

A Leap of Faith

The Innovation behind Safran's LEAP Engine Fan Blade

Prepared by:

Richard Burnell

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University of Wales Trinity Saint David

Supervisor: Alan Mumby

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Contents

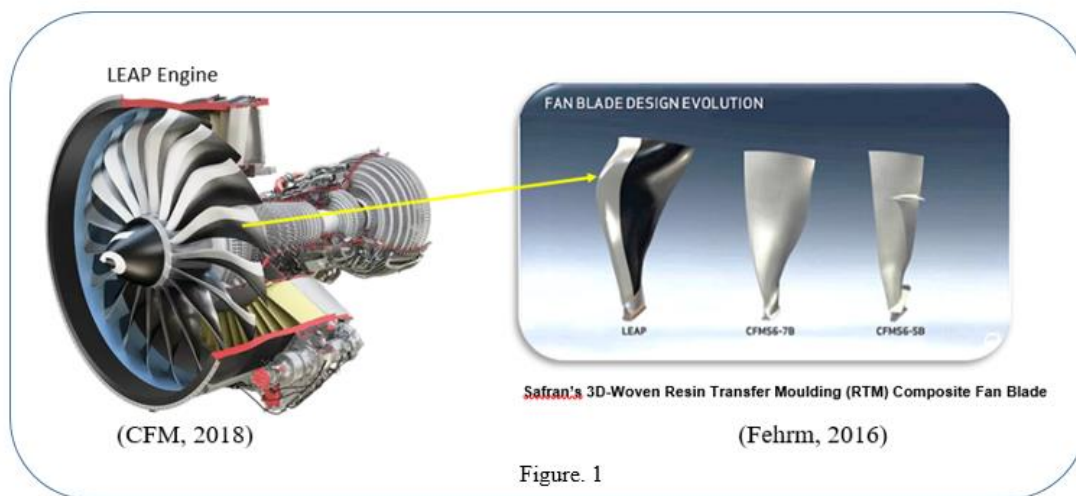
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1. Synopsis / Summary

Air travel is responsible for approximately 3% of all global carbon dioxide emissions and has become one of the fastest growing sources of greenhouse gases (ICCT, 2018). To turn this around, aircraft and component manufacturers are working tirelessly to create cleaner, quieter and more efficient aircraft by looking to new materials and technologies to make planes lighter, more aerodynamic, and more resistant to wear and tear (Boerner, 2021).

In 2008, CFM international, a joint venture between GE Aviation (USA) and Safran Aircraft Engines (France), launched the LEAP (Leading Edge Aviation Propulsion) jet engine project. Due to its innovative design, the LEAP engine reduces fuel consumption and Co₂ emissions by at least 15% compared to that of its predecessor, the CFM56 (the world's best-selling engine). Additionally, the LEAP engine offers lower operating costs than the CFM56 and any of its competitors due to less maintenance and longer service intervals, while providing an aircraft departure reliability of 99.98% (Gardiner, 2014).

One of the key innovative features in the LEAP engines ability to achieve this high performance are the fan blades. Designed and developed by Safran, the LEAP engine fan blades are unlike conventional metallic fan blades used in most modern jet engines, they are the first of its kind to be manufactured using carbon fibre strands that are woven and bonded together to construct its complex 3D shape.



The focus of this report is to review and critically evaluate the innovation process that led Safran to the development of the LEAP engine fan blades, while discussing the uncertainties and risks the organisation had to overcome during this process. Additionally, the report will review how the behaviour of the organisation, teams or individuals can assist or slow down the innovation process in regards to best practice.

2. Principal Drivers

The most significant driver for the development of Safran's innovative fan blades is that of climate change. Aviation is responsible for more than 3.5% of global greenhouse gas emissions (NOAA, 2020), a relatively small amount compared to other sectors, however, it continues to be one of the fastest growing contributors to climate change as shown in figure.2.

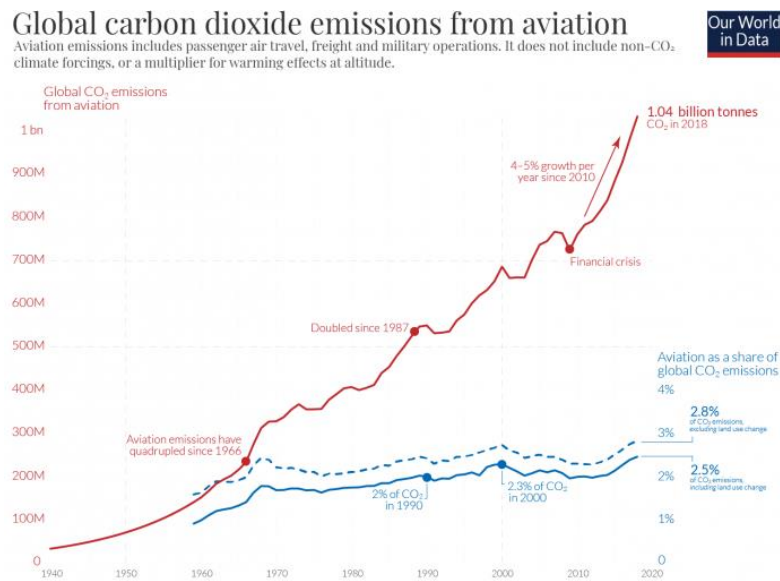


Figure. 2. Global carbon dioxide emissions from aviation (Lee et.al., 2021)

Countries across the world are ramping up their efforts to combat climate change, with many launching strategies such as the 'Net Zero by 2050 Strategy' as launched in the UK and USA, whereby strict policies and proposals that aim to decarbonise all sectors within the economy and hit net zero by 2050 have been introduced (Gov.UK, 2021).

The global aviation sector has a significant role to play in achieving net zero and airlines have a big responsibility to do all they can in contribution to hitting this target. In October 2021, all members of the International Air Transport Association (IATA), who represent 290 airlines or 83% of total air traffic, passed a resolution committing them to 'Fly Net-zero' by 2050 (IATA, 2021).

If airlines are to be successful in hitting this target, they must rely on aircraft and component manufacturers to consistently innovate and develop materials and components that are lighter and more efficient. CFM foreseen an opportunity to become the market leaders for fuel efficient engines and components such as Safran's LEAP fan blades many years prior to the 'Net-Zero by 2050' strategies launched in 2021, putting the companies in a very strong position in the engine market.

3. Barriers

The biggest challenges Safran faced throughout the innovation and development process was that of the strict regulatory requirements that must be met before an aircraft or component is approved for flight. Due to the unusual and novel design of the 3D woven composite fan blades, gaining approval and certification from the regulating body the Federal Aviation Authority (FAA), would prove to be more of a challenge than the company had anticipated.

Due to lack of adequate and appropriate safety standards in the airworthiness regulations at that time and the significant differences in material characteristics between the 3D woven fan blades and conventional metallic blades, the FAA had to prescribe 'special conditions' that had to be met at each stage of the development and manufacturing process (FAA, 2015). The 'special conditions' introduced a number of new and vigorous tests and requirements that were not foreseen by Safran's designers and engineers during the development phase, leading to first articles being scrapped and a potential re-design to satisfy FAA conditions. This would have a significant impact on the project in terms of cost and delivery as Safran had already invested a vast amount of money in the project and made a commitment to deliver to CFM on time.

Due to the conditions introduced by the FAA, the company had reached a cross roads and the company had a decision to make; significantly invest more finances and resources to re-design and develop fan blades that satisfied regulatory requirements or scrap the project completely. The latter meant that huge investments would be lost and the door would be left wide open for competitors to step up and Safran's work would count for nothing. This was not an option for Safran management, they refused to be seen as a failure and had no alternative other than to take a risk and throw every resource they had at the project to ensure it crossed the finish line (Safran, 2018).

4. Determinants

Composite fan blades were nothing new to the aviation industry when the LEAP project began. In 1995, CFAN, an earlier venture between GE and Snecma (now Safran), first used a revolutionary composite fibre polymeric material for the fan blades on the GE90 engine that could be found fitted across the entire Boeing 777 family (Hurm, 2020). Although very successful, the GE90 engine and specifically the engine fan blades were expensive and difficult to manufacture, whereby by the majority of time and resource was devoted to the process of constructing the fans complex shape by hand.

The first step in the process consisted of applying 1700 pieces of carbon fibre layer upon layer into a mould, each fan is then cured, precision machined, verified for dimensional accuracy, painted and inspected. In total, each GE90 fan blade took approximately 340 hours to manufacture (GE Aviation, 2012); this was far too long for the company and its customers as they struggled to keep up with demand. Safran seen this as an opportunity to research alternative methods to the labour extensive manual processes involved within the GE90 fan blade manufacturing process, specifically the layering of the composite fibre materials that was

ultimately the bottleneck in the manufacturing process. This led Safran into the world of textile manufacturing and specifically weaving a method used in textile production whereby yarns or threads are interlaced to form a fabric or cloth. One of Safran's engineers suggested applying the same method to produce their engine fan blades, only the threads used would be that of carbon fibre.

Safran had no experience or real understanding of the weaving process and many doubted that weaving material such as carbon fibre to construct a complex shape such as engine fan blades and withstand the stresses fan blades encounter would ever be possible.

Therefore, the most significant determinant for Safran throughout the innovation process of the fan blades came in the form of American textiles company Albany International, considered as the industry leaders in textile manufacturing, specifically weaving of complex patterns and shapes using a variety of materials. Albany International had the knowledge, skills, experience and technology such as the Jacquard weaving Looms to turn Safran's vision into a reality (Gardiner, 2014).

5. Processes and Technologies

The process and technology used to carry the innovation forward was the actual innovation itself. Carbon fibre composites in the aerospace industry were nothing new, neither was the weaving process within the textile industry. However, combining the two resulted in an industry changing innovation or 'radical innovation' (Trott, 2017), referred to as '3D-Woven Resin Transfer Moulding (RTM)' which the LEAP engine fan blade.

In order to manufacture such a complex shape such as the LEAP fan blade, thousands of carbon fibre strands are woven together using a modern version of a 'Jacquard Loom'. Developed and patented by French merchant and weaver Joseph-Marie Jacquard in 1804, the Jacquard loom revolutionised how patterned cloth could be woven. The machine made it possible for detailed and complex patterns to be created by unskilled operators in a fraction of the time it would take an experienced weaver and an assistant working manually (Science & Industry Museum, 2019). A scaled down version of the original Jacquard Loom is shown in figure 3.



Figure 3: Jacquard Loom (Science & Industry Museum, 2019)

To weave fabric on a loom, a thread called a weft is passed under and over a set of threads, called a warp. Interlacing the threads at right angles to each other eventually forms the desired cloth and the order in which the weft passes over and under the warp threads determines what pattern is woven into the fabric (Science & Industry Museum, 2019). These same principles exist in the machines that developed the LEAP engine Fan blades, only threads of carbon fibre are used rather than cotton etc.

Once the 3D shape of the fan blade is woven using a modern Jacquard loom, the next stage of the process is Resin Transfer Moulding (RTM). The RTM process begins by placing the finished woven structure into a closed mould. A low-viscosity resin is then injected into the mould under moderate pressure (between 3-7 bar) via multiple injection ports, the injected resin fills any voids within the mould, impregnating the entire surface of the carbon fibre material (Erden & Ho, 2017); an example of a typical RTM mould is shown in figure 4. Figure 5 shows the LEAP woven fan blade post RTM.

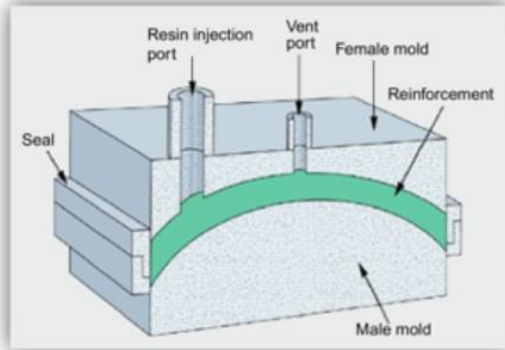


Figure 4: RTM Mould Setup (Erden & Ho, 2017)



Figure 5: Safran LEAP Fan Blade in mould post RTM (Fehrm, 2016))

Once cured, the part is machined, fitted with titanium edges and inspected. The end result of the RTM process in the case of the LEAP fan blade is that of a composite blade without any weak or unreinforced planes that could be vulnerable to delamination failures, this is an advantage over traditional 2-D fabrics. Additionally, the unique design of the fan blade delivers improved fatigue resistance at high cycles, lack of corrosion/lubrication issues and reduced noise levels (Patric, 2021).

6. External Resources

As highlighted in the earlier section (4. Determinants), Textiles Company Albany international became the most significant determinant for the innovation of the LEAP fan blade due to their expertise in weaving of materials, therefore, Safran heavily relied upon the company throughout the development of the LEAP fan blades.

The initial arrangement between Safran and Albany meant that the weaving process would take place at Albany International headquarters in New Hampshire (USA), the latter stage of the manufacturing process including Resin Transfer Moulding (RTM) would take place at Safran's engine facility in France. This worked well until issues and additional requirements from the regulatory authorities (FAA) began to appear. Both Albany International and Safran found it extremely difficult to tackle these issues while on opposite sides of the Atlantic Ocean and commitment dates began to slip. To counteract this problem and to better manage resource and support, both companies signed an agreement that would see Safran move their entire LEAP fan blade operations to the Albany factory in the USA. This allowed a one-stop shop to create the fan blades and directly ship to the CFM factory in Cincinnati (USA), reducing lead times and costs. Ultimately, it permitted Safran to closely monitor the development process and close out issues as and when they arise with support from Safran's on-site design and material engineers.

As previously discussed, the regulatory authority (FAA) had a significant part to play in the development of this innovation and they were extremely cautious due to having no experience with a process or product of this kind. The companies had to manage this very carefully as history tells us that the FAA have a reputation of thwarting innovation (Dourado, 2016). If the FAA were unsatisfied at any stage of the process, of which they were in the earlier stages as mentioned in the earlier section (3. Barriers) they had the authority to shut the project down. Safran and Albany were confident in their product, maybe too confident as regrettably they did not involve the FAA until the latter stages of development, a significant risk that resulted in the administration applying new mandatory tests and requirements at a huge cost to both companies. Once Safran had moved its operations into Albany, both companies knew they could not risk another setback. To manage this, the companies ensured that the FAA had complete visibility throughout each stage of the process and not just in the latter stages. This meant that there should be no surprises during the 'Stage-Gate Process' (see figure 6), whereby the FAA had a seat at the table and had to be satisfied prior to moving to the next gate (Safran, 2018).

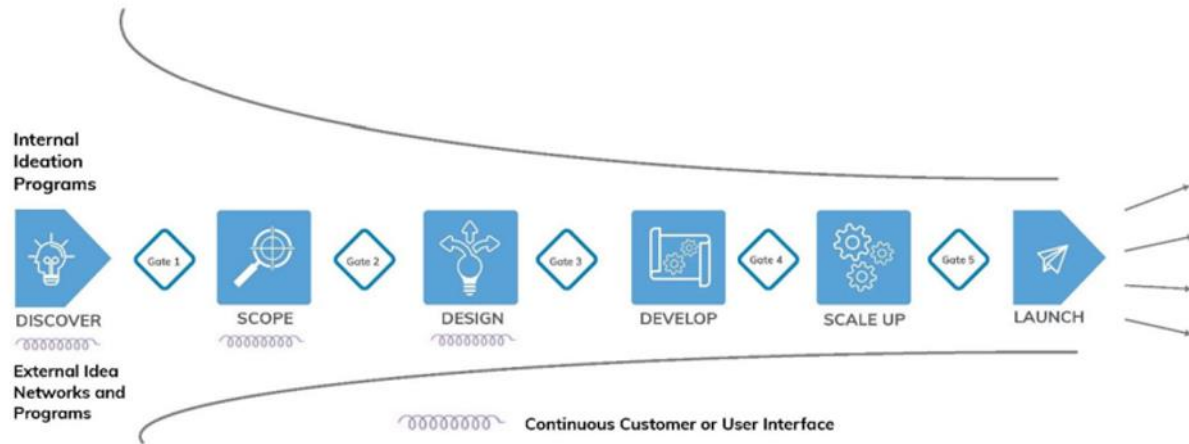


Figure 6: Stage-Gate Process (Edgett, 2018)

7. Innovation Management

Due to the many setbacks experienced throughout the development of the LEAP fan blade, the project came at much higher cost than initially planned. However, despite these challenges, Safran in partnership with Albany International, achieved what they set out to do, develop the world's first 3D –woven composite fan blade for a jet engine and still managed to deliver to CFM engine factory on time. This is a great achievement, although this does not necessarily reflect that the innovation was worthwhile or significant for the business in the medium to long term. To determine this, Goffin & Mitchell (2021) identify four areas connected to measuring innovation; Innovation performance (output of new products, services, processes and business models), Innovation investment (resources which are directly and indirectly linked to the development of new products, services and processes) and Innovation output (revenues generated from the services, products and business models).

Firstly, reviewing the 'Innovation Performance' (output), the LEAP fan blades have seen production ramp up year on year since the project launched in 2008. Once aircraft manufacturers seen the true potential of the LEAP engine and that it was delivering on its promises of reducing Co2 emissions by 15%, being quieter and more reliable than its predecessors, orders escalated at a significant rate. Since the first LEAP engine powered flight entered service in August 2016, the program has grown exponentially whereby the LEAP engine has captured 72 percent of the jet engine market share (Schoorman, 2021) in the fastest order ramp-up in commercial aviation history. As of May 2021, 2,800 engines have been delivered to a total of 136 operators worldwide and orders have surpassed 10,000 engines, (CFM, 2021). To keep up with the demand, CFM set a target to achieve production rate of 2,000 LEAP engines per year by 2023 as highlighted in figure 7, this equates to 36,000 fan blades (18 per engine) a year that Safran must deliver (Dubois, 2009).

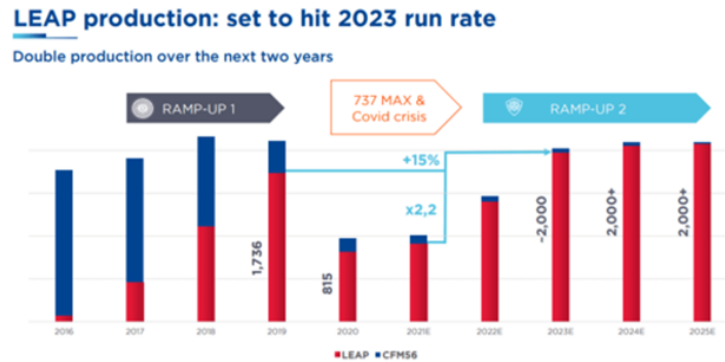
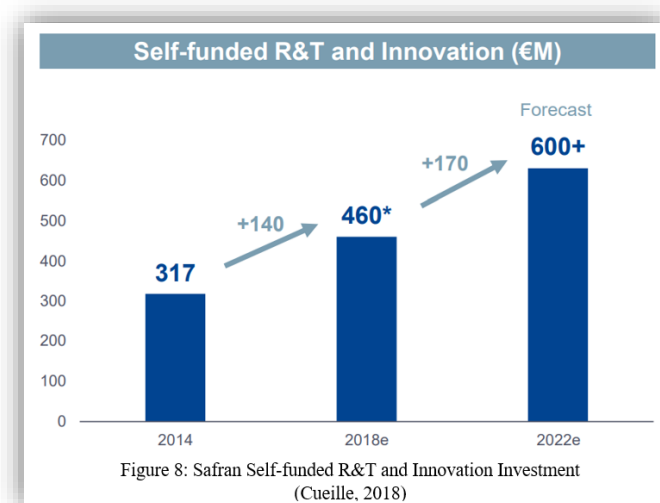


Figure 7: LEAP Engine Production Plan (Schurmann, 2021)

To meet this challenge, Safran and Albany, now referred to as Albany Engineered Composites (AEC), signed a further agreement to build two new assembly lines solely dedicated to the production of the LEAP fan blade (Safran, 2016).

Assessing the innovation, Safran's managements expectations were beyond met. The vast amount of orders received in such a short space of time for the LEAP engines was not expected but highly welcomed by the company and has delivered huge profits for the company. These profits have enabled the company to significantly increase their self-funded Research & Technology (R&T) and Innovation (I). As shown in figure 8 the company is on track to invest more than €600 million into the RT & I effort by the end of 2022 (Cueille, 2018). Referring to Goffin & Mitchell (2021), one of the four areas for measuring innovation is that of 'Innovation investment', looking at Safran's significant investment towards RT&I over the past eight years would suggest that the innovation has been a success.



As for the technology and materials (3D woven RTM composite) that led to the development of Safrans LEAP fan blades, further investment and research has resulted in more components beng developed using the same process. For example, in the next generation of LEAP engines, Safran

and Albany (AEC) have taken what they'd learnt from the fan blades and developed 3D woven fan cases, platforms and spacers, making it a key determinant to produce an even lighter and more efficient engine (Gardiner, 2014).

8. Representation of Best Practices

As mentioned in the previous section (Section 3. Barriers), the innovation process was not all plain sailing for Safran. Poor management during the development stage and failure to include the regulatory body at the earliest opportunity almost shattered the project. According to Strategic Direction (2004), “new products fail at an alarming rate”, with only a quarter of projects becoming a commercial success, if it weren't for Safran being a large company with a healthy bank account the LEAP fan blades would have almost certainly become one of these statistics.

The publication ‘Successful industrial innovation: critical factors for the 1990s’ by Rothwell (1992), is still as relevant now as when it was released and is often cited in academic papers today. Rothwell, identifies the key factors/best practices underpinning successful innovation, these are identified in figure 9.

Factor	1	The establishment of good internal and external communication; effective linkages with external sources of scientific and technological know-how; a willingness to take on external ideas.
	2	Treating innovation as a corporate wide task effective functional integration; involving all departments in the project from its earliest stages; ability to design for ‘makeability’.
	3	Implementing careful planning and project control procedures; committing resources to up-front screening of new projects; regular appraisal of projects.
	4	Efficiency in development work and high quality production: implementing effective quality control procedures; taking advantage of up-to-date production equipment.
	5	Strong market orientation: emphasis on satisfying user-needs; efficient customer linkages; where possible, involving potential users in the development process
	6	Providing a good technical service to customers, including customer training where appropriate; efficient spares supply.
	7	The presence of certain key individuals: effective product champions and technological gatekeepers.
	8	High quality of management: dynamic, open-minded managers; ability to attract and retain talented managers and researchers; a commitment to the development of human capital.

Figure 9: Rothwell's Key Factors to Successful Innovation (Ahmed, 1998)

Comparing Safran's innovation performance throughout the fan blade development to that of Rothwell's eight factors, they got the majority right. However, they could have easily got it so wrong by not conforming to ‘Factor 1’. Factor 1 is the first key step according Rothwell (1992), where ‘effective relationships are made with external sources of technological and scientific know-how’. In Safran's case, they failed at this first step by not involving the regulatory body (FAA) earlier in the process.

Building a good relationship with the FAA and establishing an effective linkage earlier in the development of the LEAP fan blades would have ensured there were no surprises in the later stages of development whereby the FAA introduced further testing and requirements.

To counteract this recurring on future innovation projects, especially where new materials and manufacturing processes are used, Safran have made it a top priority within any future developments to ensure this is captured at every stage of the FMEA (Failure Mode Effect Analysis) process and two way communication is initiated at the earliest possibility.

On the contrary regarding Rothwell's 'Factor 1', Safran's decision to work with Albany weaving company was one of the key factors that drove the innovation to success. The process of outsourcing meant Safran could level out the expertise between themselves and Albany International by infusing best practice across manufacturing, engineering, creativity, marketing and support services (Trott, 2017).

9. Innovation Critique and Evaluation

With airlines across the world aiming to become net-zero by 2050, manufacturers across the aerospace industry are relentlessly striving to develop aircraft components that are lighter, more reliable and more efficient. With the topic of climate change becoming ever increasingly prominent in recent times, this is by far the most significant determinant for all airlines and their suppliers. Through a combination of Safran's aerospace knowledge and the weaving expertise of Albany International, the partnership developed an innovative fan blade through a process that had never been seen before. The result was a fan blade that is 50% lighter than any of its metal predecessors, ultimately making one of the key factors that produced an engine that was 15% more efficient than the CFM56, the world's most efficient and successful engine prior to the LEAP programme (Gardiner, 2014). Although the companies were successful in delivering the innovation on time, the process could have been managed more effectively in regards to managing the regulatory bodies and involving them sooner to build a better relationship in the earlier stages. For Safran, a company well known for its innovation, they completely missed the ball in this instance.

Since the launch of the LEAP engine in 2008, it has become the engine of choice by the majority of the world's airlines and aircraft manufacturers, strengthening CFM's market share up to 39% (T4, 2020). This success has brought significant profits to Safran of which has enabled them to pump significant funding into research and development activities and exploring new areas where the 3D-woven technology could work such as the engine fan casings.

On paper, the innovation overall was hugely successful. However, many millions of Euros were lost and serious lessons were learnt. Although, the one thing Safran were not willing to risk was their reputation of being a world pioneer within the aerospace sector by failing to deliver on their promises to their customers, in this, they succeeded.

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