AN ANGLO-US VIEW OF AIRCRAFT DESIGN EDUCATION

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Abstract

This paper is based on 25 years' of running aircraft design courses at undergraduate level mostly in the UK but interspersed with extended periods in the United States. The major differences in project organisation between the two countries' approach to aircraft design education are, from the author's experience, based on the nature of the way the two countries' engineering degree courses are structured. In the UK courses tend to be more flexible and differ markedly from one institution to another. In the US the courses are of an equally wide variety but tend to be more highly structured. Both approaches have their value. Specifically the paper contrasts the methods of assessment and resources currently in place at Cranfield University at its Royal Military College of Science (RMCS) campus and the USAF Academy (USAFA), at Colorado Springs. Lessons learned conclude the paper.

Introduction

Design has long been recognised as pervading all engineering activities and as an integrating theme bringing together a wide range of learning. Aircraft design is an ideal vehicle to achieve this integration. In both of the institutions concerned in this paper, (USAFA and RMCS) *whole* and *new* vehicle design are addressed. It is important to draw this distinction since other institutions focus on component and/or derivative design.

Objectives

The objectives of aircraft design education are:

1. To provide realistic experience in dealing with a major design exercise and to promote an understanding of the interacting requirements associated with aircraft design.
2. To participate in a group activity and to develop teamwork, professionalism and leadership qualities.
3. To develop technical competence in the application of academic studies in multi- and cross-disciplinary situations and to appreciate the limitations of theory.
4. To develop the skills of communication in both written and oral presentation.

The many differences between engineering education in the US and UK inevitably but naturally mean that different methods are used to achieve the same goals.

Project Organisation

In both institutions aircraft design is a senior (final) year topic and consequently draws on previous years' and concurrent experience.

The major difference in organisation between UK and US institutes is that most US university courses are structured to allow only two-hour sessions at a time. At USAFA the topic of aircraft design is broken into two semesters comprising: Introduction to Aircraft & Engine Design (AE481) and Aircraft Design (AE482). Each semester classes meet on 42 alternate days.

In the case of RMCS, which runs a three-year BSc degree in Aeromechanical Systems, the topic is allocated one day/week for 27 weeks. This coincides with the project day when other students are engaged with their individual project. Organisation of the aircraft design project is shown in Fig. 1. It is believed that this is more amenable to fostering close harmony within the design team and allows more flexibility to overcome critical design phases.

Another distinguishing aspect between the RMCS and USAFA philosophies is that the former incorporates minimal lecturing input. At RMCS, emphasis is placed on the design team itself taking responsibility for acquiring knowledge and expertise. This implies that an individual student gets only a sketchy knowledge of a project as a whole and quickly becomes 'specialised'. To an extent this is true but the philosophy of the project run at RMCS is based on developing a student's own skills for research that they can apply to a team effort. The weekly, formally minuted, one hour long meetings enable individual team members to keep abreast of developments in areas other than their own and take meaningful decisions.

Another difference is the tendency to use larger teams in the UK: up to 15 students, though experience shows that 12 is the optimum team size.
At USAFA, lectures form about 40% of the allocated time, though this is concentrated in the early part of the semester and blends with Academy's more rigid structure. Another difference at USAFA is that cadets initially work in pairs on conceptual designs making heavy use of constraint analysis. The purpose of the first design review is to assess each concept, whereupon the perceived best is chosen for further development. The USAFA teams are not able to continue intact for the second semester, for several reasons. Cadets may opt for the aircraft engine design module (AE483), they may choose to work on a different aircraft in the second semester, or timetabling restrictions may break up teams. RMCS, being a much smaller institution, is not subject to these restrictions since only one basic design requirement is issued (though there may be more than one team).

Assessment Methods

One of the major and justifiable concerns over group projects is the assessment of individual effort. This is especially important when such projects count for a large proportion of final year grades.
At RMCS the assessment is made as follows:

Criteria	*Activity*
Technical competence	Project team meetings
Information retrieval	Interim *group* report
Contribution to team effort	Final individual report
Presentation and communication	Three presentations

Table 1 Assessment at RMCS

The first major assessment occurs at the end of Stage I (Fig. 1) and is based on the interim group report. Each student contributes a chapter. The document provides a formal statement of progress and is an opportunity for reflection. At the end of Stage II team members submit an in individual report detailing their own work. For completeness this will contain, as an appendix, their contribution to the interim report. In addition to these formal submissions each student is individually assessed on contributions during the weekly project meetings.
In contrast, the assessment at USAFA is made up of a much larger number of contributions, as is typical of American practice. Because the course is broken into two semesters, each semester has its own distinct contribution to a cadet's overall grade.

For example: the first semester AE481 comprises:

Assignment
Task #1
Task #2
Design review #1
Task #1
Peer rating #1
*Instructor prerogative #1
Design review #2
Preliminary report
Final report
Preliminary briefing
Final briefing
Peer rating #2
*Instructor prerogative #2

Table 2. Assessment at USAFA

Instructor prerogative grading is based on: in-class discussions, level of effort, attitude, motivation, participation. Peer rating is not currently used at RMCS.

Resources

The textbook facilities available for students involved in aircraft design appear to be fairly common on both sides of the Atlantic (e.g. Raymer [1], Roskam [2], Stinton [3,4], Torenbeek [5], Curry [6], Mattingly [7], Goldsmith & Seddon [8], etc.).
Over the last five years some excellent computer-aided-design tools have become available that are highly suited to undergraduate learning. This has arisen because much of the software has been designed by university faculty who are attuned to the needs and experience of their students. In addition, commercially available and user-friendly spreadsheet software is very valuable. In the past there was particular concern with the likelihood that undergraduates would merely accept whatever the computer spewed out. This has not been eliminated but the new software is much less inclined to encourage students to do this. Experience shows that it inspires them to go around the design circuit many times.
The variety of aircraft design software is more diverse, though some is common. An in-house method designed at USAFA deserves special mention This is VMAX, which is a particularly user-friendly package [9] developed in the Department of Aeronautics (DFAN) at USAFA. It enables the student to produce a simple 3-view drawing of the aircraft (Fig. 2), which can be imported into a 3-D draughting package (e.g. Silver Screen). VMAX is able to perform aerodynamic, performance, weight and stability analyses (Figs. 3, 4 & 5). Furthermore it

quickly allows constraint analysis (Fig 6), sensitivity analysis (Fig 7), mission performance analysis (Fig 8) and aircraft sizing to be carried out using ACSYS [7] and MISSion [7]. There are of course many topics that need investigation for which no software is currently available. Fortunately there are some excellent design texts and data sheets that help in this regard.

The use of other higher powered drawing software is invaluable for producing high quality presentations (e.g. Figs. 9 & 10). All students have embraced the use of PowerPoint for their presentations. However, the time spent is often at the cost of design considerations and students become excessively concerned with the quality of their presentation and less with the content.

Another very valuable tool which USAFA uses to good effect is a fixed-based flight simulator. The cadets at the end of AE482 are able to 'fly' their aircraft, having conceptually designed it and estimated its stability and control derivatives. DFAN is very strong in stability and control and all of the current aircraft design instructors are pilots so their experience is very valuable when assessing the quality of each aircraft's handling characteristics.

The concept of quality management is one that has recently been introduced to the aircraft design curriculum in DFAN [10]. Specifically the House of Quality (Fig. 11) is a product planning matrix used to depict customer requirements, design requirements, target design goals and competitive product evaluations. Seemingly complex at first sight, when the House of Quality [11] is broken into individual elements it is fairly straightforward. It brings home to students the need to keep quality in mind and is conceptually similar to the practice followed by American industry. There is commercially available software to allow in-depth evaluation [12].

Industry-inspired competitions

Various US organisations (e.g. AIAA, UTC, Loral, Lockheed-Martin) promote design competitions within its universities. This is a valuable component missing in UK university courses.

Typical Projects

Both of the institutions referred to here have run a wide variety of aircraft design projects. Some of these are indicated: Multi-Role Fighter, Ultra-High Capacity Aircraft (Fig. 9), ASTOVL fighter (Fig. 10), Primary Trainer, C-130 Replacement (Fig. 12), Aerially-Refuelled Spaceplane (Fig. 13).

Lessons Learned

Fundamental differences between US and UK university aircraft design practice are difficult to clearly identify. Many of the points made below, in no particular order, have equal validity on both sides of the Atlantic.

(a) Students are going to feel disoriented in the early stages of design because they have to make decisions based on superficial understanding and limited knowledge. This is commonly inevitable because much of their previous experience will have involved closed-solution problem solving. However, they should at least have some engineering common sense. They have to be encouraged to the view that an early decision based on approximate data is far superior to a late decision based on firmer data. It may never arrive.

(b) It is important to clearly assign responsibility for aspects of the design to specified students. This encourages a sense of 'ownership' and pays big dividends.

(c) The ability to produce simple sketches is a valuable skill which should form an essential part of any engineer's tool kit.

(d) The workload needs to be realistic and instructors should be prepared to restrict or enlarge the scope of the project if time shows this to be prudent.

(e) Students must be made aware that, for design work, they need to work consistently rather than expecting to achieve good results by last minute efforts. It appears that young people nowadays tend to live life more 'on the edge' than hitherto. This often does not allow time for meaningful reflection. USAFA and RMCS have this in common with most engineering schools

(f) Students do need to have the time to assimilate the fruits of their labours. There will be the tendency for students to overlook contradictions between their and other team member's design decisions.

(g) Merely providing a lot of data without analysing it is unacceptable and time must be available for the students to do this.. We need to sincerely tackle the problem of 'curriculum-stuffing'.

(h) Engineering students are quite computer-literate. With care, project handling can be carried out without excessive risk of students merely using software in a completely blind fashion.

(i) Students will always assume that the calculator or computer is correct. Switching on the brain before the computer is essential. Reality checks and self-criticism are vital.

(j) There are many aspects of design integration that still require the Mk.1 human computer to make wise decisions.

(k) It is recognised that very, very few students will become involved in conceptual aircraft design. However, the important thing is that they experience the interaction and integration of the subjects they study, in a creative as well as analytic way.

(l) Working as a team on an intellectually challenging project, where they have to make bold decisions, often based on very limited information, is of enormous personal value.

(m) There is a need to continually stress that high quality written work is important.
(n) When student presentations are made it is important to field other staff, fresh to the project, to ensure that good quality feedback is available. Instructors, working too close to a project, can occasionally obscure their view.
(o) There remains a shortage of experienced structural design and materials selection instructors.
(p) Unless there are good reasons for doing otherwise, avoid *derivative* designs, there are not as stimulating to undergraduates as *new* ones.
(q) Use 'seasoned' instructors' who provide a good balance between theory and practice.
(r) Team sizes of around 12 seem to work best[13].
(s) Experience shows that American students are highly geared towards analysis but in comparison with their UK counterparts they are less competent in the 'art' of design[14].

Acknowledgements
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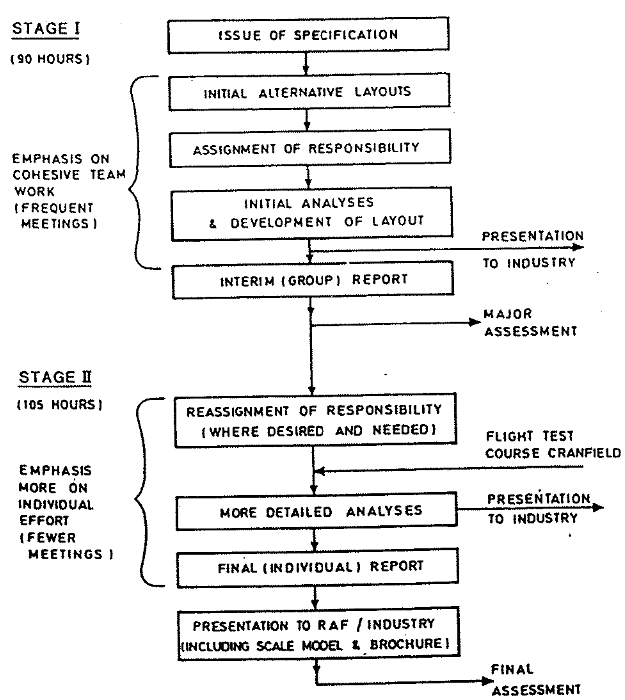

Fig. 1 Flowchart Showing Progress Through RMCS Aircraft Design Project

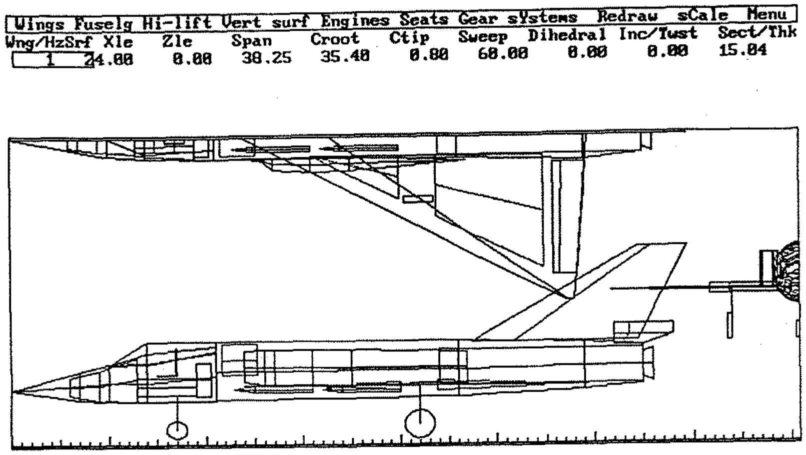

Fig. 2 Three-View Drawing from VMAX[9]

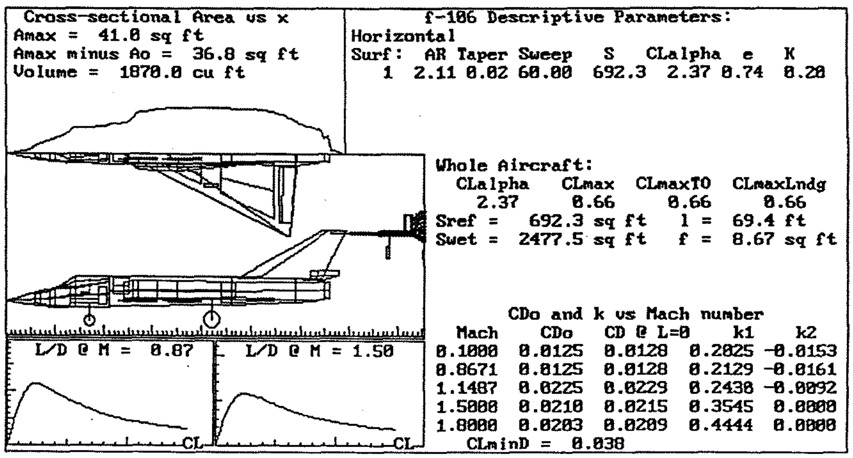

Fig. 3 Aerodynamic Analysis using VMAX[9]

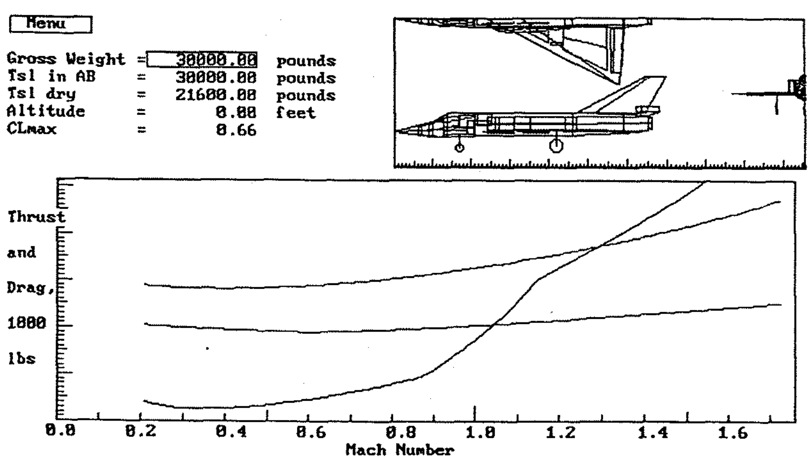

Fig. 4 Performance Prediction from VMAX[9]

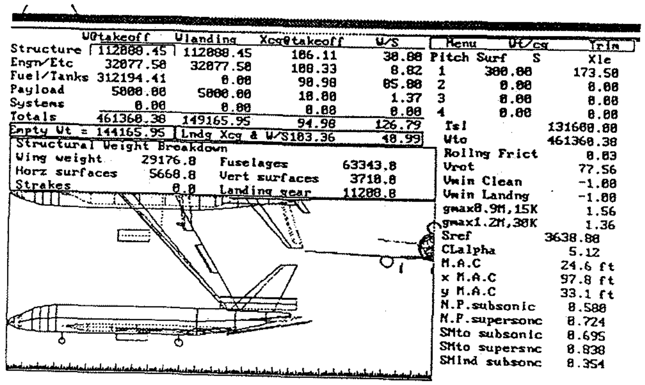

Fig. 5 Weight and Stability Analysis from VMAX [9]

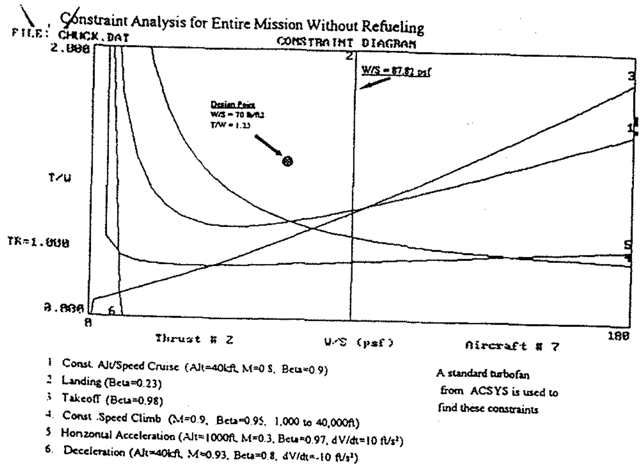

Fig. 6 Constraint Diagram using ACSYS [7]

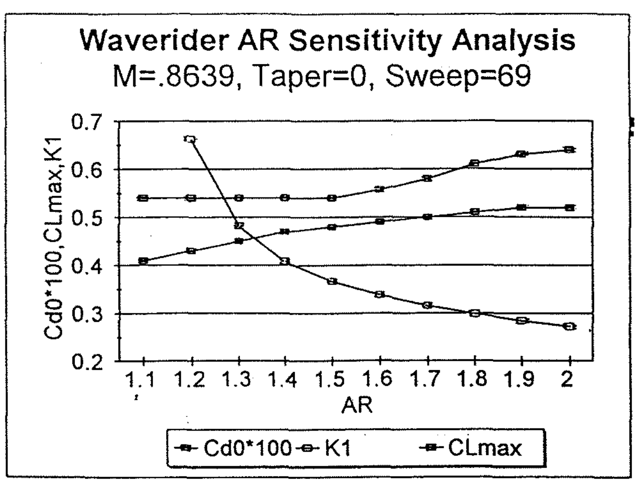

Fig. 7 Sensitivity Analysis derived from VMAX [9]

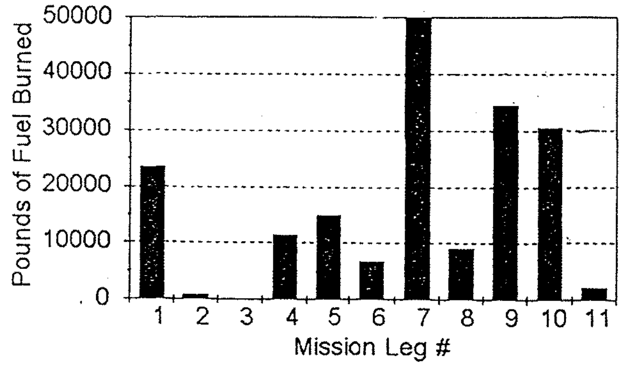

Fig. 8 Fuel Burn derived from MISSion [7]

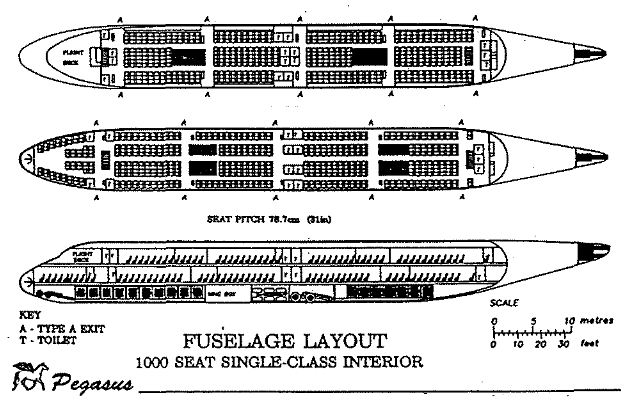

Fig. 9. Use of AutoCAD for Ultra-High Capacity Aircraft (UHCA)

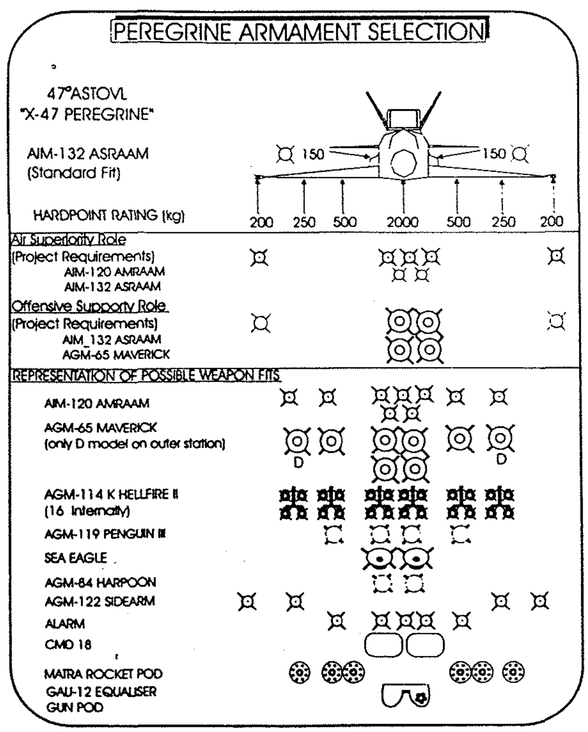

Fig. 10. Use of AutoCAD on AVSTOL Weapon Selection

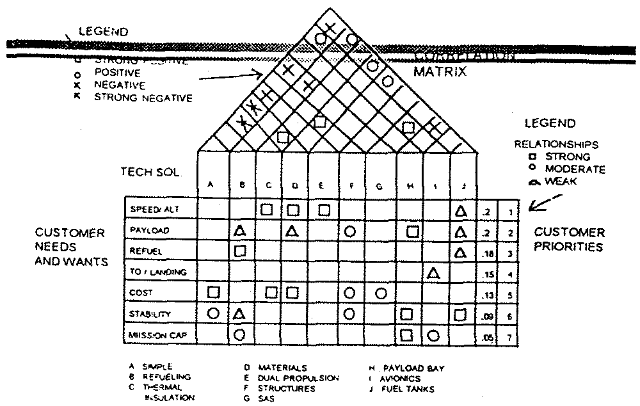

Fig. 11. QFD House of Quality

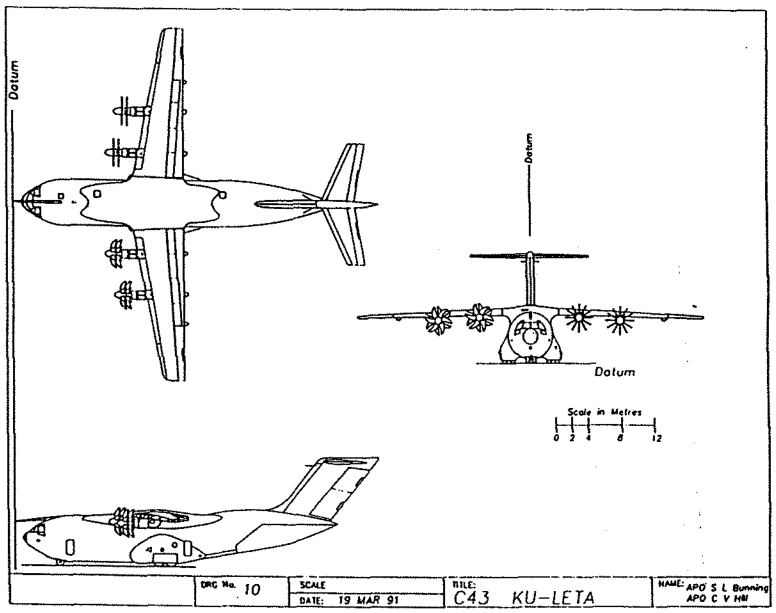

Fig. 12. Use of AutoCAD on C-130 Replacement

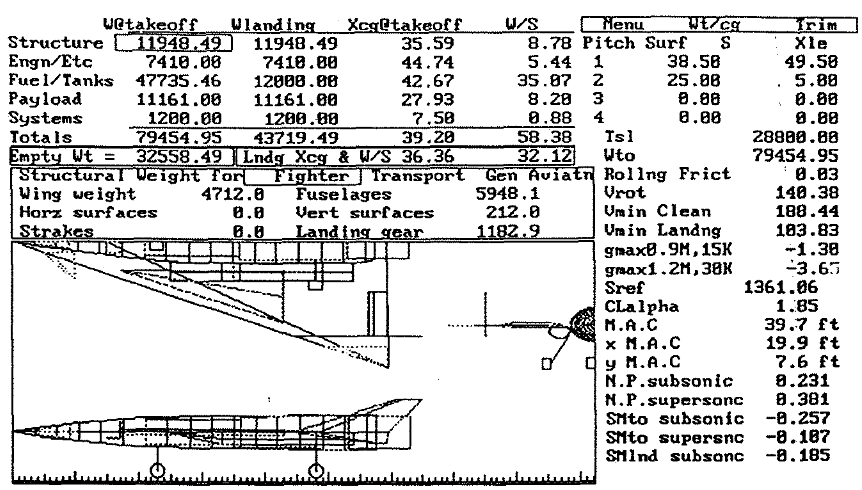

Fig. 13. Aerially-Refuelled SpacePlane from VMAX[9]