Imagine yourself stepping out onto the tarmac of New York’s John F. Kennedy International Airport. The beautiful Pan-American Worldport terminal looms large as seen in Figure 1. The year is 1960. You are about to board a brand new Pan-American Boeing 707. You have never had the chance to fly in a jet-powered airplane before, but you have heard they are a lot faster and more comfortable than the older planes to which you are accustomed. There is a rumor you will not have to stop in Canada and Ireland before landing in London. One of your friends saw an advertisement on television describing your flight as “Six and a Half Magic Hours.” [1] This flight sounds a lot more appealing than the 10 or more hours you would be spending in the air if you were flying in a propellor airplane. Just looking at the beauty and grace of the 707 seen in Figure 2 fills you with awe. It is amazing to see how fast airplanes have advanced! What could the future possibly hold?

This was the situation in the aviation industry over five decades ago. Let us compare that to today’s version of the transatlantic crossing. You arrive at John F. Kennedy International Airport, ready to board your Virgin Atlantic flight to London’s Heathrow International Airport. After the hassle of getting through
security and all the bureaucracy, you board the Airbus A340 seen in Figure 3. You are thinking about the 6-hour flight ahead of you in the cramped cabin. Soon you will be in London, but you paid over $1000 to get a seat on this flight. With rising fuel costs this price will soon seem inexpensive in comparison to the $2000-$3000 that you may have to pay in the future. Whatever happened to the glamorous days of flying?

Introduction

These two scenarios may appear to be worlds apart from each other, seeing as they are quite literally from very different eras. However, what makes the second situation so much worse is that the difference between them is not as great as one would desire or expect. At the heart of a careful comparison between the two circumstances lies the design of the two aircraft, a Boeing 707 and an Airbus A340. The first aircraft was a revolutionary concept in its time. [2] Introduced in the late 1950’s, the Boeing 707 ushered in the jet age and transformed the commercial aircraft industry like no other aircraft has done since. The second, an Airbus A340, is one of the most recent commercial aircraft models in service today. Implementing technologies that could not even be imagined in 1960, it is heralded as a modern marvel of engineering. [3] However, a comparison of the basic design of both of these aircraft reveals why it is difficult to assert that the A340 can be held up as a great engineering feat in comparison to the 707, which was designed 50 years previously. It is relatively easy to mistake an A340 for a 707 because their general design features are in many ways identical: a
cylindrical tube for a fuselage with two swept wings and podded engines. [4] This remarkable similarity is illustrated in Figure 4. This observation prompts the question: Why has the design of commercial aircraft remained substantively stagnant for half a century?

Imagining a futuristic air travel scenario will help to place the importance of this question into perspective. The year is 2025 and you are waiting as an airline passenger at New York’s J.F.K. Memorial Intercontinental Air Transit Center for your flight to London. As you look out of the boarding zone window you have a view similar to that seen in Figure 5. A remarkable new aircraft type catches your attention as it pulls up to the gate. It is a “Blended-Wing-Body” aircraft, BWB for short. BWB’s are an entirely new aircraft design that has just entered the market. It is heralded as the greatest leap forward in commercial aircraft architecture engineering since the Boeing 707 ushered in the jet age nearly 70 years ago. [5] This new aircraft is sleek and efficient, but best of all: your ticket costs much less than a seat on an old cigar-shaped jet. Airlines can now fly more passengers faster using less fuel in a BWB, so they’ve dropped their airfares significantly.

Figure 4. Comparison of Boeing 707 design to Airbus A340 design (Source: adg.stanford.edu)

Figure 5. A Blended-Wing-Body Concept (Source: flightglobal.com)
to entice more passengers to fly. When you step into the cabin your feeling about the trip gets even better. Instead of looking like the inside of a submarine with long and narrow isles, the BWB has a sprawling interior. With two decks, each with six front-to-back aisles and three longitudinal aisles, this aircraft reminds you more of a cruise ship on the inside. [6] In short, the transatlantic crossing combines speed, efficiency, and comfort in one beautiful and modern concept: the blended-wing-body.

At the present moment this new design concept appears radical and implausible. In just 15 years, could we really deploy a completely new aircraft design? Will it be possible to surpass the longstanding tube-and-wing architecture that has proven itself as a mainstay of the aviation industry for five decades? The future is never certain, but considering the benefits of transitioning to a BWB and the economic and environmental forces that continue to exert increasing pressure on the airline industry, it is inevitable that we will need to change the way we think about aircraft design.

**The Advantages of Blended-Wing-Body Aircraft**

Why are blended-wing-body aircraft the next logical step in aircraft design? In the first place, they are much more efficient than conventional configuration aircraft. BWB's offer a 20-30% improvement in aerodynamic efficiency. [7] This dramatic improvement comes from a simple but elegant philosophical change in the way we envision how airplanes ought to work. Current designs separate the work of carrying passengers and cargo from the work of keeping the airplane aloft. The first task is allocated to the fuselage and the second task is handled by the wings. As a result current aircraft generally require greater wing surface area because two distinct structures are designated to perform the two separate tasks. The BWB concept integrates these two tasks in one more efficient system, creating what is called a “lifting body.” Less overall surface area is needed to carry an equivalent amount of cargo because the fuselage of the aircraft performs multiple tasks simultaneously: lifting and storing the payload in the aircraft. [8]
Another important advantage of BWB’s derives from the strategy of combining the fuselage and the wings into one body: reduced structural weight. As illustrated in Figure 6, the distribution of loads spanwise across a traditional aircraft leads to most of the weight being carried in the center and nearly all of the lift coming from the wings. The wings must therefore be able to resist massive bending loads. However, in a blended-wing-body, the loads are more evenly distributed across the span (i.e. high weight sections have high lift and lighter portions of the aircraft generate less lift). This leads to smaller bending moments on the aircraft structure. [8] Consequently, structural requirements of the aircraft are lessened and empty weight is reduced, further increasing efficiency.

As efficiency becomes increasingly important in the age of higher fuel prices and environmental sustainability, these advantages ought resonate favorably with both aircraft designers and airlines. It

**Figure 6.** Distribution of Loads in a conventional aircraft vs. a blended-wing-body
(Source: Liebeck, Design of the Blended Wing Body Subsonic Transport)

**Figure 7.** A Boeing 787 (Source: Boeing.com)

**Figure 8.** An Airbus A380 (Source: Airbus.com)
is difficult to understand in principle why we are not already flying in blended-wing-body aircraft today. After all, both Boeing and Airbus, the world’s two largest commercial aircraft manufacturers, recently released entirely new airplanes onto the market, the Boeing 787 and the Airbus A380. Both of these aircraft continued in the tradition of using a conventional tube-and-wing design. If these aircraft manufacturers were willing to spend large amounts of time and capital in producing new airplanes, why would they not invest in a winning technology like the BWB?

**Difficulties in Designing a BWB**

There are two central reasons why a blended-wing-body aircraft is a technically challenging engineering project. The first of these reasons is the difficulty associated with the manufacture of BWB’s while the other problem stems mostly from aerodynamic design considerations. While these reasons appear daunting at first glance, sufficient research has been conducted so that all of these issues could be overcome. If aerospace companies want to push their product lines into the next era of commercial passenger transport, they need to move towards developing a blended-wing-body.

One of the difficulties that arises when considering the design of a BWB is the complicated manufacturing process that is associated with a new airplane design. Conventional tube-and-wing design aircraft have two particular advantages. Because aircraft have been made this way for half a century, much is known about how to assemble efficiently the various components, large
and small, of this type of airplane. In addition, the tube design of the fuselage makes assembly and customization quite literally a simple process of adding nearly identical cylindrical components. A blended-wing-body, by its nature, is a much more complicated structure to design, manufacture, and assemble. [9] Thankfully, research has been performed that has shown that many of the same principles that are applied to conventional designs today can be used in BWB design. Airplanes can be “molecularized” which means that its design can be separated into components that can be added and subtracted to allow for simple aircraft customization, as seen in Figure 9. This way the needs of each airline customer can be met without having to create individualized designs. This process is detailed and organized in a patent filed for and given to the Boeing Company in 2003. [9] Using this or similar methods, BWB design and manufacture could be as or more streamlined than the assembly lines of today's aircraft manufacturers.

With manufacturing problems solved, the aerodynamic concerns remain the only impediments to the success of the blended-wing-body. At the forefront of these issues is the required capabilities that must be in place to create such a design. By its very nature, the BWB is a particularly integrated system and thus the process of design requires the study of many simultaneously self-dependent variables. [8] Conventional aircraft design requires a tremendous number of aerodynamic performance studies. Blended-wing-body design will require even more analysis and computational work. Luckily, one particular advantage that modern aircraft engineers have in their design toolkit is Computational Fluid Dynamics, or CFD. This technology uses the power of computers to simulate the aerodynamics of any aircraft, as shown in Figure 10. Already a great deal of research has been done to
determine what are the best methods to use in the study of BWB's using CFD. [10] With CFD in hand, much of the work of aeronautical engineers is simplified to working with a digital model and making small adjustments to design based on theoretical intuition blended with careful analysis of simulation results. Utilization of this technology will reduce the difficulty of designing an integrated aircraft so that expertise of engineers can be focused on design and not on vast volumes of computation.

Another difficulty that arises when designing a BWB are the limitations associated with stability and control of the aircraft. Conventional aircraft have long fuselages with tailplanes located at the rear to statically stabilize the aircraft and to give the control surfaces sufficient control power. The flying wing design of the blended-wing-body aircraft improves aerodynamic efficiency in part by doing away with a tailplane. Unfortunately, this makes the task of designing controls that can make the aircraft stable and safe much more difficult. Luckily, flying wing designs have been used before and some have been quite successful (e.g. the Lockheed B-2 bomber). Sufficient research into the control aspects of BWB design has been conducted to show that the creation of a safe blended-wing-body aircraft is quite plausible. [11] Fly-by-wire technology, which routes flight control commands from the pilot through a computer which in turn controls the movements of the aircraft, will prove invaluable in making this possible. This technology has been proven safe and reliable and is now used on many commercial aircraft that are flown today. Thus, controlling a BWB would be a challenging but very possible engineering feat.

The final and most difficult aerodynamic challenge that remains is the difficulty of sculpting a passenger and cargo cabin into a flying wing. [8] Today wing and cabin design are essentially separate endeavors. However, because in a BWB the wing is the fuselage, the cabin and cargo areas must be adjusted to fit inside of an aerodynamic structure. As a result of this feature, several constraints come to the forefront of the design process. The first of these is the constraint that the wing not be too thick. Normally, airplane wings that travel at speeds approaching the speed of sound
require thin wings, but BWB designs are inherently thick because the aircraft’s payload is stored inside the wing. This problem is solved by shaping the wing in different ways so as to avoid the negative effects of Mach drag (the drag resulting from traveling near the speed of sound). Sweeping back the wings of the aircraft delays the onset of Mach drag and thus much research has been performed on the viability of using sweep to combat effectively Mach drag effects. [12] This technology could effectively solve the thickness problem while still maintaining the cabin size requirements.

The second limitation is more of an imposed constraint, but it is equally if not more important than all the others. Since the BWB will carry passengers in a non-conventional way, its design must be able to meet cabin egress requirements set by aviation authorities. Many BWB cabin designs put passengers at further distances from emergency exits than conventional aircraft, so there is the worry that people would be unable to escape a crashed aircraft within the ninety-second-time limit. However, with the use of simulation and with innovative design and emergency exit placement, it can be shown that BWB egress performance is comparable to that of a conventional aircraft. [6]

Using tools like this, the design of the BWB cabin will be a challenge not without its complications and difficulties but one that is entirely within the reach of today's engineers.

**Conclusion**

The only thing stopping the BWB from emerging as a viable design for the next generation of commercial passenger transport aircraft is the willingness of aerospace manufacturers to push the
envelope. Aircraft designers have the research and technology available today to put in place a viable design for a blended-wing-body. These companies truly have an opportunity not only to get ahead of their competition but to change the aviation industry dramatically. Aircraft can become significantly more efficient and sustainable. Passenger travel can become more comfortable and affordable. We could realistically see ourselves in the opening scene that imagines a dramatically different and better view of air travel 15 years from now.

Figure 12. Blended-wing-body optimized design
(Source: Liebeck)
References