The Blended Wing Body Aircraft

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Introduction

The goal of aircraft design is to achieve safe and efficient flight. In the world of commercial air transport, efficient, economically attractive configurations are needed. For a military fighter, extreme maneuverability, a low-observable radar signature, and cruise performance are all important.

Liebeck[1] provides the following insight into the aircraft design evolution. The first powered controlled flight was by the Wright brothers in 1903. About 44 years later, the swept-wing Boeing B-47 took flight. Another 44 years go by and the Airbus A330 takes off. The comparison of these aircraft, given in Figure 1, depicts the evolution of aircraft design in the last century and the focus toward what is regarded as the most efficient configuration. This also shows a remarkable engineering accomplishment, especially in the first 44 years. The B-47 and A330 embody the same fundamental design features of a modern subsonic jet transport: swept wing and podded engines hung on pylons beneath and forward of the wing. In the second 44 years the configuration didn't changed much, it has only matured and become more efficient. The most recent achievements that apply to this configuration concept are the Airbus A380 (Figure 2) and the ultra long range Boeing 787 (Figure 3).

A flying wing is a type of tail-less aircraft design and has been known since the early days of aviation. Since a wing is necessary for any aircraft, removing everything else, like the tail and the fuselage, results in a design with the lowest possible drag. Successful applications of this configuration are for example the XB-35 bomber (Figure 4) that flew first in 1946, and the stealthy B-2 bomber (Figure 5) that flew first in 1989.

The Blended Wing Body (BWB) (Figure 6) is a relatively new aircraft concept that has potential use as a commercial or military transport aircraft, cargo delivery, or as a fuel tanker. The BWB is basically a flying wing with the payload, i.e., passengers and cargo, enclosed in the thick, airfoil shaped, center section. Studies have shown remarkable performance improvements for the BWB over a conventional subsonic transport configuration discussed above based on equivalent technology.

The BWB Concept

The BWB concept was introduced by Robert Liebeck at the McDonnel Douglas Corporation (now the Boeing Company) in 1988. The airplane concept blends the fuselage, wing, and the engines into a single lifting surface, allowing the aerodynamic efficiency to be maximized. The biggest improvement in aerodynamic efficiency, when compared to a conventional aircraft, comes from the reduced surface area and thereby reduced skin friction drag. According to Liebeck[1], it is possible to achieve up to a 33% reduction in surface area. This reduction comes mainly from the elimination of tail surfaces and engine/fuselage integration.

Multidisciplinary Design Optimization (MDO) plays an important role in the design of the BWB. The high level of integration between the wing, fuselage, engines, and control surfaces inherent in the BWB design allows MDO to take advantage of the synergistic nature between the different aircraft design disciplines, resulting in an aircraft with better performance than a conventional design. So, MDO has been used extensively in the design of the BWB.

Initial designs of the Boeing BWB designs had 800 passengers and a 7,000 nm range at a cruise Mach number of 0.85. The passenger cabin was double decked and cargo was in the afterbody. Although those designs showed great improvements compared to a conventional aircraft with the same payload and mission, Boeing is now looking at a smaller airplane. A family of designs that carry 200 to 450 passengers is now being considered. This makes the comparison of the BWB with existing aircraft, such as the Boeing 747, Airbus A340, and Airbus A380, easier.

The Boeing BWB-450 (Figures 7 and 8) can carry 478 passengers in three-class interior arrangement over a range of 7,750 nm. The centerbody is double decked. The passengers are seated in the upper deck and the cargo is stored in the lower deck. Fuel tanks are located in the wing, outboard of the center section. The BWB-450 uses three upper surface pylon mounted turbofan engines, located at the trailing edge of the wing, for propulsion. A recent Boeing optimization study[1] indicated that a cruise Mach number of 0.90 is optimal for a range of 7,750 nm. However, the economic value of speed must be established before selecting a design cruise Mach number. For example, a slight increase in speed in longer-range missions could eliminate the requirement for a second crew. This type of consideration needs to be evaluated with respect to the increase in Takeoff Gross Weight (TOGW) of the aircraft and the increased fuel burn.

Potential Benefits of the BWB

A performance comparison of the Boeing BWB-450 with the Airbus A380-700 is given in Table 1. Both airplanes are compared for a payload of approximately 480 passengers and a range of 8,700 nm. The most noticeable result is the BWB's 32% lower fuel burn per seat. Both airplanes are using equivalent technology engines of similar thrust levels, but the A380-700 needs four and the BWB only three. The primary structure of the A380-700 is made of *GLARE* (which is a sandwich of thin sheets made of aluminum and fiberglass), except the outer wing panels, which are entirely composite. The BWB-450 primary structure is made of composites.

A recent study at Virginia Tech[2] showed a further performance improvement of the BWB can be achieved by using distributed propulsion. The concept of distributed propulsion involves replacing a small number of large engines with a moderate number of small engines and ducting part of the engine exhaust to exit out along the trailing edge of the wing (Figure 9). An increase in propulsive efficiency is attainable with this arrangement as the trailing edge jet "fills in" the wake behind the body, improving the overall aerodynamic/propulsion system. When distributed propulsion is applied to a BWB, a reduction of 5.4% in TOGW and 7.8% in fuel weight can be achieved. The savings are mainly due to the effect of the trailing edge jet on the induced drag and the increased propulsive efficiency.

Liebeck[1] discusses the BWB's potential for significant reduction in environmental emissions and noise. Firstly, the engines are located on the upper surface of the aircraft and therefore the forward-radiated engine fan noise is shielded by the centerbody, and the engine exhaust noise is not reflected by the lower surface of the wing. Secondly, there are no slotted trailing edge flaps, so a major source of airframe noise is eliminated. Further, the use of trailing edge flaps can be eliminated by obtaining high lift and longitudinal control through the use of distributed propulsion and deflection of the trailing edge jet. Thirdly, lower total installed thrust and lower fuel burn imply an equivalent reduction in engine emissions, using the same engine technology. So, it seems that the BWB offers a significant reduction in noise without any specific acoustic treatment.

What Does the Future Hold for the BWB?

Clearly the BWB shows a significant advantage over a conventional aircraft in terms of performance and weight. However, the BWB is a revolutionary aircraft concept and will require a large and expensive engineering effort to become a reality. Most likely, before being used as a transport aircraft, it will be utilized for military applications. In fact, Boeing and the US military are designing the BWB to be used as an advanced tactical transport and as an air refuel tanker (Figure 10). The BWB has a large fuselage and can carry massive amounts of fuel. Also, it can provide two permanent refueling boom stations, rather than one as in the KC-135, KC-10 or KC-767.

References

1. Liebeck, R.H., "Design of the Blended Wing Body Subsonic Transport", Journal of Aircraft, Vol. 41, No. 1, pp. 10-25, Jan-Feb, 2004
2. Ko, A., Leifsson, L.T., Schetz, J.A., Mason, W.H., Grossman, B., Haftka, R.T., "Multidisciplinary Design Optimization of a Blended-Wing-Body Transport Aircraft with Distributed Propulsion", AIAA's 3rd Annual Aviation Technology, Integration, and Operations (ATIO) Technical Forum, Denver, CO, 17-19 Nov., 2003
3. ww.airbus.com
4. www.boeing.com
5. www.ctie.monash.edu.au/ hargrave/northrop.html
6. http://archive.cs.uu.nl/pub/AIRCRAFT-IMAGES/

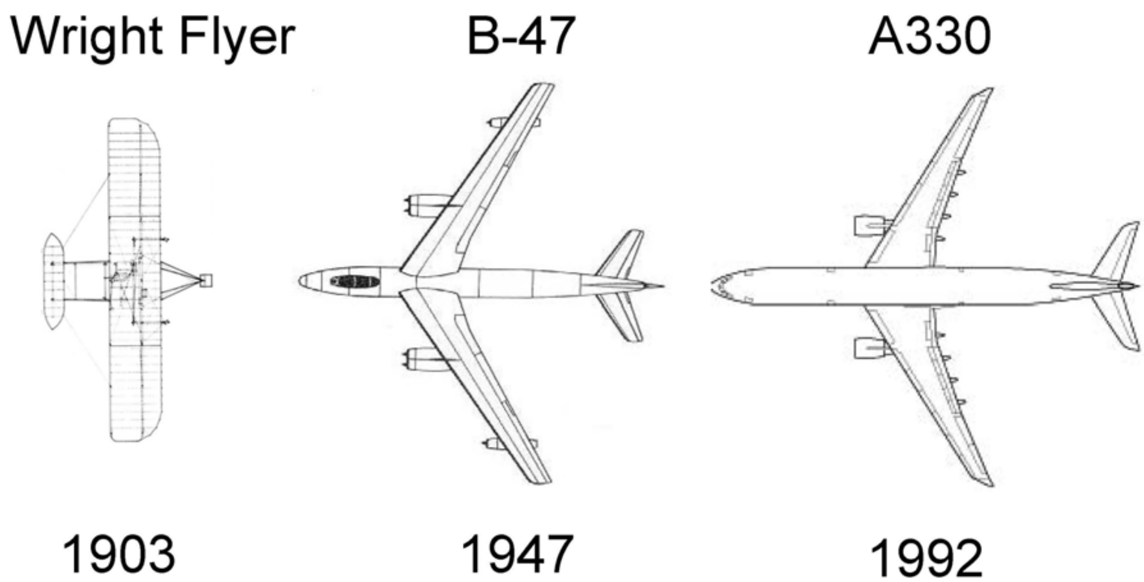

Figure 1: Aircraft design evolution, the first and second 44 years.[1]

Figure 2: Airbus A380 transport aircraft.[3]

Figure 3: The Boeing 787 transport aircraft.[4]

Figure 4: The XB-35 flying wing.[5]

Figure 5: The stealthy B-2 bomber.[6]

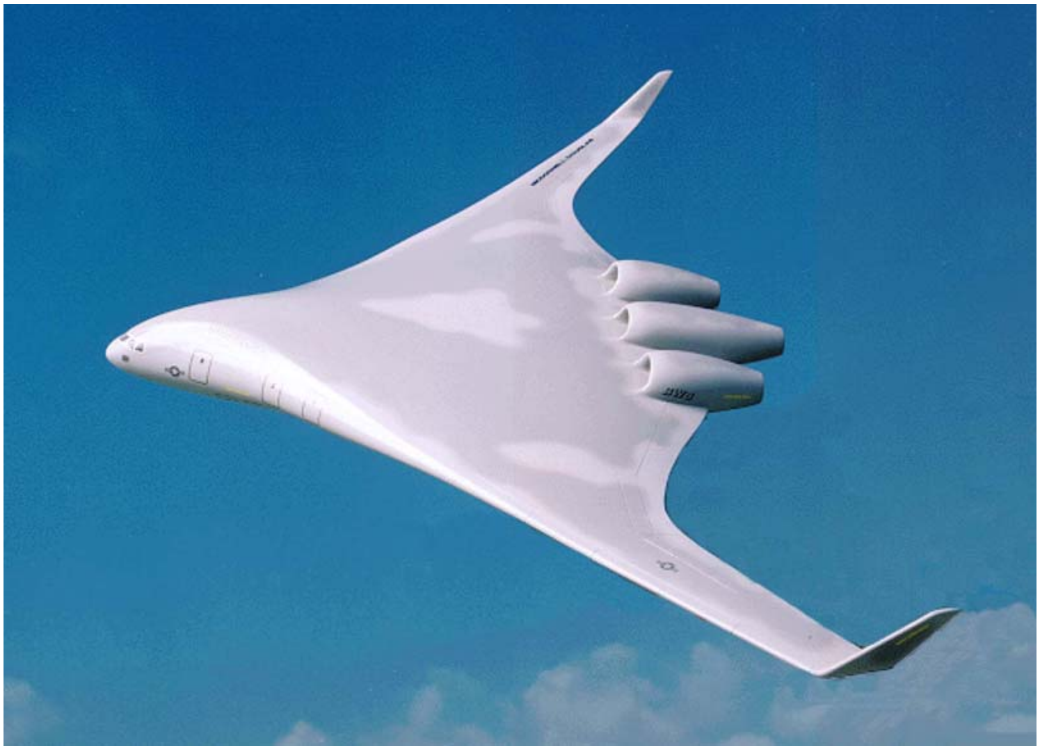

Figure 6: A BWB with boundary layer ingestion inlet engines (picture from Boeing).

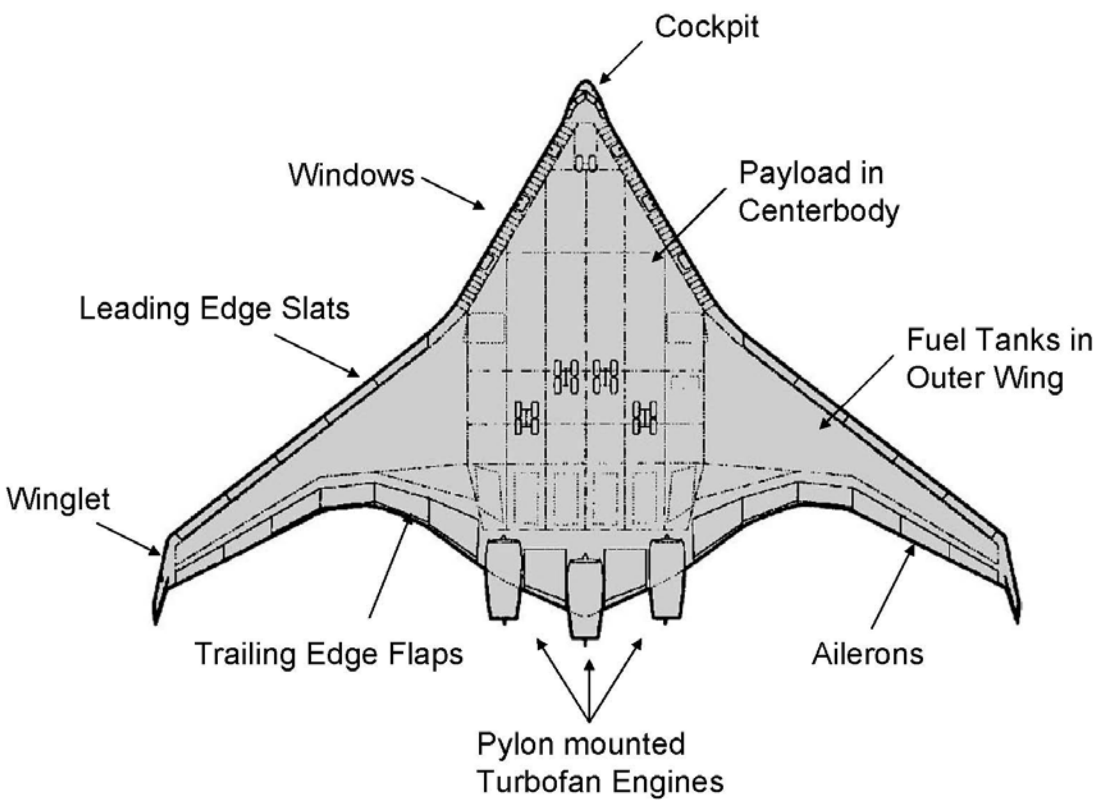

Figure 7: The Boeing BWB-450 baseline (Liebeck[1]).

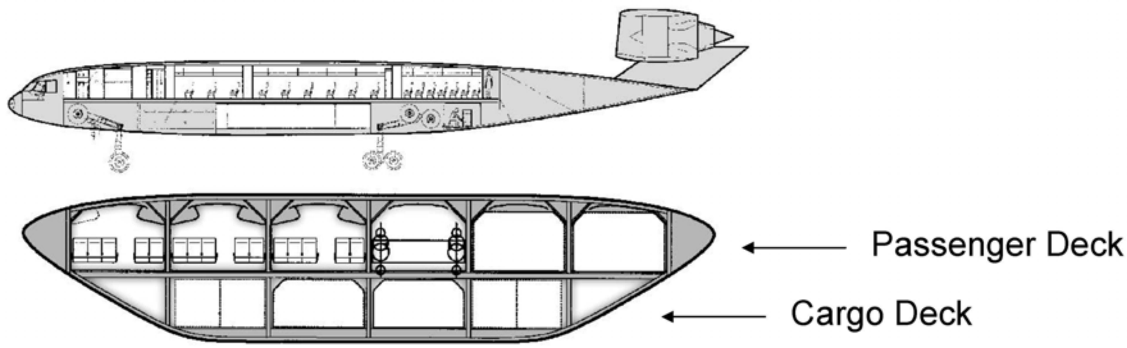

Figure 8: Centerbody interior cross section (Liebeck[1]).

Table 1: A performance comparison of the BWB-450 with the A380-700 for 480 passengers and 8,700 nm range (Liebeck[1]).

Maximum Takeoff Weight	-18%
Total Sea-Level Static Thrust	-19%
Fuel Burn per Seat	-32%

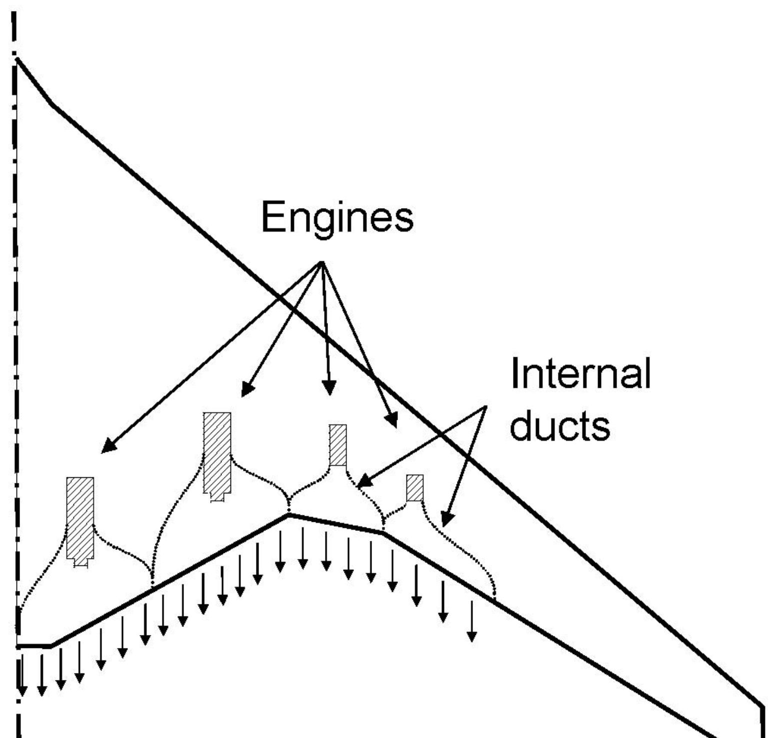

Figure 9: A BWB with a moderate number of small engines distributed along the span and part of the exhaust ducted out the trailing-edge of the wing.[2]

Figure 10: A Boeing BWB tanker with pylon-mounted engines (picture from Boeing).