Composite Manufacturing Technology Selection and Strategic Implementation Timing

Work Project with Embraer Compósitos

NOVA Master in Management
CEMS MIM
2014/15

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Date:	5/21/2015
Business Project:	Embraer Compósitos Technology Roadmap

Statutory Declaration

I declare that I have developed and written the enclosed Master Thesis completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked.

Lisbon, 21.05.2015

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Abstract

Embraer Compósitos has problems keeping up with the aerospace market requirements for the production of carbon fiber parts. This work project will investigate what manufacturing capabilities Embraer Compósitos has to implement in the next 8 years and if first-mover advantages justify an early start of development. Criteria based on market requirements, competition and the company characteristics lead to three recommended technologies: Liquid Composite Molding, Laser Ablation and Carbon Nanotubes. The assessment of first-mover advantages specifically related to the aerospace composite manufacturing industry demonstrates the benefits of a prompt start of development and the necessity of a development partnership.

Keywords: Embraer Compósitos, Composite manufacturing technology, First-mover advantage

Content

Tables

Figures

Abbreviations

AFP	Automated Fiber Placement
ATL	Automated Tape Laying
A-VaRTM	Advanced Vacuum-assisted Resin Transfer Molding
CFRP	Carbon Fiber Reinforced Polymers
CNT	Carbon Nanotubes
GKN	Guest, Keen and Nettlefolds (Aerospace component supplier)
LCM	Liquid Composite Molding
OEM	Original Equipment Manufacturer
TRL	Technology Readiness Level

1 Introduction

Carbon fiber reinforced polymers (CFRP) gain increasing importance in aerospace applications due to their impressive strength-weight ratio (see Exhibit 2) which leads to a decrease in fuel consumption of the airplane. Aircraft manufacturers have identified the potential and invest heavily in new composite technologies since the beginning of the century. (Federal Aviation Administration 2012)

With the increasing share of composite materials in aircrafts, manufacturing technology is challenged constantly and technology innovation is a continuous requirement. Embraer as the third largest aircraft manufacturer in the world particularly has to address this challenge. Embraer Compósitos is situated in Portugal and specialized on the production of primary CFRP aircraft parts for Embraer. Its portfolio is limited to the stabilizers of executive and military jets.

2 Problem Statement

In order to maintain Embraer Compósitos' competitive position, there is the need to develop a framework for the selection and implementation of manufacturing technologies. In the medium term, Embraer Compósitos requires a roadmap with specific technologies that have to be implemented in the next 8 years but for the long term this work project will provide the set of selection criteria and strategic implementation guidelines as a general standard.

3 Methodology

The problem statement implies a hypothesis connected to the selection of manufacturing technologies that will drive the analysis:

> *Embraer Compósitos needs new manufacturing technology in order to maintain its competitive position.*

Related to the implementation process there is a second underlying hypothesis that needs to be evaluated:

> *Embraer Compósitos has to implement the new technologies as soon as possible in order to gain the maximum advantage.*

The approach applied to define the selection criteria is based on an operations strategy framework which stresses the importance of market (top-down) and resource (bottom-up) perspective to evaluate any elements that affect the operations strategy. (Slack and Lewis 2014)

Looking at the market perspective in the first part, the market overview will demonstrate the increasing importance of carbon fiber in aerospace applications due to market trends and customer preferences. The competition analysis based on Porter's Five Forces (Porter 2008) assesses the pressure in the industry deriving from the competitor's capabilities related to CFRP. Furthermore, the competition analysis serves as a benchmark in terms of manufacturing technologies established in the industry. With the background that Embraer Compósitos emphasizes on its role as *Center of Excellence*, the research focuses on new and innovative technologies.

The resource perspective in the second part provides an introduction to Embraer Compósitos while analyzing its particular capabilities related to composite manufacturing. This implies the review of resources and processes.

Deriving from the comprehensive analysis, the selection criteria for composite manufacturing technologies are defined. The portfolio of technologies is assessed according these criteria and their importance. The highest scoring technologies are recommended for implementation.

Besides project management related issues for the implementation of the technologies, it is crucial to identify drivers and bottlenecks that influence the strategic decision of when to develop and implement new technologies. This work project will particularly focus on the resource restrictions and external motivators that significantly influence the decision of the point of entry of the technology. Resource restrictions are majorly influenced by access to knowledge, raw material and equipment (Window 1991). Motivators will be assessed by understanding first-mover advantages and disadvantages (Suarez 2005). For the final recommendation, drivers and restrictions will be evaluated against each other.

The foundation of the analysis is built on primary data (interviews with Embraer representative, feedback from Embraer Compósitos CEO and Head of Technology Composites, observations) and secondary data (research paper, databases, professional articles).

4 Market Overview

4.1 Aerospace industry

The differentiation of aircrafts into commercial, executive and military aviation decreases the impact of volatilities and threats. In all three segments, environmental impact reduction programs do not only become more and more important for legislators but also in the perception of customers, which makes it to a main driver of innovation in the industry. The correlation between CO_2 emission and fuel consumption motivates airlines to support this trend and push manufacturers in the respective direction who committed to reduce CO_2 emission by 50% until 2050. (Boeing 2014)

The executive jet market is struggling since the economic crisis in 2008 and although sources promote the arrival of stability, manufacturers still suffer from unpredictable demand volatility. (Bloomberg 2014)

The commercial segment is the strongest provider of revenues for most of the big players in the industry and is expected to grow with a steady rate of 3-4% over the next years (Airbus 2015). The size of commercial aircrafts in all segments is rising steadily with Boeing launching new models in the 300-450 seats section and Bombardier expanding its product range to up to 150 seats (Boeing 2014). The focus on larger aircrafts of Boeing and Airbus trickles down to Bombardier and Embraer who see new opportunities in the segment above 100 seats (e.g. Bombardier CSeries and Embraer E2-195).

4.2 Importance of carbon fiber technology

Carbon fiber reinforced polymers (CFRP) strike through their significant strength-to-weight ratio which allows 20% weight reduction compared to aluminum without compromising on safety. Considering the reduction of fuel consumption due to decrease of weight, the use of CFRP for primary and secondary aircraft structures is a promising solution. A milestone has been reached by Boeing in 2009 when they launched the 787 that was predominantly made of composite material with CFRP to the major extent. Historically, the usage of CFRP in aerospace application shows a growth rate of 10-15% per year and is expected to continue with a comparable percentage (CompositesWorld 2015). The pressure to reduce costs throughout the value chain leads to efficiency improvements in manufacturing processes, mostly through automization, and pushes down material costs (up to 20% in the next 3 years). This trend increases the commercial potential for currently untouched applications. (Kozarsky 2014)

5 Industry Analysis Embraer Compósitos

5.1 Competitive environment

Intensity of rivalry: The competition is characterized by the split between exclusive manufacturers who only produce for a specific customer (e.g. Embraer Compósitos and respective subsidiaries from Boeing, Airbus or Bombardier) and open market competitors (e.g. GKN, Aernnova, Latécoère, Triumph and Spirit Aerosystems). Usually, aircraft manufacturers have a dual sourcing model with contracts from both groups. Recent consolidations among composite material manufacturers and the expected growth rates of CFRP applications increase rivalry. (Del Pero 2012)

Bargaining power of buyers: In the open market, the bargaining power between composite manufacturers and buyers is fairly balances. Original Equipment Manufacturers (OEMs) are dependent on the know-how and process technology of manufacturers. This leads to collaborations in terms of product development and causes switching costs for customers. However, the limited amount of customers and scale of the main players with orders assuring production for the whole life cycle of an airplane compensates the bargaining power of suppliers. (Hatton 2009)

For exclusive manufacturers like Embraer Compósitos, the bargaining power is shifted to the buyer's side. Embraer Compósitos has to stay at the edge of technology in order gain business. Whereas Embraer has the option to source from other suppliers (see Exhibit 3 for a supplier overview), Embraer Compósitos' customer base is limited to one client.

Bargaining power of suppliers: The basic raw material for the production of CFRP parts (*Prepregs*) is considered as a commodity without a significant level of differentiation. Price is the main decision criteria for manufacturers (Heth 2000). More important than raw material is the manufacturing process which leads to a key position for equipment and tooling suppliers (e.g. Ingersoll or MTorres). Continuous development effort in terms of automization, efficiency and range of parts makes process technology to a main source of competitive advantage and increases the bargaining power of suppliers.

Threat of new entry: The production of composite materials is highly capital intensive and requires significant know-how. The high degree of vertical integration is an additional barrier for new entrants because the supplier-customer-relationship is strong and hard to break. However, new composite technologies like carbon nanotubes require very unique knowledge and give room for newcomers. New player in the commercial jet market particularly from Asia (MRJ, Comac) and Russia (MS-21) implicate additional competition for composite manufacturers.

Threat of substitution: Aluminum is still the material with the biggest share in aircrafts and strikes through low costs and decent strength-to-weight ratio (Exhibit 2). Embraer Metálicas with its well-established production processes is a very present threat of substitution next door. In addition, other composite materials like glass fiber (cheaper but less stiff) are widely provided by competitors like Aernnova or GKN. (Kjelgaard 2012)

Because of the strong link between CFRP suppliers and airplane manufacturers as a characteristic of the industry, composite part suppliers have to align their competitive position with their customers. The barrier to change customers and suppliers respectively creates a high degree of interdependence.

5.2 Technology landscape

In order to reduce costs, improve quality and increase the product range, competitors (see *Competitive environment*), technology centers and researchers investigate new ways of producing composite materials addressing all elements of the value chain.

Table 1: Technology benchmark in composite manufacturing industry

Technology	Description	Development/ Usage
LCM	Injected liquid resin to fix the shape of the part	Triumph, Latécoère, Bombardier, MRJ, Premium Aerotec
Vacuum Bag Only	Simplification of curing process through heated mold	Spirit Aerosystems
Laser Ablation	Process to remove excessive resin from composite part	GKN
Carbon Nanotubes	Integration of nano particles into the composite matrix	Nanocyl
Filament Winding	Tape laying process for hollow or oval shapes	Aernnova
Compression Molding	Solid resin is pressed into a form to create the part shape	Triumph
Thermoplastic Resins	Change in raw material	Triumph
Through-Thickness Reinforcement	Structural reinforcements in the vertical dimension	Hexcel
Ultrasonic Metal Welding	Bonding process for composites	Premium Aerotec
Microwave	Curing through microwave instead of autoclave	GKN
Fiber Optics	Introduction of fiber optic sensors for structural health monitoring	(Research Centers)

(Detailed descriptions and sources for each technology can be find in the CEMS Business Project – Technology Roadmap Embraer Compósitos)

The overview of technologies shows the diversity of technologies that are present in the industry and the extent to which Embraer Compósitos' competition is pushing forward R&D. None of the technologies above are currently under investigation by Embraer Compósitos.

6 Specific company factors

6.1 Embraer Holding

Embraer is the third biggest aircraft manufacturer by revenue in the world and is generating more than 50% of its sales in the commercial aviation segment. The main market is North America, followed by its domestic market in Brazil. "Diversification and expansion of the customer base" (Embraer 2015) is the proclaimed strategy for the commercial segment. The current product portfolio is offering commercial jets from 37 to 132 seats, seven different executive jet models and four military airplanes. While older models will reach end of product life in the medium term, the current development pipelines leaves potential gaps in the executive segment from 13-17 seats, in the mid-size segment from 30-70 seats and as new market opportunity in the commercial segment above 130 seats (Embraer 2015, see details in the appendix). In anticipation of expansion, these potential future products have to be considered in the further analysis.

The regional jet market (60-120 seats) is dominated by Embraer and its main competitor Bombardier. Due to their similar positioning, this market segment has oligopoly characteristics. However, new entrants like MRJ, Comac or MS-21 are threatening the established market. (Bombardier 2015)

Embraer's key strengths lie in their very competitive pricing, significantly influenced by their lean production facilities in Brazil, and a strong R&D department (see complete SWOT in the appendix).

6.2 Embraer Compósitos

6.2.1 Operations

Low quantities and multiple products require a batch process with a disconnected line flow. Lean principles with avoidance of intermediate storages and waiting times reduce working capital connected to high value parts tied in the production process. (Embraer 2010)

However, with the production volume of the horizontal and vertical stabilizers of the executive jet Legacy 450 and 500 and the horizontal stabilizers for the military jet KC390 the machines at Embraer Compósitos have only a utilization rate of around 50% (some processes like AFP even less). Due to the high investment volume of composite manufacturing equipment, low utilization has a significant impact on the operation costs.

In line with the corporate and product strategy of Embraer, the operations strategy at Embraer Compósitos has to assure high quality and the segment split between commercial and executive aircrafts. In the focus on high R&D effort and advanced technologies favors the production of large and complex parts. (J. Taborda, pers. interview 12.03.2015)

6.2.2 Supply network and aerospace ecosystem

The supply base of Embraer Compósitos consists of Hexcel for the raw material a variety of suppliers for the equipment which are crucial relationships in the aerospace industry. Few tooling suppliers have the ability to provide composite manufacturing equipment for the aerospace industry which makes them to a major contributor of know-how and experience. Equipment suppliers of Embraer Compósitos are MTorres (ATL), Ingersoll (AFP), Olmar (Autoclave), Flow (Router) and Kuka (Robotics).

The plant in Évora has only been opened in 2012 and although significant effort has been made to attract industry related companies, Embraer Compósitos is currently the only aerospace company placed on that site. The European Commission is supporting the idea of an aerospace cluster in Évora financially (European Commission 2013).

Due to the novelty of the site and lack of related companies, the supply of personal is very limited. The distance to Lisbon with its engineering schools is too significant to attract talent directly and Évora does not offer the attractiveness as the capital. The majority of Embraer’s business is in Brazil which does not allow easy transfer of employees. A technical training center in Évora is dedicated to the development of knowledge for new employees.

6.2.3 Plant and equipment

As key process technologies Embraer Compósitos is relying on a highly automated process for the placement of the CFRP textiles (state of the art AFP and ATL) and the autoclave for the curing process. Using the autoclave is assuring the highest quality standard but is connected to immense investments and operational costs. Furthermore, it limits the size of parts due to fixed dimensions of the autoclave. Furthermore, they have expertise in machining, inspection, assembly and painting of CFRP parts which means know-how in the whole value chain from raw material to the assembled part in-house.

The plant allows significant space for equipment expansion as only a share of the shop floor is occupied by the current process technology.

7 Technology Assessment

7.1 Assessment Criteria

The portfolio extracted from the Technology landscape forms the basis of the technology assessment. Building upon the previous analysis of market, industry and company, the assessment criteria have to reflect the market and the resource perspective in order to fit the **operations strategy** of Embraer Compósitos.

The **financial impact** of the technology is a major criterion for the selection. Not only lean principles of Embraer dictate cost efficiency but also the pressure from increasing competition requires focus on financial impact. This criterion implies cost of acquisition and installation, staff training and cost savings through reduces energy consumption and labor.

The high safety standards in the aerospace industry with quality approvals throughout the value chain require a high amount of **reliability**. This includes a high repeatability of the process with a low failure rate. Indication about the reliability is the degree of usage in the industry (Technology Readiness Level, Exhibit 1).

The **alignment with the product strategy** of Embraer shows the technology's ability to produce large and complex parts while providing the adequate degree of flexibility to serve different product categories (vertical/horizontal stabilizers, executive/commercial jet parts).

Derived from Embraer's strategy as provider of high quality products, particularly related to composite materials, makes the ability of the technology to contribute to the status as **Center of Excellence** to an important criterion. The assessment evaluates the level of differentiation (potential of shaping the industry), the risk of imitation and the potential of automization.

Finally, the evaluation considers the **compatibility** with the current manufacturing system at Embraer Compósitos including the supply base, process know-how of employees and possibility for integration with the current equipment.

The criteria are weighted according the specific profile of Embraer Compósitos (input from J. Taborda, pers. interview 26.03.15, see Exhibit 9) and evaluated in comparison with the current manufacturing abilities on a scale from 1 (negative contribution) to 3 (positive contribution).

7.2 Results of technology assessment

After assessing each technology in the portfolio (see *Table 1: Technology benchmark in composite manufacturing industry*), the highest scores indicate the technologies to recommend for implementation:

1. Liquid Composite Molding (LCM)
2. Laser Ablation
3. Carbon Nanotubes (CNT)

LCM leads the ranking with its cost saving potential due to elimination of the autoclave and the ability to produce large parts like commercial jet stabilizers and wing structures (Airbus 2007). The commercial usage in the industry leads to a high Technology Readiness Level (TRL) and proves reliability (see TRL scale with explanation in Exhibit 5).

Table 2: Assessment of LCM

LCM	Evaluation	Comment
Financial impact	3	- Reduced curing time - Lower energy costs
Product strategy	3	- Allows production of larger parts - Curves feasible
Compatibility	2	- Need for autoclave eliminated - Different raw material usually necessary
Reliability	3	- TRL 8: Application in several aerospace products by competitors
Contribution to Center of Excellence	3	- Required quality is feasible if process under control, but riskier than autoclave - Repeatability & integrated solution - Precise control of resin-to-fiber ratio

(Sutter 2010; Niggemann 2008)

Table 3: Assessment of Laser Ablation

Laser Ablation	Evaluation	Comment
Financial impact	2	- Capital investment required
Product strategy	2	- Potential to increase complexity through adhesive bonding - Ability to efficiently repair faulty composite parts
Compatibility	2	- Suitable with existing technology - Requires secondary operations
Reliability	3	- Very precise and reproductive - Used by GKN and can be used in-field: TRL 8
Contribution to Center of Excellence	2	- Increases the quality of the parts by cleaning the surfaces without abrasive technologies

(Dittmar et al 2013; Finger et al 2013; Palmieri et al 2013)

Table 4: Assessment of Carbon Nanotubes

CNT	Evaluation	Comment
Financial impact	2	- More expensive Prepregs
Product strategy	2	- Improved quality performance - Potential to produce more complex shapes
Compatibility	2	- Different raw material (Prepregs)
Reliability	2	- TRL 5: Laboratory tests on small parts - No changes in the process, keeping reliability
Contribution to Center of Excellence	3	- Strength-weight ratio improved by factor 10 - Decrease in thermoelectric impact - Conductivity improvement

(Lin et al 2014; CORDIS POCO 2013; Spitalsky et al 2009; Tuncer et al 2007)

The fact that LCM technology is ranked the highest makes it a prioritized option for the implementation and leads to the necessity of a closer look

The industry benchmark shows that the significant lead that competitors have towards Embraer Compósitos in composite manufacturing is significantly based on LCM technology. Although based on the same principle, each manufacturer has developed a unique process in order to fulfill the specific requirements of its customers. Referring to patents from Bombardier (*Resin Transfer Infusion*, US Patent 2009) or MRJ (*A-VaRTM*, Yamashita 2008) demonstrate the need for protection of intellectual property in order to establish a sustainable competitive advantage.

8 Strategic decision of implementation timing

8.1 Resource restrictions

8.1.1 Equipment and raw material acquisition

As presented during the analysis of the *Competitive environment*, equipment suppliers have a significant importance for composite manufacturers. When implementing a new technology, they are the main supplier of know-how. It can be seen at the example of LCM technology (see 7.2) that out-of-the-shelf solutions are not the standard for composite production processes and manufacturers are developing their unique processes (see overview in Exhibit 10). This requires development effort for the implementation of a new technology. Having this in mind makes the access to capable equipment suppliers to a crucial success factor.

Looking at the competition that recently introduced LCM as new technology (*Table 5: Overview of LCM capabilities in Embraer Compósitos supplier base*) shows that a partnership with another member of the composite ecosystem is a common practice to leverage external knowledge and share the financial risk of failing the development. For more mature technologies like LCM, collaboration partners become a scarce resource as options are limited and quickly occupied by competitors. Hexcel is a remaining favorable option for a joint LCM development.

Table 5: Overview of LCM capabilities in Embraer Compósitos supplier base

Equipment supplier	**Partner**	**Project**
Ingersoll	-	Development of high pressure diaphragm pump for resin transfer applications (Ingersoll 2015)
MTorres	MS-21, Airbus	Fiber placement technology for wings produced with LCM
Sonaca	Airbus	TANGO wingbox project (Wood 2003)
Raw material supplier		
Hexcel	-	Offers infusion resins for LCM applications (Hexcel 2015)
Toray	MRJ	Development of MRJ's A-VaRTM (Yamashita 2008)

For less dispersed technologies like Carbon Nanotubes the problem is rather the general availability of development partners. Currently, there are only two companies in the market (Zyvex and Nanocyl) that are specialized in that technology and drive R&D forward. However, early commitment can preempt the access to these suppliers and their knowledge assets. In the case of Carbon Nanotubes, raw material supply is more critical because the current production process will be affected only in terms of process parameters.

An additional consideration that has to be made related to equipment and raw material acquisition is that the maturity of a manufacturing technology has impact on investment and operation costs. Not only that the acquisition costs go down with evolving product life cycle, maintenance and operation costs could also be significantly lower for mature technologies (TRL >8). With equipment that requires significant initial investment, companies are not expected to adapt their machines with every improvement of the manufacturing technology. Hence, a first mover might have to face higher operation costs than somebody who acquired the respective machine only after a certain level of efficiency evolution.

8.1.2 Knowledge acquisition

There are four main options for the acquisition of knowledge in order to develop, install and/or run new manufacturing technology:

1. Recruitment
2. Incorporation through corporate partnerships (e.g. suppliers, research centers)
3. Workforce training
4. Empirical learning by doing

The decision about the preferred option should be made on the basis of the availability of supply, costs for acquisition and time effort.

Because for more dispersed technologies like LCM, talent developed by competitors, customers or suppliers is already available, recruitment is the fastest option to acquire knowledge. Due to limitations in availability of experienced cooperation partners, partnerships are a less feasible option. Empirical learning requires a lot of time to reach a useful knowledge level.

Less dispersed technologies like CNT do not leave the option of acquiring knowledge through recruitment and also training centers are not available. Cooperation partners (e.g. suppliers like Nanocyl) are still at the beginning of the development. Empirical learning by research and development in-house is a time-consuming but recommended option.

8.2 External motivators

8.2.1 Market awareness and brand reputation

Literature suggests that in addition to company specific elements there are two major factors that decide about the success of a first-mover: pace of technology change and pace of market expansion (Suarez 2005).

Aerospace customers are pushing for innovation (e.g. commitment to reduce CO2 emissions and weight) and the suppliers are requested to develop manufacturing technologies to meet these requirements (Boeing 2014). The significant amount of 17 composite manufacturing technologies that were identified in the research on the *Technology landscape* demonstrates the pace with which process technology is moving forward (compared to pace in rivaling aluminum part production). This number is particularly significant due to the long product life cycles and product development times in aerospace (J. Taborda, pers. interview 12.03.15). As a result of this trend the technological manufacturing capabilities are an important factor for the reputation of a company. The ability to fulfill the increasing demand for CFRP parts defines the competitive strength and hence, bargaining power towards buyers, suppliers and talent.

As shown in the *Technology landscape,* Embraer Compósitos is lacking behind in terms of manufacturing capabilities compared to its direct competitors. Dispersed technologies like LCM will not allow a significant step in terms of reputation because the technology is already established in the industry. From this perspective, a focus on new technologies like CNT is more attractive.

8.2.2 Customer tie

Embraer Compósitos is operating in the B2B business which leads to rather rational purchasing decisions. Customers evaluate the supplier possibilities with every new aircraft development and although the relationship is important, the loyalty of customers is dependent on performance, quality and price (J. Taborda, pers. interview 12.03.15). Hence, the ability to create an advantage through solid ties with customers relies on the ability of the manufacturer to create a technological edge.

For Embraer Compósitos as an exclusive supplier to Embraer, it is of significant importance to retain Embraer as a customer because reduction of business with Embraer cannot be compensated with other clients. As revealed from Embraer Compósitos' top management, supplying to other customers is only a long term.

In the long term, Embraer Compósitos could consider new, innovative technologies to attract new customer segments, but in the short and medium term the priority should be to catch up with the competition by implementing the more mature and feasible technologies like LCM.

8.2.3 Risk

The implementation of a technology that is not fully proven contains several risks. These risks are connected to the rapid change of technological change which can make previous investments obsolete. Additionally, there is the risk of underestimating the power of competitors in their ability to develop the technology faster and eliminate the competitive advantage (Basu 2015). The less mature the technology, the higher the risk that the expected outcome cannot be achieved.

Waiting with the decision of investing in manufacturing technology can create value through the consideration of a real option. Because the decision to invest in an immature technology is carrying the risk of failure, underestimated costs or overestimated benefits, waiting until these risks can be assessed more clearly has a financial value. (Luehrmann 1998)

9 Recommendations

Looking at the first hypothesis that was driving the analysis, it can be stated that Embraer Compósitos clearly needs to evolve in terms of manufacturing technology. Embraer Compósitos is recommended to implement LCM, Laser Ablation and Carbon Nanotubes technology as part of their technology roadmap. These technologies are aligned with the dynamics in industry and market and fulfill the specific requirements from Embraer Compósitos.

For the second hypothesis regarding the strategic timing of technology development, the analysis showed that Embraer Compósitos can leverage early-mover advantages with the early implementation of process technology. They need to keep up with the technology trends in the industry in order to retain Embraer as a customer. The nature of the composite manufacturing industry significantly penalizes late-movers because development partners become scarce.

The portfolio of recommended technologies provides two cases that differ significantly in their maturity (TRL scale) and give a good example on how to decide on the strategic implementation timing.

For LCM it is recommended to start immediately with the development. Hexcel has been identified as a potential development partner and should be approached as soon as possible. In order to increase the internal knowledge base quickly, recruitment of experts from the competition is recommended.

For Carbon Nanotubes and other technologies with low maturity (TRL < 8), Embraer Compósitos has to start negotiations with potential development partners (e.g. Nanocyl for Carbon Nanotubes) as soon as possible. Although, investments in this early stage bear the risk that investments do not pay off because of unsuccessful research and development or underestimating the power of competitors, the danger of not being able to enter as a late-mover is too high. Risks have to be addressed through elaborate pilot phases, in which process and product is validated (see aerospace product and process validation framework in Exhibit 11).

The fact that manufacturing technology first-movers have an advantage requires a regular assessment of technologies in the industry (e.g. as semi-annual task by the engineering department). A profound framework to assess the potential of new technologies is crucial to identify the right technologies. The presented selection criteria combined with a certain score threshold can be the foundation for Embraer Compósitos' process technology strategy.

10 Concerns

Due to the lack of data supply by Embraer Compósitos, the project was significantly relying on publicly available information. Particularly information connected to their production cycles and costs would have added value to the analysis. Furthermore, there obviously exists a technology roadmap at Embraer Compósitos but it was kept secret until the end of the project. These limitations can cause shortcomings related to the relevance of the recommendations for the specific situation at Embraer Compósitos.

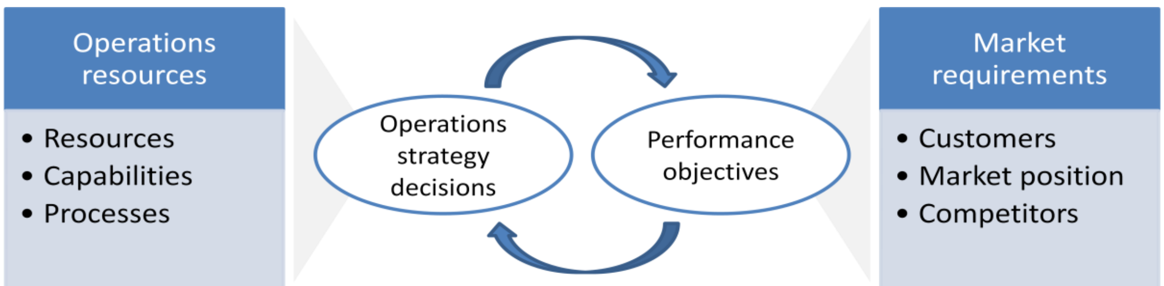
Manufacturing technology is a core element of the competitive advantage of composite manufacturers, which is why detailed information is usually not publicly disclosed. An assessment of technologies on this basis is difficult. The lack of engineering expertise in the project team additionally hindered the ability to assess the technologies reliably.

11 Reflection on Learning

11.1 Previous knowledge

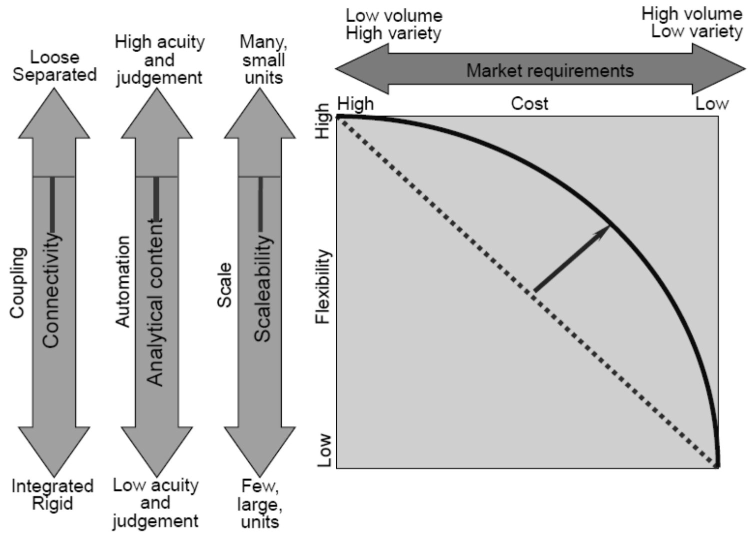
The basis for this consulting project was a framework defining the two perspectives of operations strategy: resource perspective and market perspective.

Figure 1: Resource and market determinants of operations strategy (Slack and Lewis 2014)



For a producing company like Embraer Compósitos, operations are a core element of the competitive advantage. Within operations, the manufacturing technology is a significant determinant for key performance indicators related to quality and costs. Being aware of all the implications that manufacturing technology decisions have on the overall positioning and performance of the company is crucial. When designing criteria to decide on the right process technology, the dimensions that categorize process technologies have to be taken into account. *Connectivity, analytical content* and *scalability* are process technology characteristics that are directly connected to the product strategy:

Exhibit 1: Product-process matrix and technology dimensions (Slack and Lewis 2014)



In this work, these dimensions directly contributed to the selection of the criteria. **Coupling** influences the compatibility of a new technology, **automation** has impact on repeatability, quality and costs whereas **scale** is a determinant of the alignment with the product strategy (Exhibit 6). The dimensions have to reflect the requirements given by the market.

Especially for the development of a universal set of selection criteria, a comprehensive analysis of all affected areas is crucial. Although this is a project that is placed in operations management, knowledge from marketing (assessment of first-mover advantages) or strategic management (identification of competitive forces in the industry analysis) was applied. The interconnection between the different disciplines of management is a major take-away from this project.

The consideration of both market and resource perspective for strategic decisions (technology selection and implementation) has been proven as the necessary approach in order to deliver reasonable results. The definition of technology selection criteria was an iteration process. Results from the market analysis had to be confronted with the resource platform and vice versa. Only, if the decision criteria would satisfy both perspectives it would be fully strategically aligned.

The implementation of manufacturing technology is often limited to its project management related elements like the importance of communication or the adequate project team (e.g. Kotter's 8-Step Process for Leading Change, Kotter 1996). The strategic perspective based on the resource platform and market requirements should also be applied for the decision of implementation timing. Literature review related to first-mover advantages in other technology related B2B industries (Hidding 2003) revealed that the common approach to assess first-mover advantages (technology leadership, control of resources, buyer-switching costs; Suarez 2005) is not sufficient for any situation. The dynamics in the aerospace supplier industry with its strong supplier-customer-relationships and high know-how requirements require adjustments of these approaches. By relying again to the framework introduced in Figure 1, specific determinants for the benefits of first- and late-mover advantages for aerospace suppliers could be identified and cannot only be a framework for Embraer Compósitos but also for other manufacturers in the industry.

This project demonstrates that awareness about the specific context of the problem is a crucial element when applying a business framework. The academic methodologies are provided by universities and business schools but eventually the ability of managers to understand the key rationale and purpose behind the frameworks in order to adjust them according context and problem. This project taught me that frameworks are rarely axiomatic and always have to be seen in context.

Eventually, the project clearly demonstrated the importance of access to information. The complexity that results through the comprehensive view (top-down and bottom-up) on operations strategy decisions automatically increases the complexity of information sources. Whereas this issue is definitely problematic for the company's managers, it evolves to a tremendous obstacle for external consultants. Non-disclosure policies additionally hinder the analysis and risk the relevance of the results. The unavailability of information required an adjustment of the original work plan that was based on production and financial data provided by the company. Alternatively a significant part of the analysis had to be based on qualitative information.

11.2 New knowledge

The project demonstrated very interestingly that technology and process know-how is not necessarily an intrinsic asset of one particular company but can also be defined on a general scale. The Technology Readiness Level (NASA 2003) shows that the maturity of an industry is evolving with the efforts of the ecosystem and every milestone achieved is potentially available for the other players. The potential to leverage the development effort of competitors, suppliers or research centers can vary significantly from industry to industry and even from technology to technology. The interdependence between suppliers and customers in the aerospace industry enables a vertical exchange of know-how and favors joint learning.

11.3 Personal experience

Due to my background with a bachelor degree in Mechanical Engineering, work experience in supply chain management and a focus on master courses in the field of operations, I felt comfortable with the topic of the project. My technical background allowed me an easier understanding of technology and product related problems. My work experience at the highly automated production site for automotive parts, made it easier to understand the challenges in an industrial manufacturing process of an aerospace company. I appreciated a lot to increase my learning on the basis of previous knowledge. Because the business and engineering basics were already established, the familiarization with the project went quickly and smoothly.

Related to the short familiarization phase, the project planning and management was a main success factor. As part of the project management, I felt responsible for the efficiency and effectiveness of our team meetings. The first meetings with great uncertainty related to the objectives of the project were left without a clear outcome. I took the role as the team member who enforced a clear agenda, a defined planned outcome and documentation through meeting minutes for every session. Although we had a project plan (Gantt chart) from a very early stage, the final execution of the project plan is the actual challenge. A lot of discipline is required on a weekly basis.

Furthermore, the project was facing the challenge that none of the team members had known each other before. While two students were in their exchange semester, NOVA students from finance and management do not share many interaction points. In order to overcome the first configuration problems on a personal level as soon as possible, team building efforts are important in the early phase of the project. This has some very practical and social elements like having coffee breaks together but also means the joint decision on responsibilities and expectations as a team. Having some bad experiences in other group works, I felt the need to push these aspects at the beginning.

However, the project also revealed some issues that demonstrated the need for development of soft skills of the team members, including me.

One of the team members was not as committed to the project as others which lead to unbalanced workload and tensions within the team. Expecting that each of the team members chose the project out of interest, the lack of commitment was probably due to lack of motivation. Obviously, the informal leaders of the project team (including me) were not able to understand the drivers of motivation of that particular team member and couldn't address it appropriately in order to increase commitment to the project. To have a learning experience out of this issue, I plan to have a peer evaluation and feedback session at the end of the project.

Furthermore, I underestimated the rigidity of roles within the groups. After the familiarization phase, in which the basic group dynamics are established, people automatically take over a certain role within the group. This was clearly the case in our project: in addition to the distribution of responsibilities related to different fields, the group was also divided in leaders and followers. I had to realize that with the progress in the project, the tasks and required qualifications changed but the roles remained the same. Followers were not stepping up against the opinion of the leaders although they had a reasonable point and leaders would not consider the opinion of the other team members.

11.4 Benefit of hindsight

The project outline left room for defining the scope of the project by the project team. Although the client was in favor a technical evaluation, the background of the project team did not allow a thorough technical analysis. In my opinion, we spend too much time on research of technical data connected to carbon fiber manufacturing technologies. This clearly is important in order to have an understanding of the context but does not create much value-added for the company. CEMS focuses on management studies and this is the field, in which student consulting team can add value. Embraer Compósitos has a very strong engineering team working on composite materials in Évora. It is impossible for a group of management and finance students to give new insights into technological solutions. The credibility of the project team derived from the high quality of management education, ability of strategic thinking and a reliable academic research basis. Looking back, the assessment of the technologies could have done more efficiently by engineers from Embraer Compósitos.

The plant visit in Évora gave a significant amount of new insights and understanding and was a very valuable source of information. With the benefit of hindsight, plant visits and interviews with managers and employees should have been used to a greater extent. As part of lean and six-sigma coaching "Genchi Genbutsu" (*Japanese:* "Go, Look, See"; iSixSigma 2015) is preached as the most valuable source of data. Embraer as a company that is following Japanese lean principles should have favored this initiative.

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13 Appendix

Exhibit 2: CFRP characteristics compared to other materials

Material	Density - ρ - (10^3 kg/m³)	Tensile Modulus - E - (GPa)	Tensile Strength - σ - (GPa)	Specific Modulus - E/ρ -	Specific Strength - σ/ρ -	Maximum Service Temperature (°C)
S-glass epoxy (45%)	1.8	39.5	0.87	21.8	0.48	80 - 215
Carbon epoxy (61%)	1.6	142	1.73	89.3	1.08	80 - 215
Kevlar epoxy (53%)	1.35	63.6	1.1	47.1	0.81	80 - 215
Steel, AISI 1045	7.7 - 8.03	205	0.585	26.3	0.073	500 - 650
Aluminum 2045-T4	2.7	73	0.45	27	0.17	150 - 250
Aluminum 6061-T6	2.7	69	0.27	25.5	0.10	150 - 250

(The Engineering ToolBox 2015)

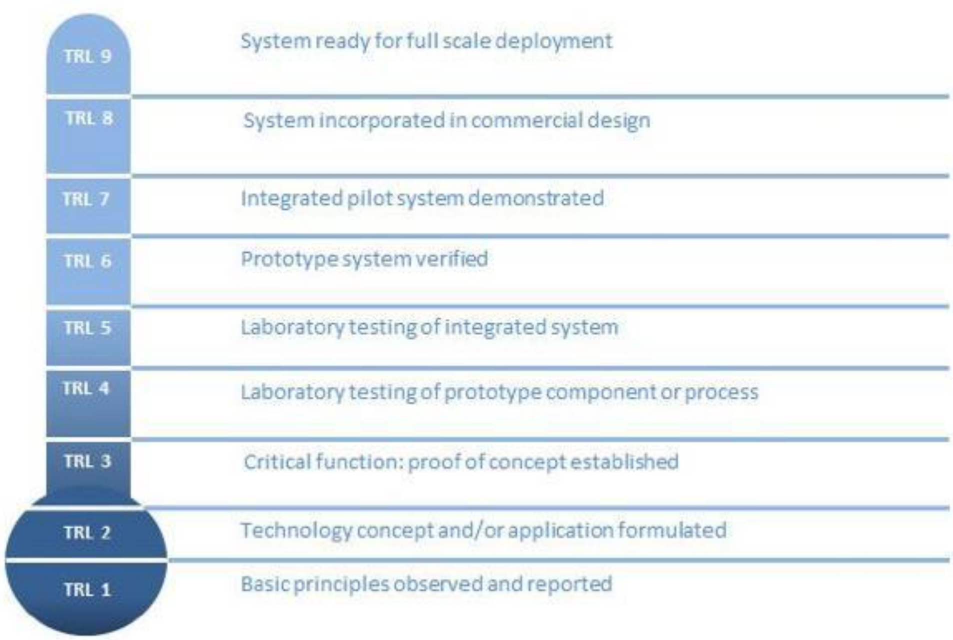
Exhibit 3: Supplier overview E2-175

(Embraer 2015)

Exhibit 4: Competitor Overview

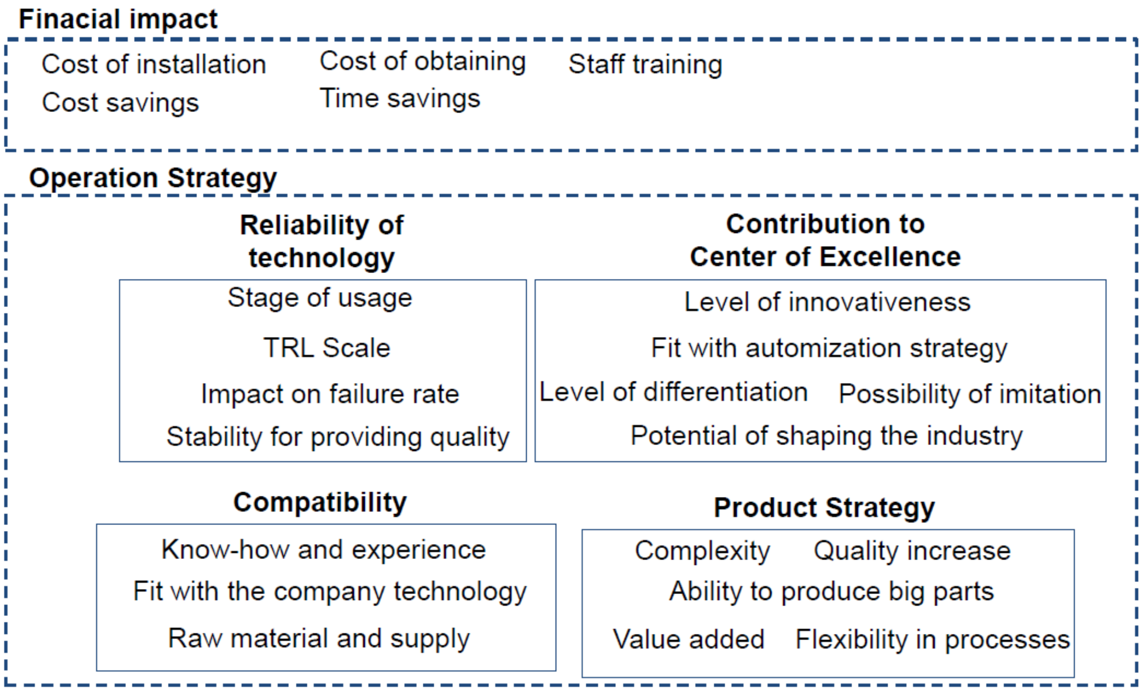
(CEMS Business Project – Embraer Compósitos Technology Roadmap)

Exhibit 5: Technology Readiness Level



(NASA 2003)

Exhibit 6: Composition of selection criteria



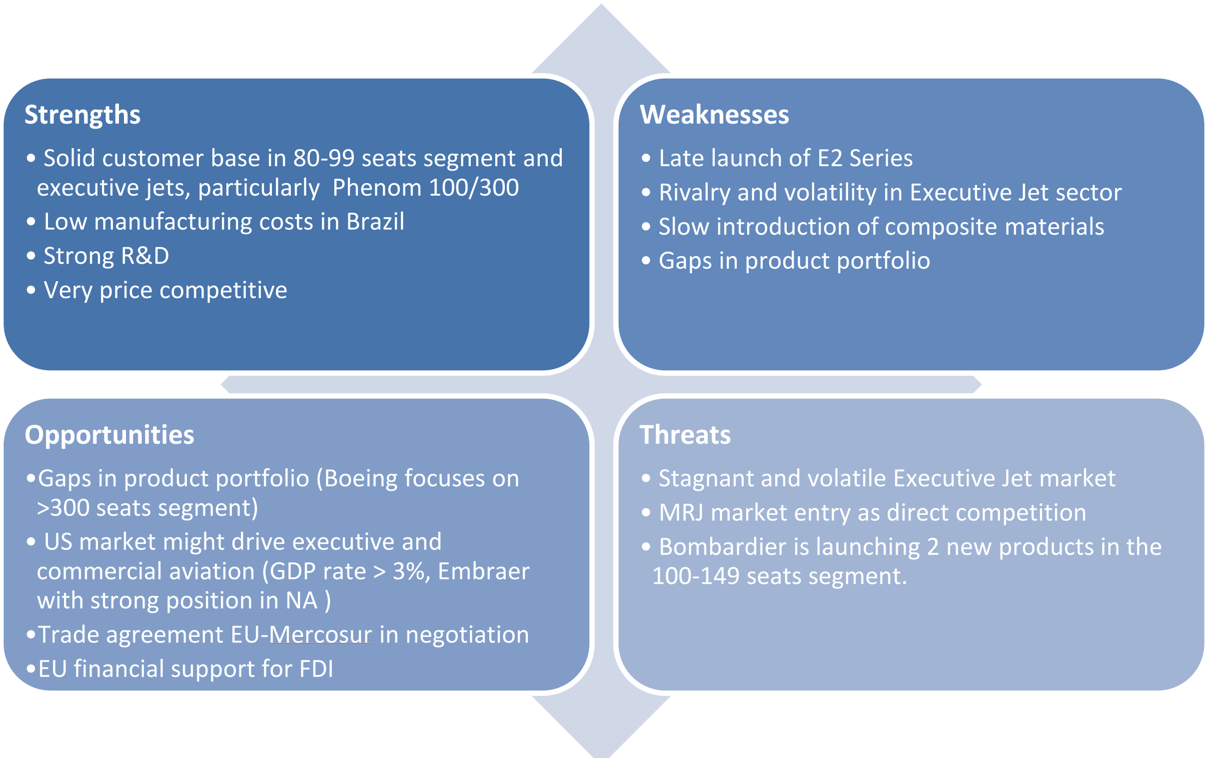
(CEMS Business Project – Embraer Compósitos Technology Roadmap)

Exhibit 7: Ranking of technologies

1. SQRTM	10 .Filament Winding
2. VARTM	11. Compression Molding
3. CAPRI	12. Thermoplastic Resins
4. Liquid Resin Infusion	13. TTR
5. RTM	14. Ultrasonic Metal Welding
6. Vacuum Bag Only	15. DDF
7. RFI	16. Microwave
8. Laser Ablation	17. Fiber Optic
9. Carbon Nanotubes	

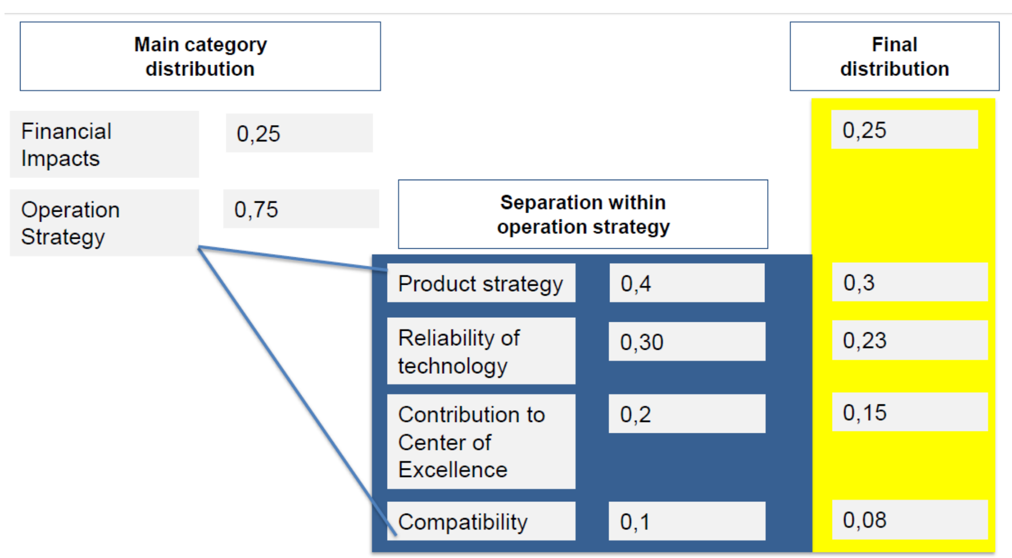
(CEMS Business Project – Embraer Compósitos Technology Roadmap)

Exhibit 8: SWOT Embraer



(CEMS Business Project – Embraer Compósitos Technology Roadmap)

Exhibit 9: Weighting of selection criteria



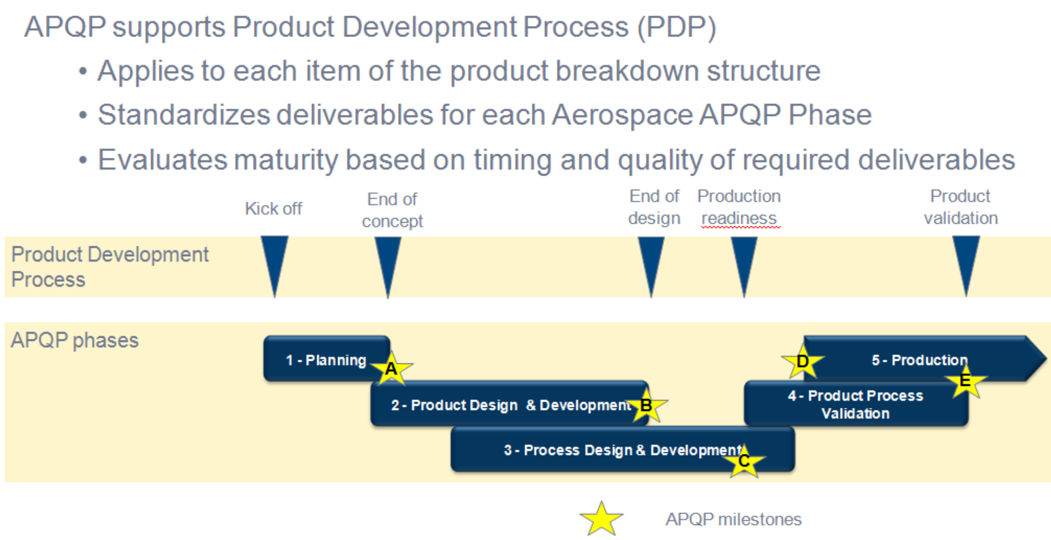
(J. Taborda, pers. interview 26.03.15)

Exhibit 10: Overview of specialties of LCM technologies

	No vacuum	Vacuum assisted	Special vacuum cycle	Rigid tool	Flexible tool	High injection pressure	Low injection pressure	Curing through the mold	Curing in the autoclave	Dry fiber	Pre-preg	Low viscosity resin	High viscosity resin
RTM	x			x			x	x		x		x	
VARTM		x		(x)	(x)		x	x		x		x	
SQRTM		x			x		x	x			x	x	
CAPRI			x		x		x	x		x		x	
RFI		x			x		x			x			x
Liquid Resin Infusion		x			x		x	x		x		x	
Resin Transfer Infusion		x			x		x		x	x		x	

(CEMS Business Project – Embraer Compósitos Technology Roadmap)

Exhibit 11: Aerospace Advanced Product Quality Planning



(IAQG 2013)