# COLLEGE OF AERONAUTICS BLENDED WING BODY DEVELOPMENT PROGRAMME

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## Abstract

*Continued pressure to achieve reductions in direct operating costs (D. O. C.) combined with ever tightening environmental constraints has left the aircraft designer with little option but to explore the possibilities offered by more novel configurations. This paper describes the programme of activities currently underway at the College of Aeronautics, Cranfield, that is intended to objectively evaluate the advantages and challenges inherent in the Blended Wing Body (BWB) configuration.*

*The programme incorporates the development of a sub scale flying demonstrator facility that should provide the capability to reduce risk in major advanced configurations studies in a highly cost-effective manner.*

## 1 Introduction

Considerable effort continues to be invested into the development of the ‘classical’ aeroplane shape of passenger jets such as the Boeing 747 or Airbus A-340.

Concurrent with the hard to achieve demands for reductions in Direct Operating Costs (DOC), environmental issues have been offsetting much of the potential performance gains. In fact, if future projections of limitations on noise, ‘greenhouse’ emissions and radiation issues associated with vapour trails producing high altitude cirrus clouds are taken into consideration it may be that, without substantial improvements in performance the very viability of air transport could be called into question.

One of the most promising ‘new’ configurations is the Blended Wing-Body (BWB). In fact if predictions can be achieved and a civil BWB transport can be realised, no conventional airliner would be able to compete.

The BWB configuration does present a number of interesting challenges, any of which could prevent a feasible solution from being achieved. A wide ranging study is underway at the College of Aeronautics (CoA) that is intended to get to grips with the known challenges and to unearth the problems that may be hidden in any detail solution.

The programme of activities will lead to the completion of 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. The design will provide a considerable degree of confidence that all major design problems have been identified and addressed. To achieve this an incremental approach is being utilised.

## 2 Historical background

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 one of the earliest tailless wing-body configurations of note which flew in 1912.

There has been significant progress in the USA with the Northrop series of flying wing bombers culminating in the YB 49 of 1949. The Armstrong-Whitworth AW-52 was a contemporary of the YB-49 but both suffered from similar problems. A more successful British project was the AVRO Vulcan which served as a strategic bomber until relatively recently. A civil version of the Vulcan, the AVRO Atlantic failed to get off the drawing board, however a recent Cranfield study has shown that a solution may exist along these lines.

## 2.1 The modern blended Wing body concept

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 which was produced as the result of a US Government-Funded national initiative involving Boeing, Stanford University and NASA.

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

The Cranfield baseline BWB configuration is similar to the Boeing concept in configuration, and currently represents the only UK National project of its scale.

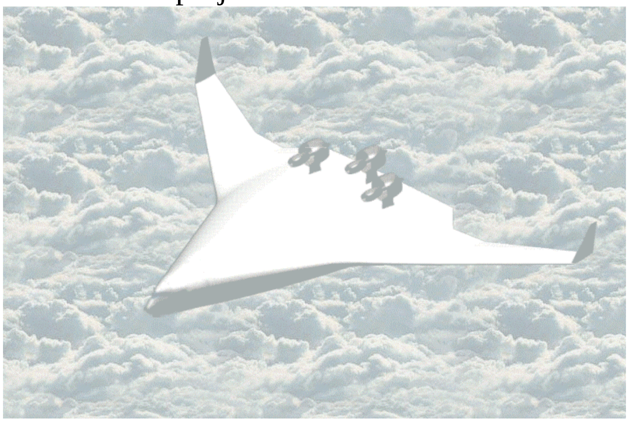

*figure 1*

## 3 Programme

## 3.1 Elements

### *3.1.1 Concepts studies*

While considering the potential benefits of any novel configuration, it is important that the designer should keep a clear idea of the intended applications. This is important as with many novel configurations, and in particular the BWB, the concept may be heavily constrained by operational aspects. A number of top-level conceptual design studies have been, and are continuing to be, performed to evaluate potential applications of the BWB. These studies are neither detailed nor optimised as the tools and methodologies to achieve this are still under development. However, the results indicate that further work on a number of applications would be justified.

### *3.1.2 Tool development*

Aircraft conceptual design tools and methodologies have been developed in parallel with the development of the classic aircraft configuration. The design of BWB aircraft is a considerably more complex process than that of conventional aircraft and as a consequence existing design methodologies are not easily adapted. Furthermore, any tools based on empirical data are unlikely to remain valid for novel designs or do not have the required flexibility of parameters to be able to model the BWB. Studies are currently in progress to redress this deficiency.

### *3.1.3 Preliminary design studies*

With the benefit of experience, the viability of a conventional aircraft design can usually be determined with a reasonable degree of confidence at the conceptual design phase. In the case of novel configurations it is essential to proceed to at least the preliminary design phase before any reasonable conclusions may be drawn. Furthermore, in the light of this lack of experience many potentially show stopping design challenges may be hidden in the detailed design. These challenges cannot be further researched, or designed around, until they have been identified.

As with the initial concept studies in section 3.1.1, the first of these preliminary design studies is not intended to represent an optimum design as the tools to achieve such a design are not yet in place. However, the intended objectives of this initial preliminary design study do not require the design to be optimum. The planned phase II preliminary design study will be positioned considerably further up the learning curve.

### *3.1.4 Key technology development*

As already discussed, the BWB configuration has been investigated in the past with limited success. The key to its success lies in the optimal application of new technology. Some of these technologies are still at a very early stage of development and this development is being continued to a point were it can be applied. Other new technologies exist but must be carefully adapted to the BWB application. If these technologies cannot be successfully utilised then the BWB concept may need, once more, to be archived until some future date.

### *3.1.5 Sub scale demonstrator*

There is considerable risk associated with the development of an unconventional configuration and measures need to be implemented to reduce this risk and its financial implications. Small-scale flight vehicles have often been used to explore aerodynamic, flight dynamic and flight control characteristics prior to full-scale flight test.

The programme includes the design, manufacture and flight of a small-scale BWB test vehicle.

## 3.2 Schedule

The programme is currently intended to run from early 1998 through until early 2002 by which time a fully optimised preliminary design study should have been completed and the sub scale demonstrator should have completed its initial flight-testing.

## 4 Concepts studies

Throughout the duration of the programme conceptual design studies, applying the BWB concept to a number of practical applications, will continue. In the initial phase these have been intended to highlight the particular strengths and weaknesses of the BWB to enable further studies to be more focused. As the programme continues, the more refined BWB design tools can be utilised as they develop.

## 4.1 Civil applications

The initial studies indicate that the BWB is well suited to two civil applications, the high capacity civil transport and the freight aircraft. The BWB's high efficiency and flexible packaging potential enable it to meet the demands of the air transport market whilst minimising the impact on the environment. The basic geometry of the vehicle combined with the constraints implied by the required cabin height for a human payload implies better solutions for the ultra-high capacity applications.

The air freight market is rapidly expanding and is likely to support an increasing number of aircraft sales. The BWB configuration offers considerable flexibility for volume limited payload applications and, assuming a reasonable fraction of palate freight, could provide a feasible solution over a wide range of All Up Weight. A passenger/freight aircraft is likely to be driven primarily by the passenger transport role.

## 4.2 Military applications

### *4.2.1 Large vehicle*

Whilst the BWB's excellent payload range characteristics makes it a strong contender for the military transport application, it's intrinsically stealthy shape brings advantages beyond anything offered by the conventional configuration. The vehicles low ground attitude should prove advantageous in loading/unloading.

The BWB configuration is not ideally suited to high density payloads, however, an air to air refuelling variant of the military transport aircraft would benefit significantly from the stealth and payload range advantages. Applications such as this could potentially make global reach a practical reality.

### *4.2.2 Small vehicle*

Until the advantages offered by low observable technology are eliminated by anti-stealth techniques the BWB is likely to be the first configuration considered for any modern combat air vehicle. The BWB finds applications from the larger strike aircraft, through the more compact Unmanned Combat Air Vehicle (UCAV) down to the smallest unmanned aerial vehicles (UAV). The conceptual design studies performed in this area will become more conclusive as the design tools become more refined.

## 5 Tool development

### 5.1 Mass estimation

Empirically based methods of mass estimation provide an efficient yet accurate method for determining the mass of aircraft at the conceptual design stage. At a more refined level low fidelity finite element based methods present a strategy for incorporation of more elaborate strength and stiffness criteria.

The BWB configuration presents difficulties in the implementation of either of these approaches. The former is hindered by the lack of empirical data and the latter by the lack of experience in BWB structural layout.

As the database of mass breakdowns starts to accumulate from the preliminary design studies, this information will be used to develop empirical techniques tuned to the BWB configuration. Furthermore, experience will be gained in how to tackle the problem of BWB structural layout design and this will assist with the more deterministic mass estimation approaches.

### 5.2 Aerodynamic prediction

Whilst a wide range of aerodynamic prediction tools is already in existence, ranging from simple empirical data sheet methods to Navier-Stokes CFD techniques, the need for multi-disciplinary optimisation dictates that the methods should be computational efficient. Simultaneously, the requirement for novel configuration applicability demands more flexibility than is offered by simple data sheet methods. Current research activities are focusing on vortex lattice methods which seem to offer a reasonable compromise. Ultimately, a multi-level approach will be required incorporating both high and low fidelity methods.

## 6 Preliminary design studies

### 6.1 Baseline configuration

#### *6.1.1 Basic requirement*

The primary requirements and specifications for the BW 98 are as follows:

To design an airliner with a similar payload and mission performance to the A3XX-200 but with superior direct operating costs. Accommodation capacity should be 656 seats in 3 class layout.

An alternative cabin layout will accommodate a maximum of 960 passengers in a single class seating.

The design range is 7650 nm cruising at Mach 0.85 with a payload of 656 passengers and their baggage. The aircraft should be compatible with existing airports and facilities.

The results of this study are too extensive to be summarised in this paper, however, the following 2 sections describe alternative centre fuselage structural designs.

#### *6.1.2 Centre wing-body (modular)*

Two approaches were considered in the design of the centre wing body structure of the aircraft. One uses aluminium alloy and classical structure members such as frames and stringers and will be considered first. An alternative configuration using composite materials is described in the next section.

Flat and vaulted shell structural configurations for the cabin bay were considered at the beginning of the project but the vaulted double-skin ribbed shell configuration was found to be superior due to the weight savings and the load diffusion. Thus the fuselage is built as a multi-bubble circular section as shown in figure 2.

This fuselage configuration requires a double-skin construction. The inner skin carries pressurisation efficiently by hoop-stress and the cabin wall is used to balance the weight of the structure above the cabin bay and the vertical component of the hoop-stress. The outer skin carries the major part of the bending moment and the shear force due to the aerodynamic loads acting on the aircraft. In addition, other structure members transfer part of the aerodynamic loads from the outer to the inside skin.

Due to the particular shape of the BW-98 the number of tubes inside the fuselage varies longitudinally. Three key cross-sections were designed in order to maximise the internal space. The first is formed from a single tube, the second is composed of three tubes and the last section is formed with five tubes where the three inner ones are used for the passengers and the outer two are used for the baggage. An isometric view of the inside fuselage can be seen below.

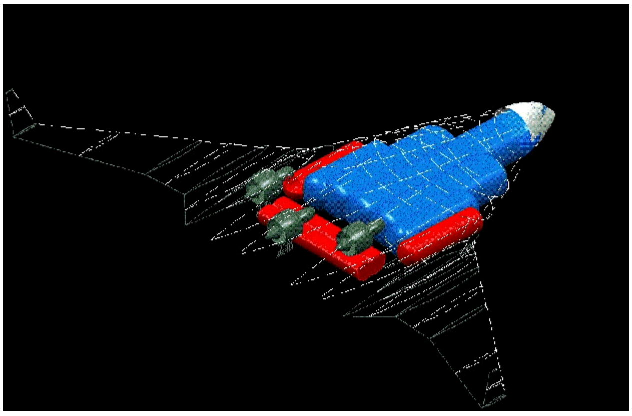

*figure 2*

Each tube used for the passengers is double decked.

Wing bending moments and the shear forces are carried by conventional spars. Ribs in the longitudinal direction are used in order to attach the inner fuselage to the main structure of the outer fuselage.

The inner and outer fuselage are designed as a conventional fuselage which skin is supported by stringers. The stringers are used to carry a part of the axial load due to the bending moment while the skin carries shear from the applied transversal external load and torsion. Furthermore, the skin of the inner fuselage will also carry the pressurisation loads.

As with a classical aircraft, frames are used in order to stabilise the aircraft structure in the transversal direction. Two frames will be used due to the special configuration of the BW-98; one for the inner fuselage structure and the other for the outer fuselage. The inner frame will be attached in the non-pressurised part of the aircraft in order to save space for the passenger bay.

Ribs in the transversal direction will also be used in order to attach the fuselage bubbles to the outside structure and also to help the frame to carry the shear and maintain the shape of the of the aircraft. In order to avoid the shear buckling of these ribs stringers will be utilised.

### *6.1.3 Centre wing-body (integrated)*

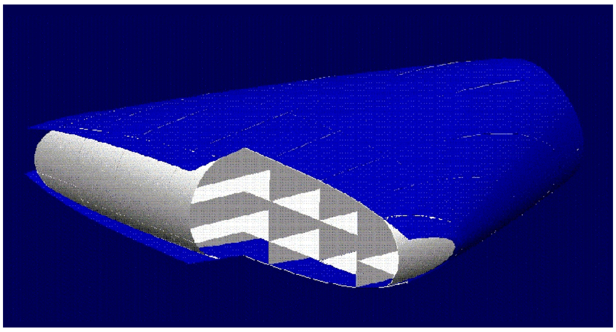

*figure 3*

The alternate solution considers an integrated approach to the design of the centre wing body section. Here the applied, inertial and pressure loads are carried through a unified structure.

The main loading comes from the pressure differential applied to the large and very slightly curved skin panels. This induces considerable bending moments in the skin panels. To limit these, some internal walls have been arranged to connect the upper and lower skin.

As the aim of the composite layout is to limit the number of parts in order to reach the lowest possible weight, the outer skin takes the pressurisation loads, without the help of additional structure.

Thus, the pressure differential is applied on the skin panels on top and bottom of the cabin, on the leading edge in the front and on curved bulkheads on the sides and in the back of the cabin.

## 6.2 State-of-the-art configuration

The full potential of the blended Wing body configuration can only be realised through the application of a number of advanced technologies. These technologies were not applied to the baseline configuration for two reasons. Firstly, the clear identification of advantages and disadvantages purely from the BWB configuration was required. Furthermore, the design tools were not then in place for designing a correctly optimised configuration and hence the integration of more advanced technologies would have been premature.

Later in the programme, as the design tools develop, the phase II preliminary design study will be performed. In addition to taking advantage of these design tools, a number of advanced technologies will be integrated with the design. The application of laminar flow technology, control configured vehicle technology combined with a fully integrated propulsion system is likely to result in a significant step improvement in performance.

This preliminary design study will not only quantify the advantages offered by such technologies but will also identify offsets in terms of mass and cost due to actual engineering solutions.

## 7 Key technology development

### 7.1 Human factors

*figure 4*

From early on in the study it became clear that human factors was the dominant issue in the design of BWB aircraft for civil transport. For all ultra-high capacity aircraft (UHCA) human factors have already become an area of interest both from an operational and certification viewpoint. The situation is considerably more acute for the BWB configuration to the point that it is likely to dominate the conceptual design. Not only must it be possible to board the passengers within a reasonable time scale, into an environment that they find comfortable, but it must also be possible to evacuate them through half the exits in less than 90 seconds. The former problem stems from the large windowless cabin volume and the latter from the limited scope for exit placement.

Due to their subjective nature, the incorporation of human factors issues into the design procedure is non-trivial. Work is currently in progress to establish design guidelines for layout of Ultra Wide Body passenger cabins to assist at the conceptual design stage. Numerical evacuation simulations have been run in an attempt to establish the influence of cabin geometry on evacuation time. Figure 5 indicates the trend in evacuation time vs. number of exits. The wide spread of the curve indicates the significance of exit locations, aisle widths and other parameters. The general shape of the curve is a function of the shape of the cabin and in this case appears to tend to a limit defined by the time taken for passengers to progress from central regions to the outer perimeter.

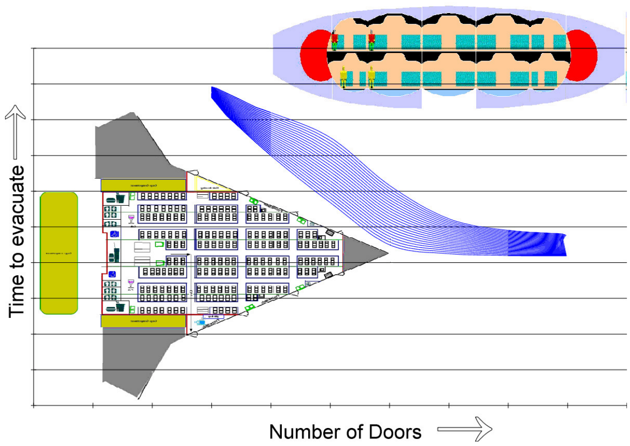


*figure 5*

### 7.2 Laminar flow technology

The BWB configuration appears well suited to the application of laminar flow technology. It should be relatively easy to accommodate the distributed part of the system between the outer skin and the inner pressure cabin or integrated with the outer structure. Experimental investigations and preliminary design studies indicate that the application of laminar flow technology to engine nacelle drag reduction is feasible and it's introduction into service could be imminent. Hopefully this will spur further development of the technology to enable its application to other parts of the airframe, in particular, the lifting surfaces.

### 7.3 Propulsion

A number of options are being considered for the propulsion units on this aircraft. The configuration tends to favour aft mounted over-wing engines as shown in figure 1. In this case the Rolls-Royce RB 529 contra-rotating project engine offers the additional benefit of lifting the core intake clear of the boundary layer. Whilst this is a novel concept, the BWB configuration offers the opportunity of a far greater level of engine airframe integration. One such novel concept being considered is a tip turbine driven remote fan powered by an engine core integrated within the airframe. This concept also offers the possibility of thrust vector control (TVC).

### 7.4 Systems integration

The design of any classical (Boeing 707 type) configuration civil airliner can be thought of as a number of weakly linked processes such as the design of the fuselage, the design of the wing, the design of the empennage and the design of the propulsion. Whilst this simplifies the design process it does constrain the various systems to, essentially, operate independently of one another. Conversely, the highly integrated nature of the BWB configuration complicates the design process, however, it offers a unique potential for the synthesis of a Systems Configured Vehicle (SCV). The SCV would exhibit an optimal balance between configuration, control system (including TVC), propulsion, laminar flow control system, high lift system, secondary power etc.

## 8 Certification issues

### 8.1 Advanced configurations issues

Modern airworthiness requirements such as the Joint Airworthiness Requirements (JAR) have been developed in parallel with the classical aircraft configuration. Hence, when applied to a novel configuration considerable interpretation is required. Studies completed so far indicate that there are two implications that need to be considered. Firstly, it is essential that any novel configuration is shown to be "airworthy". No design will be fully convincing when it can only be measured against extrapolations from the general requirements. Furthermore, from a conceptual design viewpoint, it is difficult to make direct comparisons between conventional and novel configurations if they are designed to inconsistent general requirements.

The only real precedent for this would be the design of Concorde where a new set of requirements was written specifically for this aircraft.

It is important that airworthiness philosophies are developed in parallel with the development of the configuration itself. This has already spawned a number of areas of research vital to this effort.

### 8.2 Safety

#### *8.2.1 Human factors*

Human factors issues are likely to impose a heavy constraint on the BWB configuration in addition to imposing a number of heavy engineering solutions locally. Hence, it is vital that this area be treated in a consistent manner if an objective solution to the BWB configuration is to be found.

#### *8.2.2 Crashworthiness*

The current airworthiness requirements essentially de-couple crashworthiness and emergency evacuation. The crashworthiness requirements exist in the form of limits on acceleration endured by structure associated with passenger restraint and structure likely to penetrate the cabin volume during impact.

The requirements imply that an aircraft that may be evacuated within 90 seconds is safer than one that requires 100 seconds. However, if the 90 second aircraft is more likely to incapacitate it's passengers in an emergency landing/ditching then this may not be a logical conclusion.

The BWB configuration has a number of features likely to make it more crashworthy. A planned study utilising non linear FE analysis should enable this claim to be substantiated. Further changes to the airworthiness requirements will be required for the configuration to take advantage of this.

### 8.3 Advanced technology issues

If the BWB configuration is to attain its full potential then the airworthiness requirements must allow a number of advanced technologies to be utilised albeit within the bounds of safety. Issues relating to the application of active flight control systems are already being addressed, however, they will need to be extended to both longitudinal and directional stability. The full benefits of laminar flow control can only be achieved if fuel reserves are not required to account for a total system failure. The confidence required to support such requirements may only be obtainable through the accumulation of flight hours of laminar flow equipped conventional aircraft.

## 9 Sub scale demonstrator

The concept of using sub-scale flying demonstrators to evaluate a variety of aircraft characteristics as a cost effective method of risk reduction is not new. Whilst quasi-static and some dynamic aerodynamic characteristics are more rigorously determined within the controlled environment of a wind tunnel test programme, some characteristics are more realistically evaluated during flight test.

To achieve experimentally a satisfactory understanding of the low speed characteristics of an aircraft prior to full-scale flight-test a range of wind tunnel tests would be required. A series of dynamic tests would be required beyond the usual static tests. The objective of these would be the evaluation of ground effects on take-off and landing, dynamic aerodynamic derivatives, entry into stall as a function of attitude/flight conditions/dynamics/control motivator usage, departure into spin, determination of spin modes and evaluation of spin recovery including the effects of spin recovery devices to be utilised during flight test. Beyond this, it may be necessary to evaluate aeroelasic and aeroservoelastic characteristics.

The infrastructure required to facilitate such a programme would include a static tunnel, a tunnel equipped with a internal balance model on a forced oscillation sting, a rotary balance tunnel, captive flight and free-flight tunnels and spin tunnels also using free-flight models. Even if some of these experimental set-ups can utilise the same tunnel, the programme will still require access to at least 3 fundamentally different types of tunnel. The size of these tunnels will also dictate the maximum model size. Furthermore, it is not possible to evaluate characteristics such as susceptibility to spin entry and determination of dominant spin modes. It is also difficult to simulate, in a continuous manner, the development of a spin starting from steady level flight.

Recently a NASA funded programme enabled Stanford University to develop, build and fly a BWB sub-scaled demonstrator (5.18m span,54kg mass) powered by 2 35cc two-stroke engines. NASA has now announced it's intention to flight test a jet powered BWB Low Speed Vehicle (LSV) (10.7m span, 816kg mass). This will be powered by 3 Williams WJ24-8 engines at 900N each with a total programme cost of some $25 million.

The Cranfield BWB testbed fits between these two NASA programmes but will be completed at a small fraction of the cost.

### 9.1 Objectives

The primary function of the vehicle is to evaluate the aerodynamic and flight dynamic characteristics of the BWB configuration as applied to specific concepts and in the generic sense. Further detail can be found in SMITH [1] Additional potential studies include the investigation of the coupling between the flight control system and the aeroelastic behaviour of the vehicle, enhanced control power through passive wing warping etc.

The vehicle is intended to be capable of evaluating static and dynamic characteristics in addition to stall/ pitch-up, post stall, spin and ground effect situations.

The key philosophy behind this project is flexibility. The ability to design a fully optimised full scale configuration is still in the process of development and hence the baseline geometry is not intended to represent the ideal. As this capability develops new configurations will need to be evaluated. Thus, the ability to modify the vehicle geometry in a cost-effective manner is important.

## 9.2 Basic philosophy

For the flying testbed concept to work as intended and in a cost-effective manner it was vital that the vehicle be re-configurable with a minimum of additional design hours. The scope had to include the geometry, the mass properties, the control configuration and the flight control system. Furthermore, the vehicle needed to be designed such that its capability could be extended if, at a latter date, it became appropriate.

Geometric reconfiguration was deemed vital within the scope of the CoA BWB research programme since it was known that the synthesis and optimisation tools would still be under development at the time the test-bed configuration had to be frozen. Thus, the initial configuration would serve as much as a test vehicle for the test-bed facility as a prototype for the full sized BWB. Furthermore, the test-bed would serve as a more flexible research tool if a variety of concepts could be emulated. The final design is thus intended to be reconfigurable in both planform and section.

To ensure that the vehicle was correctly scaled for mass properties it would inevitably need the capacity for ballasting to allow for manufacturing tolerances. Thus to extend this to allow for the modelling of a variety of full-scale concepts is simply a matter of extending the ballast capacity. This also allows for the variation of centre of gravity position both fore and aft and laterally (an important issue with BWB civil transports).

## 9.3 Structural concept

The main challenges for the structural design were, firstly, the need to keep the weight to a minimum and thus provide maximum capacity for ballast. Secondly, to create a structural concept that would enable the geometry to be changed in a cost effective manner.

The concept centres around an endo-skeletal structure that supports a light weight aero-shell.

The core of the structure consists of a frame intended to house the majority of the system units and provide the carry through structure for wing, control surface and engine attachments. The wing box mounts onto this with some degree of flexibility of wing sweep. This structural component is likely to be of composite construction. Mounted onto the wing box are a series of ribs which transfer loads from the aero-shell to the wingbox and provide mounting points for control hinges and actuators.

## 9.4 Systems

At the heart of the system is the Cranfield Aerospace Ltd UAV Avionics Package (used with permission of DERA Farnborough). This system was developed for UAVs known as XRAE140 and CA3 ‘Observer’, figure 6, under the DERA Short Range UAV programme. This unit has been further developed and utilised in subsequent UAVs.

*Figure 6*

Basic flight data is relayed to the ground station via radio telemetry to enable heath monitoring and assist the operator where manual take-off or landing is required.

The propulsion system consists of two 190N thrust turbojet engines. Fig 7.

The 2 AMT Olympus units are 130mm diameter by 270mm long and weigh 2.4kg each.

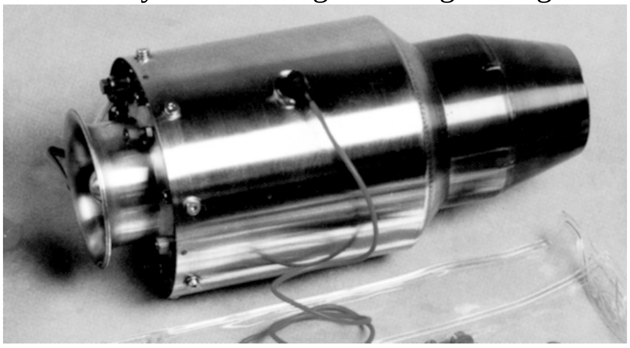

*Figure 7*

The basic recovery method is via a conventional tricycle landing gear deployed using a one-shot actuation system. Recovery from an uncontrolled flight mode or in the event of an emergency is by parachute deployment in conjunction with an airbag system. At impact the parachute will be automatically or manually jettisoned. This system would typically be activated at an altitude of 80m to minimise drift.

### 9.5 Airworthiness

Airworthiness issues are of extreme importance to all aircraft but, additionally, an area of uncertainty for UAVs. The Civil Aviation Authority's (CAA) Safety Regulation Group has considered the operation of the CoA's UAVs.
Subject to approval, the aircraft will fly under an Exemption to the Air Navigation Order.
Several locations are being considered for the flights including Warton, Salmesbury and Barrow-in-Furness.

## 10 Conclusions

In the process of completing the baseline preliminary study many detailed problems were encountered and solutions or compromises found. Some of the difficulties will be best tackled at the conceptual level and hence will feed into the Phase II study, the BW2001.

Now that a detailed design exists, many supporting studies such as human factors issues can now commence using the BW98 as a baseline configuration. These studies will, again, feed into the Phase II detailed design and ensure that it will represent a state of the art design. From this project it should be possible to make an objective assessment of the feasibility of the Blended Wing Body concept.

The Sub-scale demonstrator programme is progressing rapidly with wind tunnel testing to start shortly. There are still a number of challenges to be overcome but if the programme proves successful the result will be a very useful, and cost effective tool for the development of novel flight vehicles offering the potential for risk reduction in expensive civil and military projects. The testbed facility will also help to drive research in a wide range of disciplines.

## 11 Acknowledgements

The author would like to thank BAE Systems for granting access to the A-3XX-200 requirement and Rolls-Royce for their RB529 data used in support the baseline preliminary design study.

Engine image reproduced by kind permission of AMT Netherlands.

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[1] Smith H, Gibbons N Cranfield Blended Wing Body Flying Testbed Facility, Unmanned Air Vehicle Systems, 15th International Conference, 10th-12th April 2000, Bristol, United Kingdom.