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Aircraft design education at universities: benefits and difficulties

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Abstract

The value of teaching aircraft design at university by means of student design projects is explored. It is argued that conceptual design is an essential part of engineering education and it provides a foundation for the development of engineering judgement, which is required to establish a balance between safety, economics and functionality of an engineering system. The design process is constituted by two elements – a creative process involving the postulation of design alternatives, and an analytical process, which evaluates the envisaged designs. Detail design teaches vocational skills and instils an awareness of the complex, multidisciplinary and integrated nature of the aeronautical engineering business. The factors that limit the quality of design education include: support staff, time, financial resources, teamwork and lecturing staff. © 2000 Published by Elsevier Science Ltd. All rights reserved.

1. Introduction

There is an emphasis placed on design, and in particular Conceptual Design, in many aeronautical engineering courses. A brief description of what is felt to be a typical approach is outlined as an introduction to the substantive element of the paper.

At the University of Limerick and at The Queen's University of Belfast, Conceptual Design is undertaken in small groups of about five students. A specification for an aircraft is supplied, providing details on payload, range, speed, take-off and landing performance, etc. The students work through a classical process of conceptual design, based largely on textbook methods. Students start by producing concept sketches of the aircraft, which are evaluated and a single solution is adopted by the team. A parametric sizing follows where a design point is selected which

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satisfies all requirements on a graph of power loading (or thrust-to-weight ratio) versus wing loading. The conceptual layout of the complete aircraft is developed and an integrated report is produced which addresses not only the technical aspects of the design, but also the financial viability of the concept.

In another part of the curriculum, students participate in an on-going design project (that started in 1995) of a two-seat aerobatic aircraft. Again they work in teams, but this time students are expected to take over from the previous year's group and progress the design, rather than starting afresh. Work completed to date has included CFD analysis, wind-tunnel testing, loading actions, preliminary design of the structure and systems using 3D CAD (Pro/Engineer) and stress analysis (including the finite element analysis of critical elements). A 1/5 scale radio-controlled model is being built to further explore the aerodynamic design.

The projects are backed up by approximately 50 hours of lectures in aircraft design. The approach adopted at Limerick in teaching the subject is not unique and many similarities exist with other establishments.

2. The devil's advocate—the value of design education?

At this juncture, the devil's advocate poses the question:

> Can this teaching of design and in particular conceptual design be justified in view of the fact that there has been a progressive reduction in the number of new aircraft projects launched each decade? Very few graduates in their professional careers will ever use the techniques of tail plane sizing or matching of the power-loading requirement to a climb performance specification – techniques essential to the initial sizing of an aircraft. So is it justified to place this subject in a crowded engineering curriculum?

The answer to this question is unequivocally *yes* – not so much because of the vocational skills acquired by the students, but because such projects, in spite of their shortcomings, are superb vehicles for teaching many essential elements of engineering itself. The *design process* is central to the engineering profession.

3. The design process

Asked about aircraft design by an interviewer, Rutan [1], designer of the Voyager aircraft (Fig. 1) and many other extraordinary aircraft, replied:

> To come up with something new and address a new requirement ... you need ... to go back pretty much to a sketch board and try different things. Having the courage to try something unusual and then combined with the engineering knowledge [to determine] will it work: that is what is needed. We spend an awful lot of money on how to analyse, but we do not spend much money on creating an environment for creativity. Much of what people do, called design, is really better called analysis. So [aircraft] design is something different. You need to

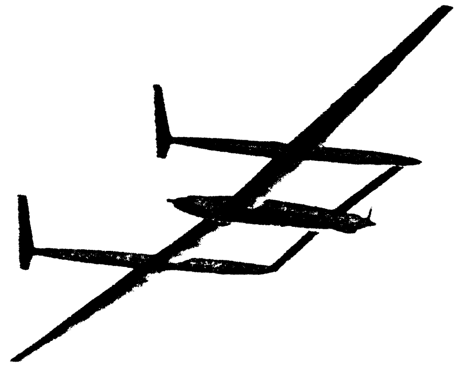

Fig. 1. The Voyager – designed by Burt Rutan [2].

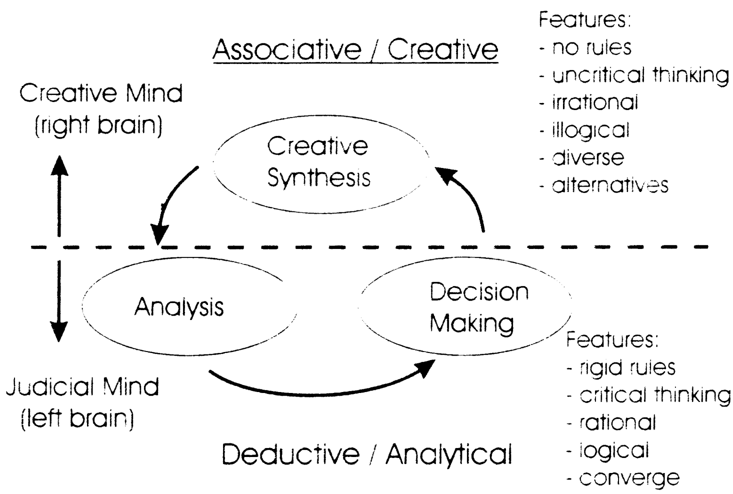

Fig. 2. The engineering (design) process from [3].

be able to visualise load paths and visualise the [air] flow over an airplane and [to know] just what it needs to do.

Aircraft design is both *art* and *science*, it is *creative* and *analytical*. The *design* process is constituted by these two elements (Fig. 2). Diverse, lateral thinking, which may even produce illogical, seemingly bizarre alternatives, is required in the creative process. The uncritical "brain storming", the borrowing of unrelated concepts from other engineering disciplines and the observation of nature, are all essential parts of original design. This irrational thinking process, without rules and constraints, produces the necessary design alternatives. Thereafter, when the essence of the concept is sketched out, the analytical part of the brain takes over. This part of the process is characterised by rigid (scientific and mathematical) rules and rational analysis. Convergence of alternatives is achieved by design reviews, which will often lead to another cycle of creativity. It is these cycles of creation and analysis that produce new solutions to engineering problems.

Aircraft design is by its very nature, an iterative process that seldom has a clear starting point and a sequential series of events that lead to the final pack of detail drawings. Instead designs evolve in a cyclical process that moves from a list of *perceived* requirements through the creative mode, to the analysis, (the objective of which is to predict the performance of the envisaged design) and then loops back to a possible review of the requirements.

The solution of a problem which clearly has no unique answer is at first shocking and uncomfortable for many young students who have grown to expect right and wrong answers to questions, but it is probably the first steps they take in developing, what is often called, *engineering judgement*. It is useful to explore what is meant by this term before returning to the value of aircraft design education.

4. Engineering judgement

The mental process of making an engineering judgement is based on *knowledge* and an awareness of the broader issues surrounding the problem: which may be called *situational awareness*. Such knowledge and awareness is acquired by study, perception, reasoning and intuition. There are essentially two categories of decision-making involving judgement: *perceptual judgement* and *cognitive judgement*. The differences are illustrated in Fig. 3.

(a) The *perceptual judgement* in this case involves the pilot making a decision (like when to initiate the flare) based on his/her recognition of height, speed, wind, terrain, etc.
(b) *Cognitive judgement* in this situation can be summed up as "as a process involving the pilot's attitude to taking risks, and his/her ability to evaluate these risks and arrive at a sound decision based on knowledge, skill and experience" [4].

Perceptive judgement is usually not an issue for practising engineers (unless they happen be working as a flight test engineer, for example), but cognitive judgement is an essential element of the creation process, which is core to the engineering profession.

A scientist discovers that which exists. An engineer creates that which never was.

Theodore von Kármán

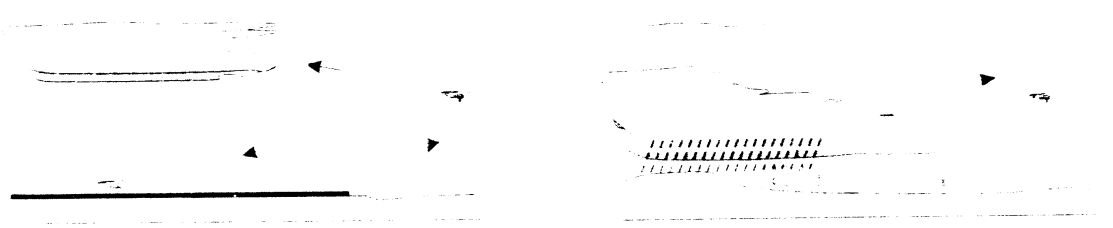

Fig. 3. (a) Perceptual judgement (b) cognitive judgement based on figure from [4].

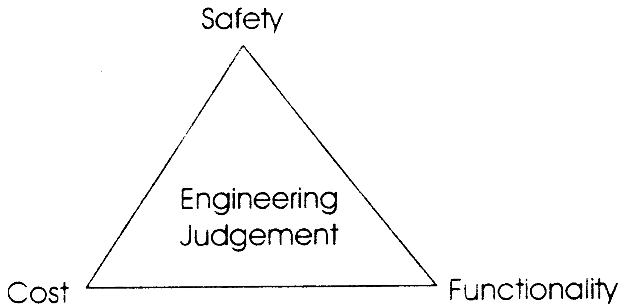

Fig. 4. Engineering judgement.

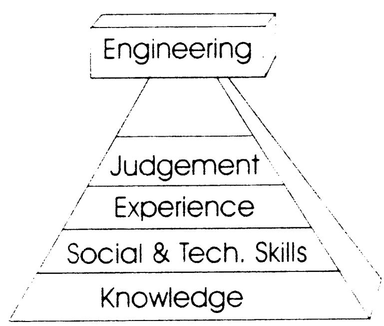

Fig. 5. Engineering hierarchy of skill.

Structural design engineers use a factor of safety of 1.5 on limit loads. A factor of 1.6 would be safer, but with the obvious weight and cost penalties. Regulatory Authorities accept a scatter factor of 3 with respect to the fatigue life of safe-life structures. These numbers are not fundamental laws set in stone, but just good engineering practice. Establishing that balance between safety, economics and functionality requires engineering judgement (Fig. 4). In short it may be said that engineering itself relies on judgement, which in turn relies on *knowledge*, *skill* and *experience* (Fig. 5).

It would be foolish to assume that universities can and should provide all the building blocks of knowledge, social and technical skills, experience and judgement – essential to the making of a professional engineer – all within a four (or even a six) year university course. Certainly, universities are well equipped to transfer *knowledge* and train students in the required *technical skills*. (There does however appear to be a lower emphasis on the *social skills*, particularly in areas like team working, conflict resolution and communication.) The higher elements of *experience* and *judgement* are largely acquired by the engineer working in industry after graduating. The university must however lay the foundation for this process and prepare the individual for life-long learning.

Design projects in universities go some way to develop this engineering judgement. They also instil an awareness of the complex and integrated nature of the aeronautical engineering business. The interdependence of the many aerodynamic, structural, systems and manufacturing problems – which can only be solved in a multi-disciplinary manner – are well illustrated in such design projects. In this broad sense, design is a life skill [5].

Koen [6] wrote: "It is the engineering methods or design process, rather than the artifacts designed, that binds all engineering disciplines together and defines the engineer". The selected vehicle for this design process – an aircraft – happens to be superbly suited to the teaching of these skills.

Accepting the merits of teaching aircraft design at universities, the devil's advocate returns to ask: "*How well is the job being done?*"

5. The criticism

McMasters [5], Senior Principal Engineer, BCAC, wrote:

> We see too many new graduates with an inadequate grasp of what engineering (as contrasted with engineering science) is and how one practises it, particularly in the currently evolving industry environment. Too few of our engineering graduates seem to have any idea of how to work in teams or how to manufacture anything. Fewer seem to understand the process of large-scale, complex system integration which characterises so much of what we do in our industry.

At an earlier session of the workshop[1] Bertolone of Alenia Aerospace spoke about the need for students to develop *systems integration* skills. New graduates have a lack of "*global vision*" he stated.

These criticisms are not levelled at the quality of teaching of subjects like thermodynamics, or mechanics of solids (which McMasters refers to as *the engineering sciences*), but rather at a failure of *design education* in its broadest sense. Academics may ask: "*Is the criticism justified?*" Anecdotal evidence suggests that the answer to this question is *yes*, but maybe not as a uniform criticism of all engineering schools, due to the diversity of curricula between different educational institutions in Europe.

6. Factors affecting design teaching quality

Five factors have been identified that broadly limit the quality of design education provided at universities.

(1) Support staff.
(2) Time frame.
(3) Financial resources.
(4) Teamwork.
(5) Lecturing staff.

[1] First session of the Fourth European Workshop on Aircraft Design Education, Torino, 8–9 May 2000.

6.1. *Support staff*

It is usually not possible to assemble a support group of academic staff within most universities with the correct mix of structural, aerodynamic and systems competence to guide students in realistic design projects. Furthermore, even if these academics were available, the requirement for skilled technicians with manufacturing know-how is often missing, limiting the opportunity to produce actual components.

6.2. *Time frame*

Project work is usually limited by the academic calendar year. Projects usually run for one or maybe two semesters. This is not enough time to fully develop the design. Many universities only present conceptual design projects for this reason.

6.3. *Financial resources*

Financial resources limit the work performed at all universities in all areas. Design is no exception; it just happens to be very costly to build flying hardware.

6.4. *Teamwork*

Modern design efforts involve teamwork and real teamwork cannot be totally replicated at university. Students who excel academically have mastered the competitive environment that universities create. The social skills of co-operation, communication and the sharing of resources, do not lend themselves to be taught in an environment that awards degrees on individual performance.

6.5. *Lecturing Staff*

This is singularly the most important element. It is argued that the requirements for an effective design lecturer professor is someone with 5–10 years of relevant industrial experience. The devils advocate asks: "*How well does the individual perform after joining the world of academia?*"

The quality of the teaching will obviously vary tremendously depending on the skills and background of the individual, but a sweeping generalisation is made based on the quality of the presentation of the lecture material and the quality of the content of the material. It is suggested that these two parameters will vary with time (Fig. 6).

The *quality of the presentation* of the lecture material rises quickly as the new lecturer develops teaching skills and lecturing experience. It plateaus and then starts to fall as other responsibilities and research demands increase, reducing preparation time. The *quality of the content* of the lecture material falls with a half-life of about 5–8 years as:

(1) The relevance of the previously acquired industrial skills diminishes (i.e. the individual does not keep up with industrial developments).

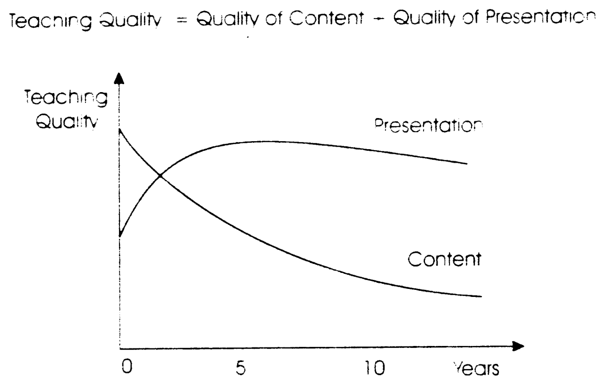

Fig. 6. Teaching quality for a new design lecturer.

(2) The sharpness of previously honed skills and technical knowledge fades (i.e. the individual forgets).

The problem is compounded by two factors:

(1) Universities increasingly demand that all academics have a Ph.D. In fact, the very requirement for industrial experience, works against the individual having this qualification. The requirement can and does discourage talented engineers from becoming full time academics.
(2) The emphasis placed on the annual "*paper count*" (i.e. how many journal papers were written) needs to be reassessed. Laboratory test campaigns like those required to study the adhesion of two structural materials yields lots of results that lend themselves to publication; however to set up a *design* experiment with the same ease, is just not possible. A likely outcome is that the individual will develop research areas outside of the aircraft design environment, in disciplines such as materials science, where he/she can acquire research funding and publish results.

These factors can exacerbate the problem of design teaching quality by soaking up time and making it less likely that the academic will work on industrial problems and keep abreast of new technologies.

7. What can be done to remedy this?

The industry should:

(1) Increase its participation in university design projects: after all, industry stands to gain the most from the process.
(2) Welcome industrial placement of students for work experience.

The university administration should:

(1) Recognise industrial experience on a par with research experience.
(2) Encourage, or better still, make it compulsory for design lecturers to spend time in industry on sabbatical every 5–8 years.
(3) Recognise that design is a unique subject within the degree course programme.
(4) Reduce the emphasis on the annual "paper count" in assessing performance and balance the appraisal with greater weighting allocated to teaching quality.
(5) Make greater use of practising engineers from industry in teaching this element of the course.

8. Concluding remarks

(1) Both conceptual design and detail design are valuable elements in a engineering course curriculum, but for different reasons.
(2) Conceptual design is an essential part of engineering education and provides a foundation for the development of engineering judgement.
(3) Detail design teaches vocational skills and instils an awareness of the complex, multidisciplinary and integrated nature of the aeronautical engineering business.
(4) Industry and university administration should accept that design is a unique subject within the course curriculum, which requires special consideration if students are to acquire the necessary multidisciplinary engineering skills.

References

[1] Rutan B. Scaled composites, in a documentary interview, undated.
[2] NASA Dryden Flight Research Center, web address www.dfrc.nasa.gov/gallery/photo/.
[3] Boeing Commercial Airplane Company. An overview of aircraft design and systems engineering. Boeing summer intern program notes, prepared by J.H. McMasters, June to August 1995.
[4] Campbell RD, Bagshaw M. Human performance limitations in aviation. Oxford: Blackwell Science, 1991.
[5] McMasters JH, Lang JD. Enhancing engineering and manufacturing education: industry needs, industry roles. American Society for Engineering Education Annual Conference and Exposition, Anaheim, CA, June 1995.
[6] Koen BV. Definition of the engineering method. American Society of Engineering Education, Washington DC, 1985.