PERGAMON

Aircraft Design 3 (2000) 217–238

AIRCRAFT DESIGN

www.elsevier.com/locate/airdes

Graduate-level design education, based on flight demonstrator projects

J.P. Fielding*, R.I. Jones

Aerospace Design Group, College of Aeronautics, Cranfield University, Bedford, MK43 0AL, UK

Abstract

The College of Aeronautics (CoA) at Cranfield University believes that the best way of teaching design is for the students to learn design by doing it, in a structured manner. It also believes in the maxim – "the devil is in the detail" and that a design is only complete when it has been built, flown and certificated. Designers need to be aware of, and experienced in, all of the intermediate stages between concept design and certification. They also need to be taught to function as members of group design teams, because that is the usual way that Industry works. All of these factors led to the establishment of a full-time Masters programme in Aerospace Vehicle Design, the focus of which is the Group Design Project (GDP). This philosophy was proved to be successful over many years and was continued and expanded in the design of the Masters course in Aircraft Engineering – the subject of this paper. This programme is a three-year part-time M.Sc. course, which comprises the same major elements as the full-time course. The students attend lecture modules, perform a piece of individual research and work on a GDP. It was this last element that particularly attracted the launch and predominant customer for the course, the then Military Aircraft Division of British Aerospace (BAe). BAe like the basic philosophy of teaching the design process by placing someone in a project group with an individual responsibility but having to cater for the needs of the group and project as a whole. In February 1995 the Aircraft Engineering course was launched with 15 students, who began the first intake, working on major modifications to the CoA's A1 Aerobatic aircraft, which itself resulted from work of former students. The GDP on the full-time course in Aerospace Vehicle Design concentrates on the preliminary and detail design of a whole aircraft, which has been previously defined in terms of basic geometry, mass, performance, characteristics etc. by staff. However, BAe and Cranfield wished to address a greater extent of the full-design process, as mentioned above. In this way the students would, in the space of three years, be given first-hand experience of a much wider extent of an aerospace project than could ever be the case whilst working on major aircraft projects in a manufacturing company. This paper will give details of the Aircraft Engineering teaching programme and describe the first GDP, a major modification programme and flight of the Cranfield A1 Aerobatic Aircraft. The students were set the task of modifying the existing single seat aircraft to a two-seat configuration with performance similar or better than that of the existing aircraft.

* Corresponding author. Tel.: 44-1234-754-741; fax: 44-1234-751-550.

PII: S1369-8869(00)00006-9

despite the weight increase of a second pilot. At approximately one year into the project, a joint BAe/CoA decision was made to progress the project to completion with an 'affordable' set of modifications, providing the basic two seat capability, increased endurance, and approaching the desired performance. The aircraft was modified by BAe and CoA personnel and successfully completed its official first flight on the 30th September 1998 at Cranfield's own airfield, flown by its own Chief Test Pilot, thus completing the first of the 5 GDPs described in this paper. Information will also be given of progress being made on more recent intakes of students. The subject for intake 2 was further modifications to the A1 to further improve its lateral manoeuvrability by means of a new composite vertical stabiliser and rudder. Intakes 3 and 4 are capitalising on Cranfield's extensive expertise in the design and flight-testing of small UAV's, to develop jet-powered UAVs to act as flight-test demonstrators for unstable aircraft with diamond and blended-wing-body configurations. These will contribute significantly to Cranfield's extensive research programmes in these areas. The fifth intake has started to design a medium altitude, long endurance (MALE) UAV which will provide a platform for Cranfield's, and other researchers in the fields of remote sensing and payloads for Micro-Satellites. Ref. [4] gives more details of the 1st and 3rd GDPs. These are exciting, but challenging projects which continue to develop the best of design teaching and relevant applied research. Fig. 1 shows how the above 5 GDPs are integrated into Cranfield's strategic aircraft configuration demonstrator programme. It includes a large number of Ph.D. studies, full-time and part-time GDPs and inputs from government-funded programmes.

1. Introduction

The aerospace industry has a large number of technically qualified young engineers, but many of them have limited experience of practical design integration. There is a need for a process that will accelerate design experience acquisition in as realistic an environment as is possible. This requirement has been partially met by the full-time Master of Science Programme in Aerospace Vehicle Design (AVD) provided by the College of Aeronautics, since 1946 (Ref. [1]). One of the main features of the AVD course is the extensive group design project. Students pick-up the design from a previously performed conceptual design and perform on an 8-month preliminary/detail design process of some 25,000 engineer-hour expenditure of effort. The teaching on this programme benefits from extensive aircraft design research activities some of which are described in Ref. [2]. Although the AVD course continues to be successful, it requires students to commit at least 12 months of effort into attendance at the full-time course. Industrial organisations are often unwilling to release their employees onto such a programme, so a 3-year part-time programme was developed from the AVD course, entitled the Aircraft Engineering course (AE). Ref. [3] describes the early stages of the latter course, which started in February 1995 (Fig. 1).

2. Part-time master's programme structure

The Programme contains similar elements to those of the full-time Aerospace Vehicle Design Course, but it has been optimised for delivery to part-time students, who are subject to significant professional work commitments. The elements are the lecture modules, individual research projects

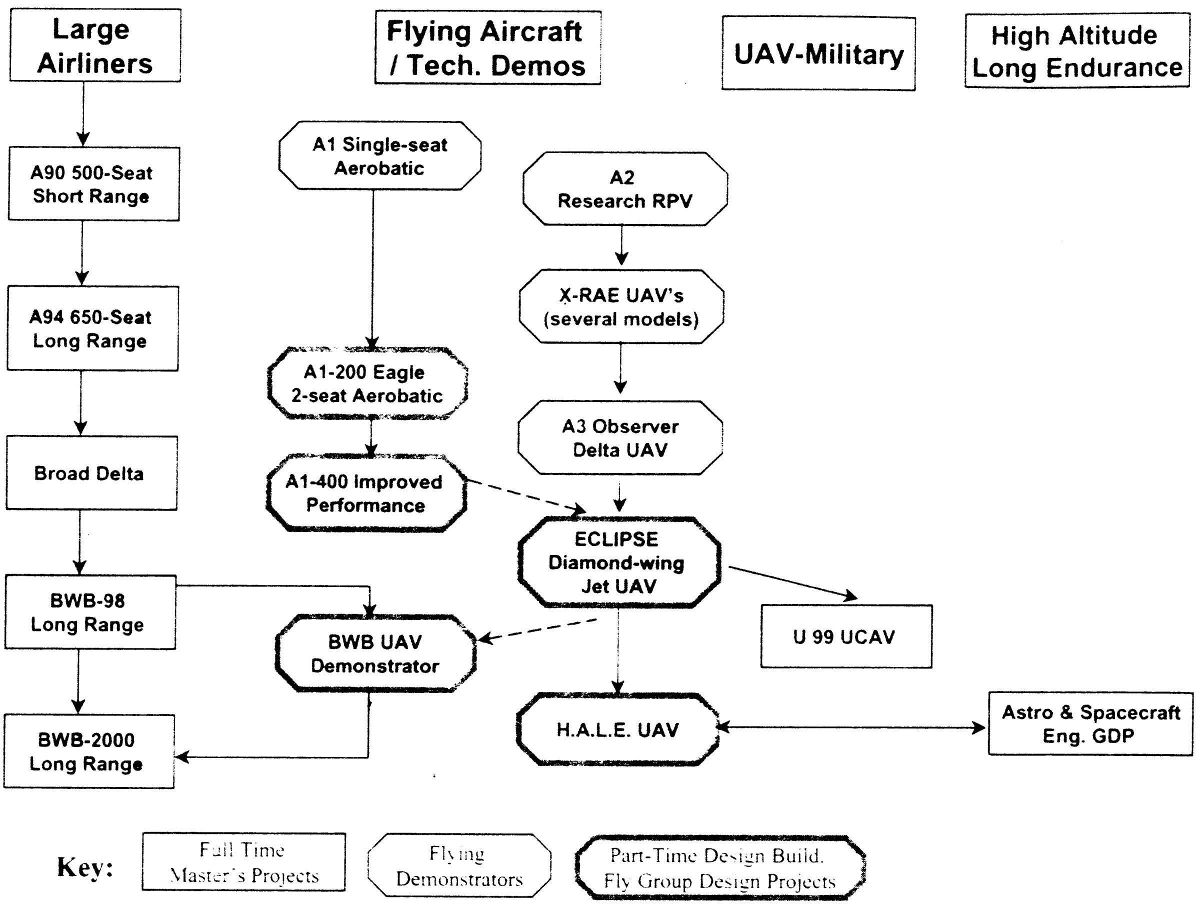

Fig. 1. Cranfield Group Projects Strategy.

(IRP) and participation in the Group Design Project (GDP) with assessment weightings of 30%, 30% and 40%, respectively, and are shown in Fig. 2. The elements are:

(i) *The lecture modules*: are equivalent to those of the full-time course and are in some cases held jointly. The modules are, effectively, assessed intensive short-courses held on the Cranfield Campus at convenient intervals over the three-year duration of the course. The introductory module is of 2 weeks duration and allows an introduction to the programme, University facilities and to the other students and staff. Further modules are of one-week duration and cover mandatory or optional topics. Students are required to attend 10 weeks of teaching modules. Assessment is by means of written examination and or post-module assignments. Some 25% of the teaching content is provided by experienced British Aerospace personnel, who bring a clear, relevant, industry perspective to the programme. There has been some modification of the lecture topics over recent years, to reflect changing education requirements, and the expertise required to undertake the later GDPs. This was particularly important in the

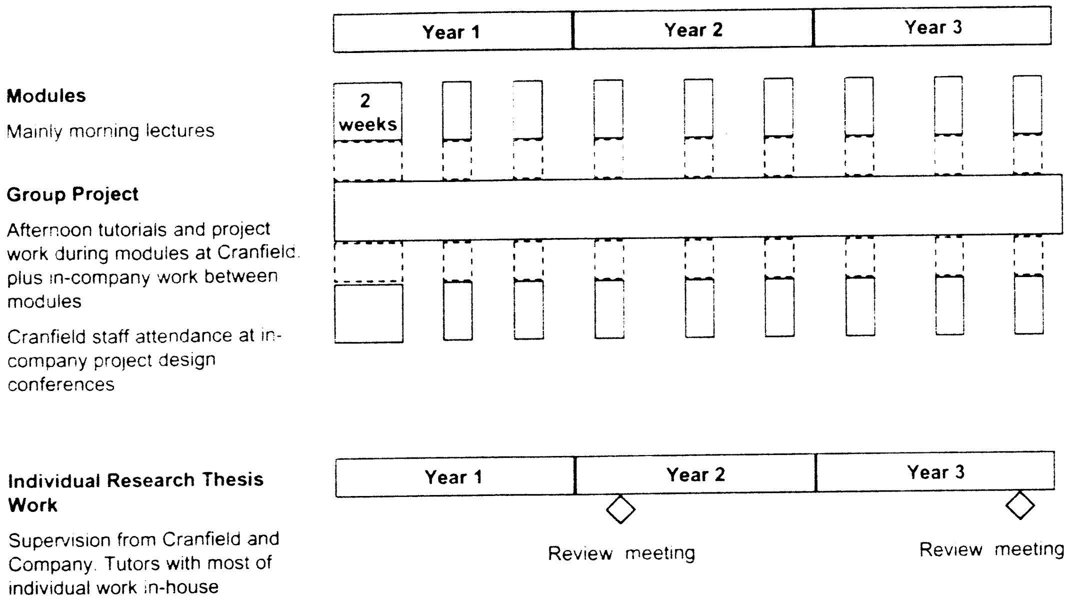

Fig. 2. Part time master's course structure.

case of Flight Mechanics and Control. The current list of module topics is:

- Initial Aerospace Design.
- Computer-Aided Design.
- Major Component Design and Structural Layout.
- Finite Element Analysis.
- Aircraft Performance and Propulsion.
- Detailed Stressing and Design Practice.
- Aircraft Loading Actions and Aeroelasticity.
- Fatigue and Damage Tolerance.
- Integrated CAD in design.
- Design for Operation and Crashworthiness.
- Airframe Mechanical Systems.
- Fibre-Reinforced Plastics.
- Airframe Fluid Systems and Avionics.
- Aircraft Flight Mechanics and Control.

(ii) *Individual research projects*: are chosen by the students, staff and Industrial Mentors. They provide pieces of good individual research or topics that are often of great help to the sponsoring company. The time allowed for this activity is some 600 h. The topics occasionally lead to discussion of Commercial Confidentiality, but conflicts have been successfully resolved. The time spent on this activity has sometimes been challenged by the enthusiasm for and demands of the Group Design Project. Careful assessment of work-load has alleviated this issue, but the demands on student time are significant. The following list gives an indication of the range of IRP topics:

- Aerodynamic Design Guidelines for Weapon Bays.
- Application of HUMS to Military Aircraft General Systems.
- Impact of Acoustic Loads on Structure.
- Design for Manufacture and Assembly.
- Determination of Fastener Shear Stiffness.
- Robust Flight Control Using Quantitative Feedback Theory.
- Airframe technology Demonstrator Programme Studies.
- Determination of Wind Tunnel Wall Interference Using CFD.
- Multi Disciplinary Design Optimisation for the Conceptual Design Phase.
- Use of Silicon Carbide for the Production of Radar Attenuating Structures.
- Automated Idealisation.
- Failure prediction of Fatigue test Specimens.
- Application of resin transfer moulding for centre fuselage structures on future military aircraft.

(iii) *Group design projects*: are at the heart of both the full- and part-time programmes and will be described in the remainder of this paper.

3. Group design project organisation

The GDP on the full-time course in Aerospace Vehicle Design concentrates on the initial design of parts of an aircraft, which has been previously defined in terms of basic geometry, mass, performance characteristics, etc. by staff. However, BAe wished to address a greater extent of the design process in the AE MSc, with progression all the way from conceptual design, through preliminary and detailed design to manufacture, clearance and flight. In this way the students would, in the space of three years, be given first-hand experience of a much wider extent of an aerospace project than could ever be the case whilst working on major aircraft projects in a present military airframe manufacturer.

The detailed organisation of the GDPs on the AE course has varied slightly from one project to the next and in the sections covering each of the projects to-date. These differences will be explained. However, there are some aspects which remain the same.

The choice of the subject of individual GDPs has significant implications in terms of financial, facilities and human resources.

To meet the basic objectives of the GDP, the subject must be such that it covers a wide extent of the whole design process from concept to flight and it is possible to do this within the constraints of a three-year time frame, the effort available from the student group (with a little external assistance) and a restricted budget for the project. In addition, the subject should involve real clearance and safety issues (to concentrate the minds of all those working on the project) and should capture the interest of the students.

The topics chosen so far have met all these requirements as well as advancing the state-of-the-art of aeronautical knowledge. Intake 3–5 topics fit directly into the College of Aeronautics developing Strategic Research and Demonstrator Plan, mentioned in paragraph 1, above.

The projects commence soon after the beginning of each student intake's course and are formally progressed through GDP meetings held at regular intervals during the following three years. There is always a meeting during each of the three lecture modules held at the CoA for that intake of students each year. In addition, there are usually two or three meetings in-between these modules. These are usually rotated around the sites where the students are located and can give an opportunity to see and, in some case, make a tour around the sites, for the benefit of those who may not have visited them before.

The GDP meetings are jointly chaired by one Cranfield member of staff and one senior engineer from BAe. The chairmen are directly involved in ensuring the overall progression of the project. However, they also act as a source of information and contacts, at BAe and CoA, useful to assist in the project.

In addition to the formal GDP meetings, the students are likely to hold further meetings, of the whole or part of the group, to address particular aspects.

As the GDP forms the largest single part, of the assessment on the AE course, there is individual output required from each student on their personal contribution to the GDP. This takes the form of interim reports presentations at around one and two years into each GDP that count towards a small part of the GDP assessment. The major part of the GDP assessment is through submission of a GDP final report or "thesis". This is submitted 3 months prior to the end of the student's three year course.

Ref. [4] gives considerable detail about all 5 GDPs, but this paper will only describe the first in some detail and summarise the remainder.

4. Intake 1 GDP — the two-seat aerobatic aircraft

The Aircraft Engineering course was launched in February 1995 with 15 students, all from BAe Military Aircraft. The GDP that they were presented with was to work on modifications to Cranfield's own single seat A1 aerobatic aircraft; Fig. 3, which had resulted from previous M.Sc.

The original single seat A1 MkII aerobatic aircraft

Fig. 3. 1995 Intake 1 group design project.

Table 1
Comparison of the specification requirements set for the two-seat A1 with that of the existing A1 MkII

	Existing A1 MkII	Two-seat A1
Max. level speed	76.1 m s^{-1} (148 kt)	80 m s^{-1} (155 kt)
Climb rate	13.5 m s^{-1} (44.3 ft/s)	12.5 m s^{-1} (41 ft/s)
G limits	$+7/-5$	$+6/-3$
Roll rate	150°/s	150°/s
Range	238 km (148 miles)	800 km (500 miles)
Stall speed	25 m s^{-1} (48.6 kt)	25 m s^{-1} (48.6 kt)

student work, to provide a two-seat aerobatic trainer. This provided the realistic possibility for a project to progress through to manufacture and flight. However, it should be noted that at the outset there was no guarantee that it would do so.

The choice of the A1 was prompted by the fact that Cranfield held complete design information and had already made significant moves towards the certification of the aircraft. The tasks envisaged were technically challenging, covered a wide range of disciplines and required an integrated design approach. Most importantly, it was felt that they could be achieved in the tight schedule without excessive costs.

4.1. Initial conceptual design phase

The students had been set an exacting specification for the two-seat aircraft, with performance equal to or better than that of the existing single seat version, the A1. This was an intentionally difficult requirement for an aircraft to be produced by modification, in order to get the students to consider some fairly radical modifications or even starting again with a blank sheet of paper.

Table 1 shows the main performance targets.

The students initially worked in three competing teams to perform conceptual designs to meet the above target, or a non-compliant "affordable" option.

Following consideration of a number of options by each team, they presented their chosen approach to the "customer" consisting of senior staff of BAe and CoA. Not surprisingly, it was clear from the options presented, that the initial specification could only be met by major modifications to the existing airframe of the A1 and/or re-engining with a more powerful unit. Therefore, the "customer" chose to specify a list of what became known as "affordable" modifications to be progressed through the remainder of the project.

4.2. Definition of individual responsibilities

The affordable modifications were defined to provide the aircraft with a basic two-seat capability and increased range with an attempt to approach the other specification requirements, without the need to resort to replacement of major airframe elements or the engine. These modifications were split into the following task areas, each the responsibility of a delegate:

Canopy,
Trailing Edge Flaps,
Fuel System Extension,
Front Cockpit Seat, Controls and Instruments,
Electrical System Extension.

In addition, to these, however, some more radical changes were also to be investigated by other students. These would allow the possibility of meeting, or more closely approaching, the full list of requirements. These "major" modifications, as they were termed, were as follows:

Composite Wing Design,
Semi-Monocoque Metal Fuselage Design,
Composite Fuselage Design 1,
Composite Fuselage Design 2.

As well as specific changes to the aircraft, a number of generic tasks, to be covered what ever changes were adopted, were also identified as necessary and defined as a responsibility of a student. These were:

Performance Evaluation,
Wind Tunnel Testing,
Mass & C.G. control and Stability & Control Issues,
Load and Fatigue Analysis,
Structural Dynamics and Aeroelasticity,
Flight Test, Instrumentation, and Certification.

4.3. *Modification design phase*

From the point that the delegates' individual responsibilities were defined, they worked on as a single group, holding regular project review meetings. Professor Denis Howe had initially taken on the role as CoA GDP chairman and, due to his invaluable experience of the A1, was heavily involved in the project throughout.

Each of the delegates produced a statement of work for their responsibility area. These were then considered together to define the necessary timescales, due to dependency on outputs from other delegates.

Twelve months into the project, a major Design Review meeting was held at Cranfield. At this the delegates presented their work to that date and plans for the remainder of the project to senior staff of BAe and CoA, again acting as the "customer". As a result of this, the commitment of both BAe and CoA to carry the project through to manufacture and flight was confirmed. Shortly after this, one of the delegates left BAe and his responsibilities for the cockpit controls, etc. were redistributed amongst the other delegates.

Over the following few months facilities for manufacturing the necessary components within BAe and, where necessary, externally were investigated. Initial costs for manufacture, bought out items and installation on the aircraft were gathered with one of the delegates taking on the role of co-ordination of these production-related activities.

By approximately 18 months into the project it was clear that the delegates' other work commitments were slowing progress on the designs for affordable modifications to the extent that manufacture and installation could not be achieved within the timescale of the course. It was decided that teams would be formed for each of the "affordable" modifications (those that would be built). This required that work on the "major" modifications had to be suspended. Although it was the original intention that the delegates working on the major modifications would return to these tasks, once the affordable modification designs were completed, in practice little time remained to do this at the end of the project.

British Aerospace also decided to finance an additional two-week placement at Cranfield, so that the students could be co-located and have good access to the aircraft and drawings. This activity enabled the project to get back on track.

4.4. Progression to manufacture

Once drawings produced by the students were completed, they were checked, along with stressing calculations, etc., by another student at each BAe site before despatch to Cranfield. The CoA retains full Design Authority on the A1, so whilst the drawings had been produced and checked within BAe and were usually issued back to BAe for manufacture. They were also checked by the Aircraft Design Group within Cranfield Aerospace Ltd.

The CoA had held discussions with the Civil Aviation Authority (CAA) at an early stage to inform them of intentions with regard to the modifications and discuss necessary procedures for certification in this case. The original A1 design had been performed to the British Civil Airworthiness Requirements, Section K. The CoA reached agreement as to which of the more modern JAR Part 23 were required to be met to achieve certification, whilst retaining much of the earlier design-standard approvals.

The majority of manufacture of items was performed by BAe at its Brough and Warton sites, and, for this purpose drawings and orders were issued to BAe for these. Therefore, BAe became a supplier to the CoA and, to satisfy the CoA's quality procedures, the CoA's Quality Co-ordinator and Chief Aircraft Inspector had to visit the BAe sites to assure himself that they were a fit supplier!

4.5. Installation and assembly of the A1-200

By the end of 1997 the initial components produced by BAe began to arrive at Cranfield for installation on the aircraft. In the meantime the aircraft had been substantially dis-assembled and stripped of its fabric covering (Fig. 4). Necessary maintenance work on the airframe and in particular its undercarriage was performed.

Installation of the modification components on to the aircraft began with the items placed within the fuselage, prior to its re-fabricing. These included the control extensions, seat and instruments for the forward cockpit, the battery tray and mounting for a new GPS navigation radio unit in the rear cockpit.

Fig. 5 shows a CAD model of the new fuel system, which was installed in the aircraft in two stages, prior to, and post first-flight.

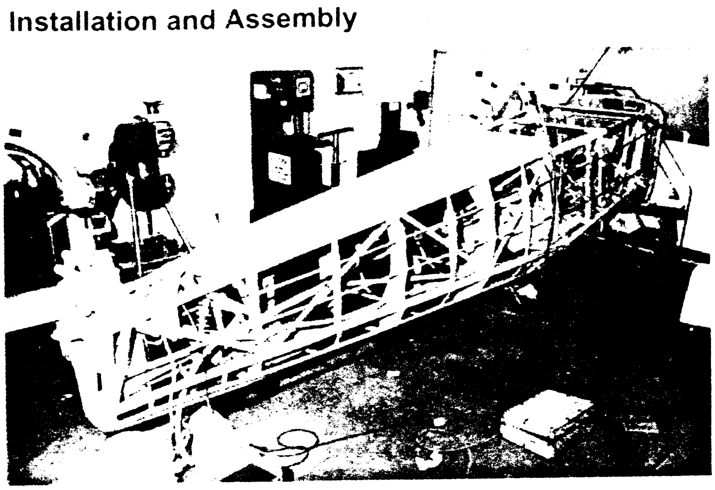

Fig. 4. 1995 Intake 1 group design project.

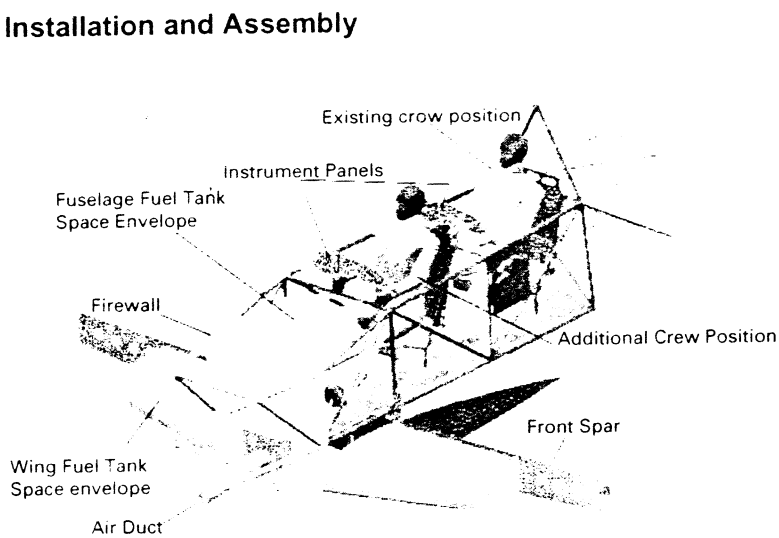

Fig. 5. 1995 Intake 1 group design project.

4.6. *Wind tunnel testing*

Whilst manufacture of the canopy was progressing, one of the students, responsible for wind tunnel testing, was investigating the aerodynamic effects of it. The $\frac{1}{4}$ scale wind tunnel model of the A1, produced during the original design work on the aircraft, was taken to BAe Warton and after some restoration work was used in the 4.0 m Low-Speed Wind Tunnel (LSWT) facility there to investigate the effect of external modifications. The changes investigated included those from the

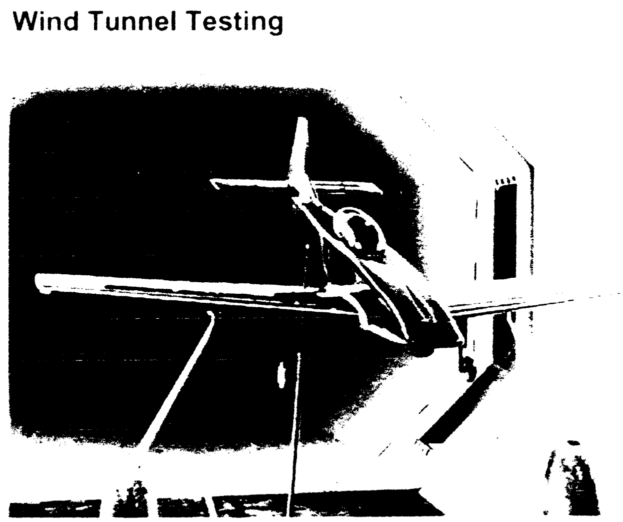

Fig. 6. 1995 Intake 1 group design project.

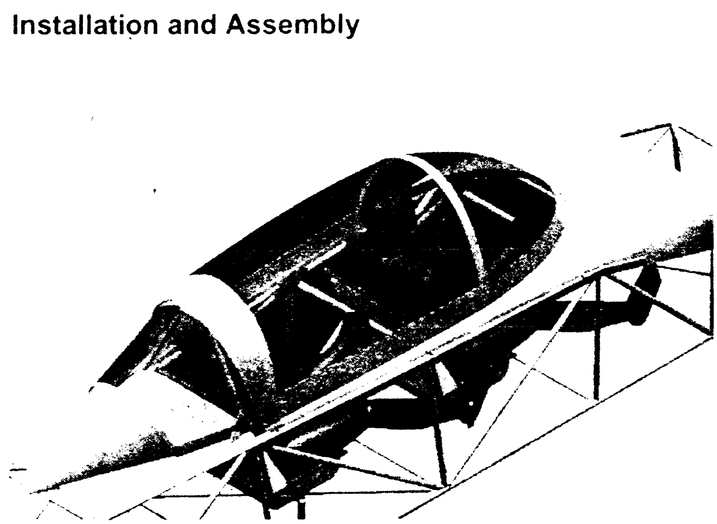

Fig. 7. 1995 Intake 1 group design project.

addition of the trailing edge flaps but the canopy changes represented a major part of the tests carried out: Fig. 6.

The wind tunnel model had two new canopy shapes added to it for these tests, one representing a canopy composed of three single curvature shapes and a second modelling the canopy shape actually produced. Both these new canopy shapes were produced directly from Computer-Aided Design (CAD) models using stereo-lithography techniques. The tests performed showed that canopy of the actual shape used had insignificant effect on the drag and acceptably small effect on stability derivatives. This was subsequently proved by flight-test. Fig. 7 shows the installation of the canopy.

First Flight

Fig. 8. 1995 Intake 1 group design project.

4.7. Conclusion of the intake 1 Project

Following re-assembly in its two-seat configuration, the aircraft was readied for its official Roll-Out at Graduation Day on 12 July 1998. On that day all 13 of the students, who completed the course, graduated with a Masters in Aircraft Engineering. This must be judged a considerable achievement on their part. Whilst playing their part in the GDP work on the A1, they had attended and been assessed in lecture modules, performed research work on an individual topic, produced theses on their individual research and GDP responsibilities as well as holding down a full-time job at BAe and meeting their family commitments.

Following the roll-out the aircraft underwent further preparation and ground test prior to first flight. The official first flight took place on 30 September 1998, when the CoA's own Chief Test Pilot, Roger Bailey, provided a limited display of the aircraft in front of an audience of invited guests from industry and the media, following naming of the aircraft the Cranfield A1-200 "Eagle" by Dr Kenny-Wallace, Vice Chancellor of the BAe Virtual University; Fig. 8.

5. Intake 2 GDP — new fin and rudder for the aerobatic aircraft

Ever since the single seat A1 aerobatic aircraft first flew in 1976 there have been attempts to improve its capabilities and flying qualities. In particular, the following year the aircraft had a more powerful engine fitted than the original unit, and a larger rudder. Even so, there are still aspects of the aircraft's handling qualities which could be further improved upon. One particular aspect is that the aircraft's flick roll capabilities leave something to be desired.

It has been generally accepted that the major factors affecting the A1's flick roll capabilities were a rudder effectiveness, which was too small in comparison to the aircraft's directional stability, and development of wing stall close to the root in the initial stages of the manoeuvre. Various measures had been introduced and attempted to address these problems, with some degree of success, but the fundamental problem with the lower rudder was that the "step" between the relatively wide fuselage and narrow fin was causing separation and thus loss of rudder effectiveness.

The students on the 1996 intake of the AE course were set the task of improving the A1's lateral stability and control characteristics, in the knowledge that the aircraft that they would modify should, by then, be a two-seat aerobatic trainer, following the work of the first intake.

Unlike the 1995 intake GDP, the 12 students who began the course were allocated individual responsibilities on the project from the beginning. These were initially as follows:

Aerodynamic and CFD Analysis.
Novel Concepts.
Fin Design.
Structural Test.
Flight Controls.
Rudder Design.
Tailplane and Elevator design.
Manufacture.
Fuselage Investigation.
Fatigue and Fracture.
Performance and Stability.
Project Management and Flight Test.

However, during the first year of the course four students withdrew and a significant reallocation of tasks became necessary.

As might be expected, the modifications to the aircraft concentrated on methods of improving the flow over the lower section of the rudder but other methods of improvement were also considered. A lack of torsional stiffness of the rear fuselage was considered to be possibly adding to the loss of rudder effectiveness and thus one student investigated methods of increasing the stiffness of the tubular steel structure in this area. Another student considered novel methods of reducing the aircraft's lateral stability by addition of a "canard fin" either above or below the forward fuselage or increase of size of the undercarriage leg fairings. Whilst none of these possibilities was in fact carried through to be embodied as actual modifications on the aircraft, they did form a useful part of the survey of possible approaches.

In practice, the major modification selected for progression to manufacture was the design of an increased thickness rudder and matching fin, removing the step at the end of the rear fuselage. This required modifications to the control circuits for rudder and elevator in the rear fuselage area, of the dorsal fin and fin to tailplane fairings.

Fortunately, the modifications to the control circuits had been defined when the fuselage fabric was removed during the work prior to the installation of the modifications for the A1-200 and, therefore, could be achieved with little disruption. Some of the preparation for other changes, for what was termed the A1-400, were also made at this stage.

Whilst there was no specific requirement to do so, considerations of weight, linked to the experience it would provide, led to the choice of composites for the new fin and rudder to be manufactured for the A1-400. However, in considering the likely cost of production of two fins and rudders, one for flight and one for structural test, it was found sensible to consider production of

Actual Modifications (Composite Replacement Fin and Rudder)

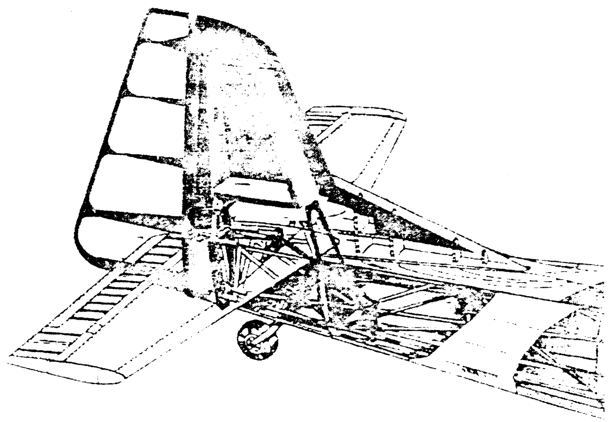

Fig. 9. 1996 Intake 2 group design project.

these items outside BAe. Following survey of, and discussion with, a number of potential manufacturers, Slingsby Aviation Ltd were chosen to manufacture the composite components incorporating metal hinges and brackets, etc. produced within BAe.

The type of structure chosen uses substantially monolithic Glass Fibre-Reinforced Plastic (GFRP) spar and rib construction with GFRP skins: Fig. 9. This structure is being produced by manual wet lay-up of cloth laminates, with inclusion of metallic, foam and wood components as necessary, using minimum tooling.

The process of production of drawings and calculations by students followed by approval and issue by Cranfield Aerospace, as for the A1-200 modifications, was again followed in this case.

At the time of writing, the metallic components have been produced, and are being incorporated in the composite fin and rudder components, being fabricated by Slingsby Ltd. They should be installed on the aircraft, later in 1999, prior to first flight in the Spring of 2000. This is to provide better flight conditions than those that might be encountered at Cranfield in the Winter! The flight-test programme will be quite extensive, due to the significant changes that are being made to the aircraft control surfaces.

6. Intake 3 GDP — the eclipse. JET UAV

Whilst the GDP subjects for the 1995 and 1996 intakes picked-up on Cranfield's unique position as a University having its own aircraft and holding design authority and approvals to modify it, the subject chosen for the 1997 intake picked-up on another unique area of the CoA's experience.

The CoA has for many years worked for, and along with, the UK Defence Evaluation and Research Agency (DERA) on development of all the aspects surrounding small Unmanned Air Vehicles (UAVs) particularly for surveillance purposes: Ref. [5]. The 11th March 1999 saw the first

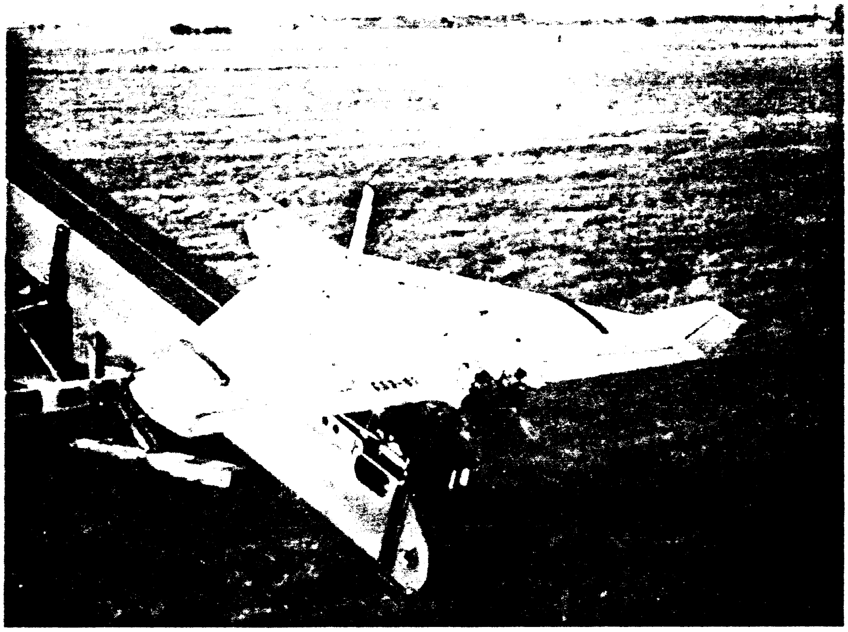

Fig. 10. A3 Observer on launcher.

flight of Cranfield's most recent UAV, the A3 Observer (Fig. 10). For the 1997 intake GDP, it was decided to utilise the experience gained to assist in the production of a UAV, to be designed from scratch, which would provide a tool for the investigation of the characteristics and suitability of various flight control laws and strategies, when applied to unconventional aircraft configurations. This also recognised a rapidly growing general interest in the use of UAVs for various roles.

6.1. Specification

The initial specification for the UAV provided to the group of 16 students who started the course was, intentionally, rather vague but contained the following key design drivers:

(1) The aircraft should be powered by jet propulsion with the capability of operation for around 15 min.
(2) It should be able to take-off from its own landing gear, which should either be initially retractable or with the intention to retract it at a later stage, and approach speed should be limited to around 40 kt.
(3) It should be capable of operating within the confines of a suitable airfield without the need for bank angles in excess of 45°.
(4) Adequate safety provision, in the event of a failure, should be provided to minimise the risk to third parties or property.
(5) The vehicle span should be less than 2.5 m and its mass low enough to allow two people to safely lift it.

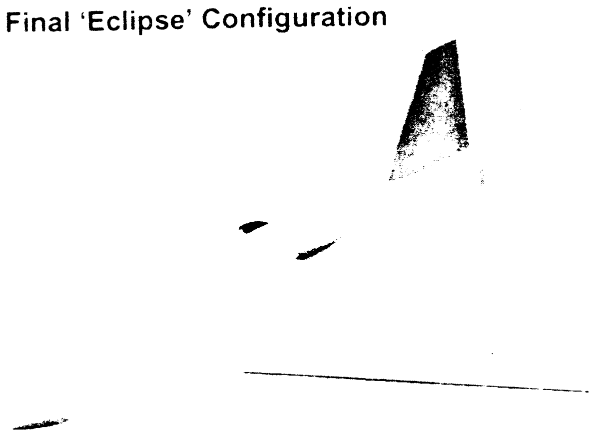

Fig. 11. 1997 Intake 3 group design project.

(6) The vehicle should be of novel configuration for investigation of the characteristics of such a configuration, preferably with a construction which would allow alterations to the configuration without major alterations to the central core systems engine element of the vehicle.

To minimise the work, and risk, involved in development of all the electronics and associated sensors and systems necessary to fly and control the UAV, permission was sought from, and granted by, DERA to use the electronics package developed by CoA in its work with DERA to fly conventional UAVs of a design which had become known as XRAE vehicles. This "XRAE crate" contains all the electronics and sensors, or connections to sensors, necessary to control and fly an air vehicle with neutral or slightly negative stability, the electronics for a command and control link and electronics for a telemetry link.

6.2. *Configuration studies*

The initial task of the group was to select a configuration for the vehicle. Configurations were suggested by most members, and after a number of interactions the configuration of Fig. 11 was chosen. It has a diamond wing, and a single small jet engine, fed from a dorsal air intake.

6.3. *Group organisation*

Although all members of the group took part in the initial configuration selection, they all selected individual roles for the project at the start. Due to the limited number of students involved, individuals generally took on more than a single role. However, in addition to the overall tasks of programme management, certification, cost, etc., the group arranged itself into four major areas:

(1) Aircraft systems (engine, fuel, flight controls, electrical power and physical interfaces with the XRAE crate).
(2) Structural Design (including integration of all equipment).

(3) Flight Controls and Simulation (concerning interpretation of aerodynamic data and development of the flight control laws to be programmed into the XRAE crate).
(4) Aerodynamics (focusing on configuration issues, aerodynamic predictions, wind tunnel testing and intake design).

6.4. Overall project status

At the time of writing, construction of the air vehicle is at an advanced stage, a number of the bought-out items have been procured and arrangements for testing of the engine are being made. Development of the flight control system is well underway and, whilst this is recognised as one of the critical paths to first flight, additional resources from the student group are being applied to this. Following completion of the airframe and some structural tests, it will be equipped with various equipment items at CoA and the XRAE crate, programmed with the relevant flight control laws, etc. The current plan is complete construction in 1999, but first flight is likely in the Spring of 2000.

7. Intake 4 GDP — blended-wing-body demonstrator

There is considerable interest around the world at present in Blended Wing Body (BWB) configurations. These have been suggested for a number of different roles, in particular, very large, 600 +, passenger airliners and global-range military transport aircraft. They represent an attempt to side-step the law of diminishing returns we see in trying to extract further gains in efficiency (both fuel and economic) from the conventional distinct wing, fuselage, tail surface configurations. However, they bring a number of difficulties, not least, the fact that many of our conventional design methods rely on essentially empirical data and are not easily applied to any novel configuration. In addition, the functions of the various elements and applicable analysis techniques for conventional aircraft allow us to break the design problem down in a way that the physically integrated BWB configuration does not.

In keeping with the world wide interest in BWB configurations, the CoA has put together a programme of research activities aimed at addressing some of the issues surrounding them. This involves individual research of M.Sc. students on a number of courses and GDPs on both the Aerospace Vehicle Design (AVD) and AE courses. The estimated total commitment of staff and student time, at present defined for the full 3-year programme, is approximately 76,000 man-hours Ref. [6].

The GDP for the 1998 intake on AE is aimed at design, manufacture and operation of a sub-scale demonstrator of a BWB. Thus, the major initial task for the 11 students who began this project was to produce a preliminary design for the full-size BWB which would be demonstrated at sub-scale.

At the outset, the students chose tasks for the preliminary design of the full-size vehicle covering the full range of disciplines that one would expect. In addition, they provisionally chose both technical and management tasks for the sub-scale demonstrator phase.

The CoA chairman for this GDP is Dr Howard Smith, who is Course Director of the full-time AVD M.Sc. and is also leading the BWB programme as a whole. He has performed a great deal of the preparatory work for this AE GDP and the AVD GDP, which worked on initial detail design

Fig. 12. "CAD" model of the BW98.

of a full-size BWB and performed by students on that course during the period October 1998 to May 1999.

At the time of writing, the AVD GDP has completed the preliminary design of the full-size BWB (Fig. 12) and the AE students have moved on to the design of the sub-scale demonstrator vehicle.

As with the 1997 intake, the XRAE crate will be used to provide the flight control, etc. hardware. In addition, present intentions are to use the same propulsion unit, the AMT Olympus, with only a single unit occupying one of the nacelles of a demonstrator, to represent the three-engined full-size vehicle. It is expected that vehicle construction techniques will be similar to those used for Eclipse. However, this vehicle is at present planned to be around twice the size and mass of the 2.2 m span and 37 kg mass predicted for the Eclipse UAV.

8. Intake 5 GDP — H.A.L.E. research UAV

The subject chosen for the GDP for the most recent intake on the AVD course is again that of a UAV. However, the role is different to that of either of the previous two GDP UAVs.

The CoA has for some time had an interest in environmental monitoring of the atmosphere and in fact has operated a Jetstream aircraft to sample exhaust gas plumes for power stations, etc. In addition, the Astronautics and Space Engineering Group within the CoA has an interest in remote-sensing, both the technologies involved and analysis of the data collected.

There have been a number of suggestions made that UAVs could be used as "surrogate satellites" for remote sensing purposes, either proving payload or techniques prior to committing to a satellite

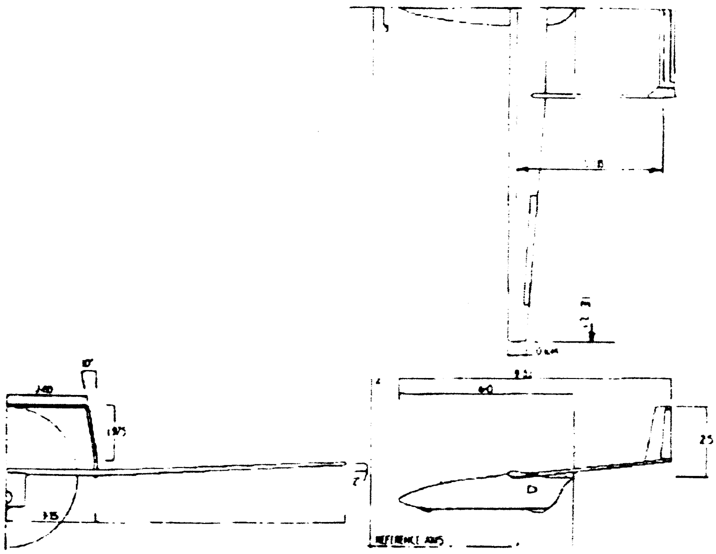

Fig. 13. Early H.A.L.E. configuration.

launch or permanently replacing satellites in some roles. In fact, the CoA has already performed a small study funded by the European Community using very simple UAV systems at low altitude to prove some of the techniques.

For a number of the in situ and remote sensing roles, for both environmental and other purposes, it is important that the vehicle stays on-station and often at reasonably high altitudes for long periods. This provides a challenge for all the disciplines of aeronautical engineering that has interested staff and students at the CoA for some time: Ref. [7]. Therefore, the GDP for the 1999 intake of the AE course has picked-up on these interests in attempting to design, build and fly a "high" altitude "long" endurance small UAV. Fig. 13 gives some idea of a configuration for this type of mission.

The 12 students in this group have been set the task of flying a proof-of-concept vehicle at 12 km altitude. Again, to reduce time and cost the XRAE crate will provide a basis for the vehicle systems. However, in this case the fact that this crate has been developed in stages, becomes a real problem. The crate, with the various support equipment, batteries, etc. weighs around 10 kg. Given time and money, a package performing the same functions as the present crate could easily be developed at half its present weight and for probably much less. Alternative strategies are therefore being investigated.

At present, the students are arranged in three competing teams, working on configuration designs to be presented to the "customer" at their next lecture module in November 1999. Beyond that point they will move on to the design of the proof-of-concept vehicle, as a whole group. There are indications of possible interest from the Astronautics and Space Engineering group, and companies they are involved, with in production of a real demonstration payload for the vehicle to fly. This could, if all goes well, lead to the "ideal" vehicle becoming a possibility.

9. Discussion

9.1. The AE programme

It was stated in Ref. [3] that "The course has been enthusiastically greeted by students and staff within the companies, and at Cranfield..... The basic formula has, been shown to be sound, despite its complexity". These comments are still true, after another two years of experience with all elements of the course.

There is no disguising the fact that the AE course as a whole is very demanding and, as a result, students have withdrawn from the course. It requires a student to study over three years a course equivalent to a full-time one-year course, hold down their job and fulfil their family commitments, often at a point in their lives and careers when their circumstances are changing rapidly. The demands of the GDP adds to this pressure and occasionally the group dynamics and excitement of the GDP take too much effort away from other elements of the programme.

One of the major non-technical benefits of the AE course and, in particular the GDP, to both the sponsor and students individually is the personal contacts that are made during the course. These provide links between BAe sites and departments. Students have been drawn from BAe's sites at Brough, Dunsfold, Farnborough, Salmesbury and Warton. This has been true, to a lesser extent, with the other organisations that have contributed students, namely the British Ministry of Defence and DERA.

The personal contacts formed between the students during the course and GDP, along with those made outside the groups, are of lasting benefit to the organisations. Whilst it may not actually be another student at another site or in another department that needs to be contacted in the future, they provide a useful and known starting point who is likely to be helpful in locating the person who is actually required.

9.2. The GDP as an education tool

The general principle of a GDP as an educational tool, that the best way to learn the design process is to do it for real, has been well-proven over the years on the full-time AVD course. However, that course only attempts to cover part of the design process and is particularly aimed at designers. The objective of the GDP on the AE course is more ambitious, in that it attempts to bring in all the technical (and some non-technical) disciplines necessary to progress an aircraft project from specification to flight. As a result, the AE GDP has successfully allowed students from various backgrounds to play a full and useful part in the project.

In addition to providing first hand experience of technical aspects which must be considered in a real project, the GDP gives very real experience of the difficulties of managing and controlling a project with constrained manpower, budget and time, with the need to prove safety. Experience with the GDPs on the AE course to-date have proved them to be all too "real" with over-runs in terms of cost and time. At least these have been of manageable proportions and no-one's career or reputation has been destroyed by the problems (at least not yet!).

It has not only been the students that have learnt valuable lessons during the course of the GDPs. Staff at CoA and senior engineers at BAe have also learnt much about each other's capabilities. The advantages and disadvantages of each other's normal methods of working and how these might be applied to advantage on future projects outside the AE course have also been highlighted.

9.3. Future developments

In future, it is hoped to widen further the sponsors of students on the course. It should be emphasised that a particular attraction to BAe was that they could integrate lectures by some of their own staff with the material provided by Cranfield. Therefore, the effects of a wider audience on the allowed material for such lectures may need to be considered. However, the difficulties this might create are outweighed by the advantages gained by all sponsors of students in having their employees exposed to the knowledge and experience of students from other sponsors with a different perspective. In fact, it has long been recognised by the regular sponsors of students on the full-time AVD course, from around the world, that one of the major benefits of the course is the opportunity for the students to mix with those from other countries and parts of the aerospace industry.

The current students on the programme come from the design and technical specialist departments of their organisations. It is planned to offer an option to the programme so that manufacturing engineers will be able to join, and contribute their skills.

To-date, subjects of the GDPs have been limited to modifications of CoA's own A1 aircraft and UAVs. These have provided topics which meet the basic objectives of this element of the course. Whilst further modifications to the A1 could be considered and further UAVs, or modifications of the present ones, are also possible, it would be good to find new subjects for GDPs, to ensure student interest.

One possibility would be a "virtual project" which would not actually produce flight hardware but digital products and possibly wind tunnel models, etc. This would certainly limit costs involved in the GDP, but whether it would capture student interest and provide the same concentration of mind on safety issues is not clear.

10. Conclusions

Both full-time AVD and part-time AE programmes are complex and demanding, but they have a proven record of providing high-quality, experienced and mature designers and engineers.

Although the GDPs, are and will continue to be very demanding of both students and staff involved, they provide an effective approach to tackling the problems of an engineer gaining real practical experience in today's employment environment.

Within the relatively short time period for which it has been running, the GDP element of the AE course has proved to be a very effective tool in teaching the students about the many technical and non-technical facets of typical aerospace projects. It has allowed students from many disciplines within BAe and beyond to be exposed to the real practical problems and difficulties in applying their own and other's aerospace engineering knowledge, in a relatively limited risk environment.

Personal links between students from different sites and departments and between CoA staff and a range of individuals in sponsoring organisations have been formed, to the future advantage of all concerned. In addition, useful lessons about the general working practices within BAe and CoA and where how these can be applied to best advantage in future have been learnt.

In the future, it is hoped to widen further the course intake to encompass more organisations within the aerospace sector. New subjects for GDPs will also need to be identified. However, the basic requirements of a project covering the full extent of the design process, within real constraints, will need to be retained.

References

[1] Fielding JP. Graduate aircraft design education. 19th International Congress of the Aeronautical Sciences (ICAS), Anaheim, California, USA, Sept 1994.

[2] Fielding JP, Smith H. Studies in generic specific and particular conceptual designs of combat aircraft. Optimisation in Industry Conference, Palm Cost, Florida, March 1997. New York: ASME, ISBN 0-7918-1248-0.

[3] Fielding JP, Battoo RS. A part-time masters course incorporating aircraft design, build and flight test. World Aviation Congress, Oct. 13–16, 1997, Anaheim, CA., SAE and AIAA paper 975575.

[4] Jones RI, Scott RG. Learning through experience: Group Design Project on the Masters Course in Aircraft Engineering RTA-AVT Conference — Aerodynamic Design & Optimisation of Flight Vehicles in a Concurrent Multi-Disciplinary Environment, Ottawa, Canada, October 1999.

[5] Preston AM, Harrison R, Littlewood R. Eclipse — A turbojet powered UAV. 14th International RPV UAV Systems Conference, Bristol, 12–14 April 1999.

[6] Fielding JP, Smith H. Towards the blending wing body airliner. The 1999 Lecture to Cranfield University Court, Cranfield University, UK.

[7] Jones RI. The design challenge of high altitude long endurance (HALE) unmanned aircraft. The Aeronautical Journal 1999;103(1024):273–80.