1999 LECTURE TO COURT.

CONCEPTUAL AND PRELIMINARY DESIGN METHODS FOR USE ON CONVENTIONAL AND BLENDED-WING BODY AIRLINERS

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ABSTRACT

It is a widely-acknowledged fact that some 50-70% of life cycle costs are "locked-in" to an aircraft during the conceptual and preliminary design processes. Traditional design methods have concentrated largely on aerodynamic techniques, with some allowance made for structures and systems and the mass properties associated with them.

The Aerospace Design Group of the College of Aeronautics, Cranfield University has been involved in multi-disciplinary design methods for a number of years and has produced a number of tools to optimise the effect of major life-cycle and performance cost-drivers. This paper will describe some of the tools developed, and show examples of ways that they may be used for trade-off studies during the early design stages. Full details are given in ref. 1, but this paper will concentrate on those applicable to conventional and blended-wing body airliners.

It will also describe two conventional-configuration group design projects, designed by the College of Aeronautics, Cranfield University, and show their strengths and weaknesses. Discussion will follow concerning the airport and environmental issues posed by such very large aircraft.

A description will then be given of the start of the innovative and comprehensive blended-wing-body (BWB) airliner programme being performed by Cranfield University, with support from BAE Systems and Rolls-Royce plc.

Examples will be given of the College of Aeronautics' pattern of proving concepts by means of flying demonstrator aircraft, and how this will be applied to the BWB programme.

The design programme has already isolated many of the aircraft design and operational challenges posed by such a configuration. Some of those challenges have already been met and many more solutions will follow as a result of the effort and initiative to be produced by the three year, 76,000 engineer - hour programme.

1. INTRODUCTION

Cranfield University's Aircraft Design environment is one which combines research activities at all levels of design and a very extensive post-graduate teaching environment of more than 100 students. It has world-class facilities in terms of computational tools, wind-tunnels, simulators, structure test facilities and an approved aircraft design and manufacturing factory. It operates a fleet of aircraft from it's own airfield and has designed built and flight-tested it's own manned and unmanned aircraft, some of which will be described in this paper. The conceptual design tools are used for research in their own right, but also feed into the student group design projects, some of which lead to flying technology demonstrations. All of these elements have fed into the blended - wing-body (BWB) airliner programme that is the main focus of this paper.

Figure 1 gives a summary of the College's strategic multi-project programme which supports the BWB activities. The left hand column shows the full-time Aerospace Vehicle Design Masters programme projects leading to the BWB. Each one averages some 25,000 student and staff hours devoted to their completion. It can thus be seen that some 100,000 hours have been invested up to the end of the BWB 98 project. The conceptual design tools shown in para. 2. feed into these projects. The centre two columns show the flight-test demonstrators, produced to validate the design concepts, some of which will be described later in this paper.

The fourth and fifth columns show parallel work being performed in military and high altitude reconnaissance/space activities.

The remainder of the paper will describe conceptual design tools, current civil market requirements, conventional airliner designs and the early stages of the BWB programme.

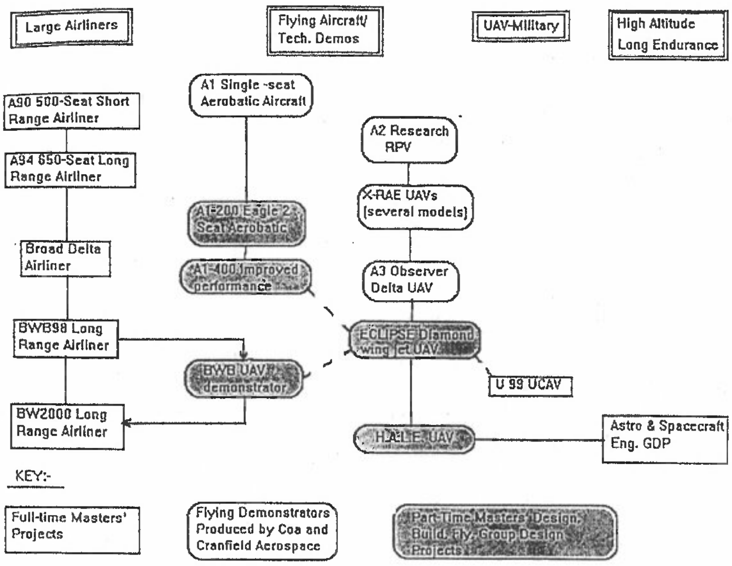


Figure 1

2. CONCEPTUAL DESIGN TOOLS.

The vast majority of the life-cycle cost-drivers are fixed during the conceptual and preliminary design phases. In many cases, negative features result from early design decisions, and it is then either impossible, or it is a very expensive process, to rectify them. One example might be the location of equipment in a very hot, inaccessible, vibration-prone part of the aircraft. This will result in poor reliability and maintainability, with consequent DOC increases. Another example might be a fighter which is optimised for good aerodynamic performance, but the wings might be too thin for a light-weight structure and have insufficient space for fuel.

Most aircraft companies have developed computerised design methodologies for use in the conceptual design process, but they are often type-specific and little work has been done towards developing preliminary and detail design tools.

Cranfield University has been involved for many years in aircraft design research and post-graduate teaching, and has developed a number of generic and particular design methodologies. The Conceptual Research Design Group of the college of Aeronautics was established in 1994 at Cranfield University to facilitate this research. It is a group of some 20 doctoral students and faculty members, with an interest in conceptual design. Fig. 2. gives an indication of the range of it's research activities (ref.1), but space constraints will limit this paper to the description of only the following areas:-

i) Multi-disciplinary, multi-variate optimisation methods.
ii) Methodologies to investigate DOC effects for variable-camber wings and configuration-specific research.

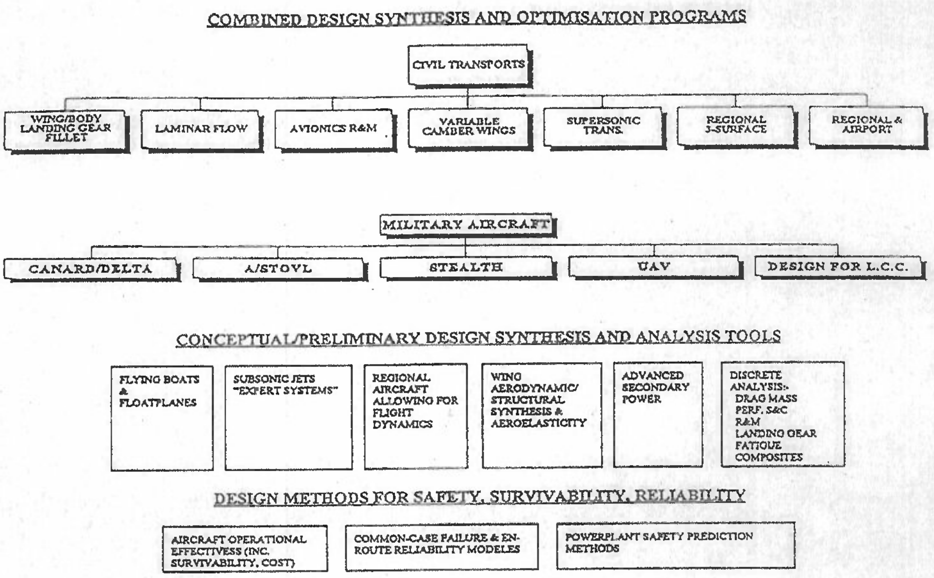


Figure 2

2.1. MULTI-DISCIPLINARY, MULTI-VARIATE OPTIMISATION METHODS

Any aircraft designer must reconcile the often-conflicting requirements of achieving low cost or weight, and high performance. One way of arriving at a good compromise is to provide the designer with tools which enable him or her to evaluate a wide range of potential candidate solutions in a short period of time. The possible solution space defined by the tools can be used to perform trade-off studies to choose the best design by use of numerical optimisation. A suitable design synthesis tool was developed initially in the late 1970's by the Defense Evaluation and Research Agency (DERA). Initial work produced tools for the design of subsonic jet transport aircraft, but more recent work addressed combat aircraft. Cranfield University was awarded a series of research contracts to develop tools, following the DERA philosophy, to allow study of a wide range of aircraft types. The detail required for the aircraft model did not allow the development of an overall generic methodology, but particular models have been developed for different classes of aircraft.

In all cases, a baseline aircraft is defined geometrically, which is then scaled to meet the user-defined constraints and cycled by the optimiser to obtain the best value of the objective function. Fig. 3 shows the output of a design for a blended-wing-body military aircraft, that has obvious potential for development of civil BWB aircraft.

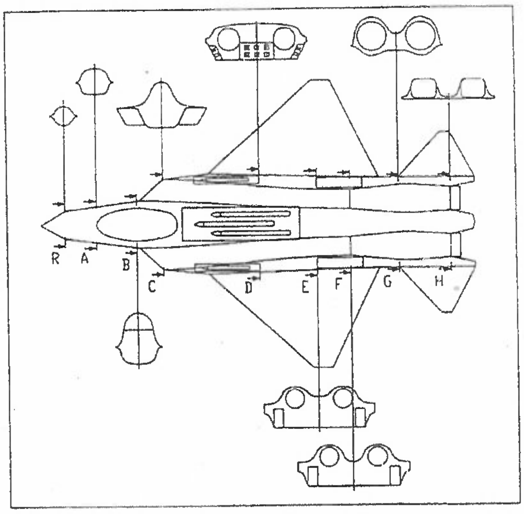


Figure 3

Mathematical expressions define the geometry at each of the fuselage stations shown, and allow the fuselage exterior shapes to vary. The method starts with the baseline aircraft shape and calculates it's mass, lift and drag and then check the aircraft performance against point-performance requirements, such as sustained turn rate. The method then models the specified flight profile and calculates fuel requirements. If the fuel volume does not match the assumed space available in the baseline aircraft, the shape of the aircraft is modified, and the cycle repeated. Most of the methodologies developed require several thousand iterations to produce an optimum design. This model used simple stability and control modeling, so, current BWB research is aimed at improving this vital aspect of such configurations. Separate programmes have produced multi-variate optimisation (MVO) methods suitable for configurations of subsonic conventional aircraft, three surface airliners, SSTs, canard-delta fighters, supersonic STOVL aircraft and various types of UAVs.

The MVO process has also been used to evaluate the effectiveness of a number of advanced technologies, below.

2.2. DESIGN METHODOLOGIES TO MODEL OVERALL D.O.C.S OF NEW TECHNOLOGIES AND CONFIGURATION - SPECIFIC RESEARCH.

2.2.1 Variable Camber Wings On Transport Aircraft (VCW).

Several computational tools were developed to describe VCW aspects and are summarised in Figur 4. A brief description of the various models follows:

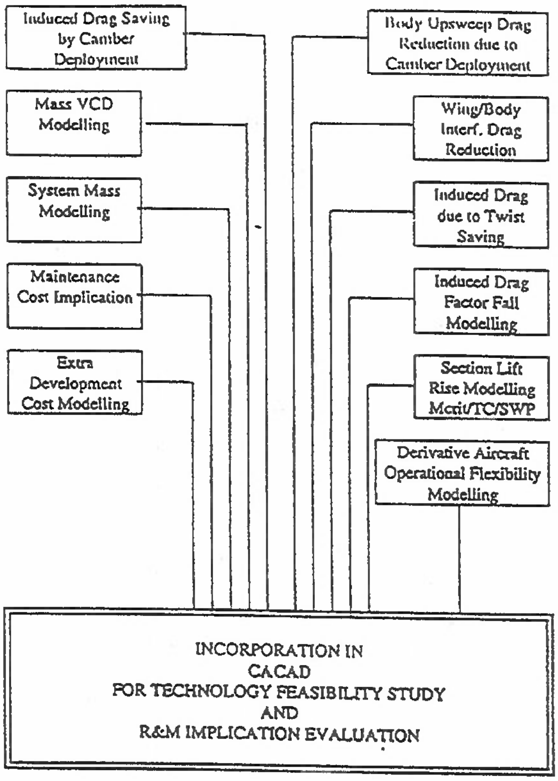


Figure 4

i) Synthesis and optimisation model (CACAD)

This is a computer-aided conceptual aircraft design (CACAD) synthesis tool to size and optimise jet transports, with special consideration given to structure and system maintenance costs. It is used to compare the overall aircraft effects of various technologies.

ii) Aerodynamic modeling elements:-

- Modelling of the drag saving due to the absence of angle of attack variation effects on rear fuselage upsweep.

- Variable camber wing/fuselage viscous interference drag reduction modeling due to effects of the absence of twist on fillet size at the wing-fuselage junction.
- Modelling of extra induced drag savings due to absence of twist in VCW aircraft.
- Modeling of drag-saving in VCW due to the absence of gradual induced drag factor increment as a result of elliptical lift distribution deterioration, through the cruise stages, in fixed camber wing aircraft (FCW).
- Consideration of experimentally-reported drag saving produced by camber variation instead of angle of attack changes. This is to reduce lift coefficient to compensate for aircraft mass reduction during cruise stages.
- Modelling of sweep-angle reduction due to lower critical Mach number of VCW as compared to FCW whose sectional lift coefficients at certain outer-wing sections are higher than the aircraft lift coefficient.
- Conceptual design of a family of aircraft with a common wing, having VCW installed on the undersized wing member of the family, to enhance operational flexibility.

iii) Mass Modelling.
iv) Maintainability, reliability and development cost modelling.

The above models were optimised using CACAD for a wide range of configurations to determine the D.O.C. benefits and penalties.

The results showed that there could be up to 2.5% overall D.O.C. improvements for long-range aircraft, subject to the assumptions used.

Subsequent work is being performed to better model the aerodynamic and structure design aspects of VCW, using advanced CFD and structural Finite-Element methods.

2.2.2. Other Technology and Configuration-Specific Research.

Extensive studies have examined the effects of hybrid laminar-flow technology, wing-tip devices, advanced systems and the reliability trade-off of increased Avionic cooling.

There has been comprehensive study of a wide range of UAV vehicles and tools to support the BWB programme. The latter include:-
i) Performance linked to platform shape and stability and control.
ii) Mass estimation and CG tools.
iii) Aircraft loading methods for BWB
iv) Passenger evacuation.
v) Cargo-aircraft versions of BWB.

Some of the above tools have been used for the BWB 98 programme and are being developed for later stages of the programme.

3. THE CURRENT CIVIL AIRLINER MARKET REQUIREMENTS

Ref.2 gives the following description of the market situation during the mid 1990s. The recent recession has slightly modified more recent projections, but although slightly delayed, the trends remain the same:-

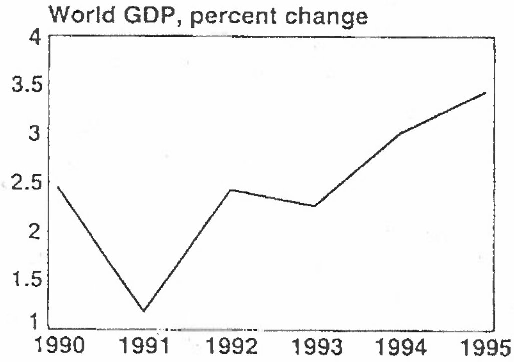


Figure 5

"The major aircraft manufacturers employ marketing departments which produce annual reports. Historical data are analysed and extrapolated in such areas as world economic indicators, Figure 5 shows gross domestic product (GDP) and highlights the recent recessions. Figure 6 shows the close correlation between GDP and the world air travel growth in revenue passenger miles (RPM)".

Further work led to predictions of world capacity requirements in terms of available seat miles (ASM) (Fig.7) and numbers of passenger seats in various aircraft size categories (Fig.8).

Figure 9 shows current trends in the productivity of large airliner in terms of available seat kilometres per hour - (ASK/km)

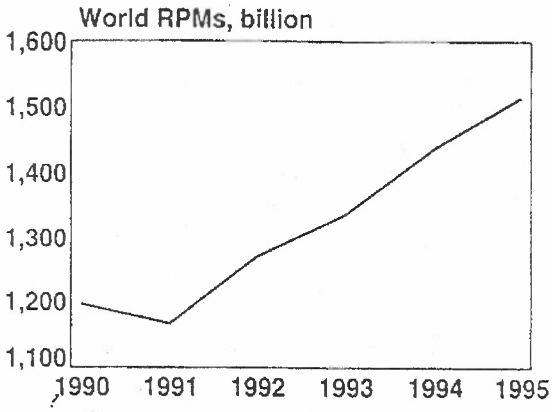


Figure 6

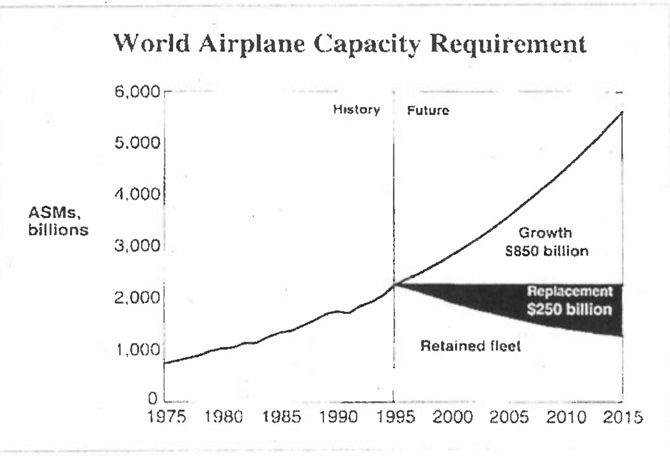
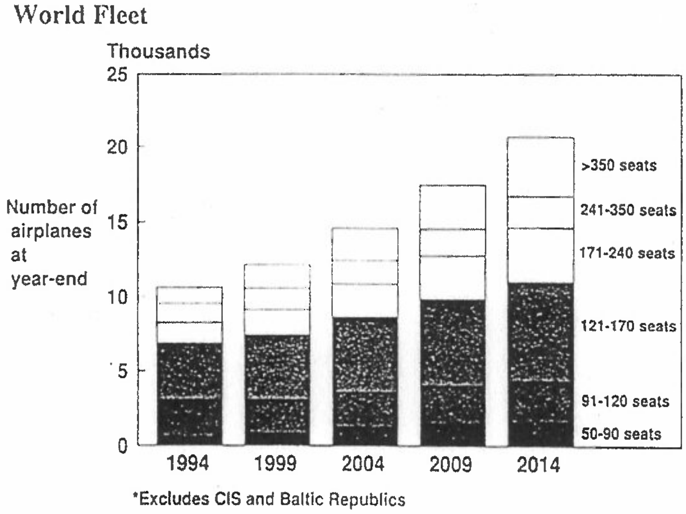


Figure 7

Figure 10 shows a map of current and projected aircraft capacities and ranges.



*Excludes CIS and Baltic Republics

Figure 8

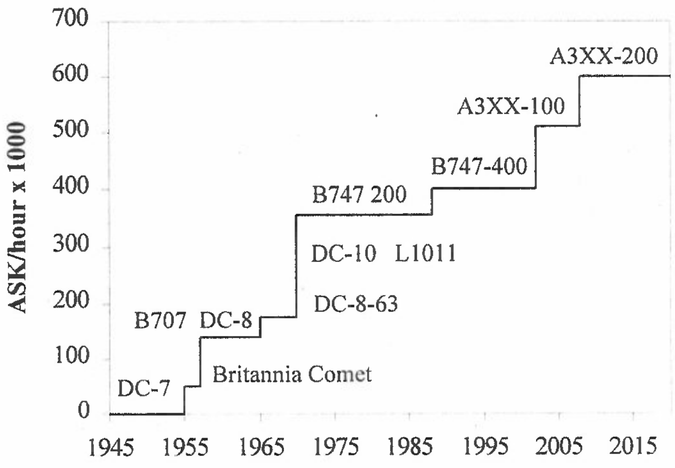


Figure 9

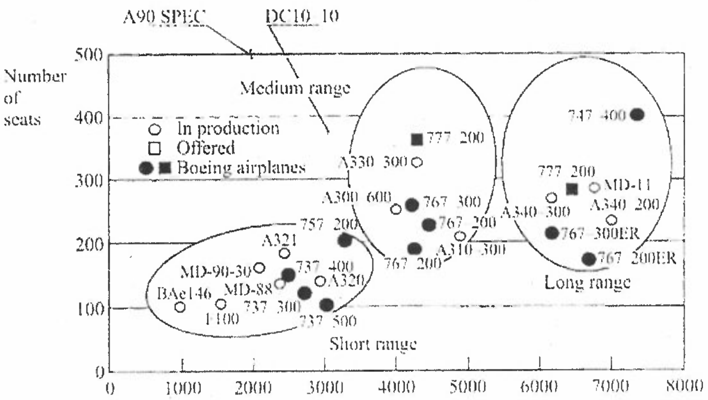


Figure 10

4. CRANFIELD UNIVERSITY CONVENTIONAL CONFIGURATION LARGE AIRLINER GROUP PROJECTS

Many Universities use group projects as powerful means of pulling together aeronautical teaching programmes in realistic applications of design integration. Design is largely taught by "doing" it. This has been Cranfield's Policy since 1946, instituted by the first professor of Aircraft Design the late Sir Robert Lickley. It's design course is unique in the magnitude of the student, staff and equipment resources used in the projects. These allow much more detailed studies than elsewhere and provide useful research investigations. Figure 11 give an example of the depth of work done in the rear fuselage of a military aircraft project. The projects are performed by 25-30 student and staff per year.

The post-graduate design students are allocated responsibility for preliminary/detail designs of major parts of the aircraft such as the forward fuselage, a flying control surface or a mechanical system such as fuel, environmental control, propulsion, landing gear or the control system. This allows much more realistic estimates to be made of mass and performance and show if the construction methods are feasible. A number of flight dynamics student model the stability and control characteristics and students from the School of Mechanical Engineering often design suitable engines for the projects. Plans are in hand to further improve the aerodynamic modelling, flight simulation and production engineering aspects of the projects. We have an extremely realistic virtual design office that is the envy of some industrial organisations. Each project expends some 30,000 engineers-hours and

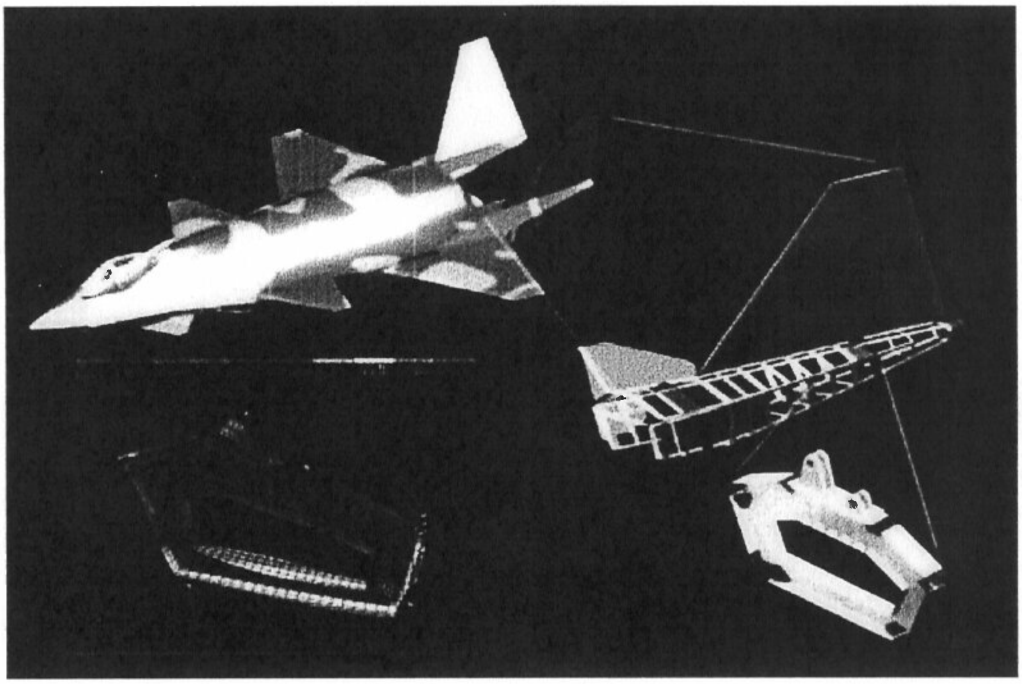


Figure 11

produces realistic results, primarily from the 8 month duration of the main phase of the projects. This paper will describe two relevant conventional projects, to set the context for the unconventional blended-wing-body aircraft, currently being designed.

4.1 THE A-90 SHORT-RANGE 500 SEAT AIRLINER

The A-90 project was performed to investigate one of the possible means of alleviating the chronic and worsening congestion at many of the world's airports, by producing a larger aircraft. The aim would be carry many more passengers up to 2000 miles on high density routes in Europe, North America and the Pacific Rim.

A full report of the project is contained in Ref.3, the main features of which are reported here.

4.1.1 AIRCRAFT REQUIREMENTS

It was decide to take the radical approach of aiming for a 2000 n. mile, 500 seat aircraft. This could replace DC10-10 and A300 aircraft over most of their operations and meet growth generated by such aircraft as the 757, 767 and A321. Discussions with a senior British Airways representative suggested there was a significant requirement for a 3,500 n.m. range for trans-Atlantic or trans-U.S.A. routes. The A-90 aircraft requirements therefore included provisions for fuel volume for such a range, although there would have to be some reduction in payload, to limit the aircraft size.

The strong predicted growth in cargo led to the requirement for carriage of standard containers above and below the main deck in cargo or COMBI versions of the aircraft and be compatible with military cargo operations, providing that this would not detract from civil operations.

The major features of the specification were:

(a) 500 mixed class passengers
(b) Carriage of under-floor LD3 containers and optional main deck cargo door.
(c) Passenger and bag range of 2000 N.miles with FAR reserves with max. cruise speed greater than 340 knots.
(d) All-up mass take off in 8300ft, landing 5660 ft, ISA, sea level.
(e) Runway loading less than that of the A330.

The speed and field requirements were based on comparison with the A-330 aircraft.

It was envisaged that the aircraft would use state-of-the art materials and technology. The operational flexibility required for a short/medium range airliner with possible civil military cargo derivatives prompted the decision to specify the use of variable camber wing flaps to optimise lift/drag ratios over a wide lift coefficient range. Such flaps were being developed at Cranfield on an independent research programme. This had the advantage of making use of good data from the computational fluid dynamics work on the aerofoil.

4.1.2 A-90 CONFIGURATION

The cross-sections of current aircraft were examined and it was decided to use a double-bubble fuselage, with a lower-lobe of similar width to the Boeing 747, with an upper lobe of similar width to the Airbus A320.

Figure 12 shows a side-view of the final fuselage configuration. All-economy seating has a capacity of 620 passengers. The main deck can accommodate two rows of 8ft x 8ft x 20ft containers in a cargo version.

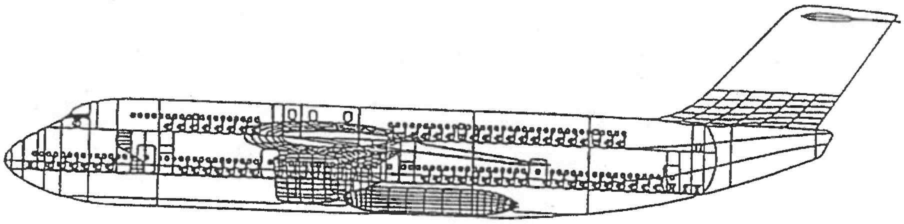


Figure 12

The controversial should-wing arrangement has many advantage, not least

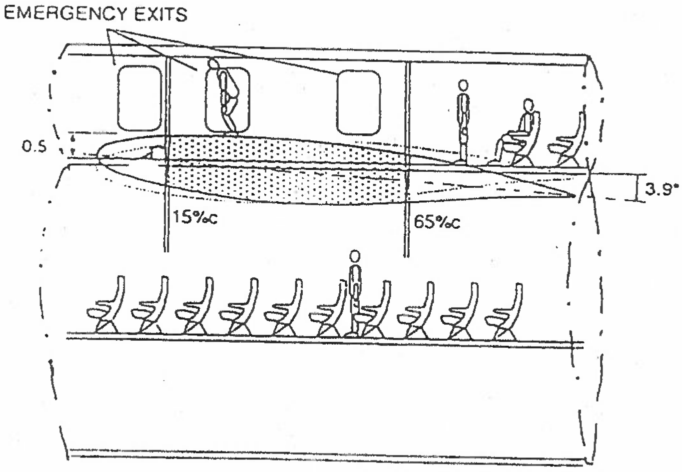


Figure 13

being good ground clearance for the large Trent wing-mounted engines. This layout led to some difficulties in the rare event of aircraft landing in water.

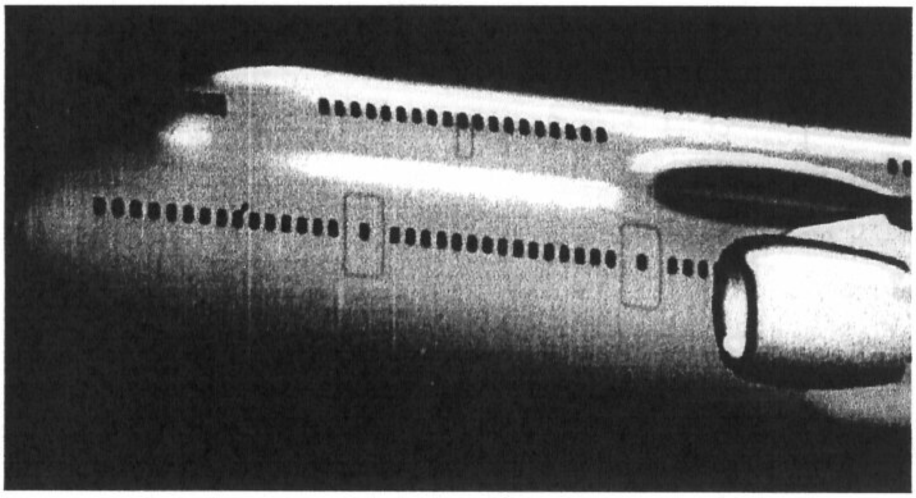


Figure 14

Figure 14 shows a CAD model showing the aircraft configuration.

4.1.3 PREDICTED PERFORMANCE

The detail designs produced by the students allowed a more accurate prediction of aircraft mass than given the original empirical methods. These showed that the Manufacturer's empty mass would be some 5 tones lighter than the target, but so many novel features could easily erode this margin.

Other performance calculations showed that the aircraft should meet or exceed its performance and operating - cost objectives with the exception of minor field-length non-compliance, that could be achieved with minor modifications.

4.2 THE A-94 LONG RANGE 600 SEAT AIRLINER

In common with industrial practice, it was decided to extend the A-90 family using as much as possible of the earlier design. The fuselage was stretched to accommodate 754 passengers in a high density layout and range extended to compete with that of the Boeing 747-400. Mixed-class capacity was 600 passengers.

The wing position reverted to the more conventional low-wing configuration, from the should-wing-A-90 and the aircraft became the A-94. (Fig.15). Two versions were designed, one with current technology and one with hybrid laminar flow on wing and nacelles. The A-94 was designed by 28 graduate students, and the flight mechanics checked by a further 15 students. Further details are shown in Ref.4.

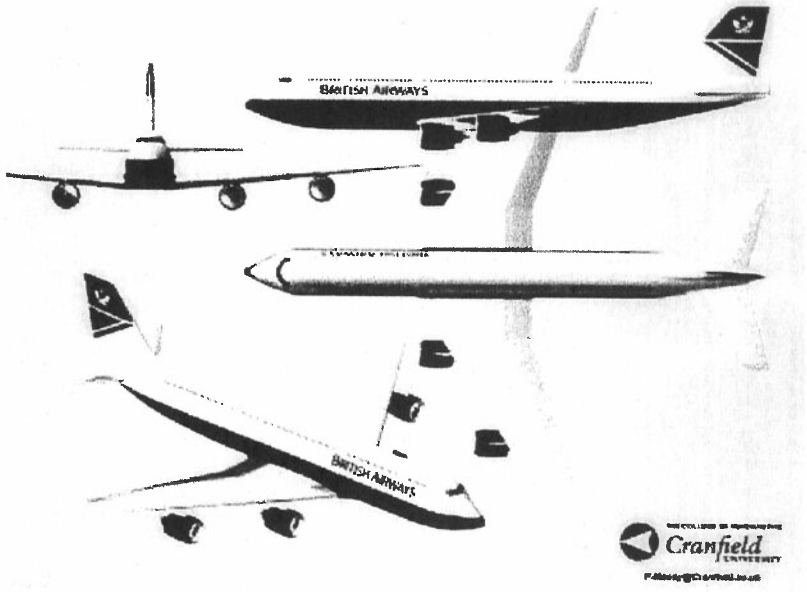


Figure 15

4.2.1 DESCRIPTION

The aircraft has a similar configuration to that of the Airbus A-3XX, being midway between the 100 and 200 models of that aircraft, in terms of passenger capacity. The A-94, however had a smaller number of seats across the upper-deck and consequently a longer fuselage.

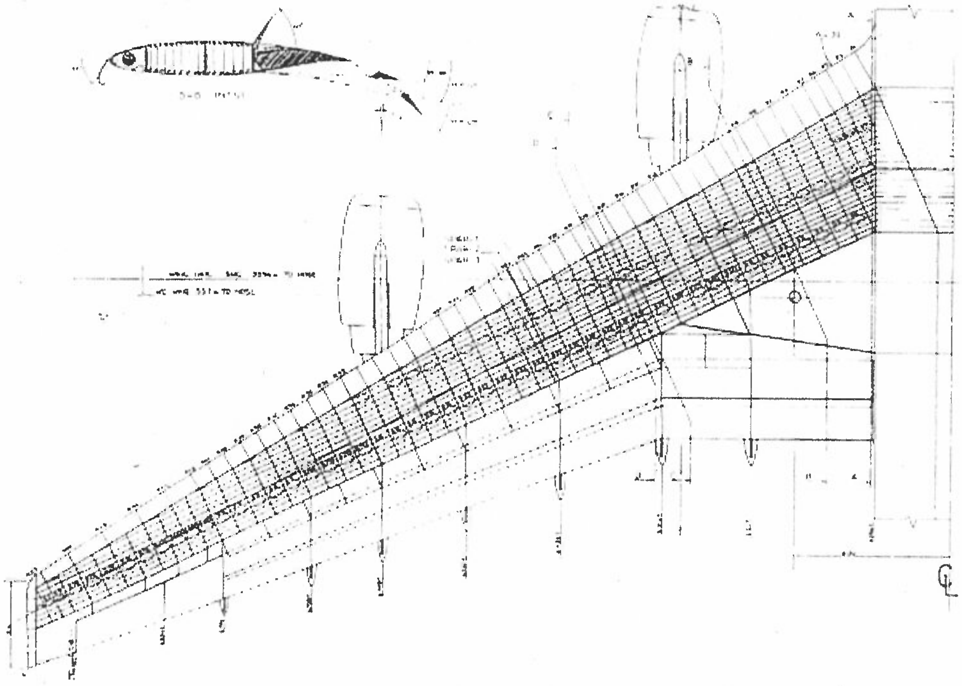


Figure 16

Fig . 16 shows a drawing of the wing showing the alternative variable-camber wing and the mounting of the Rolls-Royce Trent engines. Figure. 17 shows an initial scheme that was proposed to reduce drag by means of the use of laminar-flow cowlings.

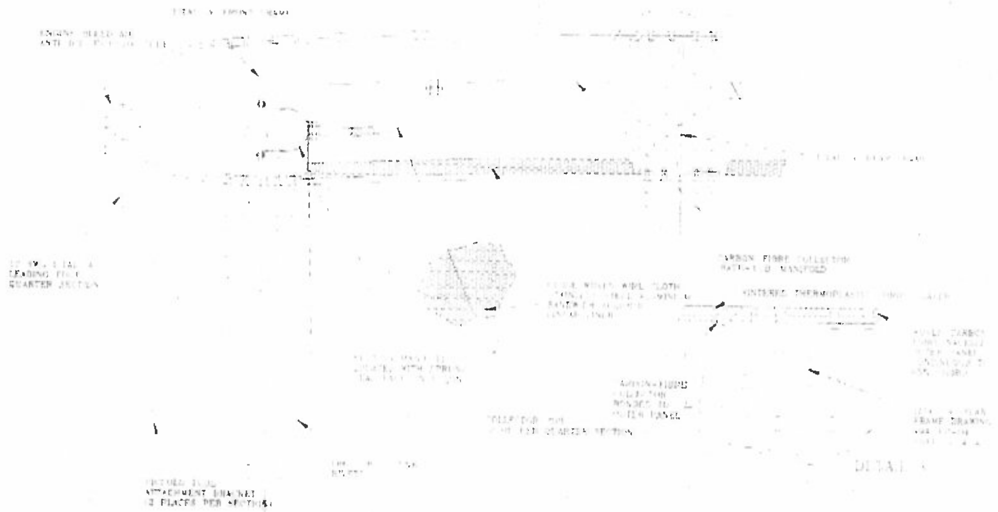


Figure 17

Such large aircraft led to the expected problems with landing gear. Figure 18 shows one of the main landing gear configurations that was proposed.

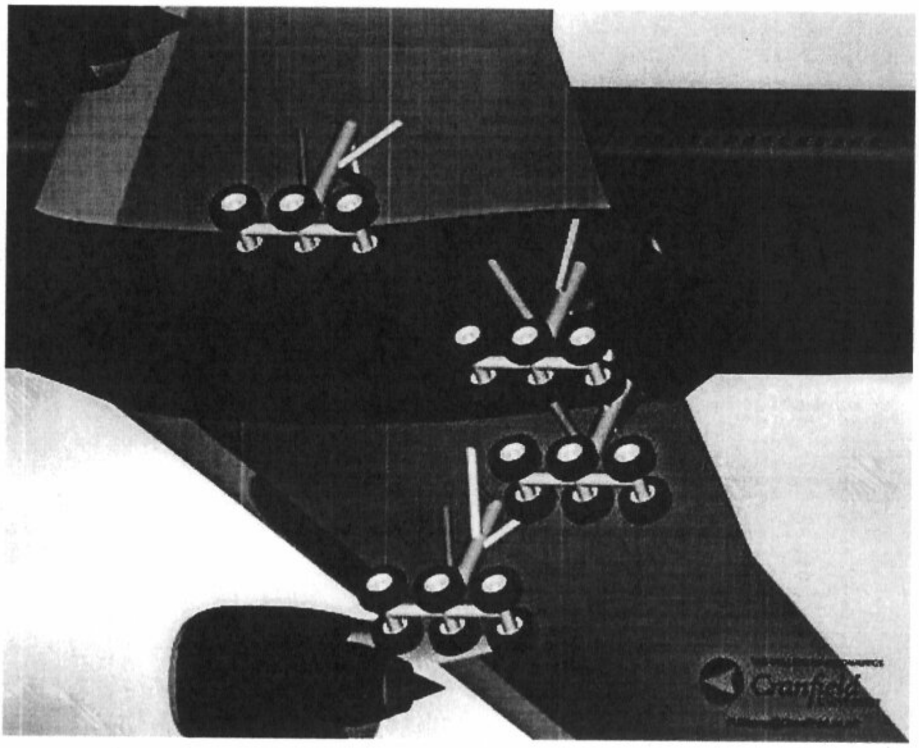


Figure 18

4.2.2 PERFORMANCE, COST AND LESSONS LEARNT

Most performance targets were met or exceeded, except for rather disappointing cost predications. Acquisition costs were typically $200m per aircraft, depending on build numbers and technology risk factors. Direct operating costs per seat mile were at best, some 12% lower than the Boeing 747-400.

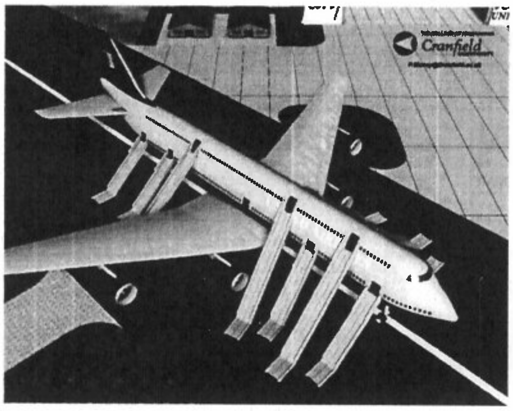


Figure 19

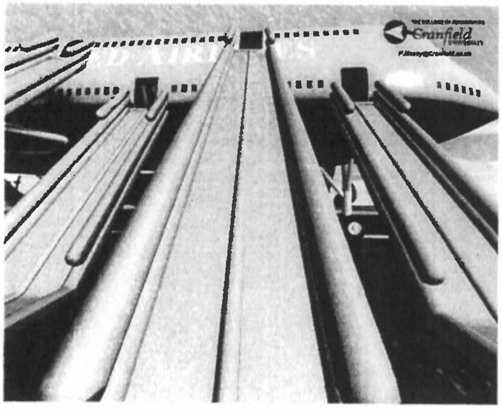


Figure 20

Emergency evacuation of passengers from such a high-capacity aircraft posed considerable problems. Fig.19 shows the proposed evacuation routes for the aircraft in ideal conditions, i.e. landing gears intact, no fire or significant cross-wind. Fig.20. shows the view of an escaping passenger would see after evacuation from the upper deck.

An interesting lesson learnt was the cargo volume limitations posed by this type of aircraft. A consequence of double-deck aircraft is the reduction in the cargo baggage container capacity relative to the number of passengers carried. This is because although the fuselage lengths are little longer than the 747, there is only the space below the main deck for baggage storage for 50% extra passengers. This is compounded by the fact that the new aircraft have bigger wings and landing gear, which further erode under-main-deck space.

The following table shows the number of under-deck LD3 containers that may be carried by some wide-body aircraft:-

TYPE	NO OF LD3s	NO OF PASSENGERS/ CONTAINER
Airbus A340-300	32	9.2
Boeing 747-400	30	14
Cranfield A-94	26	23

It can thus be seen that most of the container space is likely to be used for passenger baggage, thus reducing the amount of space available for cargo.

4.2.3. LARGE AIRCRAFT ENVIRONMENTAL ISSUES

Such very large aircraft may be more environmentally damaging than current large airliners, but strenuous efforts are being made to mitigate such effects

i) Noise Industry claims that through advanced technology particularly on engines their target is that the A3XX will be quieter than the 747-400, even with 30-50% more passengers.

ii) Emissions The A3XX should have emissions at the bottom end of the 747 spectrum for emissions of nitrous oxides during the Landing-Take-off cycle. gaseous emissions are not currently regulated in the higher atmosphere but the A3XX Class of aircraft will minimise the fuel burn per passenger by some 20%, with consequent reduction in emissions. There is still however, a significant potential problem in that the projected increase in air travel will deposit considerable amounts of nitrous oxides and other pollutants in the region of the tropopause. Even with the improved fuel consumption efficiencies already mentioned. Another significant atmospheric phenomenon is the creation of water vapour in the troposphere caused by the engine combustion process, amplified by atmospheric conditions. Large aircraft thus trail artificial clouds behind them thus artificially increasing cloud cover and probably increasing the "greenhouse effect".

iii) Wake Vortex All aircraft produce turbulent vortices, primarily from their wing tips. This phenomenon increases with aircraft mass and reaches such proportions as to be a flight hazard to smaller aircraft, particularly close to the ground. Airport separation distances are increased to overcome this effect, but this reduces runway utilisation, with consequent negative economic effects. Current research is being performed to produce wing-tip devices which may reduce vortex strengths and aircraft drag.

iv) Airport Issues Conventional wisdom limits the ground "box" size of aircraft to 80m span x 80, length. This will minimise changes to airport ground handling in terms of runway, taxi ways and gates. However the large increase in passengers will have significant affect on the passenger terminals, customs immigration and, more significantly local airport surface transport infra structure.

5. THE BLENDED-WING-BODY CONCEPT

5.1 The need for a radical approach

The aircraft previously mentioned have an aerodynamically efficient high aspect ratio wing combined with a simple to manufacture, structurally efficient cylindrical fuselage and a tailplane and fin mounted to the rear. The past 80 or so years have been devoted to refining this arrangement to squeeze out every last drop of performance, as shown in section 4, above. It appears that improvements are being made in small increments and are increasingly difficult and expensive to achieve. It seems that a more radical approach is required to achieve the large improvement demanded by the airlines.

The College of Aeronautics is currently placing itself at the cutting edge of aircraft design technology and is committed to the evaluation of new configurations and concepts through the acquisition of knowledge, the development of design tools and experimental studies.

One of the most promising 'new' configurations that has been identified as being worthy of study is the Blended Wing-Body (BWB). The benefits arising from this concept can be summarised as:

5.2 POTENTIAL ADVANTAGE OF BWB

Aerodynamics

- Low wetted area to volume ratio
- form conducive to low interference drag

Figure 21 from Ref. 5 shows some aerodynamic benefits from a modern BWB configuration.

Structures

- Efficient deep sections
- Favourable span loading

Human Factors

- Huge volumetric capacity
- Flexible cabin layout potential

Systems

- Potential for highly integrated airframe/engine
- Ideal configuration for application of laminar flow technology
- Significant advantages from control configuring the vehicle

Economics

- Particularly suitable for high capacity applications
- Significant D.O.C. reduction should be achievable

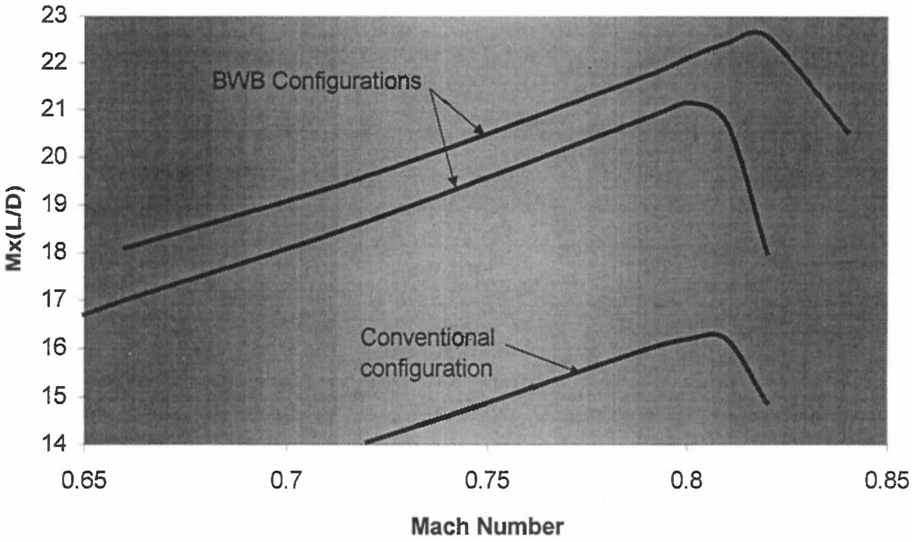


Figure 21

Figure 22, also from Ref.5 shows a comparisons of D.O.C predictions for BWB and conventional aircraft.

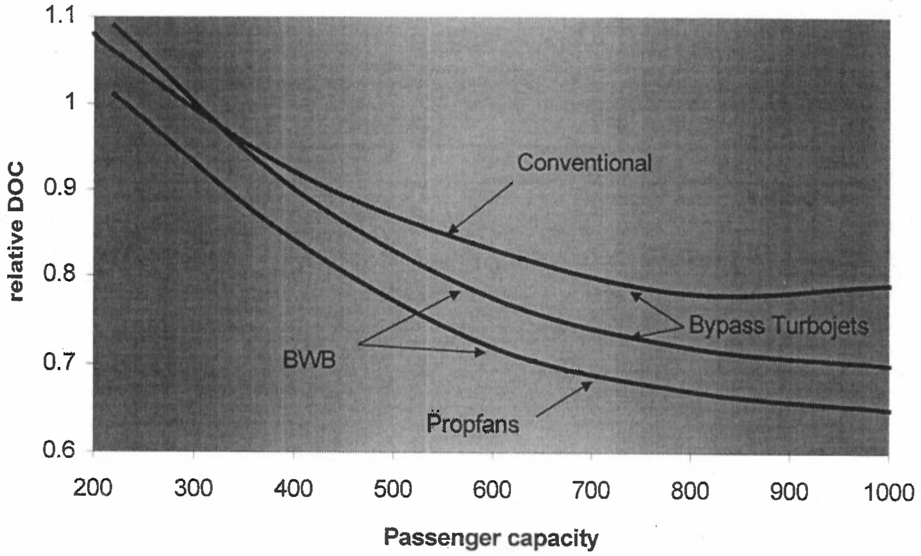


Figure 22

It is quite clear that the potential gains in applying this configuration to civil transport far exceed anything that can be achieved through the classical configuration. Furthermore, the classical configuration may struggle to meet the ever tightening environmental constraints.

5.3 BLENDED WING BODY CHALLENGES

The novel nature of the BWB concept inevitably leads to technical challenges, of which the following items are the most important:

Systems	-	design of fully integrated and novel propulsion systems
	-	Design and integration of possible laminar - flow systems
	-	Control allocation
Operations	-	Span/wheel track limits
	-	airport passenger handling
Manufacture	-	Manufacture and assembly of very large components, probably of composite materials
Aerodynamics	-	drag of thick aerofoils and the achievement of laminar flow

Structures - Unconventional layout
- non-circular cabin
- aeroelasticity
- major cut-outs for exits

Human Factors - Embarkation time
- passenger comfort/appeal
- no windows
- emergency evacuation
- pilot workload

Airworthiness Requirements - Safety
- Evacuation
- Stability augmentation

Conceptual Design - Tools
- Methods

5.4 BWB CONCEPTS

Of course, the BWB configuration has been explored from time to time over the last 90 years with varying levels of success The British aeronautical pioneer John W. Dunne designed the earliest tallies wing-body configuration of note. this pusher propeller engine biplane, which was credited with excellent flight stability characteristics, flew in 1912.

There has been significant progress in the USA largely funded again, by Government agencies. The Northrop series of flying wing bombers culminated in the YB 49 of 1949. The aircraft suffered from stability and control deficiencies which led to crashes and the termination of the programme. Advances in many areas of technology, particularly control systems led to the current B-2 Stealth Bomber. More recently some of this technology has been applied to the Boeing BWB project. This was produced as the result of a US Government-Funded national initiative involving Boeing (formerly McDonnell-Douglas), Stanford University and NASA.

Parallel activities in the UK and other parts of Europe have also led to novel Blended-Wing projects.

The Armstrong-Whitworth AW-52 was a contemporary of the YB-49 and suffered from similar stability and control problems. A more successful British project was the AVRO Vulcan which gave decades of sterling service as a strategic bomber, retiring from service relatively recently. An abortive civil airliner project, based on the Vulcan was the AVRO Atlantic. A more recent Cranfield project has taken this idea a step further to produce a promising design (Fig.23).

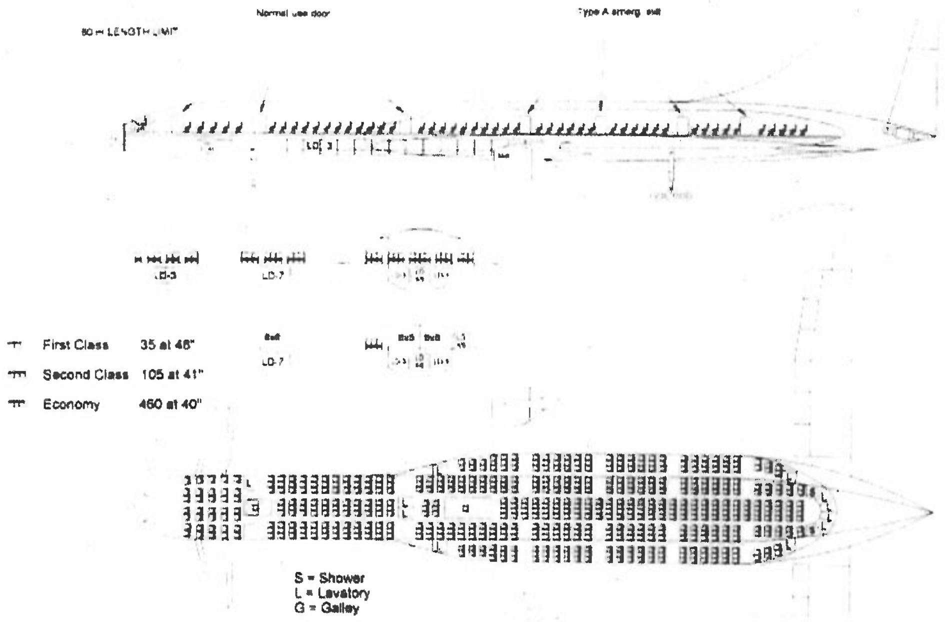


Figure 23

The current Cranfield BWB project, however, is closer to the Boeing concept in configuration, and forms the basis of a UK National project. Like the US project, the current project has industrial and University partners, but has, as yet, not had any Government support. The partners are Cranfield University supported by British Aerospace plc and Rolls Royce plc.

6. CRANFIELD COLLEGE OF AERONAUTICS BWB PROGRAMME

For those involved in the aircraft design business the design of an aircraft is usually a relatively straightforward process. The tools and procedures are readily available and proficient engineers are always at hand to offer the benefit of their years of experience. However, where a novel configuration or concept is being considered none of these advantages can be taken for granted. In the case of the BWB concept, whilst a few historical precedents have existed, it is necessary to start from first principles. Thus prior to the initiation of the design process, the infrastructure of tools and procedures must be set in place.

A programme of activities (Fig 24) is now in place to meet this requirement. The primary objective of this programme is to develop the tools, knowledge and understanding required to fully evaluate the BWB configuration and, in particular, its application to high capacity civil transport.

This gives rise to a series of objectives within the programme as follows:

* To complete a detailed design study of a fully optimised BWB configuration with integrated propulsion system, incorporating all appropriate technologies (e.g. laminar flow) within a rigorous framework of constraints to ensure that it can be successfully and profitably manufactured and operated and to the benefit of passenger appeal and safety. This will provide a considerable degree of confidence that all major design problems have been identified and addressed.

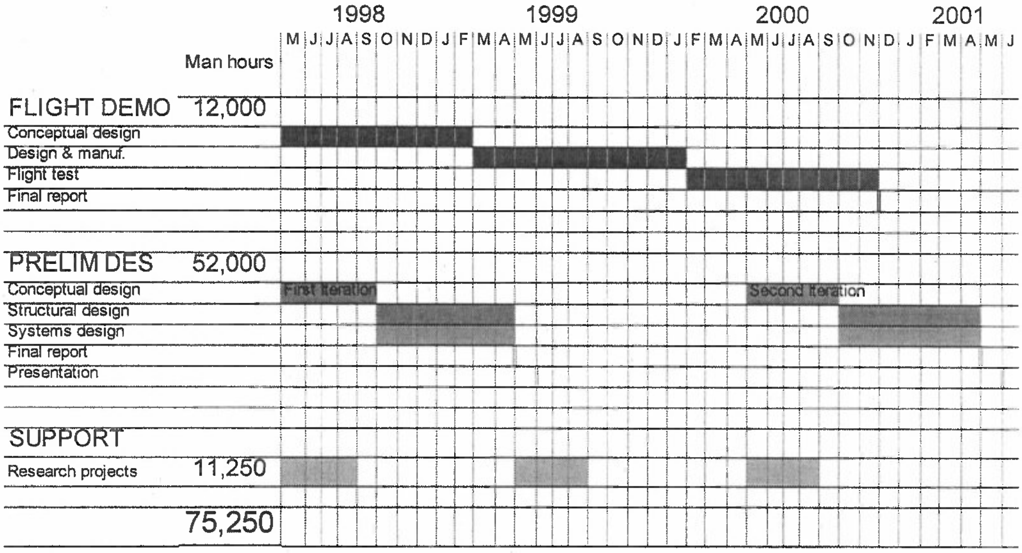


Figure 24

To achieve this an incremental approach will be utilised including:

* The creation and continued development of design tools
* Development of appropriate design methodologies
* An incremental programme of detailed design studies
* The design and manufacture of a sub-scale flying demonstrator
* Detailed studies within a number of identified Key Technology Areas feeding back into the tools and methodologies above

Nationally this programme is the only significant study of the BWB airliner currently in progress. Collaboration with Rolls Royce and British Aerospace has been vital in achieving the most appropriate direction for the work. Some 76,000 man-hours have already been committed to the study, the value of which has been estimated at £2.7m spread over a three year period.

6.1 BASELINE CONCEPT PRELIMINARY DESIGN

The programme consists of four main elements; a baseline preliminary design, an advanced technology preliminary design, a sub-scale flying demonstrator and a series of supporting studies that progress in parallel with the rest of the programme.

The first of these is a design study based on the specification of the AIRBUS A-3XX-200 high capacity civil airliner. The design will address airport operational constraints and will assume a technology level consistent with A-3XX. The study will proceed to a level of detail sufficient to resolve potential structural and system problems and explore their solution. This level of detail is required since many of the challenges, both engineering and human factors, will not be apparent at the conceptual design stage.

The current status of this phase of the programme is good with the majority of the tasks running to schedule. Fig 25 shows an early CAD geometry model. The structural layout is now complete and the Finite Element FE work Fig 26) is proceeding. The systems design is on schedule and some progress has been made in the challenging area of cabin layout for safety and comfort. Fig. 27 shows one of the many interior arrangements that were proposed.

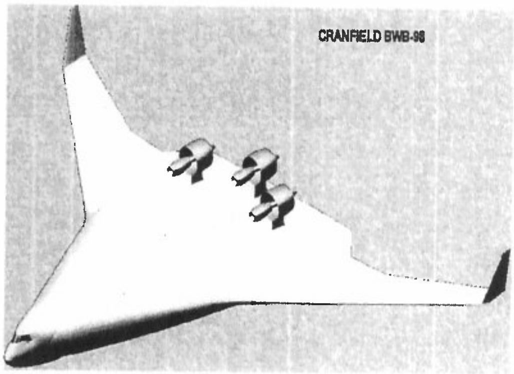


Figure 25

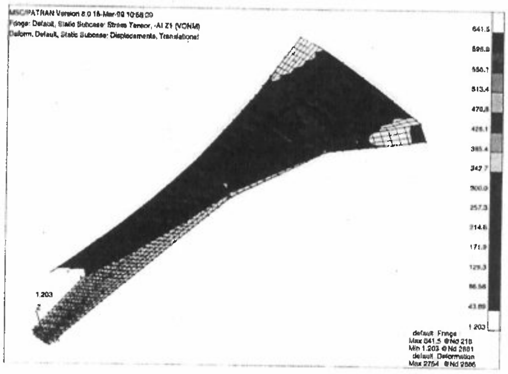


Figure 26

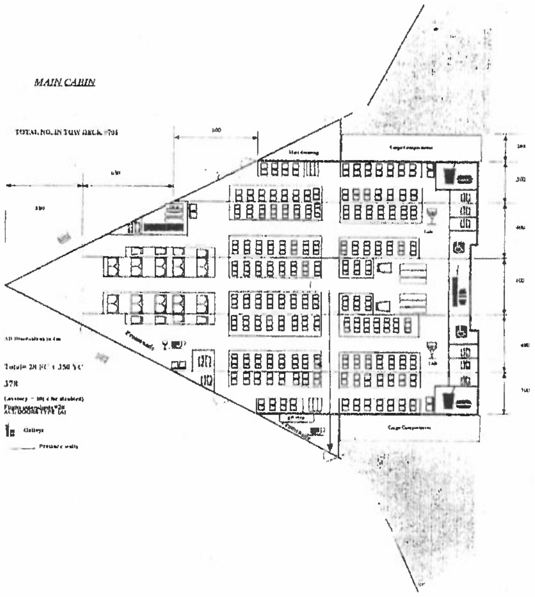


Figure 27

6.2 ADVANCED CONCEPT PRELIMINARY DESIGN

The advanced technology concept preliminary design study will build on the baseline study by incorporating a number of synergistic technologies that enable the full potential of the BWB concept to be realised. The basic A-3XX-200 specification will still be adhered to in conjunction with the operational constraints to ensure that a direct comparison may be made with both the AIRBUS A-3XX-200 and the baseline BWB design. Technologies likely to be incorporated include Hybrid Laminar Flow Control (HLFC), a Stability Augmentation System (SAS) and an advanced propulsion system.

6.3 SUB-SCALE FLYING TEST-BED

There will be a high degree of uncertainty associated with many aspects of the vehicle's aerodynamics, stability and control. As a highly cost effective method of risk reduction in these areas the programme incorporates the design and manufacture of a flying test-bed to evaluate and explore the aerodynamic characteristics of the configuration. The vehicle will be capable of flying a programme of specified maneuvers whilst simultaneously transmitting telemetry data to the ground for analysis. On the basis of the results, configurational modifications can then be re-evaluated on subsequent test flights. The College of Aeronautics has considerable expertise in the area of unmanned arial vehicles (UAV) and is certainly the UK's foremost centre of excellence. The latest vehicle is the Cranfield A-3 (Figure 28), which is produced for the MOD. It is a small man-portable research vehicle with a broad delta planform with wing tip fins and rudders. It successfully completed its first flight on Thursday the 11th March 1999. The Colleges design and production facilities are not limited to UAVs. This capability has been utilised by British Aerospace to help train their engineers to be able to execute an aircraft design project starting from a clean sheet of paper through to the vehicles flight-testing. Engineers participating in the Aircraft Engineering masters course are given the opportunity to contribute to a design-build-fly project. Previous projects have included substantial modifications to the Colleges A-1 aerobatic aircraft (Figure 29) and the production of an advanced planform UAV, the Eclipse (Figure 30). All of these capabilities are

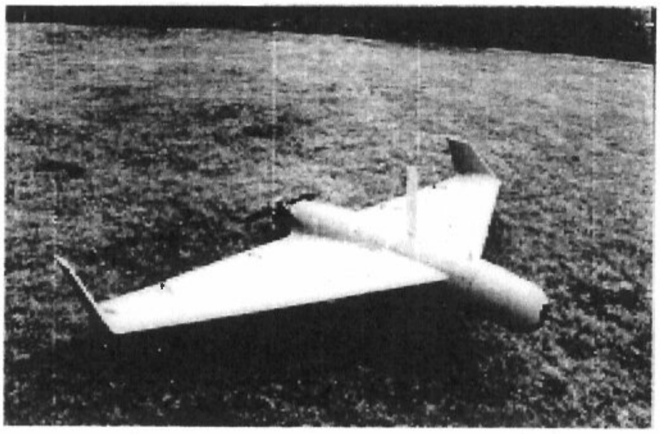


Figure 28

vital to the success of the BWB sub-scale flying test-bed and will be utilised to the fullest extent.

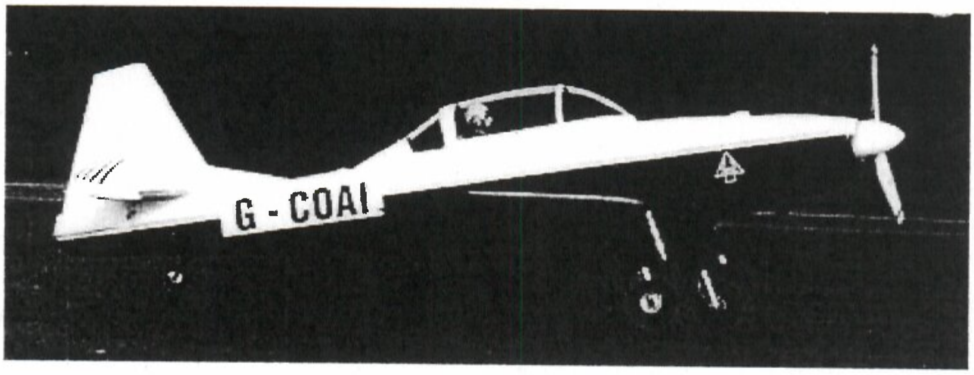


Figure 29

Figure 30

6.4 SUPPORTING STUDIES

Concurrent with the full and sub-scale design work, a variety of studies will explore some of the most challenging issues facing the design of BWB aircraft. Many of these have already been identified, such as the design of a non-circular pressure cabin or emergency evacuation, many more will only come to light as the preliminary design studies proceed. The full capability of the College of Aeronautics will be drawn upon including human factors, flow control, flight simulation, structures and materials as well as its expertise in the operational aspects of air transport. The School of Mechanical Engineering is also investigating an alternative propulsion system. The results of these studies will be fed into the advanced technology preliminary design study. Some of these activities focus upon detailed aspects of the design others are concerned with wider issues such as the application of the BWB concept to roles other than the civil transport. The intrinsically stealthy nature of the configuration lends itself to military roles such as the military transport or an air-refuelling tanker, which could achieve significantly increased range or payload performance. Combat aircraft, both manned and uninhabited, stand to benefit from the configuration's layout, structural and aerodynamic advantages.

7. CONCLUSIONS

- The vast majority of the life-cycle cost-drivers are fixed during the conceptual and preliminary design phases. In many cases negative features result from early design decisions, and it is either impossible, or is a very expensive process, to rectify them. Modern computers and their programs can be used to reduce such problems by use of multi-variate optimisation tools as well as extensive simulation. Careful design methods provide means to accurately predict in-service behaviour, using the limited information available during the early design stage. This leads to aircraft not just optimised for performance, but also for the whole of their life cycles.

- Cranfield University has produced a wide range of design methodologies and has substantiated them by extensive group design projects and technology demonstrator flying aircraft.

- This history of aviation has demonstrated the constant search for increased efficiency in terms, of cost, safety and comfort. Subsonic aircraft have reached a cruise-speed plateau and so improvements have been achieved by increased size, and more efficient propulsion, aerodynamics, structures and systems.

- Air Transport requires the acquisition of significantly increasing amounts of passenger capacity. This will aggravate already crowded airport and air-lane capacity. Such increases in activity will add to concerns about noise and atmospheric pollution.

- Increased aircraft size is attractive in terms of reducing flight movements for a given number of passengers. Increase in size and technology as in the Cranfield A90 & A94 projects can also offer improvements in passenger economies and lead to reduced fuel burn per passenger-mile, with consequent reduction in pollution. Incremental improvements in airframe and engine efficiencies will add to these benefits. It is however debatable if these improvements will compensate for the projected increase in air traffic.

- More significant reductions in operating cost and pollution require a step-change in aeronautical technology, such as that offered by the blended-wing-body concept. Significant work has been performed by the US Government-funded NASA/Boeing/Stanford University work.

- Cranfield University together with BAE Systems and Rolls-Royce has made significant progress in the exciting UK National BWB project, without the benefit of direct Government funding.

- The current work has, as planned, isolated many of the challenges of such concepts, as well as offering some solutions. This progress will continue in the remainder of the current 3-year programme and will utilise Cranfield University's whole-aircraft design, manufacture and operational capability.

- The sub-scale BWB flying demonstrator will build on the expertise already demonstrated on the A1 Eagle, the A3 and Eclipse unmanned vehicles and will provide valuable data for future aircraft.

- Cranfield University will, by this means, continue to provide experienced, innovative graduates who will rise to the highest level of the Aeronautical Business, as has happened since 1946.

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