AIRPLANE DESIGN: A MUST IN AERONAUTICAL ENGINEERING EDUCATION

R. Martinez-Val and E. Perez
Universidad Politecnica de Madrid
Madrid, Spain

Keywords: *airplane design, education, aeronautical engineering*

Abstract

The trend towards European academic homogenisation, budget cuts and other threats lead to shrinking the time for the aeronautical engineering programs. Some topics, knowledge and skills will have no place in future curricula. The paper advocates for keeping airplane design as a corner stone of the aeronautical engineering syllabi since it is the only topic that educates students in synthesis perspective, binds many independent disciplines and counter-balances 18 years of well developed analytical mentality.

1 Introduction

Let us start with some terminology to establish a common base for the presentation of the case and subsequent discussion.

Aeronautics can be defined as the science that studies the operation of aircraft. A second meaning states that it is the art or science of operating aircraft. Therefore aeronautics is essentially concerned with predicting and controlling the forces and moments of an aircraft travelling through the atmosphere [1].

On its turn, engineering is the practice of applying scientific knowledge to the design, construction and operation of machines and artifices that are required for certain recognised needs. The engineer is, essentially, a professional that solves societal practical problems.

The most relevant and distinctive task of engineering is engineering design, which can be defined as the process of devising a feasible and efficient solution to some specified needs, within given material, technological and economical constraints [2, 3]. It is a complex process, with creative and analytical steps, essentially iterative and interactive as it will be later shown, in which basic and engineering sciences are applied to convert resources into real or somehow tangible products [4]. The term design has evolved in the last decades from a vision of long hours at the drafting table, applying rules of thumb learned only after years and years of experience [5, 6], into a scientific discipline [7]. The designer has to solve a frequently ill-defined problem and has to reach the best (or one of the best) among the many possible solutions. The task is so overwhelming that a design team is required even for small components; not to mention an aircraft [8].

Due to the high degree of complexity of aeronautical engineering, the knowledge and skills the students have to master is very broad indeed. A review of engineering programs in seven leading universities carried out in the mid nineties showed that aerospace engineering required to take more of the specific engineering science than any of the five other majors analysed [9]. This proves the multidisciplinary character and systems integrating focus of such studies.

In spite of its high impact in our way of life, engineering is frequently seen as the result of square brain mentality, although the output is a very important contribution to the entangled mesh of political, sociological or artistic performances which conform our modern society [10]. Figure 1 presents engineering design, i.e. engineering creation, as a central point in a crossroads of other relevant aspects of intellectual activity. As early as in the XVIII Century the creativity of engineers was considered very close to that one of artists. The fine drawings included in the master plans of major works to build new routes, channels, harbours, etc, received considerable attention from the public and museums [11].

Figure 2 depicts the same question from another perspective. Humanities contribute with the "why", i.e. the identification of individual and societal needs. Science contributes with the understanding, facts and data the solution must be built on. Engineering aims at "how" to provide a suitable solution for the needs [12].

However, the relevance of engineering work is very seldom recognised. Humanities and liberal arts are highly respected in society and lead most of the initiatives. Science is also highly appreciated and scientists are regarded as wise men. But engineers are poor writers and communicators, so their work lies mostly in the shadow; nevertheless no other professional has contributed so much to the improvements in life style during the last two centuries [13]. Interestingly, although not always the best policy is the best one from a technical viewpoint, social leaders can never form the right judgments without knowing what is technically right [12].

2 The design process

What shape should an aircraft have to perform according to certain desirable properties? That is the key question an aerodynamic designer must concentrate on [14]. The sentence can be easily extrapolated to engineering design in general. This approach is valid for full new designs as well as for improvements of already existing types.

The method of enquiry used by designers is the so called hypothetical-deductive approach, originally developed by Kant [15] and later adopted and refined by many others [16, 17]. According to this, the creative part of design is the formation of a conjecture or intuition, following a rationale which is not logical neither illogical. As a matter of fact it does not rely on existing concepts or knowledge, but it freely flows through a period of imagination and speculation. However, once the conjecture has taken shape, it is exposed to analysis and criticism. By persistent reflection of pros and cons, advantages and disadvantages, possibilities and limitations, the designer comes up with a high degree of confidence on its creation, which then passes to a period of detailed scrutiny by colleagues, managers or customers.

This entangled, back and forth intellectual path is well depicted in Fig. 3. Our right brain creates or makes synthesis in a very complex and not fully understood process. The key words here are uninhibited thinking, no judgment, no decisions, search for alternatives, far sight perspective [4]. But this is immediately followed by the surveillance of our left brain which criticises the quite often absurd designs resulted from the previous step. Rigid rules are applied to check consistency with established knowledge and available technology. Obviously the whole process is highly iterative, and convergence is not at all guaranteed. Innovation equates to risk [18] for it goes along with irrational, uncertain, passion and endeavour. The maturity of new concepts and ideas takes long time; particularly in aeronautics for its extremely demanding leit-motiv: safety.

The left brain performance relies on a well established physico-mathematical basis and has a powerful capability of explanation and prediction. It is this prediction capability what has boosted the engineering design science to the upper posts in the ranking of usefulness and appeal. The fast technological evolution, the tight industrial competition and other factors have resulted in the need of accurate prediction tools of the size, weight, performances, and other features of the new aircraft.

To better understand the peculiarities of this new science, a good starting point is to have a look on the categories of knowledge and the knowledge-generating activities, as well as on the interaction between both [2]. The vast majority of engineering design knowledge can be categorised under the following headings:

- Fundamental design concepts and operational principles.
- Criteria and specifications, that translate the qualitative goals into specific, quantitative terms.
- Theoretical tools, mainly mathematical methods.

- Quantitative data, about materials or other physical or abstract items, frequently represented in tables or graphs.
- Practical considerations and rules of thumb, mostly learned from experience, hard to find in written form.
- Design instrumentalities, i.e. the procedures, ways of thinking, judgmental skills, etc.

On another side, the knowledge-generating activities can be classified into the following types:

- Stepping up from science, i.e. ordinary creation of knowledge.
- Invention; isolate ideas without requiring a scientific background.
- Theoretical engineering research, mainly analytical tools.
- Experimental engineering research, to provide vast amounts of quantitative data.
- Design practice
- Production, i.e. findings on the manufacturing experience.
- Direct trial, appeared in every-day operation.

The interaction between both classifications provides the matrix depicted in Fig. 4, which allows to understand the role of designers, researchers and academics.

Let us now focus on the design process as it is performed in the aeronautical industry. Although the peculiarities and the wording may vary from manufacturer to manufacturer, or between civil and military products, Fig. 5 presents the phases and major events in a very well known scheme [7, 19]. From the design viewpoint three different steps can be distinguished: a conceptual design phase, a preliminary design phase, and a detail design phase. The first one is devoted to the outlining (creative part) and assessment (judicious part) of alternative concepts fulfilling most specifications and requirements. On its side, the preliminary design task is aimed at the optimisation of a few concepts and the selection of the definitive configuration. Finally, the detail design phase has to perform the extensive and complete definition of the chosen configuration. Some researchers prefer the terms conceptual design, embodiment design and detail design [10], to make it clearer that it is in the second phase when the new product gets its shape.

The type of methods used in each design phase deserves an explanation (see Table 1) [7]. At the very beginning there is a great uncertainty on the physical characteristics. The previous experience of the designers and the existing similar products provide first estimations, but it is clear that such uncertainty together with the need of fast results oblige to using simple and not too accurate prediction tools. Later on the design progresses and the new product is better known. The optimisation process, carried out in the preliminary design phase, requires higher accuracy; although some speed is still appreciated in obtaining results. Thus, accurate but not too complex methods are used. Finally, when the configuration is fully frozen, the designers work with a well defined product and all types of complex and highly accurate methods, to deliver the product to the market in a reasonable timeframe.

From the pedagogic point of view, to close the gap between the classroom and the real industrial world, it is very important to show the students how vital are the primary objectives of a project: quality, time and cost; as shown in Fig. 6 [20]. Quality, in this picture, means performance, safety, reliability, etc, concepts that are quite clear for them. The term time implies that the project must be completed within the opportunity window provided by the market; a situation about which the students are seldom aware of. Finally, cost is a very fuzzy concept for students, but of enormous relevance for industry; and represents that the project cost must be kept within suitable budget limits.

Analogously, aiming at the same pedagogic objective of approaching students to industry it is interesting to show them the relative position of project work, and design within it, as a part of the overall life cycle and its different aspects, which are presented in Fig. 7 [7, 21]. The professional life takes always place in one or more of the various stages of the product life cycle, depending upon age, preferences and personal development.

Understanding the life cycle of a product, provides the students with a first hand feeling on the mid-long term career they will follow once enrolled in a job. For example Fig. 8 shows the financial difficulties on introducing a new product, how the market maturity means good business, or the need of updating or improving the product through new versions. The responsibility of the engineers all along this product life cycle is easily perceived [10].

3 The challenge

The academic scenario is changing in both sides of the Atlantic due to powerful forces. Let us concentrate this paper on the European side. Framed within a process of continental homogenisation the European Union authorities have undertaken what is called the Bologna process, which will directly imply the shortening of engineering curricula in many countries: France, Germany, Italy, Spain, etc.

Traditionally, continental Europe engineers have been educated with programs that lasted five or six years, with a very solid basis of Physics and Mathematics and other more specific engineering sciences. It is true that some countries also had engineers educated along only three years, but they were not recognised as fully competent professionals for their too shallow background. The so-called Bologna process will require to change to the Anglo-Saxon system of a lower level Batchelor degree, followed by Master and Doctor degrees. This system performs reasonably well in UK and USA, and the industry is well aware of all implications in career development, including for example continuous education, on-job learning, etc. The situation is not at all the same in those countries listed above, and many years will be required before the employers understand the changes in knowledge and skills of the fresh enrolled engineers.

But the problem addressed here comes directly from the shortening of the curricula, exacerbated by budget cuts and other threats. As a result from such time shrinking some topics and some knowledge will have no place in future aeronautical engineering programs. And airplane design is in real risk of disappearance for the reasons that will be presented in the next paragraphs.

One could argue about the value of design education taking into account that very few graduates will actually participate in the design of a new product in their professional careers; not to say in a new aircraft [7, 22]. Fewer than 2 percent of engineers in the aerospace industry are involved in conceptual design, plus some 8 percent in preliminary design [23]. But the design process is central to the engineering profession: it is the engineering methods and the capability of designing that binds all engineering disciplines together and defines the engineer [2, 10, 22].

What type of engineers do we have to educate for the next decades? The answer must come after considering the list of challenges to be addressed by the aerospace industry. It includes [12]:

- Continue to maintain and develop an effective transportation system, safe, secure and compliant with the needs of our society and the environment.
- Continue to contribute to the global security, properly facing the new threats.
- Contribute to providing the necessary aeronautics component for the affordable use of space, to enable the further exploration of the universe.

A well-rounded engineer [12] should master a broad spectrum of knowledge and skills to allow him the choice of a satisfactory career in one of the four major branches of professional activity, shown in Fig. 9: technical specialist, designer, program manager, or logistics and support engineering.

In the past, most efforts to reform engineering education have been carried out from a university perspective, mainly reactive to perceived needs of industry [24]. Although it is recognised that industry can and must influence engineering education, it frequently expresses varying and contradictory messages, most times uncoordinated with universities and governments. A sustained action is required to provide a strategic view of long term perspective, but not enough effort has yet been done on that side [25].

Coming back to the real challenge of curricula shortening and the subsequent disappearance of some academic disciplines, it must be recalled that airplane design is an essential component of any aeronautical engineering syllabus. Namely students must learn how other sciences and technologies (such as aerodynamics, performances, structures, materials, propulsion or aircraft systems, to mention but a few) are integrated into an airworthy, efficient aircraft [26].

What is taught by design is not learnt anywhere else [22]. Although the higher elements of experience and judgment are largely acquired in industry after graduation, the foundation for this process and the preparation for life-long learning must be provided by the university [22, 27].

Obviously, the teaching of airplane design can be performed in quiet different ways: case studies, individual projects, group projects, Master Thesis, and so on [8, 28]. Each one has certain advantages, but what is clear is the high pedagogic value of design education, mainly to gather the large amount of scattered knowledge learnt in the aforementioned disciplines, and to arrange all this knowledge to act together for a well defined objective: create a configuration and analyse its main features regarding real life operation.

The teaching of airplane design is very gratifying, but it is also plenty of obstacles for various reasons. First, the students are somehow frustrated by a topic which is appealing but at the same time not easily understandable by their analytically educated minds [27]. On another side, young lecturers are rarely competent in design since they lack experience; most professional designers are in the industry and most of them do not have a PhD degree, commonly required at universities. Moreover there is little funding for design research, and faculty members have to find additional lines of activity to establish an acceptable publication record. This problem is worsened by the fact that there are not true design journals. Finally, design requires much more time and effort than regular academic courses, which is not always well understood by academic authorities [7, 8].

4 Conclusions

Although several years of on-job learning are required to become a real professional of aeronautical engineering, the university must provide all essential background for properly performing at such a job. Moreover, the university must stimulate a life-long learning attitude to avoid the inevitable obsolescence of the initial education received.

Even though few engineers will actually participate in the conceptual or preliminary design of a new product, the great pedagogic value and rich intellectual contents of design education is well appreciated by academia and the industrial world.

In this sense, Airplane design is recognised as a science that agglutinates many other disciplines, educates the student in synthesis perspective and contributes to create in the future professional an open mind mentality. Consequently it must be a compulsory part of any aeronautical engineering curriculum.

Acknowledgements

The authors appreciate the support from Universidad Politecnica de Madrid in the preparation of this paper and its presentation at the 2008 ICAS Congress.

References

[1] McCormick, BW, *Aerodynamics, Aeronautics and Flight Mechanics*, 2nd Edition; John Wiley and Sons, New York (USA), 1995.

[2] Vincenti, WG, *What Engineers Know and How They Know It*; The Johns Hopkins University Press, Baltimore, USA, 1990.

[3] Martínez-Val, R, Cuerno, C and Pérez, E, Students' Attitudes and Performances on Airplane Design; *AIAA 99-0283*, 1999.

[4] Ertas, A and Jones, JC, *The Engineering Design Process*; John Wiley, New York, USA, 1993.

[5] Haupt, U, Taking a new Perspective on Design; *Aeronautics and Astronautics*; pp. 52-58, May 1978.
[6] Torenbeek, E, Teaching and Learning Conceptual Design in the CAD Era: Generating Problems and Integrating Solutions; *AIAA 85-3081*, 1985.
[7] Martinez-Val, R, On the science of Airplane Design; *Proc CD ROM Giuseppe. Gabrielli Centennial Conference*, Turin (I), 2003.
[8] Martínez-Val, R and Pérez, E, Teaching airplane design: a multi-level approach; International *Journal of Engineering Education*, Vol. 13, pp. 304-312, 1997.
[9] Loewy, RG, Perceptions and realities in engineering education; *Aerospace America*, p, 3, November 1996.
[10] Pahl, G, Beitz, W, Feldhusen J, and Grote, KH, *Engineering Design. A systematic approach*, 3rd edition; Springer, London (UK), 2007.
[11] Picon, A and Yvon, M, *L'ingénieur artiste* (in French); Presses de l'École Nationale des Ponts et Chaussées, Paris (F), 1989.
[12] McMasters, JH, Reflections on the future of Aeronautics- An early 21st Century perspective; *AIAA 2005-0004*, 2005.
[13] Martinez-Val, JM, *Un empeño industrial que cambio a España. 1850-2000. Siglo y medio de Ingenieria Industrial*; Sintesis, Madrid (E), 2001.
[14] Küchemann, D, *The aerodynamic design of aircraft*; Pergamon Press, Oxford (UK), 1978.
[15] Kant, E, *La critica de la razon pura* (in Spanish); Alfaguara. Madrid (E), 1978.
[16] Popper, KR, *Conjectures and refutations*; Routledge and Kegan Paul, London (UK), 1963.
[17] Medwar, PB, *Induction and intuition in scientific thought*; Methuen, London (UK), 1969.
[18] Young, TM, Aircraft design innovation: creating an environment for creativity; *Proc IMechE Part G Journal of Aerospace Engineering*, Vol. 221, pp. 165-174, 2007.
[19] Torenbeek, E, *Synthesis of subsonic airplane design*; Delft University Press, Delft (NL), 1976.
[20] Lock, D *Project Management*, 8th edition; Gower, Aldershot (UK), 2003.
[21] Lock, D, *The Essentials of Project Management*, 2nd edition; Gower, Aldershot (UK), 2001
[22] Young, TM, Draft design education at universities: benefits and difficulties; *Aircraft Design*, Vol. 3, pp. 207-215, 2000.
[23] Nicolai, L, Designing a better engineer; *Aerospace America*, pp. 30-46, April 1992.
[24] Martinez-Val, R, Aeronautical engineering education in Spain: changing needs in an evolving scenario; *European Journal of Engineering Education*, Vol. 22, Nº 3, pp. 321-333, 1997.
[25] McMasters, JH and White, BJ, Industry-University-Government roundtable for enhancing engineering education; *AIAA99-0281*, 1999.
[26] Roskam, J, Facing the crisis in aircraft design education; *Aerospace America*, pp. 24-27, April 1992.
[27] Covert, E, Engineering education in the '90s: Back to basics; *Aerospace America*, pp. 20-46, April 1992.
[28] Stocking, PJ, The teaching of aerospace vehicle design at Cranfield University with particular reference to the group design project; *Proc IMechE Part G Journal of Aerospace Engineering*, Vol. 221, pp. 225-234, 2007.

Copyright Statement

Table 1. Features of the distinct design phases

Phase	Error	Time	Cost of step	Method
Conceptual	3-10 %	Negligible	Negligible	Handbook
Preliminary	1-3%	Rapid	Low	Semiempirical
Detailed	<1%	Reasonable	Moderate	Complex

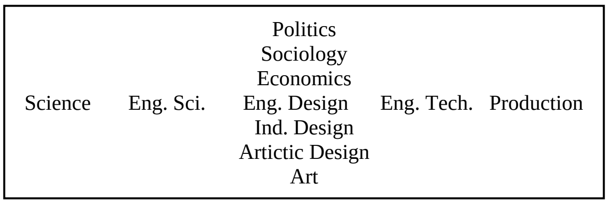

Figure 1. Engineering design in a crossroad of intellectual activities

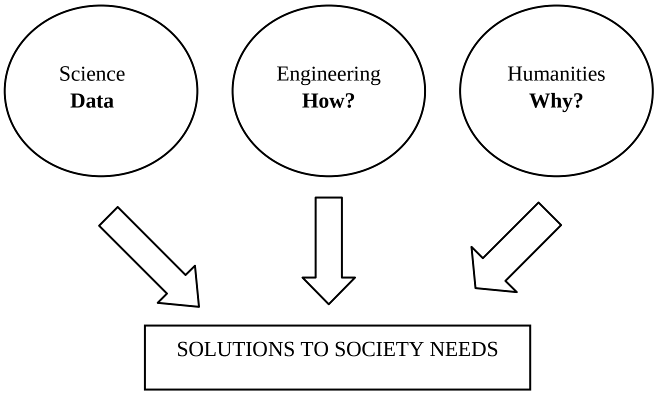

Figure 2. The role of engineering in society

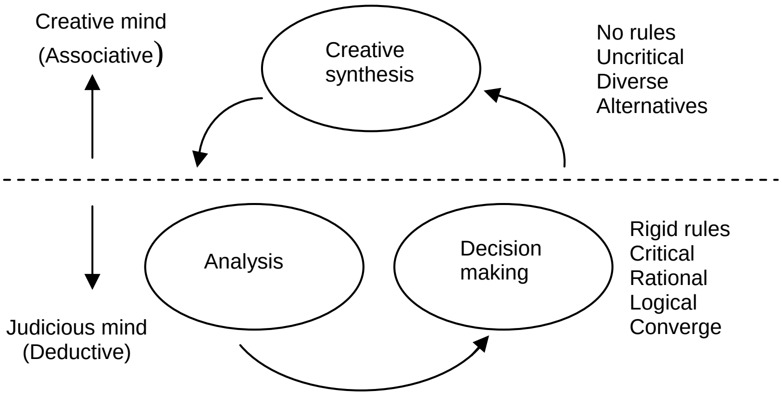

Figure 3. Required intellectual capabilities for the engineering design process

Categories Activities	FC	CS	TT	QD	PC	DI
Transfer from science			X	X		
Invention	X					
Theoretical eng research	X	X	X	X		X
Experimental eng research	X	X	X	X		X
Design practice		X			X	X
Production				X	X	X
Dirct trial	X	X	X	X	X	X

Figure 4. Relationships between categories of knowledge and knowledge generating activities

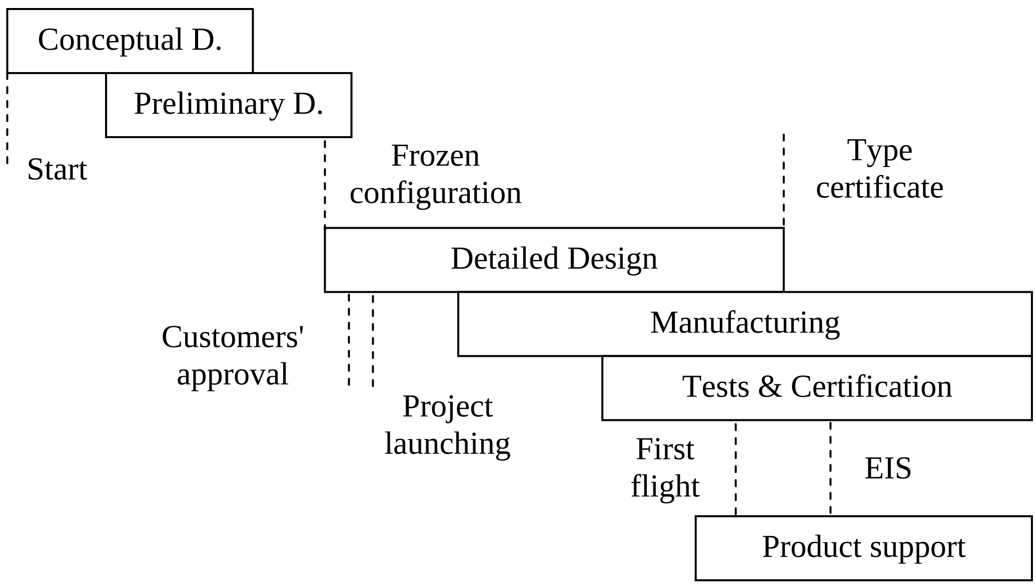

Figure 5. Phases and main milestones of a project

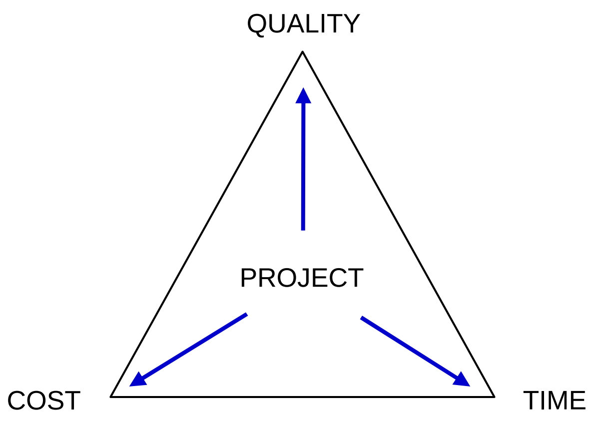

Figure 6. balancing the primary objectives of a project

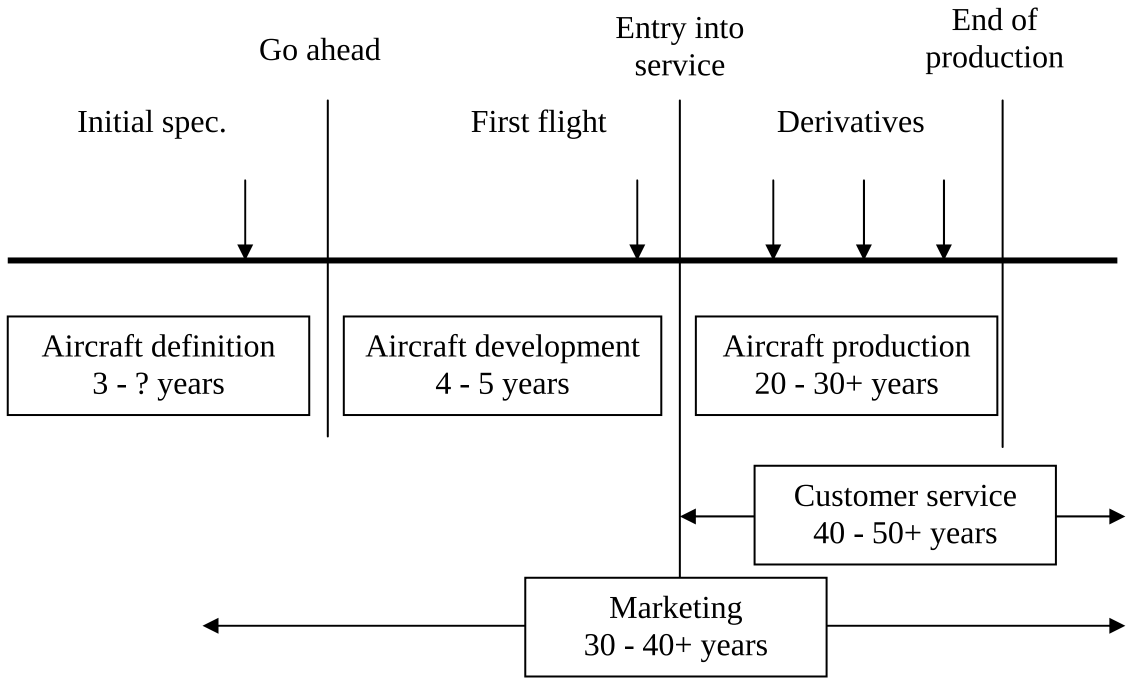

Figure 7. Life cycle of an aircraft program

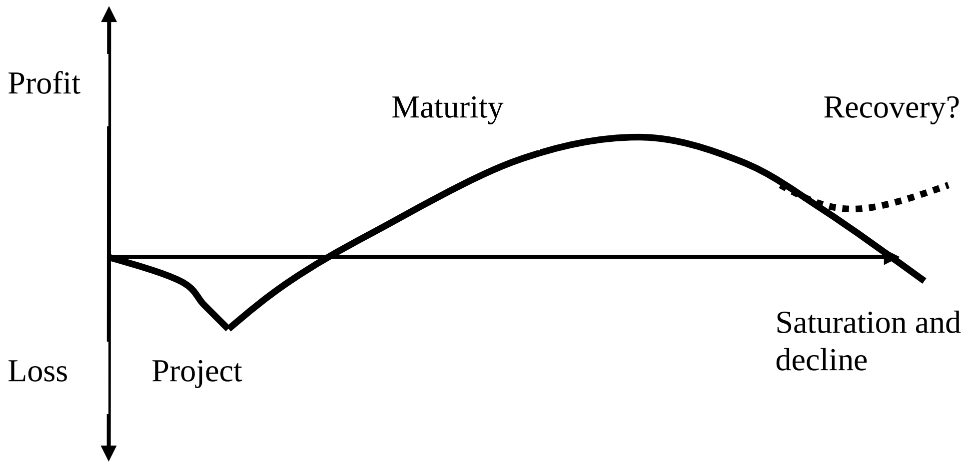

Figure 8. Financial perspective of a product life cycle