation.

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