



# Revamping the Runway: Enhancing Short Haul Commercial Aviation

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## Abstract

Short flights make up the majority of air travel and are less efficient per passenger-kilometer. These flights can be enhanced through three main categories: increasing the payload and capacity, implementing an innovative wing and fuselage design, and using alternative fuel sources. First, this paper will discuss three ways to increase the payload and passenger capacity: redesigning seats, removing certain auxiliary equipment, and implementing an alternative alloy to replace the traditional aluminum alloy. Second, it will explore the experimental blended wing body design and its promising technology. Lastly, it will discuss two alternative fuels to conventional jet fuel: nuclear and hydrogen power. It will state both the advantages and disadvantages of each source of power and their impact upon the aircraft's structure. In addition, this paper will conduct simulations using CAD software and compare the results of the enhanced aircraft and a standard commercial aircraft. This paper ignores the constraints of the real world, such as prices of manufacturing and cost-benefit outcomes. It is a theoretical solution to improving the short haul industry that can be implemented in the near future.

## Introduction

Since 2010, approximately 86% of flights have been classified as short-haul flights, meaning that it lasts under three hours [1]. Because a large majority of flights are classified as short-haul, there exists an opportunity to optimize the efficiency of the aviation industry so that these flights are cleaner, faster, and capacious in passengers.

In terms of the payload capacity, which includes passengers and cargo, there exists current problems in the wings and the cabin itself. The wings of an aircraft are made of an aluminum alloy, which is prone to corrosion and fatigue cracks. Short flights contain unnecessary services which require a certain amount of weight to be sustained, such as WiFi services, bathroom stalls, and food service, which are impractical for a very short flight. A standard economy seat ranges from 30-32 inches of space [2], which is the legroom distance from the back of a passenger's seat to the seat in front of the passenger. This can be reduced down further to seat more people based upon current special seating projects, which some airlines are thinking of incorporating. Jets require a dedicated amount of fuel for reserves, taking up a significant percentage of the maximum gross weight. For example, a Boeing 737-800 has 18,000 kg reserved for fuel, with the maximum gross weight being 80,000 kg [3].

Aviation also contains a significant impact in the trend of climate change. Aviation produces approximately 2.5% of the total carbon dioxide emissions, but it has contributed to 4% of global warming to date [4]. The problem with conventional jet fuel is that the release of nitrogen oxides and water vapor leads to the formation of contrails, which create artificial cirrus clouds that trap heat. This trapped heat contributes to the overall pattern of climate change and global warming, which is why the percentage of global warming is higher than the percentage of emissions.

## Background

### Increasing the Payload and Capacity

Aviointeriors, an Italian manufacturing company, has explored displaying vertical seating back in 2019. This was a project of Skyriders 2.0, which aims for 23 inches of legroom. The amount of legroom in Skyriders 2.0 is significantly lower than the legroom seen in traditional commercial aircraft, which is greater than 28 inches. It also weighs 50% less than a traditional economy seat, allowing for more passengers to be seated with the same maximum gross weight. Specifically, according to Skyriders, this vertical seating system would allow for up to 20% more passengers [5]. It is important to note that this seating design is intended for short flights due to the loss of comfort and seat reclination compared to a traditional economy seat. Through rigorous testing, the seat design follows all current aviation safety standards to ensure passenger safety.

Secondly, auxiliary equipment can be removed for a short haul flight to maximize the payload. This type of equipment is supplemental and does not affect the condition of flight, but it does take up space on an aircraft. One primary example of auxiliary equipment that can be removed is a bathroom stall. The average person will go to the bathroom approximately every three to four hours. A short haul flight is defined as under three hours, meaning that stalls would not be required based upon this statistic. However, there is a high chance that at least one person out of the many passengers on a flight may have to use the restroom, so one bathroom stall can remain in flight. Figure 1 shows that a traditional Boeing 737-800 would have three stalls and one catering service area. In first class, these bathroom stalls measure 36 inches by 27 inches by 77 inches. In economy class, these stalls measure 39.75 inches by 24.5 inches by 77 inches [6]. This is large enough to fit approximately two to three more economy seats per bathroom stall. This would allow the passenger capacity to increase with the removal of two bathroom stalls. While food service is another piece of auxiliary equipment that can be removed, it is less practical to do such an action in the airplane because a light snack and drink for each passenger maintains customer satisfaction. Keeping food service equipment does not take away passenger comfort and is not as consequential as bathroom stalls. For a short haul flight, getting even just nine more passengers will greatly improve the carbon footprint in the long term by allowing the same amount of people to get to their destination in fewer total flights.

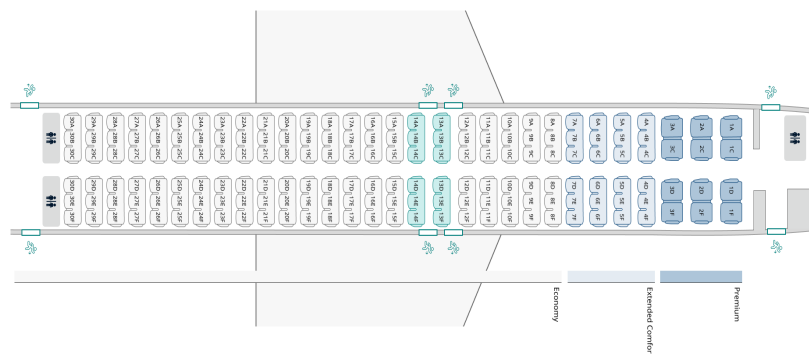


Figure 1: A Boeing 737-800 Seating Chart of WestJet Airlines (WestJet Media) [7]

Lastly, an aluminum lithium alloy can be implemented in wing design. Conventionally, aluminum metal is used in an alloy with copper and magnesium for wing design. Unfortunately, aluminum is susceptible to corrosion due to its reaction with oxygen when exposed to moisture. It can also develop fatigue cracks after repeated stress, but using this new alloy has many benefits. According to NASA's paper about aviation materials, "compared to these Al-Cu-Mg alloys, 1441 Al-Li alloy has similar strength but exhibits 7% lower density and 12% higher modulus, as well as other improved properties." [8] This alloy is stronger, tougher, stiffer, and more resistant to corrosion and fatigue than traditional aluminum used for planes. It would be advantageous to use the aluminium-lithium alloy for its lighter weight in order to ensure a higher payload for cargo and passengers.

### **Blended Wing Body Design**

A Blended Wing Body (BWB) is an airplane with a smooth transition from the fuselage to the wings. Instead of a tube shaped fuselage with wings attached, aircraft could instead have a wing that is integrated into the body which would function as an aerofoil. One significant advantage with a BWB plane is a more spacious cabin, due to the curvature from the nose to the fuselage. The BWB in the present is an experimental aircraft, developed and tested by manufacturers such as NASA, Boeing, and Airbus. A futuristic commercial design of this aircraft would have the potential to be 30% more aerodynamically efficient than today's commercial aircraft. This includes increased range, fuel, and offload capabilities [9]. It also provides increased payload capacity and reduced noise. Specifically, this design can result in 50% lower fuel consumption [10]. In addition, due to the wider fuselage, a BWB design would create a more flexible design that can increase the passenger capacity while also creating more passenger comfort with a larger aisle. This could potentially mean using a wide body seating arrangement to maximize occupancy while also staying in accordance with weight and balance limitations. Figure 2 illustrates the wider fuselage generated by a BWB aircraft. However, the current problem is that essentially zero percent of airliners are BWB designs. This is primarily because there are no full scale BWB commercial aircraft projects in operation yet.



Figure 2: Commercial Blended Wing Body Design Depiction

### **Alternate Fuel Sources**

The first clean fuel option is nuclear power. The idea of airplanes powered by nuclear fission first appeared in the 1950s. In 1956, the Aircraft Nuclear Propulsion program created the

General Electric J47 turbojet engine [11]. The problem at the time was safety concerns, as the cabin was exposed to extreme levels of radiation due to the fission reaction. In addition, others were concerned about the event of a crash and the release of the toxic radiation to the environment. In order to make a nuclear powered aircraft practical, there would have to be complete shielding so that the crew do not receive levels of radiation greater than from natural sources. Unfortunately, nuclear reactors require very heavy shielding, potentially taking up thousands of pounds. This is due to the release of gamma particles and neutrons in a nuclear reaction. Gamma rays are a form of electromagnetic radiation. Along with neutrons, they require dense materials like lead, concrete, or steel for effective shielding [12]. This significantly reduces the payload capacity, as a large amount of the maximum gross weight will be dedicated solely to the shielding of the nuclear reactor.

On the other hand, hydrogen is also a clean, alternate fuel to conventional jet fuel. To create thrust, hydrogen fuel cells are used to generate electricity that drive electric motors. Hydrogen can also be used through combustion in turbine engines. The drawback to hydrogen fuel is the low ambient density, meaning that more volume is required for storage of the hydrogen fuel than conventional jet fuel [13]. This is due to the ideal gas law, which relates pressure (P), volume (V), amount of a substance (n), gas constant (R), and temperature (T). Because hydrogen has a very low mass, it results in having a higher molar volume. In addition, as an aircraft goes higher, the surrounding pressure decreases. Because pressure and volume maintain an inverse correlation, as the pressure decreases, the volume of the hydrogen will increase [14]. To resolve the higher amount of volume needed, a hydrogen airplane can incorporate the designs of a BWB. A hydrogen, BWB combination implements the aerodynamic benefits of a wider fuselage with the environmental benefits of hydrogen propulsion. In addition, the wider fuselage will allow for more volume of space to store the hydrogen safely. According to Airbus, hydrogen fuel would be a major milestone as it would ensure zero emissions.

$$PV = nRT$$

| Variable         | Change at Higher Altitude | Effect on Other Variables (if others held constant) |
|------------------|---------------------------|-----------------------------------------------------|
| Pressure (P)     | ↓                         | V ↑                                                 |
| Temperature (T)  | ↓                         | P ↓ V ↓                                             |
| Volume (V)       | ↑                         | P ↓                                                 |
| N (moles of air) | ↓                         | P ↓                                                 |

Table 1: Inverse Correlation Between Pressure and Volume

## Proposed Model and Testing

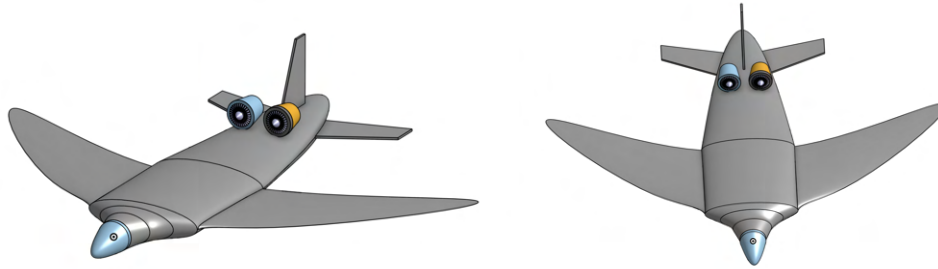


Figure 3: BWB Hydrogen Powered Airplane (Onshape Model)

This airplane was designed using onshape, a CAD software that allows for advanced modelling techniques [15]. The Onshape airplane was built primarily using the loft and extrude tools. In addition, the assembly of the engines was made possible by GrabCAD, a website that allows users to take existing CAD and incorporate it into a larger project [16]. The software for the engine was downloaded from Tarek Abdelaal's flow simulation of mechanical assembly.

### Dimensions

The proposed BWB design would have a wing span of 120 feet. This is similar in length to a Boeing 737-800, which has a wing span of 113 feet. From the nose to the aft most point of the empennage, the length of the plane measures 104.8 feet. The airplane's cabin is 7.75 feet wide at the nose of the plane and extends to a maximum of 27.9 feet at the fuselage. The cabin is 7.5 feet tall. At the rear end of the plane, the vertical stabilizer, which contains the rudder controls for directional stability, measures approximately 16.26 feet high. The horizontal stabilizers, which contain the elevator controls for pitch, spans 48.9 from each end.

### Fuselage

The fuselage is 30 feet long, and the wider fuselage will be used to store the hydrogen. In order to achieve such a result, the hydrogen must first be put in a very cold environment, specifically at  $-253^{\circ}\text{C}$ , where it will then transform into a liquid. It takes up significantly less space compared to gaseous form. According to Airbus, the energy of one liter of conventional jet fuel equals approximately four liters of liquid hydrogen gas [17]. A Boeing 737-800 typically burns about 3200 liters per hour, which would mean about 9600 liters in total for a three hour, short haul flight. To calculate the volume of the fuselage of the BWB plane, we can use the elliptical cylinder formula.

$V = \Pi abh$ , where  $a$  is the length of the semi major axis,  $b$  is the length of the semi minor axis, and  $h$  is the thickness of the 3D shape.

$$V = \Pi * 3.75 * 13.95 * 30$$

$$V = 4930.34 \text{ ft}^3$$

$$V \approx 139602 \text{ L}$$

This result indicates that there is enough volume to store the required fuel of 4(9600), which is 38,400 L. Not all of the fuselage will be dedicated to storing the fuel, as most of it will be fitting passengers in the cabin. Around just 30% of the fuselage will be for fuel, showing how storing hydrogen at a much lower temperature enables the increase in usable space for passengers and cargo, due to the ideal gas law.

### **Airfoil Shape**

The proposed BWB design uses a combination of a symmetrical biconvex and supercritical airfoil. The supercritical airfoil shape is the most prevalent in commercial aircraft and jet airliners. Combining both airfoils onto the wing allows for both advantages and disadvantages.

One advantage is a reduction in drag for high speed flight due to the low drag characteristics of a symmetrical airfoil. Supercritical airfoils compliment this because they excel in transonic flight and allow for higher cruising speeds.

However, one significant disadvantage is the complexity potentially involved in changing the airfoil geometry to optimize between the two shapes for the best performance. The aft nature of supercritical airfoils must be taken into account because its larger pitching moments may result in poorer stability and more abrupt stalls without warning.

### **Simulation Setup**

The physics performance of the proposed BWB hydrogen airplane was completed using airshaper, a website that is designed for both external and internal air flow testing [18]. This simulation tested the external airflow along the wider fuselage, the nose, and the wing. The simulation was performed using an STL file of the model downloaded from Onshape. Then, the analysis option was clicked, as that would analyze the external aerodynamics.

Air was the fluid used for this simulation, at a density of  $1.225 \text{ kg/m}^3$ . The airplane was set up to be in motion at 200 miles per hour in standard weather conditions.

### **Surface Analysis**

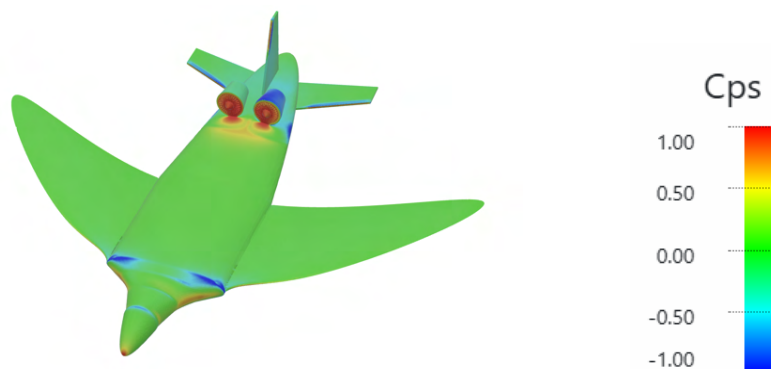


Figure 4: Airshaper Surface Pressure Test

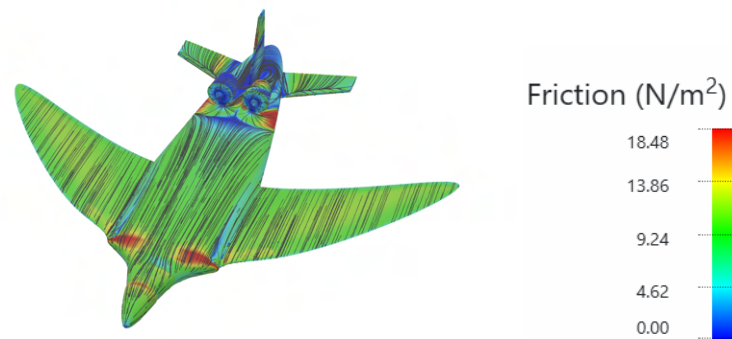


Figure 5: Airshaper Surface Friction Test

The surface pressure test indicates that the fuselage and wing top maintain ambient pressure, meaning that stable airflow is maintained in these areas with neither acceleration nor acceleration. The nose and leading edge maintains a low coefficient of pressure, which means that those regions have high speed airflow. This signifies efficient lift generation because these areas are most important for lift due to Bernoulli's Principle. The curvature of the leading edge and nose provides the efficient acceleration of the air with low pressure. The engine inlets unfortunately have pressure build up due to the disruption of the airflow, indicating that it could potentially be a factor of pressure drag.

The BWB design overall maintains moderate surface friction, which indicates healthy flow and good aerodynamic surfaces. One area that is significantly different is the engine area. The surface friction in this location is reduced, which means that the air is piling up without smoothly reattaching onto the surface. This is known as form drag, which is "caused by the separation of the boundary layer from a surface and the wake created by that separation" [19]. In order to make sure that the form drag is reduced, the engines will likely have to be moved to a more rear position, past the stabilizers, or they can go underneath each wing.

## **Streamlines**

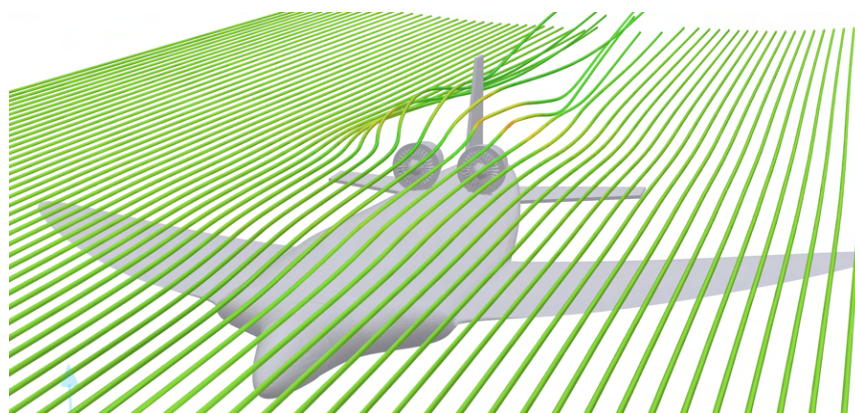


Figure 6: Horizontal Streamlines - Test of Airflow Over the Wings and Tail

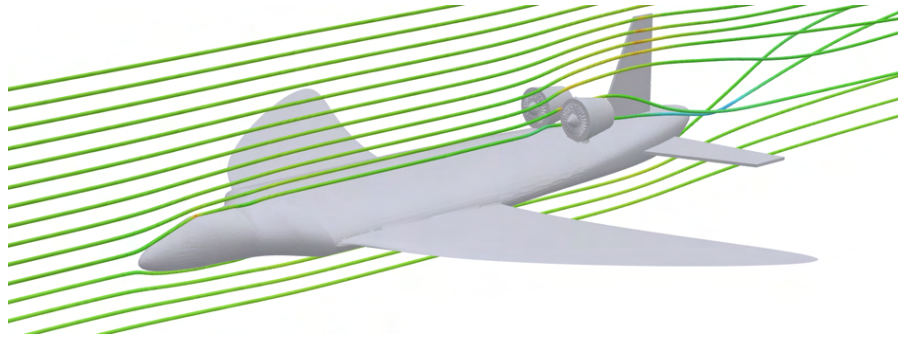


Figure 7: Vertical Streamlines - Test of Airflow Over the Fuselage

The vertical streamline test shows that the plane maintains great airflow over the wing and fuselage with straight, uninterrupted green streamlines on all three views. The streamlines pass smoothly over the nose, fuselage, and leading edge of the wings without any sign of separation. This shows that in these regions, there is an optimized aerodynamic form, which contributes to lift production and low form drag. This form drag can be even further reduced with a change in engine configuration. In the top view, the streamlines compress easily with an air flow acceleration over the wing, which indicates local air acceleration. This indicates an aerodynamic benefit that could contribute to a slight cruise speed gain and efficiency gain. However, there are areas of concern at the back of the plane. The streamlines bend and distort around the engines and vertical stabilizer. Some of the streamlines curl up and diverge, indicating the start of flow distortion and potential separation due to wake interference. Some of the aerodynamic penalties include high pressure drag, reduced engine inlet efficiency due to non-uniform flow, and high noise levels due to turbulent wake interaction.

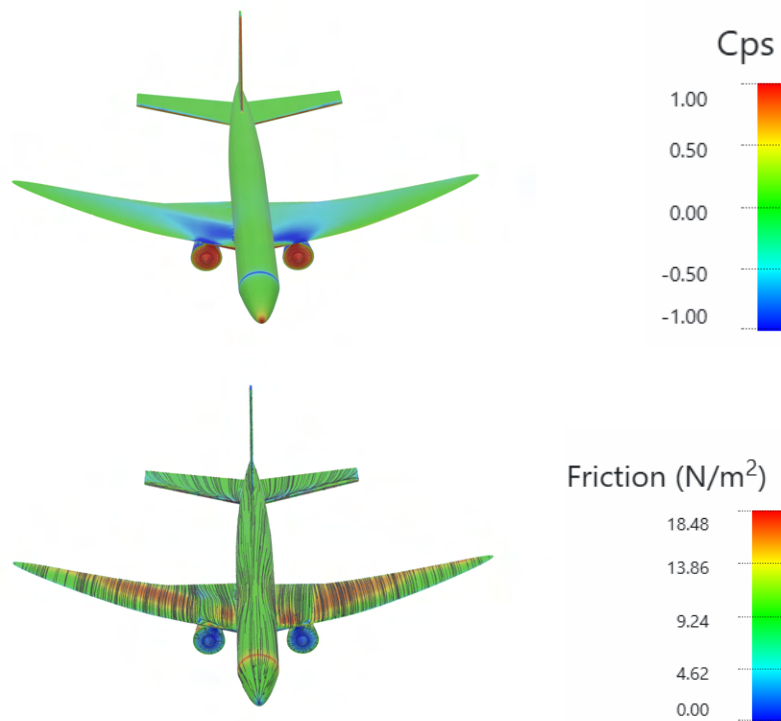
### **BWB Simulation Results**

The simulation suggests that the BWB design is very aerodynamically efficient. The wing design using a supercritical and symmetrical biconvex combination proved to be very effective. These findings highlight the importance of engine nacelle positioning in designing aft-mounted engine configurations. The only issue that would need to be resolved is the best place to put the engine. To reduce noise and pressure buildup, the engines can be moved to the bottom of the wings just like a standard commercial airplane.

### **Regular Commercial Airplane Test**

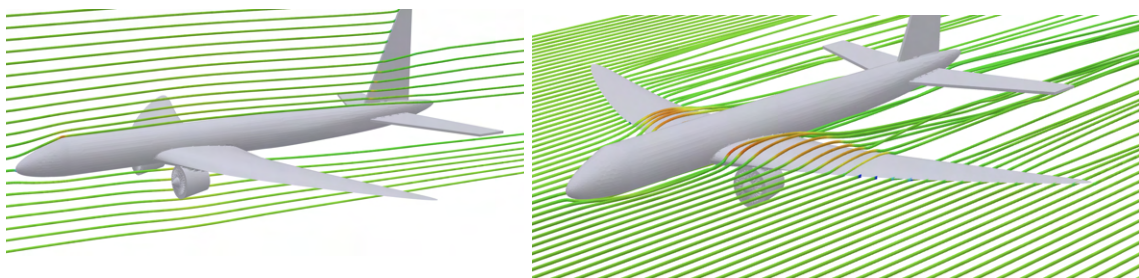
In order to check whether the BWB plane performs better than a standard plane, we will run an airshaper simulation on the standard plane as well.

The regular airplane has a length of 100 feet and a wingspan of 105 feet.



Figures 8 and 9: Surface Pressure/Friction Tests

The standard commercial plane has a similar result for the surface pressure test compared to the BWB plane. However, it has significantly more friction, especially along the wings' surface. One problem with this is that the BWB plane will not have increased aerodynamic heating, potentially causing the plane to exceed its structural limits at high speeds.



Figures 10 and 11: Horizontal and Vertical Streamlines

The streamlines indicate that the regular commercial aircraft performs better at airflow over the wing, with a high acceleration on the surface and little to no airflow disruption anywhere. This shows that the standard plane is better at high speed flight due to its supercritical airfoil shape. However, the increased drag from wing friction and high speed is a combination that leads to much more aerodynamic noise.

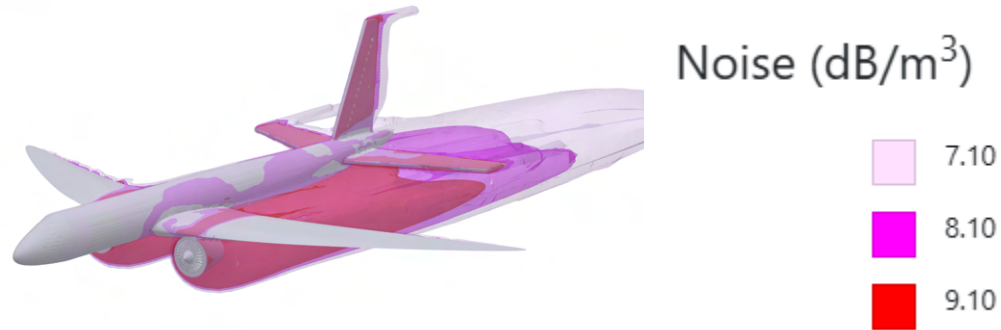


Figure 12: Noise Illustration (dB/m³)

The noise levels are around 8.15 dB/m³ on the aft portion of the plane. This is an issue that the BWB plane did not have, due to its reduction in surface friction and consistent speed across the entire aircraft.

### **Regular Plane Simulation Results**

The standard commercial plane is much better for high speed flight due to its usage of the supercritical airfoil. However, it does generate significantly more aerodynamic heat and drag compared to the BWB plane. This leads to an increase in noise levels because the friction generates sound waves, due to the disruption from airframe turbulence. Aerodynamically it performs better, but it is structurally worse than the BWB plane. For short haul flights, where higher speed is not as important, the BWB airplane has an advantage as it maintains better structural integrity.

## **Considerations and Next Steps**

Engineers must take a look at the cost-benefit outcome and see if some of these proposed ideas are a practical solution to implement. For example, hydrogen is very explosive, and it could be a risk to the cabin in the event of an emergency. Nuclear power requires very heavy shielding and therefore wouldn't be as good of a fuel option as hydrogen. Another example is that a BWB commercial plane would also change the seat layout due to the expanded fuselage, so researchers are welcome to explore its implications on the number of passengers and the arrangement so that it stays in accordance with weight and balance limitations.

Some of these features can be even improved on. The vertical seating is indeed a practical solution for short haul flights, but the weight of an individual seat is something that engineers in future can find lighter materials for. This is because while vertical seating does increase the maximum passenger capacity due to more cabin space available, the payload does not necessarily increase if the weight of the seats stay the same. If the weight of the seat is reduced further than the 50% in Skyrider, more passengers than just a 20% increase can safely be on the plane as more of the maximum gross weight becomes dedicated to occupants.

In the future, engineers can explore better ways to increase the payload. For example, researchers can find new, lighter alloys that would be used to create a fuselage that weighs less and is also much stronger structurally than lithium alloy. The technology for discovering such alloy combinations with different elements may not exist today, but possibly in the next decade could a new fuselage design be implemented by engineers.

This solution for short haul flights can also be modified to help with long haul flights. Some features can be kept, such as a BWB to keep the wider fuselage and wide body seating arrangement, and hydrogen fuel to minimize carbon emissions. However, some features can be removed, such as vertical seating to provide more comfort for a long journey, and keeping auxiliary equipment due to the extended travel time and necessity of bathroom breaks.

In conclusion, there are multiple ways that this solution can be taken to the next level. There are indeed some aspects that can be realistically achieved in the foreseeable future. In the next decade, this idea can become revolutionary and completely change air travel.

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