Economic Impact of Blended Wing Bodies in Transport Aircraft

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Abstract:

Key Terms

BWB,

Introduction:

Current transport aircraft design has remained relatively unchanged since the advent of the jet age starting in the late 1940s. These planes feature “a cylindrical fuselage, a swept wing and empennage and engines mounted on pylons under the wings” (Mialon, Fol, & Bonnaud, 2002), as on the Boeing 700 series aircraft. The conventional design for these aircraft is starting to reach the end of its life as it becomes harder to improve the design reaching their technical limits (Osterheld, Heinze, & Horst, 2001). Unconventional aircraft provide a method for further improvement of characteristics including efficiency, range and load capacity. Many theoretical designs have been proposed with unconventional body shapes, different wing styles, and other performance enhancing modifications. Most of the designs feature some sort of improvement reducing the amount of unnecessary drag on the aircraft, which is best accomplished with what is called a flying wing. Flying wings use the wing as their body surface, combining the body, wing, and control surfaces into a more aerodynamically efficient aircraft.

The ever expanding growth of air travel, with predicted expansion of about 5% a year (Mialon, 2002), coupled with rising fuel costs proves it is in the best economical interest to make a more efficient aircraft. In total, airlines spent approximately $25.7 billion on fuel in 2016 (Bureau of Transportation Statistics), showing that a 10%

increase in efficiency saves over $2.5 billion per year. The main purpose of this study is to look into the development process of a blended-wing-body aircraft (BWB), which utilizes a design very close to the ideal flying wing, and make adaptations to see if, at peak efficiency, it will have improved enough to be a viable design for replacing the current aircraft in use for transport around the world. The proposed aircraft provide an increased level of efficiency allowing fuel savings to meet the demands of the globalized world. The design represents the “purest and closest design to the nature[sic]”(Sergio, 2001). Stepping away from the conventional aircraft model, designs may be able to achieve improvements that were not possible before.

The project follows a computer design process involving an initial development of the airplane based off of designs and recommendations of various studies. After the preliminary design was completed, the aircraft produced was made to meet capacity and range requirements of a transport aircraft. The aircraft was repeatedly analyzed and tested until the design was as optimized as possible, while maintaining its functionality as a transport plane. For universal use, the aircraft requires a cabin height of 1.9 meters or higher, a wingspan of less than 80 meters as outlined by Rodrigo Martinez-Val(2000).

The design could have great impacts on fuel economy in comparison to aircraft of similar size. Increased fuel savings will translate into reduced transport costs, allowing the needs of the rising transportation crisis to be satiated as the savings will allow companies to use more aircraft. The increase in efficiency will translate to lower fuel costs and reduced emissions into the atmosphere. With these improvements, the design should be a feasible replacement for the current generation of transport aircraft.

BWB aircraft provide a possible solution to the problem of transport aircraft through the positive impacts that they will have on efficiency in comparison to that of aircraft today.

A transport aircraft must be able to carry large capacities over long distances, while remaining economically viable. The current generation of transport aircraft uses a conventional airplane design, which has good flight characteristics, but faces efficiency drawbacks due to drag created by surfaces necessary for its stability. Utilizing a BWB would decrease drag with little to no reduction in stability.

The aircraft industry currently favors the conventional design, but increasing demand for air transport and commerce is creating a rising need for aircraft that can carry more in a more efficient form. Aircraft manufacturers would be impacted by the increase in demand for their manufacture, as more planes would be replaced. The design of these aircraft can be scaled from any size of transport aircraft, but certain adaptations must be made as the size changes.

The design of these aircraft is theorized to provide better efficiencies compared to the current generation of aircraft, but the numbers are different based on the design requirements and style of BWB. Current BWB designs have proven that there is great possibility for improvement of the current aircraft design with higher aerodynamic efficiencies being shown in designs, but they are mostly aimed at the large scale. The main purpose of this study is to look at the theoretical economic impact through fuel savings for regional sized planes by means of utilizing a BWB design.

Starting with the Horten brothers' research on flying-wing gliders in the 1930s, interest has grown sporadically in the development of highly efficient aircraft featuring a BWB design, with most focus having been in the creation of military aircraft.

The largest step forward was made by the Northrop Grumman Corporation in the 1940s and early 1950s with their YB-49/XB-35 program (Smith, 2000). The design of this aircraft was very well received, but instability issues with the aircraft were too prevalent for pilots to control the aircraft without an adequate computer stabilization system.

The AVRO Vulcan was the first BWB aircraft to be introduced en masse into service, fulfilling the role of a high speed bomber aircraft. The design of the aircraft featured what is called a delta wing, which removes the rear horizontal control surfaces, or empennage, to increase the aerodynamic efficiency of the wing. The Vulcan's success shows that the design is feasible even though plans for a civilian version were abandoned (Smith, 2000).

Figure 1: DZYNE Ascent 1000 (DZYNE Technologies).

The revival of the BWB design was done with the B-2 stealth bomber, which was able to overcome the instability issues of the YB-49 due to advancements in computer stabilization systems. The advancements made in stabilization systems were transferred to a joint project done by Boeing, Stanford University, and NASA (Smith,2000). The project succeeded in designing a BWB transport aircraft that would be suitable as replacement for the current generation of aircraft. The project included making practical models for testing the design and control systems. Stanford University built a testbed for the controls under NASA sponsorship (Liebeck, 2004).

Due to the rise in air commerce, researchers at ONERA and Airbus France conducted a study on the procedural improvement of BWB aircraft through repeated design refinement to optimize the planes for subsonic flight. During their analysis they made two initial designs, which they repeatedly modified to improve their characteristics through the “cut and try” method (Mialon, Fol, & Bonnaud, 2002). This design process is not as optimized as one done by an algorithm, but it provides significant improvement without the need for development of a specialized algorithm for improvements. The designs of their aircraft were significantly improved without the use of an algorithm showing how it is still useful even if it is not the most optimized means of development. Their research provided airfoil designs tailored to tailless configurations like BWB aircraft.

The design process as outlined by Rodrigo Martinez-Val and Erik Schoep (2000) features the initial sizing of the aircraft and the parameters it will follow. One of their most notable design considerations was a speed of mach 0.8, which is slower than many current aircraft, but allows for no development of sophisticated airfoils. The plane was sized to accommodate people like a traditional transport plane. Their design features estimations of Maximum take-off weight (MTOW) and estimations of material weights to get an idea for the capacity of the aircraft. After the design was completed, it was analyzed for its characteristics, such as lateral stability and its performance compared to the specifications it was designed to meet.

Modern BWB designs were compared to aircraft of similar scale, with the blended wing body aircraft reaching from 13% to 32% increases in efficiency over contemporary aircraft (Martinez-Val & Schoep, 2000; Liebeck, 2004). The aircraft designed by Martinez-Val saw improvements of ranging from 13% to 15% compared to the Airbus A330 and Boeing B777 respectively. Liebeck’s research provided data showing even higher fuel efficiencies of comparable aircraft. The main difference in fuel economy is caused by the reduction in engines with the BWB design due to the lower weight that reduces the necessity for additional thrust. These designs have been made to not require any change to normal air procedures, making them easy to adopt into service.

Problem Statement

Current regional-sized transport aircraft (i.e. Boeing 737) are difficult to improve in terms of fuel efficiency due to the maximum aerodynamic efficiency being very close to being reached. Aircraft designers must improve characteristics like weight and engine efficiency, which are already becoming harder to improve with less returns on improvement. The lack of room for improvement on the current aircraft coupled with rising fuel costs promotes the need for an aircraft design that is able to provide further improvements through change in aerodynamic design. Blended wing body aircraft have been proposed for making the improved aerodynamic efficiencies, but have mostly been designed for large use cases (i.e. Airbus A380 and Boeing 747).

Overarching Research Question

The most common aircraft designs are improved through means that do not require a change in conceptual design. These updates act as a means of improving existing designs without having to spend time and money on the development of new aircraft. Blended wing bodies provide a possible means of having improved efficiencies over the current aircraft in use. Can the efficiency of transport aircraft be increased by a large enough margin through implementation of BWBs to make them economically feasible?

Hypotheses

- Null: The cost savings made by the aircraft will less than the proposed 25-30% made by the initial studies on developing BWBs.
- Alternative: The cost savings made by the aircraft greater than the proposed 25-30% made by the initial studies on developing BWBs.
- Dependent Variable: The economic impact of blended wing bodies
- Independent Variable: Fuel efficiency improvement provided by the aircraft.

Methods and Data Collection

The data for this project was obtained through secondary data analysis from google scholar, airline financial reports, researchgate, etc. The data used was for current aircraft fuel use in comparison with the fuel used by an existing airline to determine the cost savings that could be achieved.

Southwest Airlines was chosen for the implementation of the aircraft due to their current exclusive use of the Boeing 737, which is the active comparison against the proposed blended wing body aircraft. The fuel prices were received from a Southwest Airlines expense report that listed the amount of fuel used, its purchase price, and its total expense for the company.

The data for the proposed aircraft, the BWB-165 designed by DZYNE Technologies, was taken from the study by Yang (2018). The design was scaled from 19 passenger business jets to 210 passenger jetliners, but the 165 passenger configuration was chosen due to its conformation with the airline chosen. The data provides an active comparison of the proposed aircraft compared to existing aircraft from 2005 and 2015 through weight, fuel efficiency, cruising speed, thrust and range.

The data for the fuel expenditure was altered from gallons of fuel used to pounds through the conversion factor of 806.5g/l or 6.730 pounds per gallon of jet fuel. The conversion was done in order to allow the fuel expenditure to more easily align with the figures given for the proposed aircraft.

Final data will be on the cost reduction that could be achieved based on the number of available passenger miles by Southwest Airlines.

Data Analysis

		DZYNE BWB-165	737-800 IWG	Δ (DZYNE BWB vs. Baseline)	737 MAX 8	Δ (DZYNE BWB vs. Baseline)
Passenger Provisions	pax	165	162	2%	162	2%
Mission Passengers	pax	165	162	2%	162	2%
Wingspan	ft	147.2	118	25%	118	25%
Range	nmi	3500	2940	19%	3620	-3.00%
Cruise Mach	n.d.	0.8	0.785	2%	0.8	0%
Gross Weight	lbs	139490	174200	-20%	181200	-23%
Initial Cruise Altitude	ft	40000	34000	18%	35000	14%
Engine	n.d.					
Sea Level Static Thrust	lbs	25000	27300	-8%	29300	-15%
Bypass Ratio	n.d.	10.5	5.7	84%	9	17%
Fuel Burn	lbs	21079	38800	-46%	35,362	-40%
Fuel Burn / Pax-nmi	lb/nmi-pax	0.037	0.081	-55%	0.06	-39%
NOx Emissions	-			-60%		-40%

Figure 2: DZYNE BWB-165 compared to the Boeing 737-800 and 737 MAX 8

In figure 2, it can be seen that the Dzyne BWB translates to a fuel burn of 0.037 lb/nmi-pax. This fuel burn is 39% less per passenger than the current aircraft in production and uses 55% less fuel than the 2005 design which is still in wide use.

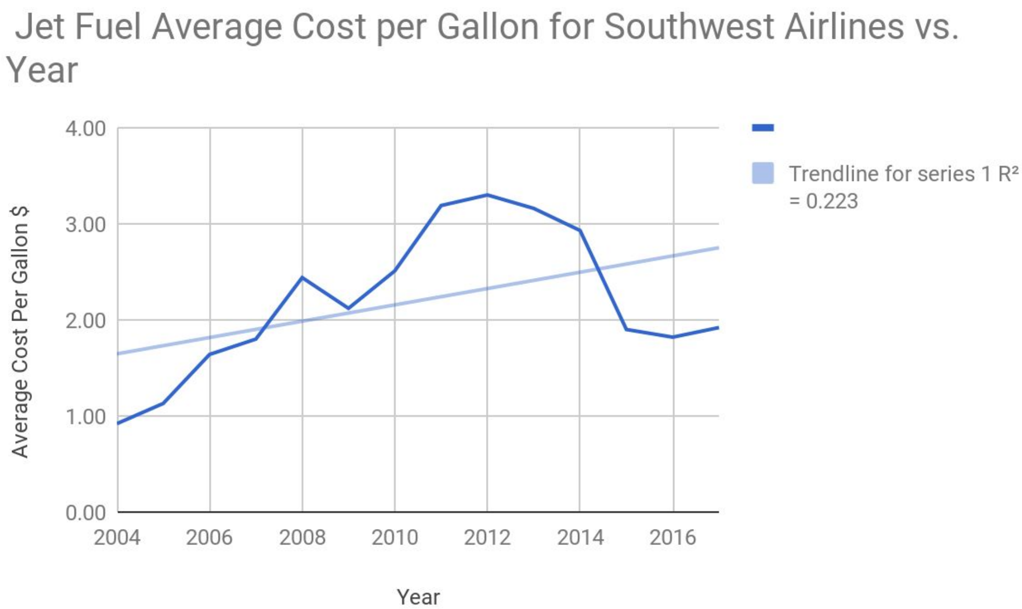

Figure 3: The average cost per gallon per year for Southwest Airlines since 2004.

Since 2004, fuel price has risen significantly, but as can be seen with the low R^2 value in figure 3, predicting future fuel price is not viable. The instability of this future price prediction led to the fuel price used being based on the average fuel price for 2017.

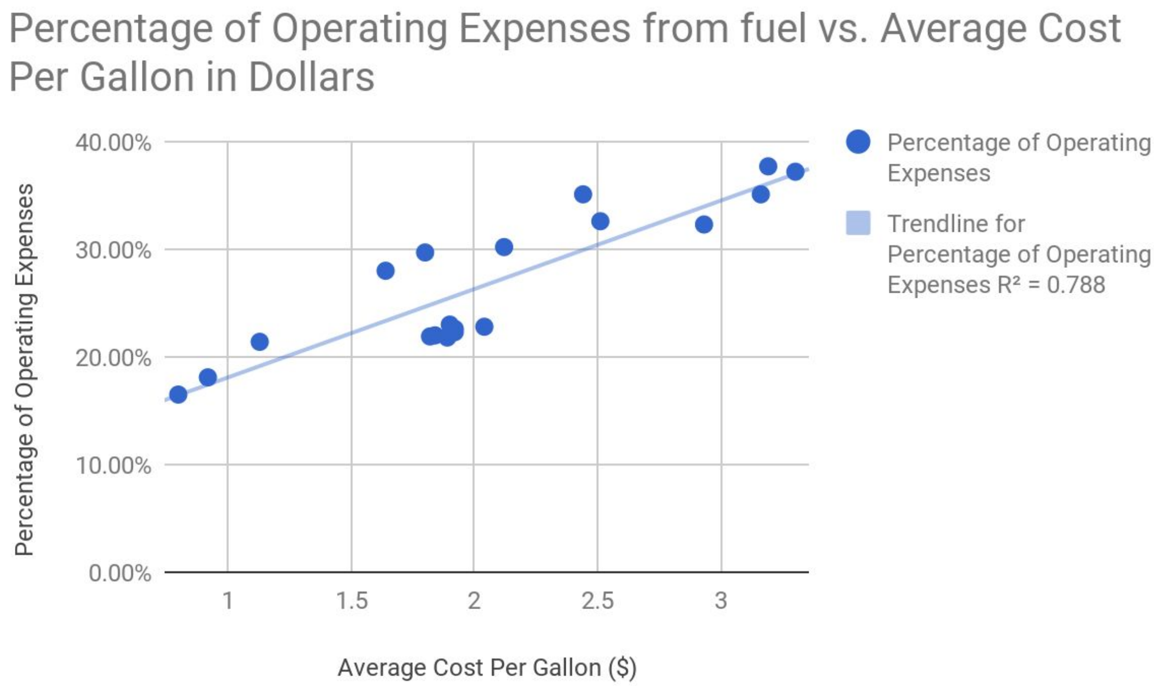

Figure 4: The percentage of operating costs accounted for by fuel expense for Southwest Airlines

For Southwest Airlines there is a correlation between the average price of fuel and the amount spent on operating expenses, with an R^2 value of 0.788. This value is high enough to indicate that is correlation is viable.

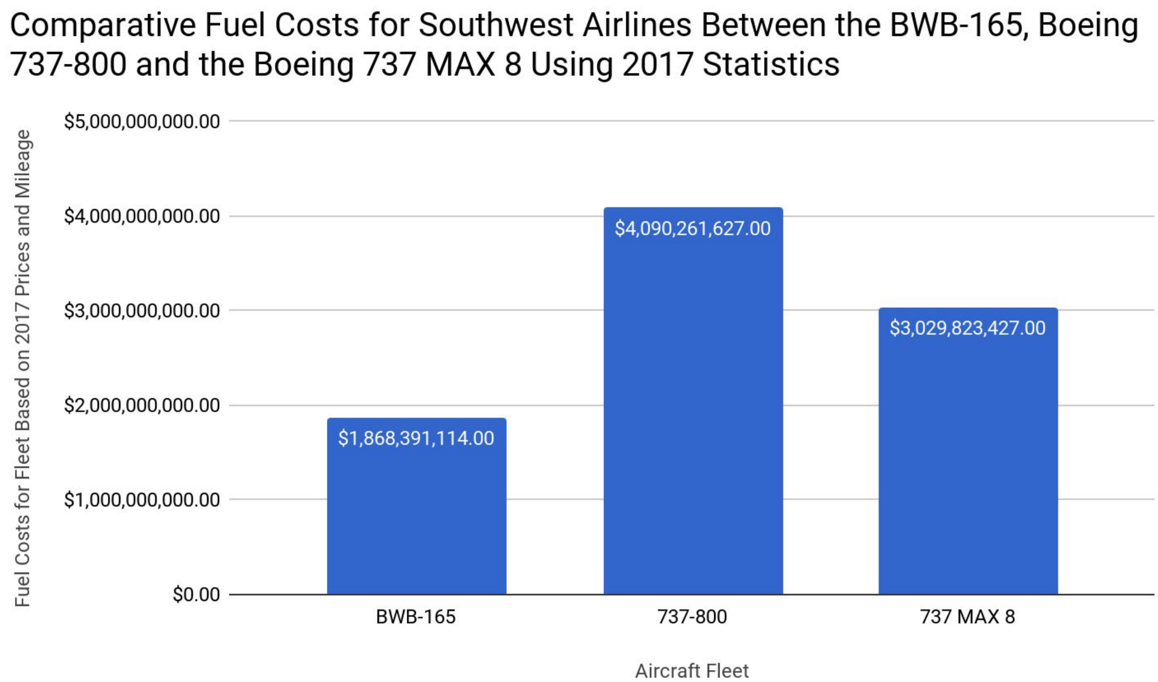

Figure 5: Projected fuel expenditure for the aircraft fleet based on the available passenger miles for Southwest Airlines.

From Figure 5, the projected fuels for the aircraft fleet based on the available passenger miles traveled by the airline. The fuel for the proposed BWB-165 fleet is estimated to cost $1.87 billion which is 55% less than the Boeing 737-800 fleet would spend on fuel, while also costing approximately 39% less for fuel than the 737 MAX 8.

Discussion and Social Change

The data from above supports my hypothesis that the change enacted will be greater than the 25-30% predicted by the initial studies starting in the early 2000s. The design used predicted a fuel consumption of 55% less than the Boeing 737-800 and after translating that cost savings, the fuel costs were also reduced by same amount.

The reasoning behind choosing the figures from 2017 instead of predicting the fuel prices and future prospects of the company is the fuel price has little correlation with time, as the R^2 that was taken from getting a best fit line for the fuel prices over the years was very low. Without a strong correlation there is little that can be done for future price prediction that is not mere speculation. One of the main causes of fuel price fluctuating so greatly is geopolitical factors which cannot normally be accounted for. There has been an upward trend of fuel price over time, while unpredictable, it shows the need to reduce fuel use to avoid increasing amount of expenditure going to fuel consumption.

However, the cost per gallon of fuel has a much higher correlation with the percent of expenses that fuel accounts for a much higher R^2. This correlation indicates that as fuel price rises, an even larger portion of airline expenses will be taken up by fuel costs. With increased expenses it is in an airlines best interest to reduce their fuel use by as large of a margin as possible to increase their profit margins.

The data analysis was done based on the available passenger miles traveled and the average fuel prices for 2017 for Southwest Airlines. The actual fuel expenditure by Southwest was not taken into account during the analysis, but the predicted value based on the aircraft efficiency values was only 4% more than the actual fuel expenditure with only general estimations made.

The fuel expenditure data is based off of the approximately 154 billion available passenger miles flown by Southwest in 2017 (EXPENSE REPORT) as well as the average fuel price for 2017. Due to Southwest’s fuel hedging, the prices remain relatively constant for the year. The pricing data was made from approximations based on range and does not account for extra fuel use on the ground and in situations that need extra thrust such as takeoff and ascent.

The BWB is able to have increased efficiency in part by its design allowing for less aircraft weight for the same capacity due to the blending of fuselage and wing as well as a lack of empennage. The extra weight reduction means that the aircraft needs to use less power to stay aloft, contributing to its efficiency.

One of the main factors that did not make BWBs viable at their introduction after WW2 was the lack of stability that was provided by the platform. If not under proper conditions they can lose control and crash. However, computer control has allowed them to be put into use today with the same level of control as other aircraft in use.

The data, though based off of approximations still indicates a very large increase in aircraft fuel efficiency. However, the amount of cost savings that will be available once the aircraft is implemented in its proposed deadline of 2025 could be reduced in comparison to newer generation aircraft that have not come out yet.

Conclusion

Overall, aircraft could greatly benefit from the implementation of blended wing bodies, with great improvements in efficiency. With these improvements it is feasible that the aircraft could be adopted into commercial use due to their highly increased efficiencies over current generation aircraft that promote cost savings and could increase profit margins.

Sources of Error and Limitation

One of the major sources of error in this project is the simplification of airplane fuel efficiency. The fuel efficiency used did not account for the amount of fuel used in taxiing, takeoff, ascent, descent, and landing. Without these accounted for the figures for the amounts of fuel used by the aircraft would be off by a margin. This error could be accounted for through more accurate simulation that takes into account all steps of the flight process.

Also, flights of varying distances have different levels of fuel efficiency as the aircraft performance increases with less fuel. On longer distance flights the aircraft fuel efficiency decreases due to the added weight of the fuel. A deeper analysis would need to be done with the aircraft to account for this again.

Through the data provided on the aircraft an in depth statistical performance cannot be done, as the figures used for fuel consumption were generalized through simple arithmetic as opposed to the calculations that would normally have to take place to account for all factors that the aircraft would normally account for.

Without an accurate fuel price prediction it is much more difficult to get a proposed cost savings because of the constant fluctuations of fuel prices. However, current fuel prices are adequate for the calculation of how the aircraft can compare to those in use today and can give a relative idea of how they would be beneficial to be implemented.

One major oversight in this project is the lack of price prediction made for the aircraft. The cost to develop and produce the aircraft offsets the benefits that it would achieve once put into use. The fuel savings may not be enough to cause the plane to replace fleets rapidly if there is too much costs associated with buying the planes. The increased costs would only make it viable for some companies to use and it would be unable to replace entire fleets at once because of the associated costs of buying new aircraft.

Further Work

The next step to be taken with this study is to implement these designs through a computational analysis. This method of design would be most useful because of its ability to allow for the visualization and quick evaluation of different models for their effectiveness. Through computational analysis a more comprehensive understanding of the efficiency of the aircraft can be made due to increased control over variables.

Doing the study through computational analysis would be an important step in finding the efficiency increased in flights of varying distances because of the non-linear track of aircraft fuel efficiency based on travel distance. Through a computational model, varying travel distances could be analyzed for their relative efficiencies allowing for a more in depth comparison of the proposed design to the aircraft in use.

Another improvement that could be made to the model is to develop a model that could predict different fuel prices based on varying economic conditions. Through this model multiple scenarios could be predicted for the development of the aircraft and its implementation.

Aircraft price prediction would be one of the final factors of further work to be done. With a more accurate price prediction that is made, the aircraft could be reanalyzed for its efficiency gains in comparison to its price and how long it would take to realize these gains. Using a model like this, it would be viable to do a more in depth cost benefit analysis for the aircraft and provide its overall gains for the future.

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