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A METHOD FOR ASSESSING THE IMPACT OF TECHNOLOGY INFUSION IN AERONAUTICAL PRODUCTS

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Abstract. *This paper presents a method for assessing the impact of technology infusion in aeronautical products in early design phases. The global socio-economical and political environment changing is building a scenario in the aeronautical sector which demands products characterized by low operational and acquisition cost, better performance, safety and quality, and environmentally friendly. In order to achieve this demand, it is necessary to infuse technologies that yield improved product and/or processes. However, prior to that, it is necessary to bring and deal with information about the impact of technology infusion to the early phases of the aircraft design, taking into account the product life-cycle and the stakeholders' needs. This provides a better decision making about which technologies are more adequate to use. The proposed approach is a response to the need of assessment and estimation information on the impact of technology infusion in aeronautical product under the new scenario, improving the decision making process at the early phases of aircraft design. This goal is achieved through a process that uses various moderns approach, tools and techniques that address both, product and technology perspective, such as, System Engineering, Concurrent Engineering, Technology Scouting and Technological Forecasting. Finally, this method is applied to a theoretical case to illustrate the overall process and results that could be expected.*

Keywords*: technology impact assessment, technology evaluation, product development, aircraft design*

1. INTRODUCTION AND MOTIVATION

The global socio-economical and political environment changing is being a remarkable phenomenon over the last decades of XX century and the beginning of XXI century. The airline industry market deregulation started by USA and followed by others countries, the airlines crises brought by the September 11th terrorism attacks, the increase and changes in the environmental regulation, the forecasting raise of world air traffic, the programs of Research, Technology and Development funding by USA and European Community are samples of the changes. All these put together with the overcoming desire for products with better quality, comfort and safety are some of the main features that configure the world scenario and have important impact at the aeronautic market.

1.1. Airline Deregulation

Airline deregulation has led to profound changes in the structure of the industry. Deregulation removes restrictions on entry and exit, gave airlines carriers the freedom to set fares, expand and rationalize their route structures (Berry *et al*, 1997). The consequence was a drastic change on the commercial airlines in the recent years, especially on market structure, flight network organization and price competition.

By giving the airlines freedom of entry and exit, deregulation allowed a rationalization of route structures. The result is the almost complete shift in network organization, from "point-to-point" to "hub-and-spoke" (Berry *et al*, 1997; Pasin and Lacerda, 2003). Concentrating traffic on the spoke routes in ad out of hub airports, the airlines could exploit 'economies of traffic density', increasing returns at the rout level, make a better use of the all fleet (Brueckner, 2004).

The transformation due to deregulation process and the hub-and-spoke network has caused two main results: it raised the number of airlines and it triggered a new kind of airliner: the low-cost/low-fare companies, LCC. (Oliveira, 2004; Pasin and Lacerda, 2003). These new companies came to fill up the small markets that were abandoned by the existing airlines when they establish the hub-and-spoke networks.

The increased competition has forced many airlines to reduce ticket fares, increase passenger amenities, and increase customer-oriented services in order to maintain or increase market share. In the international air transport market, it has led to decline in company profits, and the airliners' monopoly positions have been challenged. Many airlines have been forced to undertake major restructuring in order to reverse the declining profit by improving productivity and efficiency (Oum and Yu 1998)

The deregulation has brought a number of benefits to the passenger and has interrupted of a cycle of high profitability of the airline operators.

1.2. September 11th terrorism attacks:

The September 11th of 2001 terrorism attacks has worsened the situation to the airline industry. Although the airline industry has always been highly cyclical, it has traditionally been able to withstand through temporary economic downturns. The impact of September 11th on airline demand has been so severe; however, that demand until 2003 remained well below pre-attack levels more than two years after the attacks (Ito and Lee, 2005).

Time-series data from 1986-2003, has shown that September 11th resulted in both a negative transitory shock of over 30% and an ongoing negative demand shock amounting to roughly 7.4% of pre-September 11th demand. This ongoing demand shock has yet to be dissipated (as of November 2003) and cannot be explained by economic, seasonal, or other factors (Ito and Lee, 2005).

1.3. Increasing and Changing in Environmental Regulation

Regarding to the environmental aspects, an awareness of preserving the global environment is a growing factor. Balancing the demands for industrial growth with the aspirations for sustaining and improving the quality of the environment is a global challenge. Environmentally friendly aircrafts normally evocates both noise reduction and emission reduction.

Technology developments in engine and airframes aligned with more restrictive regulations, as ICAO - International Civil Aviation Organization - stages regulation and airports specific restrictions, have been brought down the aircraft noise emission level along the years (Lord, 2004).

Regarding to emission regulation, the great pressure is to reduce the CO_2 and NO_X aircraft emission. Nowadays, the total contribution of aircraft emissions to total anthropogenic carbon dioxide (CO_2) emissions was about 2-3 percent in 1990. This might be a misleading figure, but as the air traffic in the world is growing, and will likely continue to grow (Boeing, Airbus, Embraer and Bombardier Market Forecasting), based in the fact that the aviation is 90% based in petroleum fuel consumption (EC, 2001; NAS, 2006) and the aviation was not considered at the Kyoto Protocol; by the year 2050 the amount of pollution originated from aircrafts will be higher than the amount of pollution of all the rest of economy together, what is a unacceptable scenario (EC, 2001).

For future systems to comply with forthcoming or current regulations, technological advances in the state-of-the-art must be made. In general, technological advances imply complexity, which implies increased costs (Kirby, 2001).

1.4. Forecast Raise of World Air Traffic

The projected commercial travel growth is also affecting the aerospace industry. In the Boeing Current Market Outlook 2006, Boeing predicts that over the next 20 years, from 2006-2025, the growing world economy, world trade, and airline competition will generate annual passenger traffic growth of 4.9 % and freight growth of 6.1 %; at the same way, Airbus Global Market Forecast from 2006-2025 predicts that the world passenger traffic is expected to increase by 4.8% per annum and freight traffic is expected to grow at 6.0% per annum.

Embraer forecasts that the world jet fleet in the 30 to 120-seat capacity segment will increase from 3,998 aircraft in 2005 to 9,548 in 2025. A global demand for 7,950 new jet aircraft deliveries in the 30 to 120-seat segment, valued at approximately US$ 180 billion, to satisfy growing passenger demand and to replace ageing equipment. At the same way, Bombardier predicts that in the 20-year period from 2006-2025, Bombardier forecasts a demand for 11,000 aircraft in the 20 to 149-seat category, representing a total value of $370 billion.

Based on the prediction, airlines need to increase their efficiency with lower costs in order to survive in this highly competitive environment. In this sense, aircraft manufacture has the role to properly deploy aircraft capacity to match market demand, which has become even more important in the current competitive environment.

New technologies will define the standard for next generation aircraft. Effective use of these technologies will permit manufacturers to optimize the design points of their aircraft offerings more closely to specific market segments.

1.5. Research, Technology and Development Programs funding by USA and European Community

Associated to aeronautical products, there are plenty of technological advances related to both product and process. However, besides all advances, it is still expected for new aircrafts a better performance and the accomplishment of the current and futures regulations. It is naturally that these expectations shall be addressed by Research, Technology and Development efforts that must be incorporated to the products.

USA and European Community plays the main role regarding to the demand and offer of new technologies to the sector (ACARE, 2004; NAS, 2006; EC, 2001). USA model of support to the pre-competitive R&D for civil aeronautic is based on NASA and the European Community model is based on Framework Programs - FP - which are public politics instruments to drive project elaboration.

1.6. Innovation, Product and Technology:

The aeronautical scenario demands innovative products that result in lower costs, raised profits, better performance, environmental friendly and better quality. But to get products that satisfy the demands it is expected that technological advances should be incorporated to the products.

In the innovation context, the technology just became relevant, under a business viewpoint, when it's applied commercially. It means that, to innovate, there may be a bridge between the technology and the market – this bridge is the product. However, in the case of high-complexity products, in general, when new technologies are incorporated into products, it increases complexity, which, by its turn, results cost rising. In the case of high-complexity products, there isn't a direct relationship – one to one – between a given technology and a product. In this case, the product is complex assemblage of several technologies, with all level of integration, from components to sub-systems to systems (Balaguer *et al*, 2007).

In order to achieve this demand, when designing an aeronautical product, it is necessary to infuse technologies that will result in improved product and/or processes. However, before that, it is necessary to bring and deal with information about the impact of technology infusion to the early phases of the aircraft design, taking into account the product life-cycle and the stakeholders' needs.

1.7. Life cycle considerations

The life cycle phases of an aircraft include conceptual, preliminary, and detailed design, production, service, and retirement (Raimer, 1999).

The decisions made in the early phases have a considerable impact on the aircraft system in question. In particular, there is a strong "cost-knowledge-freedom" dependency from conceptual design to production, which can significantly influence the entire life cycle of a system, specifically cost and quality, or customer satisfaction (Kirby, 2001; Curran *et al*, 2005).

As the design progresses from conceptual design to product release in the traditional design approach, the decisions related to aircraft configuration and technologies take place in the very beginning phases. However, at the initial phases, the knowledge level of the product is very low. Consequently, higher cost commitment of the project is made when the knowledge level about the product is still very low. The outcome is that, as the product design goes on from the conceptual to manufacture, the knowledge of the product raise, which could imply in changes to the product specifications. But, any changes to the product specifications that occur in later phases have significant cost implications.

Thus, fostering raise the level of knowledge about the product in the beginning phases of its development, brings in information of potential technologies to be inserted, provides a better decision making on which technologies to use and reduces the chances of late changes.

In addition, when assessing the quality and robustness of a product, the complete life cycle of the product must be considered. So, it is equally important to assess and quantify the impact of new technology on performance and economic parameters of the product. To do so, these parameters must be focused on the stakeholders needs and one must know who the stakeholders are and what their demands are.

2. OBJECTIVE OF WORK

The answer to the challenges of the aeronautical scenario described above is to raise the knowledge level of the product when at the initial phases of its development process. This is carried out by bringing in and dealing with information of potential technologies to be inserted into the product /process. Thus, the present work proposes a method to assess and estimate the impact of technology infusion in aeronautical products, taking into account the product life cycle and the stakeholders need

3. ENABLING TECHNIQUES

In order to respond to a generic process to assessing the impact of technology infusion in aeronautical products, enabling techniques from product and technology fields must be identified so as to determine possible solutions to the shortcoming of the process and approaches presented.

The techniques include Concurrent Engineering, System Engineering, Technology Assessment, Technology Forecasting, Technology Description Process and Technology Scouting, all of those addresses the product, technology or both points of view.

3.1. Design Frameworks and Approaches

Concurrent Engineering

The term 'concurrent engineering' was coined in 1986 by the Institute for Defense Analysis (IDA) Report R-338 (IDA, 1986): 'Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements.'

Loureiro (1999) provides a brief review of the CE techniques used throughout the manufacturing industry to capture, communicate and analyze those requirements. These methods and their aims are:

- Quality Function Deployment (QFD): communicates customer requirements throughout the development, manufacturing and production stages of the product life cycle;
- Taguchi methods: brings robustness concerns through experimental development of products;
- Axiomatic design: summarizes a set of good practice rules into design axioms and use these axioms as a reference to guide and evaluate the decisions taken during the design process.
- Theory of inventive problem solving (TRIZ): proposes a systematic way for evolving engineering systems
- Design for Assembly (DFA): anticipates assimilability requirements to the early stages of product development;
- Group Technology (GT): most commonly used for production planning, but its cluster algorithms can also be used to relate product requirements to customer requirements and manufacturing requirements to product requirements and to optimize the allocation of resources.
- Value Engineering (VE): makes a balance of the value of product functions to the customer and the cost to implement them. It can anticipate cost constraints to the early stages of product development.
- Failure Mode Effects Analysis (FMEA): analyses the effects of potential failure modes at all levels of the product breakdown structure.
- Hazard Analysis: analyses the gravity, frequency and risks of hazards related to the product life cycle.

System Engineering

The IEEE-Std 1220-1994 (1995) provides a modern definition of 'systems engineering': "an interdisciplinary collaborative approach to derive, evolve, and verify a life cycle balanced system solution that satisfies customer expectations and meets public acceptability".

The IEEE-Std 1220-1994 (1995) also defines two other terms to support its definition of systems engineering:

- Life cycle: the system or product evolution initiated by a user need or by a perceived customer need through the disposal of consumer products and by-products.
- Customer: a person or organization ordering, purchasing, receiving, or affected by a product or process. Customers include developers, manufacturers, testers, distributors, operators, supporters, trainers, disposers, and the general public.

One of the most important aspects of the system engineering is the analysis dimension. The analysis dimension defines the different types of analysis that are undertaken to identify the requirements and attributes of the product. They are requirements analysis, functional analysis and physical analysis (Loureiro, 1999). They can be applied while evolving a system from requirements to actual physical realization or when analyzing an existing system.

Integrated Product Development

Loureiro (1999) defines integrated development as a product development approach for the integrated and concurrent development of a product, its life cycle processes and their performing organizations. It takes into consideration, from the outset, life cycle process and organization requirements which, together with the product specific requirements, drive the product development process. Integration of product, life cycle process and organization takes place by recognizing that their attributes affect each other and that a balanced solution that satisfies stakeholder requirements cannot be achieved without consideration of the relationships among those attributes.

Raimer (1999) points that increasingly aircraft design is being done in what is now called an Integrated Product Development environment.

Summary of Design Frameworks and Approaches

The Current Engineering, System Engineering and Integrated Product Development approach contain pieces needed for the development of a method for assessing the impact of technology infusion in aeronautical products.

Both approaches addresses the life cycle consideration of a product and at the heart is the focus on the stakeholders and meeting the stakeholders need.

Kirby (2001) emphasizes that the payoffs of applying the principles of the design frameworks presented to the design of a product are reduced cost, reduced development time, and reduced risk while simultaneously increasing quality. These payoffs are achieved due to the integration of design, manufacturing, business, and supportability considerations in the early phases of the design process.

However, no specific means of the issues associated with the evaluating or infusion of new technologies are captured in the framework, nor how to generate the information required making informed decisions.

3.2. Technology Approach

Technology Assessment, Technology Forecasting, Technology Monitoring are the main terms used by literature to point out process and even methods to analyze the course of technological development and the way that technologies promote innovation.

Poter and Weisbecker (1993), based on a report of UN Branch for Science and Technology for Development, say that "Technology assessment ultimately comprises a systems approach to the management of technology reaching beyond technology and industrial aspects into society and environmental domains. Initially, it deals with assessment of effects, consequences, and risks of a technology, but also is a forecasting function looking into the projection of opportunities and skill development as an input to strategic planning".

Coates (2001) defines Technology Forecasting as a purposeful and systematic attempt to anticipate the potential direction, rate, characteristics, and effects of technological change, especially invention, innovation, adoption, and use". Balaguer (2005) defines technology forecasting in a broad way as "Technological Prospective is both a process that looks to the future and the results of this process, which anticipate, extrapolate or forecast capacities, applications and functionalities of machines, process and techniques.[…] The process outcomes, expressed in words or numbers, are showed in a useful way to the decision and policy makers, consequently increasing their state of alert about future's threats and opportunities (2005)."

A subset of technology forecasting is the Technology Description.

Technology Description involves reducing a technology to as few and as simple a set of words as possible. The goal of technology description is to enable a competent individual to quickly grasp the form and value of a technology with which they are unfamiliar (Walsh, 2001).

In this sense, technology description process helps to distill the essence of an emerging new technology into a few sentences that most people can understand, it emerge as a powerful tool to allow one to simply express what a technology is about. It involves series of questions that serve as a minimum guideline of what needs to be known to understand a technology, by answering questions, become a competent non-specialist on the technology (Walsh, 2001).

Regarding to technology monitoring, recently, Paap (2006) has systematized and amplified the monitoring aspect to a Technology Scouting focused on innovation perspective.

Technology Scouting is defined as an organized approach to looking externally for technology that can be adapted to meet the tactical or strategic development needs of an organization. In this way, technology scouting provides a link between the organization (internal) and the environmental (external).

Summary of Technology Approach

Since the beginning of 1990, it is possible to note a movement to put at the same basis Technology Assessment, Technology Forecasting, Technology Monitoring.

Poter and Weisbecker (1993) embed Technology Assessment with Technology Monitoring and Forecasting. Monitoring consolidates available knowledge on a particular technology and its context (technological and social). Forecasting anticipates future developments. Assessment is integrated with monitoring and forecasting, rounding out a system approach.

In fact, the treatment and analysis regarding of technology vary enormously depending on the needs of the study users and is even more driven as a system approach to get into account the aspects of the purpose of what the technology are planned to be used.

4. THE METHOD PROPOSED (ITI_AEM: Impact of Technology Infusion_ Assess and Estimate Method)

The method proposed herein is depicted in Figure 1: It aims to assess and estimate the impact of technology infusion in aeronautical products, taking into account the product life cycle and the stakeholders need

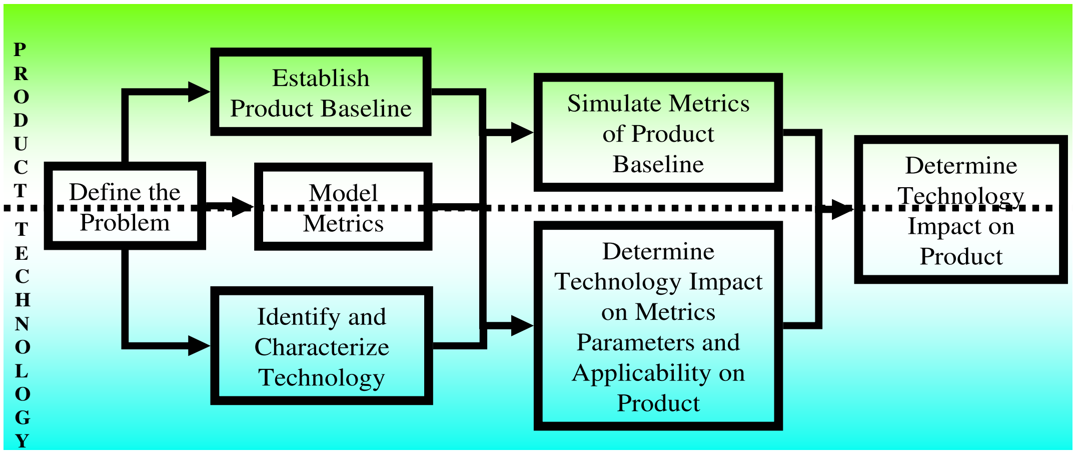

Figure 1. Process to Assess the Impact of Technology Infusion in Aeronautical Products

The method is described step-by-step as follows

Step 1 – Define the Problem

The first step of the proposed method is to define the problem to be analyzed. In order to formulate the problem, a stakeholder need must exist or a request for proposal must be stated to drive the design of a product and the identification of technology that might be infused into the product. The definition of the stakeholders' requirements must capture the needs of the airframe and engine manufacturer, airlines, airports, passengers, and society as a whole through operational and environmental regulations. And, they must be mapped into some economic, engineering, or mathematically quantifiable terminology.

At this step, the needs may be objectives or constraints and they must be translated into system metrics, or a system attribute that is tracked for the purpose of decision making. The system metrics are the thresholds the system under analysis can be measured with.

Step 2 – Establish Product Baseline

Once defined the problem in terms of system metrics, objectives, constraints and evaluation criteria the next step aims at defining a product baseline.

Initially, the experience, knowledge, and intuition of the designer are used to identify potential solutions to meet the customer requirements. In general, one alternative concept is established to begin the feasibility investigation and is named Product Baseline. At this point, is expected that conventional or existing technologies are chosen in order to minimize investment costs and program risks. It is important to emphasize that the Product Baseline could be a new design or an existing product.

Step 3 – Model Metrics

A fundamental requirement for any decision making process is the ability to quantitatively assess the customer requirements that drive a design. This can be achieved through Modeling and Simulation. Thus, this step aims to translate the stakeholders' requirements defined in Step 1 into quantifiable engineering parameters. These, by their turn, are affected by the Product Baseline and by Technologies under investigation. An important aspect to be taken into consideration at this point is the level of fidelity of the model, which is dependable of the desirable results and its accuracy.

Step 4 – Simulate Metrics of Product Baseline

Once the stakeholders requirements were translated into system metrics and a product baseline established, this step consist of establishing datum values for all customer requirements (system metrics) identified and modeled in Steps 1 and 3 for the product baseline set up in Step 2. The result is the metrics quantified for the case of baseline.

Step 5 – Identify and Characterize Technology

Based on the problem defined in terms of system metrics, objectives, constraints and evaluation criteria, this step aims at looking for technology that could address one or more objectives or constrains that affect the system metrics.

For this purpose, it is possible to use the approach of technology monitoring and technology scouting described in Section 3.2. Once identified some possible technology that address the defined problem, it is necessary to characterize this technology. To do so, the technology description approach described in Section 3.2 is used.

Step 6 – Determine Technology Impact on Metrics Parameters and Technology Applicability on Product

At this point, it is necessary to identify whose engineering parameters modeled in step 3 are prone to be impacted by the technology under evaluation. Also it is necessary to express such impact is in terms numerical values. The impact that each technology cause on engineering parameters may be obtained from three sources: expert team questionnaires, physics-based modeling or literature reviews. It is also part of the activities of this step to find out the answers for "where" and "how much" the candidate technology is applicable on aeronautical products

Step 7 – Determine the Technology Impact on Product

Finally, the technology is applied to the product baseline and evaluated. To carry out this assessment, the product baseline metrics simulated at Step 4 are modified by the technology impact and balanced by the technology applicability, both determined at Step 6. As a final result, a design team can evaluate the effect of technology infusion on the product through the modification of the system metrics at the product level.

5. CASE STUDY

The method described herein has been applied to evaluate the impact of infusing one single technology in an existing airplane, considering a scenario of replacement or improvement of this product in the next 10 years. The objective of the case study is to show the feasibility of the method rather than to discuss the technical aspects of the product or technology.

Step 1 – Define the Problem

Boeing B737 family and Airbus A320 family are worldwide recognized successful aircraft products in the segment of single aisle, narrow body commercial passenger jet aircraft, with capacity of around 150 passengers and range of about 5700 km. Boeing and Airbus together have a fleet of more than 9000 aircrafts delivered to airlines worldwide.

However, the products design date from the 1990's decade. Taking it into account that the usual life cycle of an aircraft is about 25 years; there is a great expectation of the whole aeronautical community for a replacement or major improvement of a product in this segment by the year of 2015. But, the replacement product must incorporate technology advances that lead to a product that meet the requirements of the scenario pointed out at Session 1.

An important aspect to be taken into account in the new aeronautical product is the structural efficiency of the airframe in terms of weight and cost of material. Reducing structural weight could result in a single or combined of the following effects: less fuel consumption, more paid load and more range. Material cost reduction leads to reduction in acquisition cost of the aircraft. All these represent important marketing and sales aspects for the aircraft manufactures.

Problem Definition: Reduce airframe weight and cost of material for the aircraft segment of a single aisle, narrow body commercial passenger jet aircraft, with capacity of around 150 passengers and range of about 3000 nm (5700 km).

Step 2 – Establish Product Baseline

The product baseline is assumed to be the similar to the A320. Table 1 shows the A320 characteristics, where the product baseline characteristics are taken from.

Table 1. Product Baseline Characteristics (Airbus A320 Webpage)

AIRCRAFT DIMENSION		DESIGN WEIGHTS	
Overall length	37,57 m	Maximum ramp weight	73,9 tons
Height	11,76 m	Maximum takeoff weight	73,5 tons
Fuselage diameter	3,95 m	Maximum landing weight	64,5 tons
Cabin length	27,51 m	Maximum zero fuel weight	61,0 tons
Wing span (geometric)	34,10 m	Maximum fuel capacity	23,860 litres
Wing area (reference)	122,6 m^2	Typical operating weight empty	42,4 tons
Wing sweep (25% chord)	25 degrees	Typical volumetric payload	16,6 tons

Note: As there is a growing tendency of using of composite materials in structural aircraft application, the weight of the product baseline is halved in composite and metallic.

Step 3 – Model Metrics

The two metrics to be modeled at this case are: Weight (focused on structural weight), and Material Cost

Weight Modeling:

Based on Raimer (1999) the following equations represent the weight breakdown:

$$\begin{aligned} W_{TOGW} &= W_{crew} + W_{payload} + W_{fuel} + W_{empty} \\ W_{empty} &= W_{Structure} + W_{System} \\ W_{Structure} &= \sum_i W_i \end{aligned} \tag{1}$$

where:

- W_{TOGW} is the takeoff gross weight
- W_{crew} is the crew weight
- $W_{payload}$ is the payload or passenger weight
- W_{fuel} is the fuel weight
- W_{empty} is the empty weight which includes aircraft structure and systems that are not considered in any of the previous components.
- $W_{Structure}$ is the weight of aircraft structure, which includes wing, fuselage, stabilizers and others
- W_{System} is the weight of aircraft system, including avionics, engines, landing gear, interiors and others.
- W_i is the total weight of the structural parts made of material type "i".

Material Cost Modeling:

The material cost, $\$M$, depends of three parameters:

- the cost of the raw material per weight, $\$RM$,
- the ratio of the finished part weight and raw material weight needed to produce this part, $W_{finished\_part} / W_{RM}$
- the weight of finished part, W_i

As the method is to be used at the preliminary design phases, there are no needs of high fidelity models, thus the figures to be used can be taken as medium values.

The following equation represents the material cost model:

$$\$M = \sum_i \frac{\$RM_i \cdot W_i}{\left(W_{finished\_part} / W_{RM}\right)_i} \text{, where "i" represents different material type} \tag{2}$$

Step 4 – Simulate Metrics of Product Baseline

The characteristic and attributes defined at the product baseline have to be translated in terms of the parameters established at Step 3.

Weight Metrics:

It is assumed that: $W_{TOGW} = \text{Maximum Takeoff Weight} = 73500\text{ kg}$ (see Table 1)

For this type of aircraft, Raimer (1999), points out that:
$$W_{empty} = 0{,}47 \cdot W_{TOGW} = 34500\,kg$$
$$W_{Structure} = W_{System} = 0{,}5 \cdot W_{empty} = 17273\,kg$$

As defined at Step 2, $W_{Composite} = W_{Metallic} = 0{,}5 \cdot W_{Structure} = 8636\,kg$

Material Cost Metrics:

The medium cost of composite raw material per weight is determined taking into account the amount of resin and fiber used in a typical structural and the raw material cost (Hexcel Products, 2007). Likewise, the medium cost of metallic raw material per weight is determined through the typical usage of aluminum, titanium and steel in aircraft structure and the cost of raw materials (Alcoa Aerospace Products, 2007; Corus Products, 2007). The values are shown at Table 2:

Table 2. Material Cost Metrics for Product Baseline

Metrics	Metallic	Composite
$\$RM_i$	USD 9 / kg raw material	USD 80 / kg raw material
$\left(W_{finished\_part} / W_{RM}\right)_i$	5%	40%

Based on equation (2), the material cost metrics is set as: $$\$M = \sum_i \frac{\$RM_i \cdot W_i}{\left(\frac{W_{finished\_part}}{W_{RM}}\right)_i} \cong USD\ 3.3 \text{ millions per aircraft}$$

Step 5 – Identify and Characterize Technology

At this point, technical specialists are consulted to get the technology characteristics and quantify their impact. Regarding to the aircraft structure weight and cost, there has been having a raise of adoption of composite for structural applications. But, better performance of the composite material is waited with the merge of the nanotechnology at this type of material. Specially, Carbon Nanotubes (CNT) have been focus of research and development in the entire world, although, there isn't so far commercial application of this technology. Thus, composite with CNT is a "hot" technology whose impact claims to be evaluated when it might be infused in aircrafts.

Composite with CNT could be described as advanced composite materials where CNT is added at the resin or to the fibers. This technology presents better mechanical and electrical proprieties when compared to the traditional composite materials. On the other hand, it is still a low-maturity-technology, which implies in higher risks and costs.

In terms of applicability of the technology at aircraft structures, it is possible to be used in all of the components made by traditional composite material. And, it is expected that the amount of CNT utilized to produce a structural part is going to be less than 0,05% of the finished part weight.

Step 6 – Determine Technology Impact on Metrics Parameters and Technology Applicability on Product

Two metrics defined are affected by the technology: $W_{Composite}$ and $\$RM_{Composite}$.

$W_{Composite}$ is expected to be reduced by 20% when compared with traditional composite structure.

Regarding to cost, it is expected to add USD 100 per kilogram of CNT used to the $\$RM_{Composite}$ actual value.

In terms of applicability, this case study analyzes the impact of infuse the Composite with CNT technology in 100% of composite structure.

Step 7 – Determine Technology Impact on Product

Finally, the simulation of the impact of infuse the technology of Composite with CNT is made by applying the modified metrics to the product characteristics. The results of the modified metrics are show at Table 3.

Table 3. Weight Benefits and Penalty of Composite with CNT infusion on Product

Weight Benefits			
	Product Baseline (kg)	Product with Composite with CNT (kg)	%
$W_{Composite}$	8636	6909	-20,0
$W_{Structure}$	17272	15545	-10,0
W_{empty}	34545	32818	-5,0
Cost Penalty			
	Product Baseline (USD)	Product with Composite with CNT (USD)	%
$\$RM_{Composite}$	80	425	431,8
$\$M_{Composite}$	1,73 millions	7,3 millions	325,5
$\$M$	3,3 millions	8,9 millions	171,3

The benefit of empty weight could be transferred to any other weight component of the takeoff gross weight, as raising the payload, or the fuel and consequently the range, as some example, or also be transferred to the takeoff gross weight and result at the end in less fuel consumption. The great penalty on material cost could suggest a reduction on the applicability of the technology, focusing its application in specific structural parts to attempt raise the local weight benefit in order to compensate the material cost penalty. This analysis could also be held by the proposed method.

6. CONCLUSION

This paper has described a method for assessing the impact of technology infusion in aeronautical products. The seven-step procedure has been detailed: problem formulation, product baseline establishment, modeling of the system metrics determined, simulation the system metrics with the product baseline, identification and characterization of technologies to be infused, determination of the technology impact at the metrics and applicability on product, and determination of technology impact at product metrics level.

The overall benefit gained from this new approach is the ability to bring and deal with information about technology, product and requirements (system metrics) in order to assess benefits and penalties at the product level, taking into account the product life-cycle and the stakeholders' needs.

The feasibility of the method has been demonstrated on an example problem involving the investigation of effects of infuse a new material technology on the system metric of structural weight and cost material for the aircraft segment of a single aisle, narrow body commercial passenger jet aircraft, with capacity of around 150 passengers and range of about 5700 km, accounting for benefits and penalties.

Key further developments in this approach include research of the impact assessment in the presence of technological uncertainty, the impact assessment in the presence of not only one but a set of technologies at the same product and the development of appropriated and automatic tools in order to improve the effectiveness and efficiency of the method.

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