A98-31617

ICAS-98-4,10,5

THE BLENDED WING-BODY CONFIGURATION AS AN ALTERNATIVE TO CONVENTIONAL SUBSONIC CIVIL TRANSPORT AIRCRAFT DESIGN

Nikolaos Kehayas
Consultant
5 Gelonos St., 115 21 Athens, Greece.

Abstract

Since the late fifties subsonic civil transport aircraft technology has advanced substantially, but the basic aircraft configuration has remained essentially unchanged. It has been put forward that conventional subsonic civil transport design is nearing its evolutionary potential and a departure in the form of a new configuration is needed. As a result, a number of alternative configurations have been proposed. Among them, the Blended Wing-Body (BWB) has attracted most support. In this paper a conventional subsonic civil transport aircraft with projected technology advances is compared with a BWB design. The objective is to compare technology with configuration, that is, a conventional configuration encompassing suggested projected technology advances with a novel configuration at the present level of technology. By means of a simple case study, the performance of the two designs is evaluated in terms of fuel consumed. The problems associated with the BWB design are also discussed. The case study indicates that the projected technology conventional configuration is superior to the BWB. However, this result is conditional on the feasibility of projected technology advances.

Introduction

Since the introduction of the jet engine in the late fifties, considerable improvements have been made in subsonic civil transport aircraft aerodynamics, structures, propulsion and systems, but none could be regarded as a revolution, thus the basic aircraft configuration has remained essentially unchanged.

It has been suggested that the present subsonic civil transport aircraft configuration is nearing its full evolutionary potential, and a number of alternative configurations have been proposed (1,2,3,4,5,6,7). Among them, the Blended Wing-Body (BWB) has attracted most support(1,2,3,5,6).

The BWB is a version of the flying wing. It differs from a typical (spanloader) flying wing in that only part of the wing span, the central span, is used to house the passengers. The rest of the span, the outer span, functions in the same way as in a conventional configuration.

A spanloader flying wing has a lower structural weight due to the distribution of weight, lift and, possibly, landing loads along its span(8,9,10,11); aerodynamically, it is inferior to an optimum conventional configuration(8,12,13).

As a passenger aircraft, due to its configuration, the flying wing has a low payload density which in turn produces a low wing loading. And the poor aerodynamic performance of the flying wing is, to some extent, a result of its low wing loading.

The BWB concept is an attempt to exploit the flying wing's advantage of smaller wetted surface while avoiding the penalty of its low wing loading.

In this paper, by means of a simple case study, two subsonic civil passenger aircraft designs - the BWB and one based on projected developments in current technology - are evaluated and then compared. In addition to these two a third, existing, BWB design is included in the comparison.

21st ICAS Congress
13-18 September 1998
Melbourne, Australia

Methodology

Comparison Approach

The objective of this study is to compare technology with configuration, that is, a conventional configuration encompassing suggested projected technology advances with a novel configuration (BWB) at the present level of technology.

The usual approach to civil transport aircraft technology assessment is to estimate the effect of technology on Direct Operating Costs (DOC).

However, a comparison of the two designs in terms of DOC is beyond the scope of this paper. A simpler approach will therefore be adopted: choosing fuel costs as the criterion. The choice of fuel costs, and hence fuel consumption per passenger and distance travelled (g of fuel/seat-km), presupposes that all DOC, other than fuel costs, are similar for the two designs. This is not an unreasonable assumption if the two designs are the same size, provided their development costs are also comparable.

In order to evaluate the two designs, and then compare them according to the adopted criterion, the Breguet equation will be used. For this evaluation the various parameters of the Breguet equation must be estimated or, in cases where this is not possible, chosen from the available sources for each design.

For the evaluation and the comparison of the two designs, range, speed and payload have to be specified. A first estimation of payload as 72,600 kg is based on a three-class, 800 passenger aircraft. Range and speed are set at 13,000 km and 490 kt (M 0.85 at 35,000 ft) respectively - both typical of long-range subsonic civil transport aircraft.

Technology Level Definition

Another problem facing a comparison of two very different concepts is the definition of the technology of each concept.

The aim of this study is to weigh one design against the other. Consequently, technology features that characterize one design must not be present in the other. For example, laminar flow is a projected current technology design feature not to be available in the BWB design.

The development period of each design is difficult to predict, a situation well known in aerospace projects. It is equally difficult to assess the technology level that can be achieved over this period. For the present comparison study, a nominal development period of seven years is proposed and a corresponding technology reference date of 2005 is set.

Projected Current Technology Design Evaluation

In a brief comparison study it is not possible to do more than assess available data on current technology. From the available data on current technology, lift-to-drag (L/D) ratio, specific fuel consumption (sfc) and structural weight reduction, are projected into the 2005 technology reference date. Then, using the Breguet equation and the specified range, speed and payload, the performance of the Projected Current Technology design is evaluated.

Data on current technology is scarce. Therefore, it is necessary to make a number of assumptions in the course of processing, and then projecting, the available data into the year 2005.

Lift-to-Drag (L/D) Ratio

The principal sources of information on L/D ratio are References 1, 11, 14, 15, 16 and 17. With the exception of Reference 11 from 1978, these references were published between 1989 and 1996 and hence provide recent appraisals of the aerodynamic potential of subsonic civil transport aircraft.

References 1, and 11 give actual values of L/D ratios for past, present and proposed future designs. L/D ratio values of References 14, 15 and 16 are relative with respect to an unspecified datum. Actual L/D ratios from these references are derived by assigning specific values found in References 1 and 11 to the unspecified data. Reference 17 provides relative aerodynamic performance indirectly, in terms of energy consumed; and the corresponding L/D figures are found using the Breguet equation. In particular, References 14 and 15 illustrate the aerodynamic development of the Airbus family of civil transport aircraft from the A300 to a planned design for the year 2000.

L/D ratios for various subsonic civil transport aircraft designs presented in references cited above, are shown in Figure 1 against year of aircraft introduction. Figure 1 correlates well with Figure 5 of Reference 1 of maximum Mx(L/D) against year of aircraft introduction, given that the speed of subsonic jet-engine civil transport aircraft has not changed dramatically over the last 35 years. The projected L/D ratio for 2005 is found to be around 27.

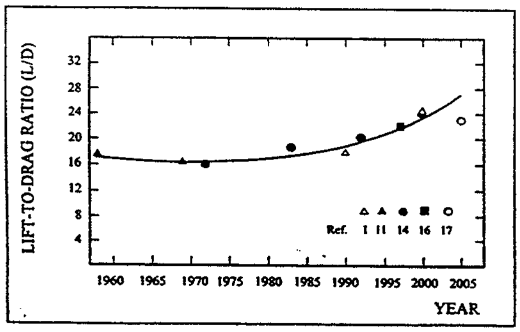

Figure 1. Current technology L/D projection

Specific Fuel Consumption (sfc)

Data on large commercial engine sfc trends are provided by References 1, 16, 17, 18, 19 and 20. References 18 and 19 provide actual values while other values are relative to a datum. The same procedure as used with the L/D data is followed in order to plot actual and relative sfc values against year of introduction of engine (Figure 2).

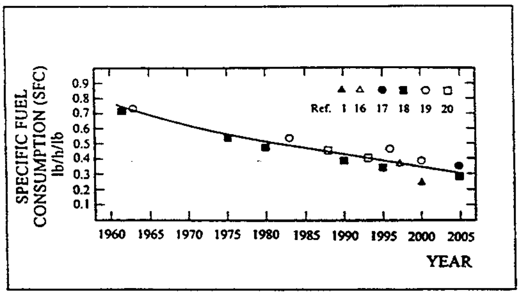

Figure 2. Current technology sfc projection

As indicated in Figure 2 there is good agreement between the sets of data. The data do not represent cruise sfc; therefore, they have to be scaled accordingly. Assuming a 1993 technology cruise sfc of 0.55 lb/h/lb, the corresponding 2005 projected cruise sfc is found to be 0.435 lb/h/lb.

Reduction in Structural Weight

In order to evaluate, and then compare, various aircraft designs in respect to structural weight, a reference point is needed. This is needed because structural weight reduction is, by definition, relative to a datum. Therefore, a Baseline Aircraft design has to be established.

The Baseline Aircraft follows the payload, range and speed specifications that have already been set. For a better technology projection it is based on recent technology (1993). Using the Breguet equation with L/D ratio and sfc values for 1993 extracted from Figures 1and 2, the specified payload, range and speed, and an assumed value for the ratio of operational empty weight to take-off weight the Baseline Aircraft design is evaluated.

To find the Baseline Aircraft's structural weight, the weight of the operator's items are substracted from the operational empty weight (OWE) to give the manufacturer's empty weight (MWE), which is essentially structural weight. It is assumed that the operator's items weight represents 20 % of the payload weight. The 1993 Baseline Aircraft data is shown in Table 1.

References 1, 11, 16, 17 and 20 are used to evaluate the progression of structural weight reduction shown in Figure 3.

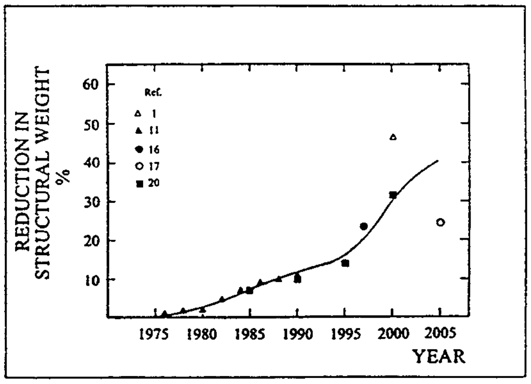

Figure 3. Current technology structural weight projection.

The datum is the year 1976 of Reference 11. Using the 1993 Baseline Aircraft structural weight that has been previously defined, and Figure 3, the structural weight of the 2005 projected current technology concept can be established. The structural weight reduction in relation to the 1993 Baseline Aircraft is found from Figure 3 to be approximately 27.5 %.

BWB Design Evaluation

The Proposed BWB design is shown in Figure 4. According to our comparison approach, that is, projected technology against configuration, the Proposed BWB design features 1993 level technology aerodynamics, structure and engines, as represented by the 1993 Baseline Aircraft.

The suggested superior performance of the Proposed BWB design - in relation to a conventional configuration - results from its higher L/D ratio which is entirely due to its configuration.

This is achieved in two ways: firstly by having a smaller wetted surface, and hence a lower zero lift drag, and secondly by having a high enough wing loading that ensures the full use of the wing's lift capability.

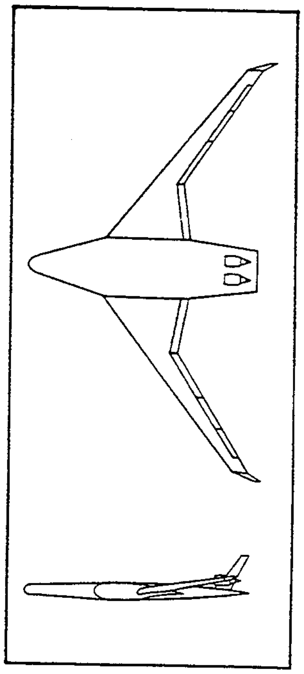

Figure 4. Proposed BWB design

The Proposed BWB design (Figure 4) exhibits some similarities to the Callaghan and Liebeck "first generation" BWB(1) and the Airbus "Integrated Airliner"(2) concepts. It is made of a central part, in the shape of a non-lifting symmetrical airfoil at zero angle of attack, where the passengers are housed and a pair of wings which extend as a continuation of the central part. The central part accomodates the passengers in a single deck layout. The engines are located in the rear end of the central part. Swinging wing-tips cater for a wing span of over 80 m.

Assuming an operating empty weight/take-off weight (OWE/TOW) ratio of 0.58 and a C_{D0} value of 0.008, taken from the Callaghan and Liebeck "first generation" BWB(1), and after a few iterations, a L/D ratio of 28.3 is found for the Proposed BWB design. The C_{D0} value of 0.008 is not only characteristic of the Callaghan and Liebeck "first generation" design, but of other designs as well as evidenced by Torenbeek(13).

The L/D and OWE/TOW ratios, the baseline sfc of 0.55 and the specified range, speed and payload are then used in the Breguet equation to evaluate the performance of the Proposed BWB.

Results and Discussion

The results are shown in Table 1. In addition to the two designs - the Projected Current Technology and the Proposed BWB (Table 1, columns 2 and 3) - the 1993 Baseline Aircraft (column 1), a scaled down version of the Liebeck, Page and Rawdon "second generation" design(21) (column 4) and an advanced technology engine (sfc 0.439) version of the Proposed BWB (column 5) are presented.

The Liebeck, Page and Rawdon "second generation" BWB is included because it represents the current trend in BWB design(5,21,22). It is scaled down in order to be in line with the other designs in respect to payload; in its original configuration(21) it had a payload above the 72,600 kg specified for an 800 passenger design.

The advanced technology engine version of the Proposed BWB is included with the purpose to be compared, purely

	Baseline Aircraft (1993)	Projected Current Technology (2005)	Proposed BWB (sfc 0.550)	Scaled Liebeck, Page, Rawdon (Ref. 21)	Proposed BWB (sfc 0.439)
Range (km)	13,000	13,000	13,000	13,000	13,000
Passengers (3-class)	800	800	800	800	800
Cruise Mach (altitude ft)	0.85 (35,000)	0.85 (35,000)	0.85 (35,000)	0.85 (35,000)	0.85 (35,000)
Cruise L/D	19.50	27.00	28.83	23.20	28.83
Cruise sfc (lb/h/lb)	0.550	0.435	0.550	0.439	0.439
Change in Structural Weight (based on MWE/ TOW ratio) (%)	-	-27.5	+15.8	-1.8	+13.8
OWE (x10^{-3}kg)	306.4	87.2	296.7	173.3	220.7
Payload (x10^{-3}kg)	72.6	72.6	72.6	72.6	72.6
Fuel (x10^{-3}kg)	211.8	45.4	127.9	84.1	78.2
Fuel Reserves (x10^{-3}kg)	22.0	5.2	14.3	9.5	9.1
TOW (x10^{-3}kg)	612.8	210.4	511.5	339.5	380.6
g of fuel consumed/ seat-km	20.36	4.37	12.29	8.09	7.52

Table 1. Results.

from the design point of view, with the Liebeck, Page and Rawdon "second generation" BWB.

In the comparison of various aircraft designs a difficulty arises in relation to aircraft passenger capacity. In the case of an aircraft design which does not exist - such as the 800 seater conventional configuration Baseline Aircraft - the difficulty is even greater.

Even if such an aircraft existed at present, there would be problems in its performance evaluation according to our criterion, fuel consumed per seat-km, because of numerous seating accommodation layouts and passenger-cargo and payload-range combinations. For example, the B-747-400 has a three-class seating arrangement of 421 and a maximum seating capacity of 660 passengers; its payload varies from 39 to 60 t depending on range(23).

Each aircraft design is optimized for a certain seating-payload-range and, consequently, in this sense, cannot be compared with other designs of similar take-off weight, but different seating-payload-range specifications. At the end, all these parameters reflect on the OWE/TOW ratio and, since a three-class seating was specified for all the competing designs, the closest available figure for this ratio, that of the (three-class, 13,000 km) B-747-400, was used for the evaluation of the Baseline Aircraft.

It should be mentioned that the reason why the 1993 Baseline Aircraft of Reference 24 exhibits much lower fuel consumption per seat-km is, mainly, its assumed one-class high-density seating layout.

The problem with the OWE/TOW ratio evaluation equally exists for the BWB designs, but for different reasons. In contrast to the lower structural weight spanloader type flying wing, BWB designs seem to have high structural weight. For example, both Callaghan and Liebeck(1) and Liebeck, Page and Rawdon(21) designs have OWE/TOW ratios well over that of conventional designs.

On the BWB aerodynamics, which are due to design, it should be noted that the best configuration involves a thin central part (body) - wing combination. For a three-class, 800 passenger aircraft this configuration dictates a single-deck layout. It is considered the best configuration because it offers lower zero-lift drag than the thicker double-deck BWB designs(5,21,22). In addition, this configuration of a non-lifting (zero angle of attack), airfoil shape central part which accommodates the passengers and extends into wings, provides the wing loading which is necessary in order to take full advantage of the lift capability of the wings. The Proposed BWB is, hence, the best configuration in terms of wetted area and wing loading for a passenger-only subsonic civil transport aircraft.

The only disadvantage of this configuration is a wing span over the 80 m limit dictated by airport compatibility considerations. Nevertheless, this disadvantage can be eliminated by some means of aircraft span reduction while on ground. Folding wing-tips have been put forward as a means of reducing span. Here another solution is suggested: ground swinging wing-tips. The complication and structural weight increase associated with this solution will be more than offset by the improved aerodynamic performance.

The results of the comparison with respect to the amount of fuel consumed per seat-km (Table 1) indicate that the Projected Current Technology design is by far the best. The Liebeck, Page and Rawdon "second generation" BWB(21) comes second and the Proposed BWB third. But, if we consider the Proposed BWB design with engine technology at the Liebeck, Page and Rawdon BWB design level (sfc 0.439), then this design takes the second place, just ahead of the Liebeck, Page and Rawdon BWB.

These results are subject to the assumption of a OWE/TOW value of 0.58 for the Proposed BWB. Although it has been pointed out that some BWB designs(1,21) demonstrate OWE/TOW ratios which are much higher than those of conventional configurations, it is difficult to perceive how configuration (BWB) alone can have such an effect on aircraft structural weight, even if it is assumed that advanced materials have not been used.

In percentage terms, the Proposed BWB, the advanced engine technology (sfc 0.439) Proposed BWB and the Liebeck, Page and Rawdon "second generation" BWB burn 181, 72 and 85 % more fuel per seat-km than the Projected Current Technology design.

The results of Table 1 show that the performance of the Proposed BWB is wholly based on aerodynamics due to configuration; the Liebeck, Page and Rawdon "second generation" BWB on sfc and, to a lesser extent, on aerodynamics; and the Projected Current Technology design on a balance between aerodynamics, structural weight and sfc.

Concluding Remarks

In this simple case study a proposed BWB and a projected current technology conventional configuration design are evaluated and then compared with fuel consumed per seat-km as the criterion. In the comparison a third, existing, BWB design was included. The comparison showed that the Projected Current Technology conventional configuration design is clearly superior to the BWB. However, this result is conditional on the feasibility of projected technology advances. It should be underlined that, up to the present, envisaged subsonic civil transport aircraft technology advances in aerodynamics, structures and engines have not materialized to the suggested degree.

References

1. Callaghan, J.T., Liebeck, R.H., Subsonic Transport Aircraft for the 21st Century, Aerospace Engineering, February 1991, pp 9-11.
2. Airbus Shapes Integrated Airliner, Flight International, 4 March 1989, p 26.
3. Airbus' Jumbo Flying Wing, Flight International, 1-7 May, 1991, p 4.
4. Mass-Transporter, Flight International, 1-7 April 1992, p 22.
5. Covert, E.E., Evolution of the Commercial Airliner, Scientific American, Vol 273, No 3, September 1995, pp 82-85.
6. Morris, S.J., Advanced Aerodynamic Configurations and Their Integration into the Airport Environment, Potential Impacts of Advanced Aerodynamic Technology on Air Transportation System Productivity, NASA TM 109154, September 1994.
7. Kroo, I., McMasters, J., Smith, S.C., Highly Non-planar Lifting Systems, Transportation Beyond 2000: Technologies Needed for Engineering Design, NASA CP 10184, Part 1, February 1996.
8. Sears, W.R., Flying Wing Could Stealthily Reappear, Aerospace America, July 1987, pp 16-19.
9. Lange, R.H., The Spanloader Advanced Transport Concept, SAE Paper 750616, 1975.
10. Whitener, P.C., Distributed Load Aircraft Concepts, Journal of Aircraft, Vol 16, No 2, February 1979, pp 72-77.
11. Poisson-Quinton, Ph., Energy Conservation Aircraft Design and Operational Procedures, AGARD LS-96, Paper No 9, October 1978.
12. Foa, J.V., The Flying Wing Reconsidered, Canadian Aeronautics and Space Journal, Vol 30, No 1, March 1984, pp 62-65.
13. Torenbeek, E., Aerodynamic Performance of Wing-Body Configurations and the Flying Wing, SAE Paper 911019, 1991.
14. Greff, E., The Development and Design Integration of a Variable Camber Wing for Long/Medium Range Aircraft, Aeronautical Journal, Vol 94, No 939, November 1990, pp 301-312.
15. Hiblig, R., Szodruch, J., The Intelligent Wing -Aerodynamic Developments for Future Transport Aircraft, AIAA Paper 89-0534, 1989.
16. Big Problems, Flight International, 24-30 November 1993, pp 34-36.
17. Schmitt, D., Advanced Technology-Constant Challenge and Evolutionary Process, Aeronautical Journal, Vol 94, No 940, December 1990, pp 335-340.
18. Highton, D.R., Chrispin, W.J., Future Advanced Aeroengines-The Materials Challenge, AGARD CP-449, Paper No 4, March 1989.
19. Swihart, J.M., Cost Effective Transportation and High Technology, Aeronautical Journal, Vol 90, No 897, August/September 1986, pp 249-261.
20. Robinson, P., Brown, D.G., Short Haul Transport for the 1990s, Aeronautical Journal, Vol 83, No 827, November 1979, pp 413-436.
21. Liebeck, R.H., Page, M.A., Rawdon, B.K., Evolution of the Revolutionary Blended-Wing-Body, Transportation Beyond 2000: Technologies Needed for Engineering Design, NASA CP 10184, Part 1, February 1996.
22. Denisov, V.E., Bolsunovsky, A.L., Buzoverya, N.P., Gurevich, B.I., Shkadov, L.M., Conceptual Design for Passenger Airplane of Very Large Passenger Capacity in Flying Wing Layout, ICAS Paper 96-4.6.1., September 1996.
23. Airliners of the World, Flight International, 6-12 December, 1995, pp 50-86.
24. Kehayas, N., A Brief Comparison of Powered Lift, Flying Wing and Current Technology Subsonic Civil Transport Aircraft Concepts, ICAS Paper 96-4.6.3., September 1996.