A Work Project, presented as part of the requirements for the Award of a Masters Degree in Finance from the NOVA – School of Business and Economics.

Reflection on the CEMS Business Project and real options in the context of technology implementations in Embraer Compósitos

Nuno dos Santos Cochito Lopes de Sousa, Nº643

A project carried out on the Finance Master, under the supervision of:
Professor Alper Nakkas

May 2015
Abstract:

This Work Project is divided into two major parts. I start by providing my individual reflection on the CEMS Business Project developed this semester, which focused on answering the question “what manufacturing technologies does Embraer Compósitos have to develop within the next 8 years and how should they be implemented” (section A). I will then perform a new analysis, relating my Business Project with my masters in finance, developing an intuitive framework for Embraer Compósitos to value manufacturing technologies with imbedded real options to abandon (section B). First, I explain why implementing technologies with a pilot phase creates a real option to abandon the project. I then present a binomial framework to value such option and show that incorporating the option valuation into the financial assessment increases the technology value not only by limiting potential losses but also by decreasing the overall risk of the project.

Keywords: Technology Roadmap, Embraer Compósitos, Real Options, Binomial Valuation
# Table of Contents

## A. REFLECTION ON THE CEMS BUSINESS PROJECT ................................................. 4

1. **Brief Context** ........................................................................................................ 4
   1.a. *Client Description* .................................................................................................. 4
   1.b. *Market Overview* .................................................................................................. 4
   1.c. *Current Client Situation* ......................................................................................... 5
      1.c.i. *Current Production at Embraer Compósitos* ....................................................... 5
      1.c.ii. *Current Manufacturing Technology at Embraer Compósitos* ......................... 6
   1.d. *The Business Project Challenge* ............................................................................ 7

2. **Reflection on the Work Done** ................................................................................ 7
   2.a. *Problem Definition* ............................................................................................... 7
   2.b. *Methodology and Work Plan* ................................................................................ 7
   2.c. *Analysis* ................................................................................................................ 9
      2.c.i. Embraer’s Product Strategy and Market Positioning ............................................. 9
      2.c.ii. Operations Strategy at Embraer Compósitos ....................................................... 9
      2.c.iii. Technology Benchmarking in the Industry and Research Pipeline ..................... 10
      2.c.iv. Technology Assessment Criteria ........................................................................ 11
   2.c.v. *Assessment Results, Recommendations and Implementation* ............................. 12
   2.c.vi. *Concerns and Risks* .......................................................................................... 14

3. **Reflection on Learning** .......................................................................................... 14

## B. REAL OPTIONS IN THE CONTEXT OF TECHNOLOGY IMPLEMENTATION IN
EMBRAER COMPÓSITOS ............................................................................................. 16

1. **Objective of My Analysis** ....................................................................................... 16
2. **What are Real Options** .......................................................................................... 16
3. **Real options in the context of the CEMS Business Project** ................................ 17
4. **Valuation framework description** ........................................................................ 17
5. **Valuation of projects with imbedded real options to abandon** ............................ 20
   5.a. *Standard NPV with static management* ................................................................ 20
      5.a.i. *Embraer Compósitos’ Cost of Capital* ............................................................... 20
   5.b. *NPV with dynamic management and option valuation* ........................................ 22
6. **Numerical Example** .............................................................................................. 24
7. **Conclusion** ............................................................................................................. 25

## C. BIBLIOGRAPHY ..................................................................................................... 27

1. **Bibliography Section A** ........................................................................................ 27
2. **Bibliography Section B** ........................................................................................ 32
A. Reflection on the CEMS Business Project

1. Brief Context

1.a. Client Description

The client of the CEMS business project is Embraer Compósitos, a subsidiary of Embraer located in Évora, Portugal. Embraer Compósitos is part of an investment of Embraer, together with Embraer Metálicas, with the objective of creating centres of excellence for manufacturing aircraft parts in composites and aluminium, respectively. Operations started in 2012, resulting from an initial investment of 77€ million (Embraer Compósitos alone).

Although Embraer Compósitos is an independent entity and my group considered it to be our final client, we also have to take into account the role of their mother company given that they are currently an Embraer’s exclusive 1st tier supplier.

1.b. Market Overview

Embraer Compósitos operates in the industry of manufacturing aircraft parts in composites. Although composites include very different materials, in the aerospace industry the main composite used is Carbon Fiber Reinforced Plastic (CFRP).

Carbon fiber is a relatively new concept in aviation and is experiencing an exponential growth in demand in the last two decades. If we take as an example Airbus’ aircrafts, the famous A320 model, introduced in 1988, has approximately 10% of its structure weight in carbon fiber. By contrast, the most recent model A350 has carbon fiber representing 53% of the whole structure weight. Boeing 787 follows the same trend, with 50% of the weight in composites (slide 32, Business Project). The growth reflects not only the material’s advantages towards traditional metals (steel and aluminium), mainly its high strength-to-density ratio, but also key trends in the aerospace industry (e.g. fuel efficiency) and a significant reduction of the manufacturing costs of this material (slide 35, Business Project).

Embraer is not an exception and recently announced their newer version of the commercial aircrafts, the E2 seriers, which will precisely have a higher presence of carbon fiber (although still lagging behind the percentages of Airbus and Boeing).

Because carbon fiber is a composite, the manufacturing process can vary a lot, which makes the material interesting from a research perspective and, ultimately, opens the possibility of having carbon fiber products with very different characteristics given the different manufacturing technologies used.

In this industry there are two types of competitors: the open market and the exclusive suppliers. Open market suppliers produce to different aircraft manufacturers, whilst the exclusive ones only
supply to one (most of the times these are in-house production, as Embraer Compósitos for Embraer). Our main open market competitors are: GKN (United Kingdom), Triumph Group (U.S.A), Spirit Aerosystems (U.S.A), Aernnova (Spain) and Latécoère (France). On the other hand, the main exclusive competitors are: Bombardier Aerospace (United Kingdom), Mitsubishi Aircraft Corporation (Japan), Boeing (U.S.A) and Airbus (France) (slide 64, Business Project).

1.c. Current Client Situation

1.c.i. Current Production at Embraer Compósitos

Embraer Compósitos is currently fully owned by Embraer and exclusively manufacturers to them as a 1st tier supplier, hence Embraer’s product cycles are of extreme importance for our client. Embraer current portfolio is currently divided into the following aircraft families:

- Executive aircrafts:
  - Phenom 100 & 300 Family (announced in 2005);
  - Legacy 450 & 500 Family (announced in 2008 to replace the older Legacy 600 & 650);
  - Lineage 1000 (announced in 2006).

- Commercial aircrafts:
  - E-Jet Family (announced in 1999, with capacity ranging from 80 to 122 passengers). In 2013 Embraer announced the new line of such aircrafts, the E2-Jet Family, with a first delivery expected in 2018.

- Military aircrafts:
  - A29 Super Tucano (fighting aircraft announced in 1999);

Production at Embraer Compósitos encompasses the more recent models of Embraer. The firm is currently producing the following parts (slide 47, Business Project):

- Legacy 450/500 horizontal stabilizers
- Legacy 450/500 vertical stabilizer
- KC-390 horizontal stabilizers

Although Embraer Metálicas already secured the production of components for the new E2 airplanes, the same is still not the case for Embraer Compósitos (which could happen in the near future, specially for the 175 model, whose first delivery is expected to be in 2020).
1.c.ii. Current Manufacturing Technology at Embraer Compósitos

An important step of the Business Project was to analyse what manufacturing technologies the firm currently uses and how the production is organized in the factory.

The process starts with the main raw material: carbon fiber prepregs, normally supplied by Hexcel. These prepregs are CFRP matrixes that already have epoxy resin impregnated. The first stage of the production is where the prepregs are placed into a mould. Embraer Compósitos currently uses two technologies for this process:

- Automated Tape Laying (ATL): this is a computer-guided process in which the carbon fiber layers are laid into a mould. As the layers are put on top of each other, uncured epoxy resin is used. The equipment used is supplied by MTorres.
- Automated Fiber Placement (AFP): this is a similar process to ATL, with the difference that the technology is more precise, hence is used for more complex parts, when curvatures or sharp angles exist. Ingersoll supplies the equipment installed.

The next stage is the curing, where Embraer Compósitos uses an autoclave to cure all the carbon fibers and the resin in order to form a unified component. The carbon fiber parts are consolidated through heated air in vacuum chambers at controlled levels of air pressure inside the autoclave. The autoclave system used by Embraer Compósitos is supplied by Olmar.

After the curing, the components go into a machining process that encompasses routing, drilling, trimming, milling and marking. This is a sensitive process because it shall not damage the component, which at this stage has a lot of value added already. In addition to conventional tools, high-speed waterjets are used for the more sensitive parts in order not to disrupt the alignment of the fiber layers. This process is done in the “Composites Machining Center” supplied by Flow.

After the machining, the parts go through inspection. The inspection phase is of the maximum importance in order to verify the quality of the components, which are almost at their final stage. This is currently done in a two-step process:

- Waterjet Ultrasonic Inspection: this technology uses ultrasonic waves, propagated through high-speed waterjets in order to detect defects in the components. The equipment installed is supplied by Tecnatom, using Kuka robots.
- Visual inspection.

When the carbon fiber components are successfully inspectioned, they would be assembled into the final product. In the case of the stabilizers, the firm puts together outsourced components (e.g. metal structures) and the composite parts produced in-house. As Embraer Compósitos is a 1st tier
supplier, the final product must be in a stage where it just needs to be shipped and directly assembled into the final aircraft in Brazil.

1.d. The Business Project Challenge
Although Embraer Compósitos is a subsidiary of Embraer, they have to make sure they are competitive in their market. If Embraer could find higher quality or lower cost aircraft parts from another supplier, Embraer Compósitos would then not be able to supply the mother company. This means that they have to constantly assess whether they are competitive in the market and what changes they need to make in order to achieve that. This constant assessment of technologies is especially important considering Embraer’s strategy of using Embraer Compósitos as a centre of excellence in composites manufacturing. In addition, the entry of new competitors in the commercial segment like Mitsubishi is creating higher pressures for innovation and cost efficiency, at the same time the biggest players in the market (Boeing and Airbus) appear to be ahead in the curve of composites development (currently with aircrafts already with 50% of their weight in composites). All these forces create the need of constantly assessing the manufacturing technologies both available in the industry and in development in research centres. Therefore, Embraer Compósitos objective with the Business Project was to formulate an 8-year technology roadmap.

2. Reflection on the work done
2.a. Problem Definition
As described above, the main objective of Embraer Compósitos was to get an 8-year technology roadmap. The first task was to explicitly describe the problem statement underlying all of the project’s work. For this, we needed to define what type of technology the project would focus on. Given that the business of Embraer Compósitos is to manufacture aircraft parts in carbon fiber, the group decided, together with the firm, that there could be more value added if the project would be focused on manufacturing technology (rather than operations processes technology). In addition, rather than only recommending technologies, we decided to also focus on their implementation. The project’s problem statement was then defined as: “what manufacturing technologies does Embraer Compósitos have to develop within the next 8 years and how should they be implemented?”

2.b. Methodology and Work Plan
In this section I will describe the approach we followed to answer the above mentioned problem statement. This encompasses different, although linked, perspectives:
- How did the group design a structure of the Business Project that would be effective in achieving its ultimate goal of answering the problem statement;
- How did the group interact and operate during the life of the Business Project;
- What were the main sources of data.

On the first perspective, the group decided that using a funnel approach would be the most effective strategy. Therefore, our structure for the Business Project would start with high-level analysis and would narrow down its scope with the ultimate goal of finishing with objective and concrete recommendations to Embraer Compósitos. Having said this, our structure follows the following steps:

- General description of carbon fiber and its relevance for the aerospace industry;
- Current situation of our client. This process starts by analysing Embraer (the mother company) itself, its current aircraft portfolio and their aircraft pipeline. Then we move on to understand the role of Embraer Compósitos on the value chain of Embraer, also analysing the manufacturing technology currently in place. At this stage an explicit analysis of the firm’s operation strategy was performed;
- Industry analysis, identifying its main competitors. Then, we would try to understand what manufacturing technologies are being used in the industry;
- Analyse manufacturing technologies in pipeline, that is, in an early research phase;
- Assess the identified manufacturing technologies (both currently available or still in research pipeline) according to pre defined criteria;
- Develop the recommendations and the final Technology Road Map, where we would also focus on the implementation of each technology.

On the second perspective of the methodology, relatively to the group dynamics, we agreed that the best approach would be to allocate specific working fronts to each member as the Business Project would go along. Giving each person clear responsibilities would create the right incentives for the smooth progression of the work and to create a sense of responsibility. In order not to segregate the work flow too much, and because most topics are not mutually exclusive, the group had biweekly meetings where we would discuss what each one had done (and provide feedback) and how that would link with the others, ultimately making everyone responsible for the other’s work. In addition, these biweekly meetings were used to brainstorm how the group should approach each stage of the Business Project, to which we always reached a consensus. In
order to have an effective planning and on time progression, we used a Gantt graph that would be constantly updated with all the relevant developments of our work (slide 9, Business Project).

For this research we relied heavily on secondary research (scientific reports, academic papers, professional articles, etc.) and personal interviews with Dr. João Taborda (who also gave us feedback from the Head of Technology at Embraer Compósitos and the CEO of Embraer Portugal). Given the firm’s confidentiality concerns, we had no access to inside data or proprietary information.

2.c. Analysis

2.c.i. Embraer’s Product Strategy and Market Positioning

Analysing Embraer’s product portfolio and its closest competitor (Bombardier), we identified three gaps that may translate into possible future aircraft programs for Embraer (slide 43 Business Project): a recent version of an executive jet with capacity of 13 to 17 passengers; a turboprop aircraft with capacity of 30 to 70 passengers; a commercial airplane with capacity higher than 130 passengers. These possible future aircrafts create more opportunities for Embraer Compósitos in the medium-long term and have to be taken into account in our assessment of the technologies.

Although Embraer and Bombardier have been sharing an oligopoly in the regional jet market (60-120 seats), the recent emergence of the MRJ plane by Mitsubishi (with planned first flight for 2015) with capacity to 70-90 passengers will create higher rivalry in the market (slide 44, Business Project). This translates into higher pressures for Embraer Compósitos to produce parts with a competitive cost and to continue innovating.

2.c.ii. Operations Strategy at Embraer Compósitos

In order to provide meaningful recommendations to Embraer Compósitos it was important to explicitly analyse the firm’s operations strategy. In a brief description, their operation strategy is an output of three dimensions (slide 52, Business Project):

- Resource Platform: in this dimension we highlight the state of the art facilities and equipment, the lack of industry cluster in Portugal, the ecosystem where the firm operates and the fact that Évora is considered a “Center of Excellence” within Embraer;
- Competition & Market: in this dimension it is important to highlight the competing environment in high quality parts and high degree of innovation in this industry, the uncertain and possibly volatile future of the executive segment and some new entrants in the commercial segment like Mitsubishi (increasing cost pressures).
Product Strategy: this must be a major pillar of any recommendation we make. Here the most important highlights are the heterogeneity of the production (with KC-390 and Legacy side by side, with completely different characteristics) associated with the need to diversify the product portfolio (e.g. wings) and the focus of only producing in-house big and complex parts (while outsourcing the rest). We also have to take into account future possible products: the E2 and Phenom in the short term (although only the E2-175, with first delivery expected in 2020, would not require Embraer to redesign the program suppliers, which manufacturers avoid doing) and the three possible portfolio extensions described above in the medium-long term (higher capacity commercial jet, turboprop and higher capacity executive jet).

The result is an operations strategy that has to ensure high quality products and repeatability, allows segment split between commercial and executive aircrafts, allows producing big parts and considers cost efficiency in the medium/long term (slide 53, Business Project).

2.c.iii. Technology Benchmarking in the Industry and Research Pipeline

Once we had analysed Embraer Compósitos thoroughly we then started researching for potential composites manufacturing technologies, both the ones currently in use by its competitors and those still in research phase. Therefore, after a technology benchmarking of the main peers (GKN, Bombardier, Latécoère, Mitsubishi, Aernnova, Spirit, Triumph and Premium Aerotec) and an analysis of both the main scientific databases on the field (CORDIS, Clean Sky, AIA and ASD) and important research centers (e.g. ADVITAC), we were able to identify a wide selection of technologies, which we then described individually on the Business Project:

- Microwave Curing (slides 77 and 78, Business Project);
- Carbon Nanotubes (slides 79 and 80, Business Project);
- Fiber Optic systems for monitoring and damage detection (slides 81 and 82, Business Project);
- Through Thickness Reinforcement (slide 83, Business Project);
- Out of Autoclave manufacturing (slides 84 – 90, Business Project);
  - Vacuum Bag Only (VBO)
  - Resin Transfer Moulding (RTM)
  - Vacuum Assisted RTM (VARTM)
  - Same Qualified Resin Transfer Moulding (SQRTM)
  - Controlled Atmospheric Pressure Resin Infusion (CAPRI)
  - Resin Film Infusion (RFI)
- Liquid Resin Infusion (LRI)
- Compression Moulding
- Thermoplastic CFRP (slides 91 and 92, Business Project);
- Filament Winding (slide 93, Business Project);
- Double Diaphragm Forming (slide 94, Business Project);
- Laser Ablation (slide 95, Business Project);
- Ultrasonic Metal Welding of Aluminium Sheets to Carbon Fiber (slide 96, Business Project).

2.c.iv. Technology Assessment Criteria

The group opted by using a weighting framework to compare the possible technologies. We defined the important criteria and then scored each of them with a value of 1 (negative contribution), 2 (neutral) or 3 (positive contribution) for each technology. Therefore, one crucial step was to define the factors that will be assessed and their weights. These were the outcome of both the analysis of Embraer Compósitos previously performed and interviews with the firm itself. After careful deliberation the following factors and weights were considered:

- Financial Impacts (25%)
- Operation Strategy (75%)
  - Product Strategy (40%)
  - Reliability of technology (30%)
  - Contribution to Centre of Excellence (20%)
  - Compatibility with current technologies (10%)

Financial impacts include the capital expenditures needed to implement such technology (equipment and knowledge acquisition) and changes in the operation costs relatively to the existing technologies. Although the financial impacts are currently not the main strategy of the firm, cost pressures in the industry arising from both new entrants and fierce competition from the open market suppliers still make it relevant for the assessment.

Product Strategy is the most important sub factor of operations strategy because any recommendation that we make must be aligned with the crucial objective of the firm to gain the production of the E2 and to expand its current product portfolio. In addition, new technologies have to be aligned with firm’s strategy of only producing in-house the most complex and bigger parts of the final assembled products.

Reliability comes just after because this is crucial in such industry where security and predictability are of the greatest importance, limiting the value in the Technology Readiness
Level (TRL) scale that a technology may have. Currently Embraer Compósitos requires a TRL of 6 to start a pilot phase and TRL of 8 to introduce the technology in serial production. Contribution to Centre of Excellence is also an important factor because we must not forget the ultimate objective of Embraer in setting up such factory in Portugal: create a Centre of Excellence that would be the reference in composites manufacturing. This means that the firm must be ready to innovate so that it stays state of the art, at the same time that automation plays a major role in the production process. Finally, the assessment must also evaluate the compatibility with the already installed technologies, the in-house knowledge and the raw materials currently used (slide 99, Business Project).

2.c.v. Assessment Results, Recommendations and Implementation

The conclusions taken out of the assessment were (please consult the Business Project for the individual assessment of each technology: slides 104 to 120):

- The technologies that ranked higher were all from the Liquid Composites Moulding (LCM) family, that is, the Out of the Autoclave technologies that rely on a mould and resin injection system;
- The highest ranked technologies that did not belong to the LCM family were Laser Ablation and Carbon Nanotubes.

After analysing the several LCM technologies and what the competitors are using, we advised Embraer Compósitos to tailor-made and patent its own system rather than buying an available out-of-the-shelf technology. Not only this is what the main competitors are doing (Boeing with the CAPRI technology, GKN with Resin Film Infusion and Bombardier with Resin Transfer Infusion), but also that is a need arising from the fact that the out-of-the-shelf solutions (eg: standard RTM) may not allow for the specifics of the manufacturer’s needs, on top of not allowing Embraer Compósitos to differentiate itself (slide 124, Business Project).

Therefore, the recommended technologies were the following:

- Tailored LCM technology: such technology not only allows for lower manufacturing costs relatively to the autoclave, but also allows for the production of larger and more complex parts. In addition, this is a technology with high diffusion in the industry and advanced reliability, thus allowing for a fast implementation.
- Laser Ablation: this technology has not only the potential to increase the quality of the final product (by removing spare resin matrix leftovers after machining), but it also allows for repairing of damaged parts and creates the possibility of adhesive bounding (although this
would need additional technologies), which creates the possibility of new products. In addition, it is a highly automated technology.

- Carbon Nanotubes: this is currently a pace-maker technology in the industry, still not diffused, creating the possibility for Embraer Compósitos to differentiate itself as a centre of excellence. In addition, it has low capital requirements (as no equipment is needed) and has potential for significant improvements in the mechanical, electrical and thermal performance of CFRP, eventually allowing the production of more aircraft parts in composites.

When analysing the implementation of such technologies we identified four main aspects that Embraer Compósitos will have to tackle effectively (slide 128, Business Project):

- Equipment/raw material acquisition: selecting the right supplier is not a simple task, specially if a long-term partnership is desired;
- Knowledge acquisition: this encompasses four areas, which have different importance for each technology, given their different maturities and risks:
  - Work force training;
  - Hiring of field experts;
  - Internal research group;
  - Developing research partnerships with both suppliers and technology centers;
- Risk mitigation: the main way to mitigate risks is by creating a pilot phase to produce prototypes. In addition, anticipating potential problems and defining hypothetical action plans is a crucial exercise;
- Clear plan and communication: an effective communication to all stakeholders, clearly explaining the reasons behind adopting certain technologies, creates the necessary energy and buy-in for and effective implementation. In addition, having a clear multifunction team dedicated to the implementation, on top of having top management support, are crucial factors.

After analysing each of the above-mentioned aspects for every technology, we then developed the final technology roadmap and timeline (slide 148, Business Project). We recommended the start of the pilot phase for the LCM technology and Laser Ablation in mid 2015, while starting the pilot phase for the Carbon Nanotubes later in mid 2017. This delay is justified given the low TRL of this technology (still a TRL of 5) and a better balance of resources. An important note is that the pilot phase of the LCM technology is expected to be the fastest (given the higher TRL and the urgency to enter the E2-175 program).
2.c.vi. Concerns and Risks

The implementation of the recommended technologies has risks that Embraer Compósitos must be aware and in position to mitigate them. The following are what I consider the major risks in these projects:

- Problematic equipment or raw material acquisition: choosing the right equipment and raw material will have to be a careful exercise. Not only does Embraer Compósitos have to develop and sustain close relationships to those suppliers, they should always have a backup plan with another supplier.

- Problematic knowledge acquisition: acquiring the right knowledge to implement and operate effectively a new technology is a substantial challenge. As I already described, the firm will have to choose the correct mix of training, external hiring, internal research and external partnerships that best suits each technology.

- Problematic communication: having a clear and strong support by top management and effectively conveying across the organization the reasons behind the adoption of each technology are a crucial exercise, without which the implementation may be severely damaged.

- Unsatisfying results: even with the correct equipment and knowledge the firm may reach the conclusion in a later stage that the expected returns of a technology will not be achieved. This may be a result of insufficient quality of the product, inability to conciliate the new and already existing technology and/or higher capital needs and expenses.

In order to tackle and anticipate these risks the best strategy is to introduce the technology in a pilot phase, whose duration will be a function of the level of each of the above risks. After a successful pilot phase, through which the company gained empirical knowledge, created sustainable partnerships with suppliers and research centres, confirmed the potential quality of the products and its manufacturing costs, they would be in a much better position to effectively implement the technology in the serial production.

3. Reflection on Learning

Without any doubt this Business Project helped me develop a wide range of skills, which will be of the greatest value in my work life. The following are the skills that I feel were most developed during the Business Project:

- Managing different expectations within the group: this was a major challenge through out the Business Project. At the same time there were people in the group that dedicated their time
and attention to it, there were also those who had different levels of effort, often with a passive posture that did not contribute to our moments of brainstorming (sometimes the most challenging times of the work).

- **Managing conflicts**: because of the nature of the project, which lasted 3 months, and the heterogeneity of people in the team, it was natural that some conflicts would appear. For example, there were times when a member of the team would ask for some time off the Business Project. Most of the times this was not a problem because we would then split the work-load of that week among the other members. But other times, given the urgency to have something done or the existence of a very important meeting, it was necessary to reach a balanced agreement. These negotiations were not always easy.

- **Overcoming limitations**: this Business Project had two big limitations that could have damaged the value of our work. These were the complete lack of pre-existing knowledge on the content, which most of the times required an engineering background, and the fact that the company was not able to provide us with in-house data (given confidentiality concerns). If there was a moment in the beginning of the semester where we doubted we would be able to produce anything valuable, that was proven wrong, since we ended up overcoming those limitations and delivering something much better than we initially thought.

- **Research Skills**: as we had no access to inside data from Embraer Compósitos and no previous knowledge about this industry, we had to rely on our own secondary research. Performing an effective research is not a trivial exercise and requires not only problem solving skills but also clarity on the information you want to find.

In addition to these skills that were deeply improved, I also realized the importance of other skills I had already developed in the masters that helped me substantially during the Business Project. Although I did not use many hard skills learnt in the finance masters (as the topic of my Business Project had little connection with it), I did take advantage of important soft skills developed during the masters, namely:

- **Time management and prioritization**: given the high-pace of the masters in finance, I gained time management skills that contributed to an effective progression of the Business Project, both by always providing internal deadlines in the team and doing a work plan where we exhaustively planned the work needed in the weeks ahead.

- **Working with multicultural teams**: I found my experience in the masters very valuable since I had to continuously have group works with people from different nationalities, showing me different ways of thinking. This helped me being open-minded in the Business Project and
able to manage the culture impact that makes each team unique. I quickly understood the “working style” of the group and found a common set of working norms that allowed an effective work.

- Managing group meetings: in my opinion, one of our strengths were the effective handling of the group meetings, to which I consider to have contributed substantially given my experience in the finance masters. At the start of each meeting I would make a list of the topics we would like to address and put a time limit (normally 1h30m). When things started drifting apart, I would make a summary of the conclusions of what we were discussing and ask if we could move to the next topic. At the end, we would have very effective team meetings in which we would discuss the work done, brainstorm future work and separate tasks, all in a short period of time.

B. Real Options in the context of technology implementation in Embraer Compósitos

1. Objective of my analysis
In this section of the Work Project I connect my Business Project with my masters in finance by going beyond the work developed on the former with the objective of explaining to Embraer Compósitos how they should value an investment project in which there are embedded real options abandon. Therefore, my ultimate goal is to provide Embraer Compósitos with an easy to use and intuitive financial framework that they should apply in real life, instead of developing a framework that would be too complex to have any useful application. Because the client was not allowed to provide any financial information, I will try to provide a framework that, although comprehensive and detailed enough to add value, is general and flexible enough to be applied to different projects and technologies.

2. What are Real Options
Real options are choices/alternatives that firms have embedded into investment opportunities. In simple terms, they are the application of financial options when dealing with “real” assets. A plain vanilla financial option is the right to buy (sell) an asset at a predetermined price (strike price) on a predetermined date (option maturity). The important mechanism to understand is that these contracts allow their holder to wait until the maturity, analyse the state of the world at that stage and only then decide if they exercise the option or not, hence having an embedded value before maturity. In the context of real options, the firm can today create certain conditions that allow it to wait to assess future states of the world and then make a decision relatively to a business investment opportunity.
3. Real options in the context of the CEMS Business Project

The objective of my Business Project was to deliver to Embraer Compósitos a technological roadmap with technologies they should implement in the next years. When they adopt the recommended technologies, they will do so in phases instead of a one-time event. Therefore, the introduction of a new technology will have at least two stages:

- Initial pilot phase, where the firm allocates some limited resources (labour and capital) to develop prototypes and learn empirically how to use the technology;
- Integration of the technology into the production process for serial production.

The key mechanism here is that the firm today enters into the pilot phase and in a future date it has the option of going into the second phase only if certain criteria are met, hence being in the presence of an option to abandon.

4. Valuation framework description

An important step is to understand the dynamics of the investment decision and how it evolves with time. For that, I will use a binomial tree with the following dynamics, as in figure 1. I will afterwards describe briefly the needed inputs.

![Diagram](image)

Figure 1

- At $t = 0$ the firm invests $I_0$ to start the pilot phase of a new technology;
- At $t = t_1$ the firm is able to assess if the pilot phase was a success (which happens with probability $p$ and denoted by subscript S) or a failure (with probability $1 - p$ and denoted by subscript F). They then invest $I_1$ to expand the technology into the firm’s production processes.
At \( t = t_2 \) the firm gets a return of \( R \) from the technology. This return will either reflect a good state of the world (with probability \( \pi \) and denoted by subscript G) or a bad state of the world (with probability \( 1 - \pi \) and denoted by subscript B). However, both the returns and the probabilities will depend on whether the initial pilot phase was a success or failure. Therefore the firm can have four different returns (\( R_{S,G} \), \( R_{S,B} \), \( R_{F,G} \) and \( R_{F,B} \)) and the probability of a good state of the world at \( t = t_2 \) will be either \( \pi_S \) or \( \pi_F \).

Initial Investment (\( I_0 \))

This is the investment that the firm has to make in the pilot phase. In order to make the framework simple, this value encompasses all the investments during this stage, discounted to \( t = 0 \). Therefore, the following cash flows have to be taken into account:

- Investments in equipment needed to produce the prototypes;
- Knowledge acquisition costs (e.g. Research and Development, experts hiring, etc.).
- Manufacturing costs associated with producing the prototypes: raw materials; labour costs; use of already existing machines and space; energy consumption.

Probability of Success of the pilot phase (\( p \))

Embraer Compósitos will first have to decide what factors they consider to assess whether pilot phases are a success or failure and attribute probabilities to them. Although these factors depend a lot on the firm’s goals and may be specific of each technology, the following factors may be examples of important decision criteria:

- Quality of prototypes;
- Ability to use the technology with the estimated manufacturing costs;
- Knowledge of the work force regarding the technology, that is, if the firm feels that sufficient know-how was developed during the initial phase;
- Conclusions of market research conducted during the project.

Investment needed to fully integrate the new technology (\( I_1 \))

These are all the required investments in order to integrate the technology into the production process. This will depend on the technology and on \( I_0 \), as some technologies require a lot of new equipment to start the pilot phase that can then be used for the second stage. To keep the framework consistent, \( I_1 \) must encompass all the required investments discounted back to \( t_1 \). Examples of investments are:

- Investments in equipment needed to start the production with the new technology;
- Research and Development needed to start fully operating the technology.

There is an important distinction between $I_1$ and $I_0$ that needs to be clarified. Because the pilot phase is not expected to generate any income, $I_0$ must encompass all the expenses of that phase. On the other hand, $I_1$ must not include the manufacturing costs of the new technology because they will be taken into account for the variable $R$ at $t = t_2$. Note that it may happen that the value of $I_1$ changes whether the pilot phase is a success or failure (for simplicity I will assume it stays the same).

*Probability of a Good State of the World for the production phase ($\pi$)*

This measures the probability of the technology, once incorporated into the production, delivering good returns. This probability depends on whether the pilot phase is a success or not ($\pi_s > \pi_f$) and needs to be defined at $t = 0$. To do that, the firm has first to define what a Good State of the World is and understand the drivers of the technology returns, which will be discussed now.

*Return generated by the technology ($R$)*

By return generated I mean the Unlevered Free Cash Flows attributable to that specific technology from $t = t_2$ onwards. To structure the analysis when estimating such cash flows, I advice Embraer Compósitos to perform the following segmentation:

- Products that may only be produced once the new technology was introduced:
  - In this case the analysis is simpler because the delta of the income/costs is all the income/costs generated by the new products. Note that this refers both to new products and higher quantity of already existing ones.

- Products that would be produced regardless of introducing the technology:
  - In this case the firm has to analyse carefully the delta of the costs, which will depend on the type of technology. Therefore, it is important to analyse the cost drivers of the specific technology. Examples of cost drivers are:
    - Time per unit produced: $\Delta Costs = \#units \times cost\ per\ minute \times \Delta time\ per\ unit$
    - Cost per unit of time: $\Delta Costs = \#units \times \Delta cost\ per\ minute \times time\ per\ unit$
    - Cost per unit of space: $\Delta Costs = \#units \times sqm \times \Delta cost\ per\ sqm$
Embraer Compósitos will have to perform this exercise for the four different scenarios \( (R_{S,G}, R_{S,B}, R_{F,G} \text{ and } R_{F,B}) \). Note that for consistency \( R \) must be the present value at \( t_2 \) of all future returns.

5. Valuation of projects with imbedded real options to abandon

5.a. Standard NPV with static management

The standard approach to value an investment decision is to discount future statistically expected cash flows with a cost of capital that reflects their systematic risk. Static management means that one does not consider the possibility of the firm abandoning the project after the pilot phase. If \( r \) were the appropriate cost of capital, the NPV of the technology introduction with static management would be defined with equation I.

\[
NPV_{\text{static}} = -I_0 + p \left[ -\frac{l_1}{(1 + r)^t_1} + \pi_S \frac{R_{S,G}}{(1 + r)^t_2} + (1 - \pi_S) \frac{R_{S,B}}{(1 + r)^t_2} \right] +
\]
\[
+ (1 - p) \left[ -\frac{l_1}{(1 + r)^t_1} + \pi_F \frac{R_{F,G}}{(1 + r)^t_2} + (1 - \pi_F) \frac{R_{F,B}}{(1 + r)^t_2} \right]
\]

This equation basically discounts every expected cash flow of the binomial tree to \( t = 0 \) with the project’s cost of capital. The second and third term of the equation represent the present value of the future project cash flows if the pilot phase is a success or failure, respectively. However, this traditional NPV analysis systematically undervalues the value of the projects in which there is managerial flexibility relatively to future investments (Amram and Kulatilaka 1999), as in the case of a technology implementation with a pilot phase.

5.a.i. Embraer Compósitos’ Cost of Capital

The interest rate \( r \) in this analysis should be the one reflecting the systematic risk of the project. Depending on the corporate policy of Embraer, Embraer Compósitos may be using a hurdle rate imposed from the mother company in Brazil. Although the latter is a recurrent practice in multinationals, it can lead to inconsistencies, especially when we are dealing with different currency zones. There are two solutions for this:

- Use Embraer’s stock to compute an unlevered beta relatively to a well-diversified world index (e.g. MSCI World) and using a risk free rate from the currency of operations (in this case the euro). This would assume that the systematic risk of Embraer Compósitos is the same as of Embraer. Being an exclusive 1st tier supplier, this assumption is acceptable.

- Use publicly listed companies that operate in the same industry to estimate the unlevered beta of Embaer Compósitos, also relatively to a well-diversified world index. Note that these peers may have different operating businesses that Embraer Compósitos (e.g. some may also
produce aluminium aircraft parts, some may not only manufacture the aircraft parts but also sell the final assembled aircraft. The following are examples of publicly listed competitors:

- Airbus (AIR FP Equity);
- GKN (GKN LN Equity);
- Boeing (BA US Equity);
- Bombardier (BDRBF US Equity);
- Latécoère (LAT FP Equity);
- Triumph Group (TGI US Equity);
- Spirit Aerosystems (SPR US Equity);

After computing the levered betas of each firm (using excess daily returns of the last two years for both the stocks and the MSCI World), the next step is to unlever each beta according to the capital structure of the company, using the standard formula assuming the beta of the tax shields is the asset beta\(^1\) (Koller et al 2010). For this we need an estimate of each firm’s beta of debt, to which I followed Demarzo and Berk (2010) approach, using its credit rating to get the beta of debt estimate. This analysis is summarized in table 1, with data as of April 2015:

<table>
<thead>
<tr>
<th></th>
<th>Embraer (BRL)</th>
<th>Airbus (EUR)</th>
<th>GKN (GBP)</th>
<th>Boeing (USD)</th>
<th>Bombardier (USD)</th>
<th>Latécoère (EUR)</th>
<th>Triumph (USD)</th>
<th>Spirit (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Levered Beta</strong></td>
<td>0.69</td>
<td>1.06</td>
<td>1.37</td>
<td>1.03</td>
<td>0.65</td>
<td>0.96</td>
<td>0.89</td>
<td>1.17</td>
</tr>
<tr>
<td><strong>Net Debt (Millions)</strong></td>
<td>103</td>
<td>-3103</td>
<td>601</td>
<td>-4022</td>
<td>5194</td>
<td>320</td>
<td>1347</td>
<td>777</td>
</tr>
<tr>
<td><strong>Market Capitalization (Millions)</strong></td>
<td>17400</td>
<td>48817</td>
<td>5789</td>
<td>99233</td>
<td>4554</td>
<td>132</td>
<td>2989</td>
<td>7068</td>
</tr>
<tr>
<td><strong>Standard &amp; Poors Rating</strong></td>
<td>BBB</td>
<td>A</td>
<td>BB</td>
<td>A</td>
<td>B</td>
<td>BB</td>
<td>BB</td>
<td>BB</td>
</tr>
<tr>
<td><strong>Beta of Debt</strong></td>
<td>0.10</td>
<td>0.05</td>
<td>0.17</td>
<td>0.05</td>
<td>0.26</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td><strong>Unlevered Beta</strong></td>
<td><strong>0.68</strong></td>
<td><strong>1.13</strong></td>
<td><strong>1.26</strong></td>
<td><strong>1.08</strong></td>
<td><strong>0.44</strong></td>
<td><strong>0.40</strong></td>
<td><strong>0.66</strong></td>
<td><strong>1.07</strong></td>
</tr>
</tbody>
</table>

Table 1

If we use Embraer’s own market information, then Embraer Compósitos unlevered beta would be 0.68. On the other hand, if we use the peers market information we get a big dispersion of unlevered betas (from 1.26 of GKN to 0.4 of Latécoère). Therefore, I would be more comfortable with using Embraer’s own beta.

Using the CAPM framework with a risk free of 0.37% (10-Year Germany Government Bond yield on 30\(^{th}\) of April) and a market risk premium of 5% yields an unlevered cost of capital of

\[ \beta_u = \beta_i \frac{E}{E+D} + \beta_d \frac{D}{E+D} \]
3.77%. By discounting the project’s cash flows with this cost of capital (unlevered cost of equity), the firm may then separately evaluate any impact of financial decisions (eventual tax shields or subsidies).

5.b. NPV with dynamic management and option valuation

If we incorporate the ability of management intervention during the life of the project, then, at $t = t_1$, the firm has the ability to decide whether to continue with the second phase of the project or abandon it. Assuming that the branch of the tree that follows a successful pilot stage generates a positive expected return (otherwise the firm would not even start the pilot stage), the firm will wish to abandon the technology at $t = t_1$ if the NPV of keeping the technology is negative:

$$-I_1 + \pi_P \frac{R_{FG}}{(1 + r)^{(t_2 - t_1)}} + (1 - \pi_P) \frac{R_{FB}}{(1 + r)^{(t_2 - t_1)}} < 0$$

If the firm realizes at $t = 0$ that this is the case, then the binomial tree will change, as in figure 2.

![Figure 2](image)

The first intuition is to use the same reasoning as $NPV_{static}$ (equation I) ignoring the now nonexistent branch of the binomial tree, as in equation II:

$$NPV_{dynamic} = -I_0 + p \left( -I_1 \frac{R_{FG}}{(1 + r)^{t_1}} + \pi_S \frac{R_{SG}}{(1 + r)^{t_2}} + (1 - \pi_S) \frac{R_{SB}}{(1 + r)^{t_2}} \right)$$

(II)

However, this is not correct, as the new project clearly has not the same risk as the old one, meaning that the discount rate should no longer be the same. Therefore, the firm has to separately compute the value of the option and add it to $NPV_{static}$ (Hogan and Hibbard 2002, Trigeorsis 1996), as in equation III:

$$NPV^{*}_{dynamic} = Option Value + NPV_{static}$$

(III)

As I already explained how $NPV_{static}$ should be computed, I will now cover the valuation of the option. To value the option I advice Embraer Compósitos to use a simple binomial model with discrete
compounding, similar to the approach followed by Cox, Ross and Rubinstein (1979). This is so because the underlying asset of this option is not a financial asset that can be continuously traded in the market, hence violating a major Back-Scholes assumption (Hull 2009). Although a binomial model also assumes that the underlying asset can be traded to create a replicating portfolio, it allows for discrete time (Hull 2009). In addition, using a binomial model avoids assumptions about the stochastic process behind the underlying asset (e.g. Geometric Brownian Motion assumed by Black-Scholes), relying rather on managerial inputs and their forecasting ability. This allows for the easy introduction of jump risk, very common in projects with binary outcomes like the ones presented (Damodaran 2015). Finally, using a binomial approach makes the exercise more intuitive and hence easier to explain to upper management for their buy in (Kodukula and Papudesu 2006), on top of being more customizable to each specific business situation (Copeland and Tufano 2004). However, note that using option theory to price real options is always prone to estimation errors given the inability of using a replicating portfolio to arbitrage the option payoffs (as the underlying assets are not publicly available in the market).

To value an option with a binomial model we need the following inputs:

- Payoff of the option in the up state (success of the pilot phase): \( O_u \)
- Payoff of the option on the down state (failure of the pilot phase): \( O_d \)
- Risk-neutral probability of an upwards move (success of the pilot phase): \( p^* \)
- Annual Risk free rate (e.g. the 10-Year German Government yields): \( r_f \)

If the firm assesses a negative NPV from going further with the technology investment in the case the pilot phase is a failure, then the option to abandon the technology provides a payoff symmetric to that value. Hence, the payoff provided by the option is:

\[
O_d = \max \left( -I_1 + \pi_F \frac{R_{F,G}}{(1+r_f)^{T_2-T_1}} + (1-\pi_F) \frac{R_{F,R}}{(1+r_f)^{T_2-T_1}}; 0 \right)
\]

On the other hand, if the pilot phase is a success, the firm would continue with the technology investment, hence the option provides no payoff \( O_u = 0 \).

In order to value this option we are lacking the risk neutral probability \( p^* \). For this we can use the conventional formula in the context of a binomial valuation with discrete compounding (Hull 2009), as in equation IV:

\[
p^* = \frac{(1+r_f)^{t_1-D}}{U-D} \quad \text{ (IV)}
\]

Where \( U \) and \( D \) are the growth and decreasing rate, respectively. That is, the proportion by which the value of the project will change in each state of the world \( U \) in case of a success of the pilot
phase and \( D \) in case of failure). As the underlying asset of this option is the present value of its future cash flows, the value of the underlying asset at \( t = 0 \) can be computed using equation V:

\[
S_{t=0} = p \left[ \pi_S \frac{R_{S,G}}{(1+r)^{t_2}} + (1 - \pi_S) \frac{R_{S,B}}{(1+r)^{t_2}} \right] + (1 - p) \left[ \pi_F \frac{R_{F,G}}{(1+r)^{t_2}} + (1 - \pi_F) \frac{R_{F,B}}{(1+r)^{t_2}} \right]
\]  

(V)

Therefore, the growth and decreasing rates can be computed as the ratio between the expected value of project at \( t = t_1 \) and \( S_{t=0} \) as in equations VI and VII.

\[
U = \frac{E[S_{t=1}|\text{Pilot phase is a success}]}{S_{t=0}} = \frac{\pi_S \frac{R_{S,G}}{(1+r)^{t_2-t_1}} + (1 - \pi_S) \frac{R_{S,B}}{(1+r)^{t_2-t_1}}}{S_{t=0}}
\]  

(VI)

\[
D = \frac{E[S_{t=1}|\text{Pilot phase is a failure}]}{S_{t=0}} = \frac{\pi_F \frac{R_{F,G}}{(1+r)^{t_2-t_1}} + (1 - \pi_F) \frac{R_{F,B}}{(1+r)^{t_2-t_1}}}{S_{t=0}}
\]  

(VII)

This way we have already all the inputs to compute \( p^* \) with equation IV. The value of the option will thus be computed as in equation VIII (Hull 2009), where the option payoffs are weighted by the risk neutral probabilities and discounted with the risk free rate.

\[
\text{Option Value}_{t=0} = \frac{[p^*o_u + (1-p^*)o_d]}{(1+r_f)^{t_1}} = \frac{(1-p^*) \left[ -I_1 + \pi_F \frac{R_{F,G}}{(1+r)^{t_2-t_1}} + (1 - \pi_F) \frac{R_{F,B}}{(1+r)^{t_2-t_1}} \right]}{(1+r_f)^{t_1}}
\]  

(VIII)

Finally, the correct NPV of the investment, \( NPV^{\text{dynamic}} \), can then be computed with equation

III. Note that: \( NPV^{\text{static}} < NPV^{\text{dynamic}} < NPV^{*\text{dynamic}} \)

This relation shows how having this option increases the value of the project:

- Eliminating expected negative payoff: \( NPV^{\text{dynamic}} = NPV^{\text{static}} \)
- Reducing the overall risk of the resulting cash flows: \( NPV^{*\text{dynamic}} = NPV^{\text{dynamic}} \)

To find the true cost of capital of such project we have to first know its true value and then find the \( r^* \) that is compatible with equation IX:

\[
NPV^{*\text{dynamic}} = -I_0 + p \left[ -I_1 \frac{\pi_S \frac{R_{S,G}}{(1+r)^{t_2}} + (1 - \pi_S) \frac{R_{S,B}}{(1+r)^{t_2}}}{(1+r_r)^{t_1}} \right]
\]  

(IX)

At this stage we have all the values of that equation except for \( r^* \), the true cost of capital that we want to discover. Therefore we can solve that equation to find that missing variable, which would lead us to the following relation: \( r_f < r^* < r \). This explains why \( NPV^{\text{dynamic}} < NPV^{*\text{dynamic}} \).

6. Numerical Example

To exemplify my analysis, I will now perform a hypothetical example. Suppose that Embraer Compósitos decides to implement the LCM technology recommended in my Business Project. Assume that the investment needed to start the pilot phase is 2.5€ million and to fully implement the technology is 10€ million. The pilot phase has a good chance of being a success, say 60%. If
the pilot phase is a success, the technology will return 30€ million in a good state (probability of 70%) or 10€ million in a bad state (probability of 30%). On the other hand, if the pilot phase is a failure, the technology is expected to generate a return of 20€ million in a good state (probability of 20%) or null returns in a bad state (probability of 80%). The pilot phase is expected to last 2 years and the first aircraft parts are expected to be sold in 4 years. Suppose Embraer’s Compósitos’ cost of capital is 3.77% and the euro risk free rate is 0.37%. All these values are summarized in table 2.

<table>
<thead>
<tr>
<th>$I_0$</th>
<th>$I_1$</th>
<th>$p$</th>
<th>$\pi_S$</th>
<th>$\pi_F$</th>
<th>$R_{S,G}$</th>
<th>$R_{S,B}$</th>
<th>$R_{F,G}$</th>
<th>$R_{F,B}$</th>
<th>$r$</th>
<th>$r_f$</th>
<th>$t_1$</th>
<th>$t_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>10</td>
<td>60%</td>
<td>70%</td>
<td>20%</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>0</td>
<td>3.77%</td>
<td>0.37%</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2

With these inputs, $NPV_{static} = 2.01$, $NPV_{dynamic} = 4.35$, $NPV^*_{dynamic} = 4.47$.

A good measure for the undervaluation of the standard $NPV$ analysis would be:

$$\frac{NPV_{static}}{NPV^*_{dynamic}} = 46.3\%$$

This means that if the firm would use a standard $NPV$ analysis it would value the above project at 46.3% of its true value. It is interesting to see how this undervaluation changes with different inputs. For example, a higher $p$ would substantially decrease the undervaluation of $NPV_{static}$ (a value of 0.8 would make $NPV_{static}$ 82.4% of $NPV^*_{dynamic}$), which is intuitive as the probability of the firm exercising the option to abandon is reduced, hence decreasing its value. In addition, either increasing $t_2$ of decreasing $t_1$ increases the $NPV_{static}$ undervaluation (increasing $t_2$ to 5 years would make $NPV_{static}$ 38.8% of $NPV^*_{dynamic}$), as it increases the payoff of the option if exercised. Finally, a higher cost of capital leads to a larger undervaluation (a cost of capital of 5% would make $NPV_{static}$ 28.9% of $NPV^*_{dynamic}$), as this also increases the payoff of the option when exercised.

In this numerical example the true cost of capital of the project ($r^*$) would be 3.44%, higher than the risk free rate ($r_f = 0.37\%$) and lower than the cost of capital without the real option ($r = 3.77\%$).

7. Conclusion

I first showed that when Embraer Compósitos decides to implement a new manufacturing technology in phases, with a pilot phase before a full implementation, they are in the presence of a real option to abandon. Afterwards I showed how Embraer Compósitos should value that
investment decision. Because they are in the presence of a real option, they should not just perform a standard NPV analysis but also value the option separately, which I show how to do with a binomial approach. Valuing appropriately the real option leads to a higher valuation of the project because of two intuitive reasons: limiting possible losses given the option to abandon the technology, and decreasing the risk of the resulting cash flows of the project. This means that if the firm does not take this option into account it will be undervaluing the value of a technology, which can lead to underinvestment in otherwise value-creating projects.
C. Bibliography

1. Bibliography Section A

- CompositesWorld. (2013). Large industrial microwave system.
  http://www.netcomposites.com/guide/filament-winding/54
- Ingersoll Rand. (2009). ARO Introduces the PH30F 2:1 High Pressure Diaphragm Pump
- NASA. (1970). TRL Scale
2. Bibliography Section B

- Copeland and Antirakov (2003), Real Options: A practitioners Guide.
- Cox, Ross and Rubinstein (1979), Option Pricing: A simplified approach
- Hull (2009), Options, Futures, and Other Derivatives, Prentice Hall; 9th Edition
- Kodukula and Papudesu (2006), Project Valuation Using Real Options.