NOVEL DESIGN CONCEPTS FOR AIRCRAFT WITH REDUCED NOISE AND GLOBAL WARMING CHARACTORISTICS

Mistry S., Smith H., Fielding J. P.
Department of Aerospace Engineering, School of Engineering, Cranfield University, Bedfordshire, MK43 0AL

Keywords: *Environment, Aircraft Concepts*

Abstract

The paper will summarise the main drivers that are prompting the development of environmentally-benign aircraft.
It will then describe Cranfield's novel aircraft contributions to the Silent Aircraft Initiative. Particular attention will be given to a number of promising broad-delta designs.
The paper will then continue to show investigations of aircraft designed to tackle broader environmental issues. Two extensive postgraduate group design projects will be described. The first is the A-6 Greenliner concept, which produces low emissions primarily from advanced technologies that are made more effective by slightly reduced cruise speeds. The concept of civil aircraft flight refuelling has been examined during the MRT 7 programme.
These alternative approaches will be discussed, and recommendations made for future work.

1 Introduction

The impact of aviation on the environment has been a growing concern for at least two decades. Significant steps are required to alleviate aircraft emissions in a growing air transport market.
A significant initiative was taken in Europe in 2001 with the publication of quantified targets. These were summarized in Ref. 1 as:-
"Europe…has it's Advisory Council for Aeronautical Research in Europe (ACARE), which, in 2001 committed the industry to develop technologies that would cut CO_2 by 50% per passenger kilometer, cut NO_X by 80% and halve perceived noise levels by 2020, relative to 2000 standards".
Such very large reductions will not only require new technologies and operating techniques, but will also need new aircraft and engine configurations. Previous Cranfield University projects and technologies are described in Refs. 2-5, and current work is described here.
The initial section concerns reduced-noise configurations, whilst other lower global-warming concepts will be described later.

2 Low Noise Concepts

2.1 Background

Initial work was associated with the Cambridge/M.I.T. Silent Aircraft Initiative and a joint aircraft specification was agreed as suitable for a medium-range air transport with twin engines, a 269 passenger payload, cruise speed of Mach 0.8, and a range of 4,020 nautical miles.
A baseline conventional aircraft was designed to meet these requirements, with current levels of technology assumptions being made. The results were very close to those for equivalent current aircraft.

2.2 Low Noise Configuration Development

The derivation of novel designs concept was aided by group brainstorming sessions to identify possibilities for different airframe configurations.
Ref. 4 gives a full description of the structured down-selection process which led to the configurations shown in Fig 1.

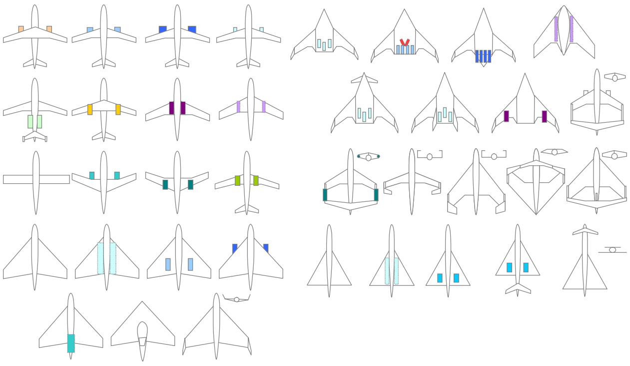

Figure 1 A Selection of 'Silent' Concepts

The more conventional configurations were examined in the baseline design and the twin-tail shielded aft engined arrangement was chosen for the Greenliner (below). Cranfield University has performed considerable research into blended-wing-body aircraft designs, including the Cranfield/BAE SYSTEMS Kestrel aircraft shown in Fig 2.

Figure 2 Kestrel
(*courtesy BAE Systems*)

It was therefore, decided to concentrate effort on the broad-delta aircraft shown below, although further work was done on blended-wing-body and joined wing concepts.

2.3 Broad Delta Concepts

The Broad Delta (BD) was one of the most promising low noise configurations. It has many similarities to the baseline aircraft, as it has a conventional fuselage , but combined with a low aspect ratio delta wing. Two variants of this aircraft were designed in parallel, to determine the effect that a stabilizing horizontal tail surface had, both on noise, and on performance.
The large delta wing is closely integrated with the fuselage in a similar manner to the Avro Vulcan subsonic strategic bomber. Such a configuration allows the partial or complete submerging of large-diameter powerplants within the wing section, with significant noise shielding and aerodynamic benefits.
Wing aspect ratio and taper were optimized to produce minimum aircraft gross mass and incorporated winglets, which produce significant induced drag benefit benefits at such low aspect ratios.
The fuselage is of a conventional cylindrical design, with a single-deck passenger layout, and the aircraft has conventional landing gears.

Fig. 3 Tailless Broad Delta (BDSF)

Fig. 3 shows an impression of the tailless aircraft broad delta single fin (BDSF), which incorporated semi-buried very high bypass ratio engines (12). Four engines were chosen rather than two, to keep engine diameters to acceptable levels.
The V-tailed broad delta (BDVT) was more aerodynamically efficient, as the tail could be used to trim moments from leading and trailing-edge devices to increase lift coefficients for take-off and landing. This allowed a significant increase in wing loading and cruise lift/drag ratio, and led to reduced fuel burn and mass.

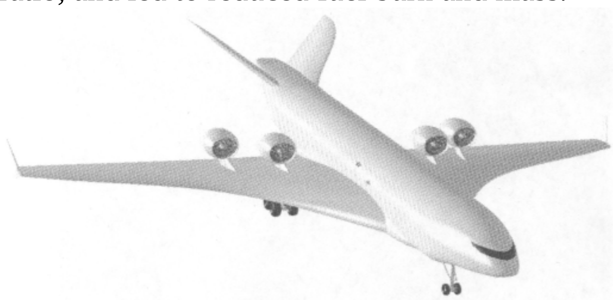

Fig. 4 Tailed Broad Delta (BDVT)

Fig. 4 shows an early design of this aircraft fitted with podded powerplants.

A large number of design iterations were performed to refine the design of both concepts. These included aerodynamic analysis using the AVL code, as shown in Fig.5.

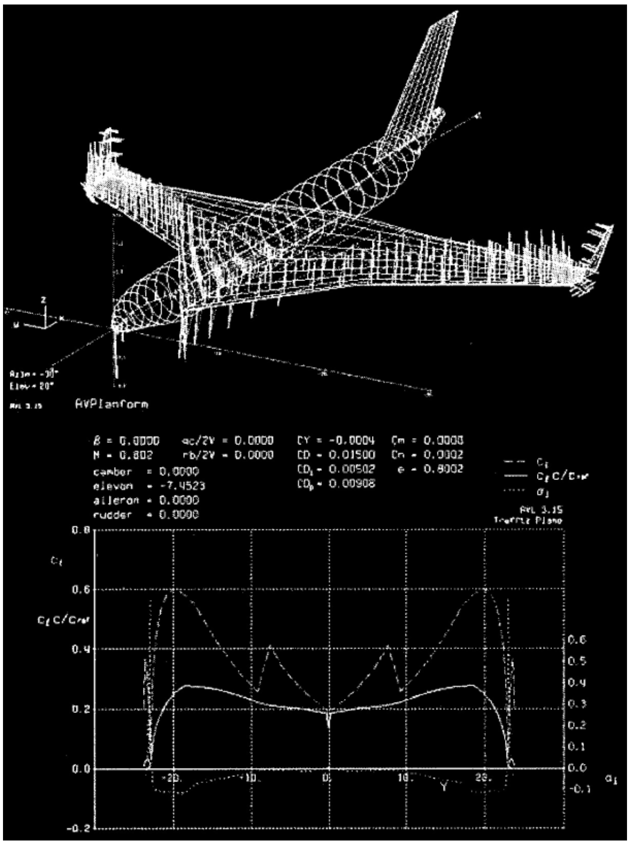

Fig. 5 Early Aerodynamic Modelling of the BDSF

More sophisticated methods will be needed in the future, particularly in the powerplant and winglet regions.

2.4 Performance comparison of the Baseline, BDSF and BDVT Concepts

Consistent methods were used to compare the performance, mass and noise characteristics for the baseline design and the two broad delta concepts. These are summarised in Table 1.
BD noise performance was similar, but the tailed BD was chosen as the best BDVT configuration because of it's better performance with respect to fuel burn and global warming.
It can be seen that the broad delta has significantly better noise characteristics, than the baseline concept, but all concepts have the potential for more improvements if fairings, brushes and displaced thresholds are used.

Another significant comparison is that for the same payload, range and speed, the broad delta (BDVT) consumes some 70% of the baseline fuel with obvious global warming benefits. But these figures will need further substantiation.

3 The Cranfield A-6 Greenliner Group Design Project

3.1 Group Design Project Activities

Many Universities use group projects as a means of synthesising aeronautical teaching and to give experience of team work and design integration. Cranfield's design course is unique in the depth of the student, staff and equipment resources used in it's annual projects. They allow significant in-depth design solutions at conceptual, preliminary and detail design stages. 50 graduate students were allocated responsibility for preliminary/detail designs of major parts of the A-6 aircraft such as the forward fuselage, a flying control surface or an airframe system such as fuel, environmental control, propulsion, landing gear, avionics or the control system. Further topics included performance, cost, reliability and maintainability. This allowed much more realistic estimates to be made of mass and performance and demonstrated that the construction and system design methods were feasible.
This 8-month programme, using industry-standard design tools and methods, was supervised by more than 10 faculty staff and was operated in what Cranfield term as a 'virtual industrial environment'. Some 50,000 man-hours of work are summarized in 50 project theses and in Stocking et al (Ref. 5).

3.2 Greenliner Description

The limitation of global warming and noise effects were the main motivating factors. The A-6's design specifications and requirements were chosen to help the aviation industry to meet the foreseen environmental challenges, both local and global. The aircraft conceptual design was performed by Smith (Ref. 6) and was the starting point for the group project. 4 design variants were explored, namely composite and metallic airframe variants of aircraft with alternative V and U-tailed configurations. The baseline aircraft was the V-tail composite variant (Fig. 6).

Fig. 6 Greenliner CAD Model

The Aircraft performance is that of a long-range, high-capacity aircraft in the class of the Boeing 777 or Airbus A330-600 (see Table 2). Considerable efforts were made to reduce fuel burn and aircraft noise whilst producing low operating costs and high passenger comfort.

The wing was designed to use a Natural Laminar Flow (NLF) aerofoil section with a very high aspect ratio to achieve significant drag reduction and thus reduce the fuel consumption. This also achieved a large direct reduction of carbon emissions. This decision however led to a very low wing sweep which limited the cruise Mach number to 0.74. The aircraft's engines were high-mounted on the aft fuselage with a 'butterfly' tail to provide noise shielding. All team members took care to achieve weight reductions through trade-off studies, in order to attain better aircraft performance. Sustainability and weight reduction were the main factors considered during the material selection processes. Opportunities for better comfort and health of passengers during flight were also explored during the design of A-6 cabins.

These took the form of significantly increased fuselage cross-section, improved seating, combined with a higher humidity and lower cabin altitude fuselage (Fig. 7).

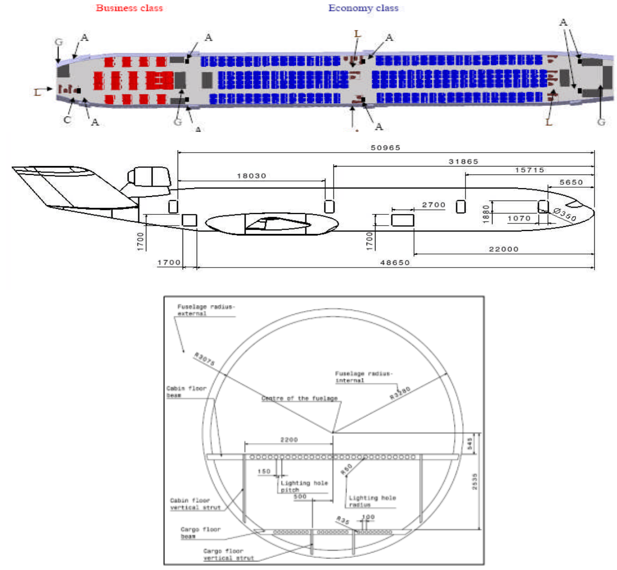

Fig. 7 A-6 Fuselage

Figure 8 shows an example of the extensive finite element structural analysis that was used to aid design.

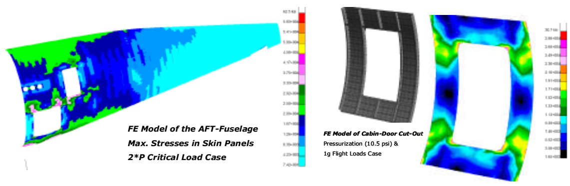

Figure 8 Rear Fuselage Finite Element Model

Several powerplant options were examined and Fig. 9 shows the baseline Rolls-Royce Trent 500, with negative scarf intake.

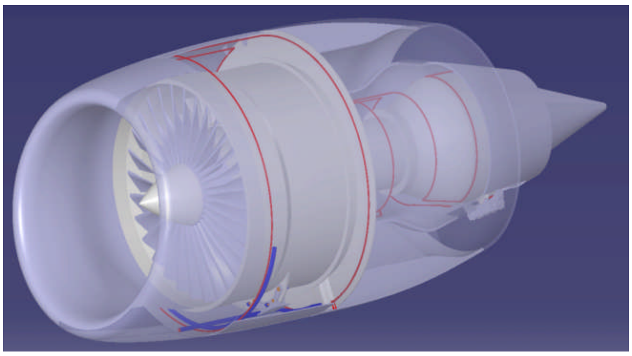

Figure 9 Greenliner Powerplant

3.3 Greenliner Predicted performance

Extensive calculations showed that the A-6 should meet or exceed it's specified performance targets. The baseline composite

structure, V-tail version offered the most mass reduction and minimum fuel burn and pollution.
Acquisition and operating costs estimates have shown that the aircraft should be competitive with aircraft planned to be operated in the 2020 period.
The main penalty of the aircraft is that it's cruise speed is some 90% of current aircraft values. This will lead to small increases in flight durations at short and medium ranges, but becomes more significant at long ranges. The increased cabin volume, lower cabin altitude and advanced avionics will make the aircraft more comfortable. This should give some compensation for the increased journey times, as should the fares lower than those for other aircraft that would follow with increased fuel costs and if carbon taxes were to be imposed.

4 The MRT 7 Flight Refuelling Tanker Project

Air-to-air refuelling is commonly used by the military services worldwide. It allows an extended flight range for bombers and fighters and potentially increases endurance for patrolling aircraft and AWACS.
The current project was to design a future tanker aircraft with refuelling as a priority, not a modification to current civil aircraft. 52 postgraduate students and more than 10 faculty performed preliminary designs of a family of aircraft, as described in Refs 7 and 8.
A family was chosen so that development cost could be more widely spread and to investigate the possibility of civil flight refuelling such that an airliner sized for 3500n. miles could efficiently fly at 7000n. miles, following a refuelling. The family of aircraft were:-

- **MRT7-T**:
  Tanker: Fighter, UAV, civil aircraft refuelling capability
  Troop Transport & Military Transport: 294 soldiers
  Aero medical evacuation: Patient support pallets (45 litters + 15 wounded on economic seats)
  Airlift: Standard military pallets (14 pallets)
  AWACS
- **MRT7-8-3-3R**:
  Main configuration: 38 Business Class and 258 Economy Class passengers
  Optional configuration: 1-Class: 333 Economy Class seats, 3-Class: 12 First Class, 35 Business, 198 Economy Class
- **MRT7-8F**:
  11 types of standard containers and pallets in 14 standard configurations

Fig. 10 shows the baseline military tanker deploying hose and drogue units, but it is also capable of centre-line boom deployment.

Figure 10 Military Refuelling

A more radical approach is shown in Fig. 11. The lead aircraft is the short-range MRT7-3R, which has a refuelling receptacle in the lower rear fuselage. The tanker aircraft has an actively-controlled, retractable forward boom. Extensive design, modelling and safety analyses have been performed to show the viability of this concept.

Figure 11 Tanker approaching MRT7-3R of civil fuelling

The project has only recently finished but there are strong indications that this is a sound concept and that significant cost, fuel and pollution savings could be made.

5 Conclusions

- Aircraft-related noise, local air quality and Global Warming are recognised as serious issues. They must be quickly mitigated by new operational, economic and technological means.
- Very significant noise reduction can be made if novel propulsion, airframe configurations and advanced technologies are developed
- Intermediate technology aircraft configurations, such as the Cranfield Greenliner, should be able to significantly reduce costs, noise and Global Warming. This has modest risks but requires lower cruise speed.
- The broad-delta appears to be a promising low-noise and emissions aircraft but at more risk. The blended-wing-body aircraft appears to offer even more performance advantages, but at more technical and economic risk.
- Civil flight refuelling offers significant cost, fuel burn and pollution benefits. The configuration risks are limited, as are flight safety risks, but further work is needed. Such a concept requires a global network of refuelling stations, as proposed in the Cranfield MRT07 project.

6 References

[1] A. Turner, "Changed Climate-Special Report," in Flight International Magazine, 19-25th June 2007.

[2] J. P. Fielding, H. Smith, "Development of Environmentally-Friendly Technologies and Configurations for Subsonic Jet Transports," International Congress of the Aeronautical Sciences (ICAS) 2002, Toronto, Canada.

[3] S. Mistry, G. Doulgeris, J. P. Fielding, P. Pilidis, "Development of Silent Airframe Concepts and Innovative Cycle Propulsion Systems to Reduction of Aircraft Noise," International Congress of the Aeronautical Sciences (ICAS) 2006, Hamburg, Germany.

[4] G. Doulgeris, S. Mistry, J. P. Fielding, P. Pilidis, "Development of a Brad Delta Airframe and Propulsion Concepts of Reducing Aircraft Noise around Airports," Paper 2007-01-3806, Society of Automotive Engineers (SAE) AeroTech Congress and Exhibition 2007, Los Angeles, CA, 17-20th September 2007.

[5] P. Stocking et al., "A6 Greenliner Environmentally Benign Aircraft," Project Executive Summary, Cranfield University, October 2006

[6] H. Smith, "A-6 Project Specification", Cranfield University, October 2006.

[7] H. Smith, Multi-role Transport Aircraft MRT-7 Project Specification, DES 0700-T, Cranfield University, October 2007.

[8] P. Stocking et al, MRT7 "Harbienger Military Air-to-Air Refuelling Tanks with 'Meridion' Civil Transport Variants. Cranfield University, May 2008.

7 Copyright Statement

Description	Symbol	Units	Baseline	BDSF	BDFT
Wing Area	S	$[M^2]$	245.1	509.0	355.7
Wing Span	B	[M]	44.3	45.9	41.6
Wing Aspect Ratio	A	-	8	4.13	4.87
Wing Quarter Chord Sweep	$\Lambda_{1/4}$	[deg]	33	25.6	30.2
Wing Taper Ratio	λ	-	0.207	0.181	0.283
Thickness-to-Chord Ratio	t/c	-	0.11	0.1013	0.1013
Lift-Drag Ratio (Max)	L/D	-	17.7	18.4	19.9
Cruise Lift Coefficient	$(C_L)_{cr}$	-	0.55	0.242	0.338
Operational Empty Mass	M_{OEW}	[kg]	94,595	77,422	74,061
Mass of Payload	M_{PAY}	[kg]	23,760	23,760	23,760
Mass of Feul Required	M_f	[kg]	44,694	37,857	30,912
Total Static Thrust	T_0	[N]	579,130	428,139	405,952
Total Overall Mass	M_0	[kg]	160,886	139,039	128,732
Noise at ICAO Point	-	dB(A)	93.8	73.5	72

Table 1 Performance Comparison of Baseline BDSF and BDVT Concepts

Specification	Values
Airframe Life:	70,000 hours (approximately 25 years)
Design Mission: Range Passengers	 7500 nm 375 (Two Class)
Accommodation & Capacity:	
Maximum Certified Capacity:	440 (Single Class)
Typical Configurations:	400 Econ. (Single Class) 345 Econ. & 30 First Class (Two Class) 228 Econ., 54 Business & 24 First Class (Tri-Class)
Cargo:	32 LD-3 (Type A)
Principal Geometry: *Fuselage -* External Diameter Internal Diameter Overall length *Wing -* Span Aspect Ratio Gross Wing Area Leading edge sweepback Aerofoil Section	 6.56 m 6.15 m 67 m 64 m 11.6 352.6 m^2 7.636° HSNLF(1)-0213 - Natural Laminar Flow (NLF)
Mass: Normal Take-off Max Landing Empty (OEM) Payload Fuel load	 209,410 kg 168,500 kg 110,465 kg 35,625 kg 63,320 kg
Power Plant: Model	 Rolls-Royce Trent 500 Derivative
Thrust (SL Static Rating)	266.2 kN
Field Performance: Max. Certificated Runway FAR Landing Distance	 2500m (Max. All Up Mass takeoff @ ISA SL) 1752m (Max. Landing mass @ ISA SL)
Cruise Speed:	Mach 0.74
Cabin Altitude:	< 5,500ft (average) to 7,000ft (max)
Design Requirements:	EASA CS25 (Certification Specifications for Large Aeroplanes) AVD DES 0600/1 A-6 Project Specifications
Specification Structural Limitations:	+3.2g / -1.2g (SL, OEM, Gust Velocity 17.07 m/s)
Design Objectives:	To minimise the environmental impact of the operation of aircraft in the broadest sense including the reduction of both global and local impacts, better cabin comfort and considerations for sustainability issues.

Table 2 Greenliner Design Specification