FLIGHT TEST AND ITS INTEGRATION WITH MODELING AND SIMULATION IN A NEW STRATEGY OF AIRCRAFT DEVELOPMENT

Edmar Thomaz da Silva, edmar.thomaz@Embraer.com.br
Empresa Brasileira de Aeronáutica – EMBRAER; Av. Brig Faria Lima 2170 São Jose dos Campos SP CEP 12227-901

Luís Gonzaga Trabasso, gonzaga@ita.br
Instituto Tecnológico de Aeronáutica – ITA; Praça Mal. Eduardo Gomes 50 Vila das Acácias São José dos Campos SP CEP 12228-900

Celso Braga de Mendonça, celso.mendonca@Embraer.com.br
Empresa Brasileira de Aeronáutica – EMBRAER; Av. Brig Faria Lima 2170 São Jose dos Campos SP CEP 12227-901

Abstract. *This paper analyzes the flight test performance in the development of a new aircraft inside a traditional model of development called "V model". The analysis shows that this strategy causes a late defect identification that impairs program objectives associated with costs, schedule and product final quality.*
A literature review associated with an analysis of the best practices in the world shows that it is necessary to change this strategy by the incorporation of the support of modelling and simulation in the process.
One case study that apllies this approach is presented. It indicates that changes are necessary in order to keep adherence with crescent aircraft reliability requirements in a cenario characterized by time and budget constraints.
It is also presented an exercise for future developments. This exercise analyzes changes in three dimensions: (1) process, (2) tools and (3) people.
By comparing the future with and without this new strategy, it is possible to conclude that the risk of new developments go out of budget and schedule can be reduced, since defects can be detected and solved in early stages of the product development cycle.

Keywords*: flight, test, process, modeling, simulation.*

1. INTRODUCTION

"Why Embraer Flight Test Division is not able to sustain a hundred flight hours per mount per prototype?" This question was raised by Embraer program managers at the beginning of this decade during EMB 170/190 aircraft family certification process.

After that, a diagnostic study demonstrated that the total time spent by Embraer from program go ahead until certification, was very competitive however, time spent since first flight until certification was always out of schedule. Embraer development process was clearly centered in flight test as a main resource to develop and to show compliance with requirements.

A change was needed since flight test is the most expensive and time consuming means of development. With this motivation, in 2005 a set of technological development project was started with the goal of obtaining a reduction in flight test cycle and in the level of corrections after aircraft release to test and release to field. The aim of this integrated project was to dominate key technologies associated with flight by wire and systems integration based on a modeling and simulation strategy.

The Flight Test Division started also one project with the main goal of optimizing the flight test campaign by the transfer of the development effort from flight test to ground test and modeling and simulation.

A literature review and a benchmarking research were done and indicated the necessity to change the traditional "V" model with the incorporation of modeling and simulation strategy.

One case study, product of technological development, proved that the use of aerodynamic data bank in supporting flight test can produce significant savings in the entire flight test campaign.

It is also presented an exercise for future developments. This exercise analyzes the changes in three dimensions: (1) process, (2) tool and (3) people. It indicates the necessary changes in these aspects to keep adherence with crescent restrictions in aircraft reliability parameters.

This manuscript is organized as follows: section 2 describes the flight test performance inside the traditional integrated development process; section 3 is a literature review and benchmarking analysis; section 4 describes a case study of using the modeling and simulation (M&S) in supporting flight tests; section 5 analysis future perspectives and their impacts on people, process and tools; section 6 describes the key conclusions.

2. FLIGHT TEST WITHIN THE TRADITIONAL INTEGRATED DEVELOPMENT PROCESS

Aircraft development process is characterized by high complexity and ever-decreasing lead times throughout for shortening time-to-market as an outcome. (Silva, 2004)

Inside this macro process there is the flight test phase, whose main goal is to develop and gather data during flight of an aircraft, and then to analyse the data to evaluate the flight characteristics of the aircraft and validate its design, including safety aspects. The flight test phase accomplishes two major tasks: 1) to find and to fix any aircraft design problems; and then 2) to verify and document the aircraft capabilities for government certification or customer acceptance.

The flight test phase of a complete development and certification of a new aircraft comprises hundreds of flight test campaigns and usually it is necessary to performe more than 2000 flight hours to receive from authorities the "Type Certificate", the document that assures that the particular design of a civil aircraft, engine, or propeller has fulfilled the regulating airworthiness requirements for the safe conduct of flights under all normally conceivable conditions.

A development process approach, based on concurrent engineering (Huang, 1996), has been used in the aircraft design process. This approach aims at integrating product design and production process planning in a concurrent and simultaneous activity (Pahl, 1996). The main effort of the concurrent engineering approach takes place into the conceptual phase of the product development process, allowing the anticipation and solution of relevant problems of the design process and a better-cost distribution throughout the life cycle.

Based on this approach, Embraer created a process named Integrated Development Process (IDP) (Cunha, 2007), described in the next paragraph.

2.1. Integrated development process at Embraer

IDP at Embraer aircraft life cycle is constituted of phases, and all the process that supports the project is defined. Figure 1 describes the major process associated with the IDP.

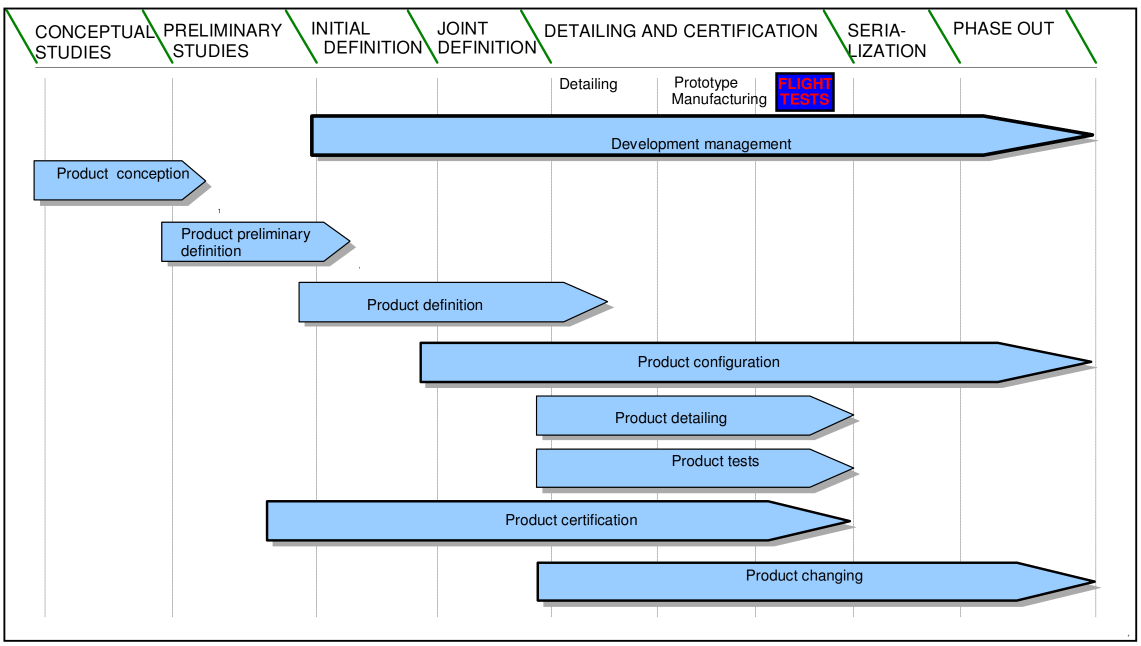

Figure 1. Depiction of Integrate Product Development (Cunha, 2007)

Based on this figure, it is possible to see that the flight test is the end of a complex process that is composed by hundreds of sub process and tools that carries themselves a great number of uncertainty. These uncertainties are a natural consequence considering the novelty character of a new aircraft that tries to go beyond previous development using new technologies to satisfy costumer expectation and requirements.

With focus on aircraft development (Barp, 2005), one generic representation known as "V model" (Forsberg, 1991) is shown in Fig.2.

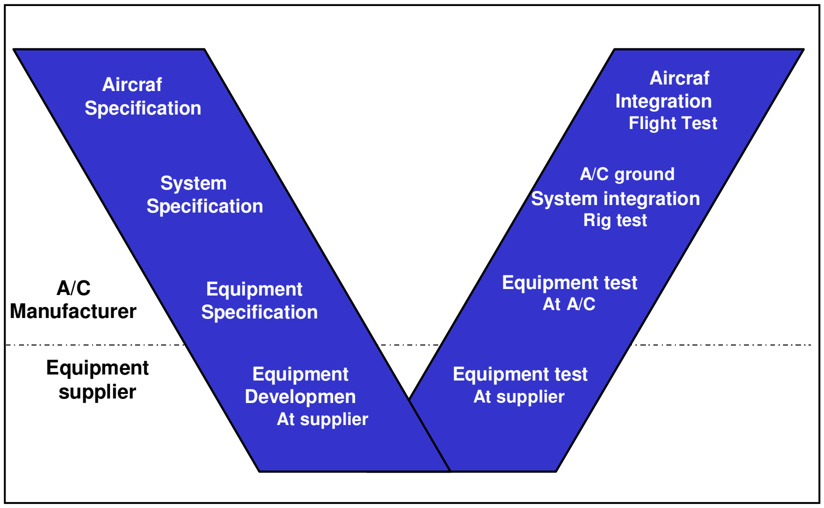

Figure 2. Aircraft development "V" model

The V-model is a graphical representation of the aircraft development lifecycle. It summarizes the main steps to be taken in conjunction with the corresponding deliverables within aircraft system validation framework.

The left "V" leg (verification) represents the specification, starting from the aircraft until the equipments. At the vertice of V equipments hardware are ready to be manufactured and tested. The right V leg (validation) represents the fabrication, integration and tests starting from de equipments until the final aircraft prototype.

Once again, this representations shows that tests are made only at the end, when the physical means (test articles) are available.

As a consequence of this strategy all non conformities and failures are discovered after what is called "release to test phase" (the moment when the tests with the first test article starts). Figure 3 (Boehm, 1981), represents this scenario.

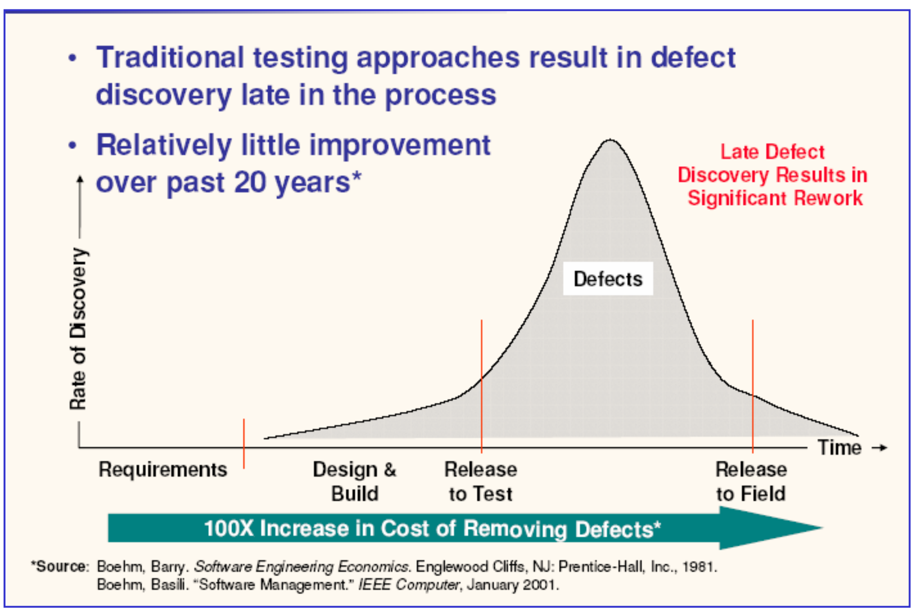

Figure 3. Late defect identification

2.2. Flight test impacts

Development delays experienced in single systems, systems integration and those due to design oscillations (design non compliances identified during flight tests that demand re-design and new test campaign), represent the main threats for Embraer as a hole, and, for Test Organization in particular, to accomplish the market and certifying boards schedules. Most part of these problems can be associated with low test articles and prototypes maturity. Due to the argument stated in paragraph 2.1, all of these problems have a huge impact in Test Organization. These impacts are depicted in the next paragraphs

2.2.1. Typical flight test evolution in a development and certification campaign

One of the key parameters to evaluate the impacts of low prototype maturity in the flight test campaign is the evolution of the flight test hours per month. For the sack of clarity, the following analysis considers this parameter for only one of the prototype designated for a test campaign.

Figure 4 shows the evolution of this parameter for a civil aircraft development and certification flight test campaign.

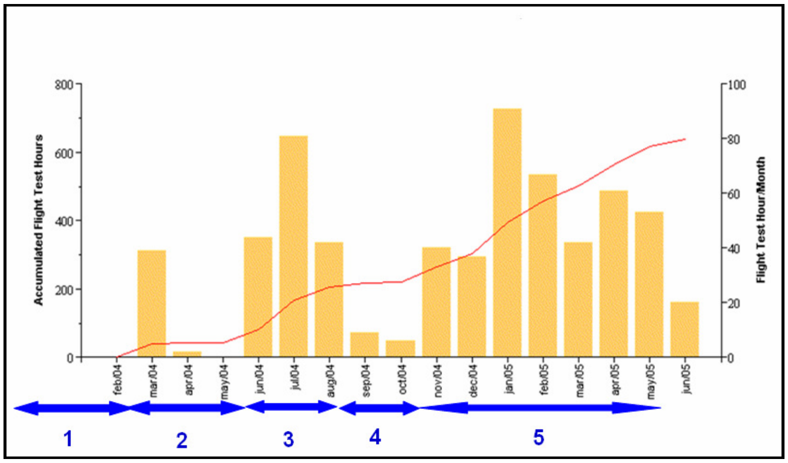

Figure 4. Flight hour evolution during a development and certification campaign

The behavior showed in Fig. 4 is a pattern in all new programs with great technological gaps. The flight test campaign starts with a low rate of flights and with great interval for prototypes lay ups (maintenance activities to correct defects and update prototype configuration). As long as the flight test campaign evolutes, it is possible to notice an increase in the rate of flights as a consequence of reduction in the lay up time.

In order to better understand the problems, Figure. 4 has been divided in phases marked by numbers. The real problems that happened with this specific prototype are the following:

1. Three months of delay in the first flight caused by the delays in prototype fabrication and delivery for test. Usually the manufacture delays are caused by problems in system developments and integration.

2. After the first flight, 40 flight hours per month followed by a lay up of 2 months to complement pending items from the manufacture process (immature systems and functions incorporated later).

3. Three months of flights with an average of 45 flight hours per month with maximum value of 80 flight hours.

4. Two months of lay up to correct aerodynamic problems.

5. Full flight test performance after the prototype reached a maturity stage in which it was available for flight without interruptions. Average of 52 flight hours per month with maximum of 90 flight hours.

It is clear, that this pattern was caused by a typical defect identification pattern showed in Fig. 3.

2.2.2. Impacts in the number of prototypes, total flight hours and schedule

One of the typical approaches associated with the flight test planning is based on the fact that all requirements needed to award the type certificate are represented by international standards. In Brazil one of the applicable standard is the RBHA 25; its similar in the United States is the FAR 25; whereas in the European community it is the CS 25. It can be assumed that there is a fixed number of requirements to be demonstrated in a certification process and as a consequence a fixed number of flight hours to show compliance with this requirements. If one assume an average flight rate per prototype it is possible to infer that the schedule can be shortened by the allocation of more prototypes.

Figures 5 and 6 show a comparison between Embraer products and others aircraft manufactures in terms of flight hours and time spent in the development and certification campaign:

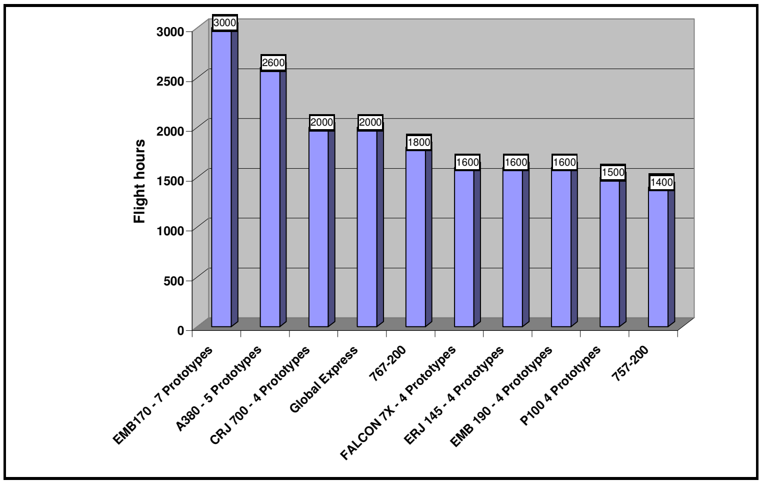

Figure 5. Total flight hours for aircraft development and certification.

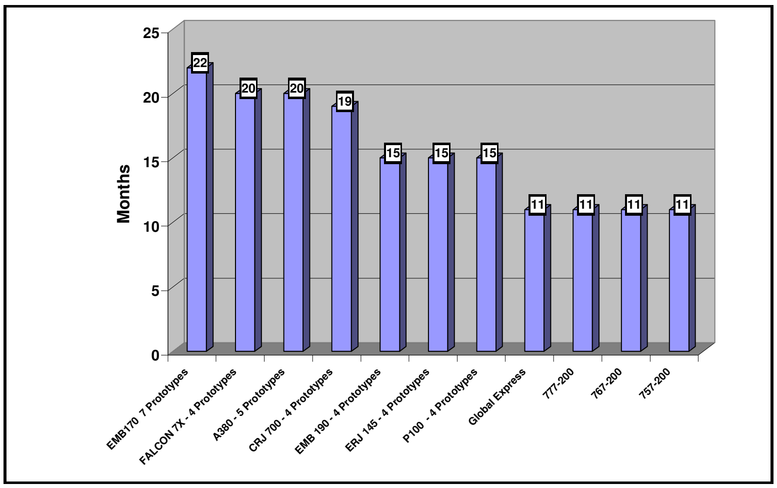

Figure 6. Time spent for aircraft development and certification.

These graphics shall be analyzed with restrictions, considering the different manufactures capacity and aircraft complexity. But, at least, it is possible to notice that the strategy described above fails. The low prototype maturity causes two effects:

1. Increase in total flight hours. Probably it is necessary to spend 1500 total flight hours to accomplish the requirements, whereas. EMB 170 spent 3000 flight hours in the certification process. Most part of the exceeded flight hours are due to defects correction and regression flights to correct this defects in all 7 prototypes.
2. Increase in schedule. Considering ideal conditions the type certificate could be reached in 15 months. But, the time spent in regression flights associated with great and long periods of lay ups to correct failures and update the prototypes impair the schedule. It was only possible to reach the TC with a delay of 10 months (flight test campaigns was originally planned for 12 months).

Another collateral effect of this strategy is the massive increase in the work force to keep 7 prototypes updated and configured for specific flight test campaigns.

2.2.3. Additional considerations

Based on these problems, one could ask how Embraer could be the third aircraft manufacture in the world, the only one in the south hemisphere, with a back log that reached more than U $ 20 billion. The answer rely on the fact that Embraer was able to find a specific and profitable market with high qualities products (after they reach good maturity).

So, the problem and motivation of this work consist in define another optimized aircraft development process and tools to anticipate this good level of maturity.

3. LITERATURY REVIEW AND BENCHMARKING

Aircraft market, despite the economical crisis, experiences a period of expansion. It is expected that 16000 new commercial aircrafts will be manufacture in the next 20 years. This grown represents a total amount of 1 trillion of euros. Naturally, the search for economical aircrafts with high level of safety, respecting the environmental restrictions associated with low poluents emission and noise reduction will be the key for the manufactures perpetuity. In order to reach these new requirements, the aerospace industry has been investing in research and development (R&D). The next paragraphs show the tendencies in Europe and the United States.

3.1. European community, EADS and the challenges of A380.

European community is in the search of new concepts and breakthrough technologies with focus on 4 requirements:

1. Reduction of the aircraft production costs in 35% and time to develop in a range from 15% to 30%.
2. Reduction in fuel consumption in 20%.
3. Reduction in Nox emission in 80% and CO_2 in 20% as well a reduction in 10 db in noise level.
4. Reduction in maintenance costs in 25%.

All these parameters have as reference the state of art in aerospace technology in 2002.

In order to reach this goal, government support has been increasing in the last decade. On the other side due to the A380 development, EADS invested 758 millions of euros in R&D from 2004 to 2006. With focus on systems development and integration EADS have been develop a concept called Common Virtual Bird (Develier, 2004).

The concept of the project is to have the means of simulation developed early in the definition phase of the aircraft and detail them during the development of the project in order to have representative models of the aircraft and its systems ready to do engineering and assembly of parts simulations.

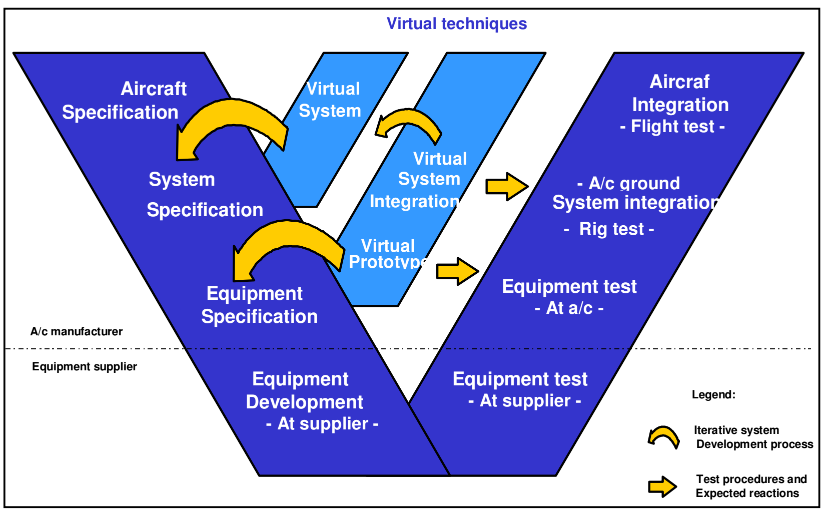

Figure 8. Airbus virtual bird concept.

Figure 8 represents the classical V model described in paragraph 2.1., with addition of lines that represent virtual techniques applied in the process.

The goal of CVB is to conduct the virtual flight simulator of the aircraft and its systems before the physical tests and to promote the involvement of the authorities during the development of models and simulators. These models are used in the certification of aircraft with a reduction in the physical tests and increment in the aircraft maturity by the use of simulation to identify defects in previous stage of development as shown in Fig. 9.

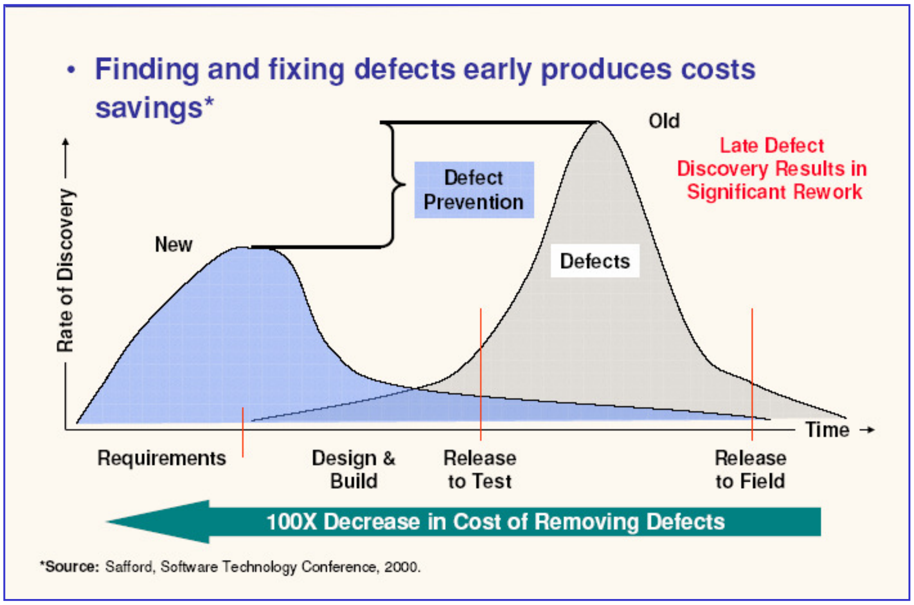

Figure 9. Early defect identification – future approach for aircraft development (Blackburn, 2000)

3.2. United States, the defense market and the world hegemony.

The United States have focus in keep world dominance. The defense market in particular the Air Force (USAF) drives the main requirements and breakthrough technologies in aerospace industry. Similarly to EADS, USAF is looking for reducing the development cycle and increase systems/aircraft performance.

In order to reach this goal, USAF stimulates the intensive use of modeling and simulation and its integration with test and evaluation (Skelley, 2004). As a result of this strategy, they expect a better maturity in the projects, better risk management, identification and solution of problems in an anticipated fashion and the efficiency and suitability of the systems to accomplish its mission immediately after release to field phase.

Boeing is one of the most important players in this market. Considering the paradox of developing complex systems or “systems of systems”, in an environment characterizes by strong restrictions in schedule, budget and high maturity in the entry into service phase, Boeing created a Division called Analysis, Modeling and Simulation (AMS).

AMS is responsible for the implementation and integration of systems models and to search a continuous matching of these models with real systems behavior not only in the development phase, but also during the entire product life cycle, increasing continuously the models adherence to real behavior.

3.3. Brazil, Embraer and the perpetuity dilemma.

In opposition to the strong government support to aerospace industry R&D in Europe and United States, Brazil’s support to R&D in aerospace industry is weak and fuzzy. Without a long term strategy and commitment with results, the industry can’t rely on the government to support it in filling the technological gap necessary to assure product maturity and adherence to the best practices and results.

Immersed in the Brazil’s political and economical context, considering the problems explained in paragraph 2 and the technological gap between Embraer and other players demonstrated in paragraph 3, in 2005 Embraer reinforced its own budget to launch a R&D strategy. This strategy is based on two stream lines, one with focus on systems integration and the other on the platform efficiency.

Inside the strategy of systems integration, three main projects were launched: Flight by Wire, Virtual Aircraft (with the same philosophy of Airbus CVB) and Test Campaign Optimization.

In the next paragraph it is described the main goals of Test Campaign Optimization project and some results that validate the irreversible tendency to use M&S in the development of complex systems.

4. TEST CAMPAIGN OPTIMIZATION PROJECT.

In the context describe in paragraph 2, in 2005 it was started Test Campaign Optimization project with the main goal to develop new methodologies and tools to allow a better effectiveness in test campaign execution considering that this test campaign will have the minimum scope (it will contain only the aspects that really aggregate value), optimizing the results that could be achieved starting from a more mature prototype (here it is expect that Virtual Aircraft project could improve the prototype maturity specially in release to test phase);

In order to improve test campaign effectiveness it was proposed the following goals:

1. Definition of a generic process that allow the construction of a minimum test campaign. To do only what is necessary to assure quality and safety operation;

2. Transferring of test campaign from the prototype to ground test articles (iron birds, test benches, integration labs etc) and from both to M&S;

3. Research of new test campaigns methodologies; and

4. Negotiation with regulatory organisms in order to assure that the authorities accept the new approach to show compliance with requirements (example: how to accept a proposition to change one demonstration that usually uses the flight test to use M&S)

4.1. Case study – use of the aerodynamic model to optimize handling qualities campaign.

The project analysis has covered different technologies areas of systems development, integration and aeronautics. In order to clarify previous propositions, it will be considered an analysis based on the use of aerodynamic model to optimize the handling qualities test campaign.

The working group was composed by specialists in flight mechanics, handling qualities, M&S and flight test. Mori (2009), described the entire work in its report "Evaluation of simulation use during a flying qualities certification campaign".

The group focuses on three main subjects: stall characteristics; stability; controllability and maneuverability. These subjects represent 53% of all requirements that should be demonstrated in flight for handling qualities evaluation.

Starting from specific requirements the group analyzed if that requirement could be represented in part or totally by the aerodynamic model. Every test point (minimum task that should be done in flight) that was necessary to demonstrate the requirement has been filtered considering this assumption.

Figure 12 shows one output of this work.

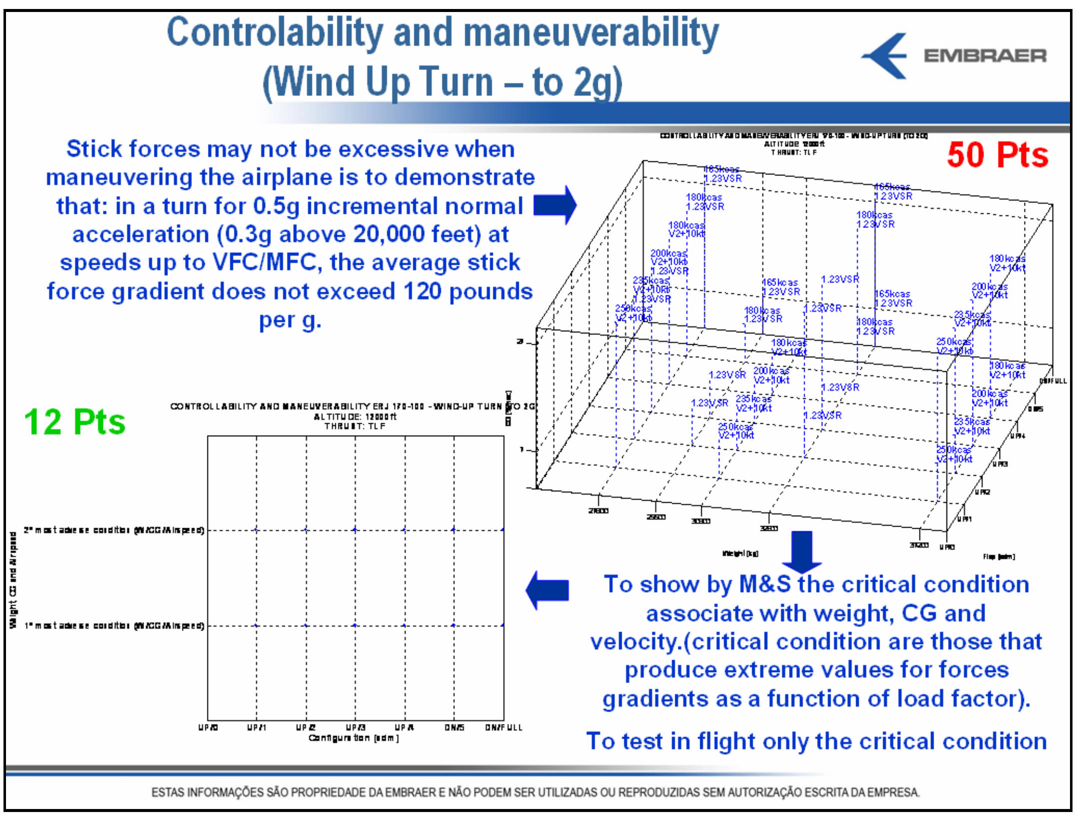

Figure 12. Test matrix optmization considering the use of aerodynamic data bank.

At the left up corner of the figure, it can be seen the requirement that shall be demonstrated as specified in FAR 25. In the right upper corner, the test matrix (the number of test points that actually have been executed to demonstrate the requirement in the EMB170 certification). At the right bottom corner it is shown the premises assumed to use the aerodynamic model and, at the bottom left corner, the new proposition for test matrix.

In this particular case it was possible to notice that the test matrix could be reduced from 50 to 12 test points.

The analysis was applied for the 3 subjects described previously and table 1 gives the result.

Table 1: Potential savings caused by the use of M&S applied to handling qualities subjects.

SUBJECT	NUMBER OF TEST POINTS			SAVINGS (%)
	EMB 170	EMB 190	EMB 170 + M&S	
Stall characteristics	354	92	67	81
Controlability and maneuverabilitty	352	293	110	69
Stability	233	105	38	84

Considering only these 3 subjects, it is expect a reduction of 30% of the total flight test hours expend in handling qualities campaign.

Naturally the cost of implementing this strategy relies on the existence of an aerodynamic data bank that matches the real aircraft behavior. To reach this stage of evolution at the beginning of the certification process, all the process and tools used to develop the data bank has to be changed. This is the object of further work.

5. FLIGHT TEST PERSPECTIVES.

Considering the future scenario were aircrafts will become more complex to accomplish new safety and economic requirements, the traditional way to do flight tests and the entire context of development have to be changed. These changes will affect the following dimensions detailed in the next paragraphs:

5.1. Process, model of development and organizational structure.

Traditional V model and associated process will no longer be applicable, since it causes a late defect identification scenario in the most expensive phase of development when the test articles are ready. New process affecting even the organizational structure will have to be incorporate. The development and update of models with real systems/aircraft behavior and the concept of virtual tests will have to be incorporated in a structure similar to that proposed by Airbus in the Virtual Bird concepts. The organizational structure will have to be changed in order to foster simulations sector. This sector will embrace all the technologies used to develop aircrafts and will be responsible to define patterns of model's creation and integration. This area will have to be merged with test divisions (ground and flight) in order to produce a synergetic effect when integrating M&S, ground test and flight test. Models will have to flow along the entire aircraft life cycle, being updated continuously in order to allow the reuse by all players. This will be object of further work.

5.2. Tools.

M&S and all the tools necessary to implement what could be conceived as a full aircraft model (aerodynamics, systems and their integration) must be the goal of the aircraft developers who wants to stay in the market in an advantageous position. This strong proposition relies on a future vision in which the reliability requirements will become so restrictive that, to demonstrate reliability using test articles will conduct the program out of budget and schedule.

Future use of high Reynolds wind tunnels, where test aircraft models can be tested at the actual flight Reynolds numbers of the full scale aircraft, will have to be considered in the development.

Numerical methods and processes for highly accurate multidisciplinary simulations of aircraft in order to produce the solution of Navier Stockes equations for an entire aircraft in real time, together with the aero elastic model, have to be considered for the next generation's aircraft development. This will be object of further works.

5.3. People.

Flight test engineers (FTE) formation is based on a multidisciplinary approach. FTEs usually has to test all the systems. In order to do this, it is necessary not only to develop a good situational awareness but also to understand (more than a user) all the functionalities and architecture associated with every system that composes the entire aircraft. With the insertion of M&S in this future scenario, and, considering a strategy based on the principle "Find the worst (using M&S) flight the worst", the FTEs will be invited to develop their expertise in M&S, or, at least, to understand how well the models can predict what will happen during one flight.

6. CONCLUSIONS.

This paper has demonstrated that the future of aircraft development relies strongly on a change in traditional process of development and on the way flight tests is done.

In order to demonstrate that, a literature review and a benchmarking research was done.

One case study was presented showing that the use of aerodynamic data bank in supporting flight test can produce significant savings in the entire flight test campaign.

It has been also presented an exercise for future developments. This exercise analyzes the changes in three dimensions: (1) process; (2) tool; and (3) people. It indicates the necessary changes in these aspects to keep adherence with crescent restrictions in aircraft reliability requirements.

7. REFERENCES

Barp, A., “Visibilidade para a ANAC – Desenvolvimentos Tecnológicos” – Avião Virtual, 2005.

Blackburn, M., “Why Model-Based Test Automation is Different and What You Should Know to Get Started” . Software Technology Conference, Safford, 2000.

Boehm, B., “Software Engineering Economics”. Englewood Cliffs, NJ : Prentice-Hall, 1981

Cunha, E.L., “Processo de desenvolvimento integrado do produto”, Embraer normative system, 2007.

Develier, D., “Future os simulation modelling at EADS”, Presentation 16th. Forum ORAPE, Paris, 2004.

Forsberg, K. and Mooz, H., "The Relationship of Systems Engineering to the Project Cycle," First Annual Symposium of the National Council On Systems Engineering (NCOSE), October 1991

Huang, G.C.,“Design for X - Concurrent Engineering Imperatives”, New York: Chapman&Hall, 1996.

Mori, A. K., “Evaluation of simulation use during a flying qualities certification campaign”.São José dos Campos: Embraer web reports, 2009.

Pahl, G., Beitz, W., “Engineering Design : A Systematic Approach” , New York: Springer Verlag, 1996.

Silva, E.T., 2003, ”Quantitative methods for management decisions in flight test campaigns for aeronautical certification”, Master degree thesis, Vol.1, pp. 8-9.

Skelley, E.L.,” Integrated Test and Evaluation for the 21st Century”, California: DTE summit, 2004.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.