A COMPREHENSIVE REVIEW ON BLENDED WING BODY AIRCRAFT

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ABSTRACT

Latest development in aviation are focusing on designing an aircraft which is aerodynamically efficient, environment friendly emitting less carbon emissions, optimally stable efficient aircraft and are able to carry more payload at greater distances with reduced cost as well as for the integration of advanced gears. Taking all these points on notes the new aircraft design is facing huge challenge to compete in real challenging practical world. But Aerospace giants such as Boeing and Airbus are doing hard work on this BWB to induct in commercial flight sooner or later by 2035.This BWB aircraft shall incorporate advanced systems and concepts like laminar flow technology, jet flaps and distributed propulsion. The BWB aircraft also provides necessary implementation of alternative propulsion concepts such as distributed and hybrid propulsion systems which are to be tested and introduced into aviation industry. This review paper summarizes the worldwide research efforts in the design and development of a Blended Wing Body aircraft related to its ongoing challenges and way to minimize those problems with this comprehensive study.

Keywords: *Aircraft, BWB.*

1. Introduction

Demand for the fuel economy, low noise, low carbon emission, greater lift gave the researchers and the technical aerospace engineers to build a unique aircraft of its kind known as Blended Wing Body Aircraft which is a cross between a conventional plane and a flying wing design whose airframe merges efficient high-lift wings with a wide airfoil-shaped body, allowing the entire aircraft to generate lift and minimize drag thus helps to increase fuel economy and creates larger payload. Thus this unique aircraft which characteristics fascinated the great aerospace giants such as Boeing, Airbus, etc. marked its entry in the aviation world as a futuristic aircraft comprising necessary characteristics needed in aerospace industry. The BWB Aircraft's potential design is as a multi-role, long-range, high-capacity military as well civilian aircraft.

From the Past, the flying wing design has proven itself potentially the most efficient aircraft from the point of view of aerodynamics, structural weight and better configuration. Since flying-wing shape incorporates thick airfoil-shaped fuselage section to potentially maximize overall efficiency by integrating all the parts of the aircraft into a single lifting surface. As we know the conventional aircraft 'tube with wing' configuration, in this configuration only the wing that is generating lift for the whole aircraft. In the BWB design, as the fuselage is incorporated into the flying wing, the fuselage in BWB therefore does generate lift for the aircraft. According to recent studies it is estimated that in just ten years, a plane that flies using a radical hybrid wing shaped body could become a reality. A scale version of the 'Blended Wing Body' (BWB) aircraft is currently being tested at a NASA facility. NASA says commercial designs will be available by 2035.

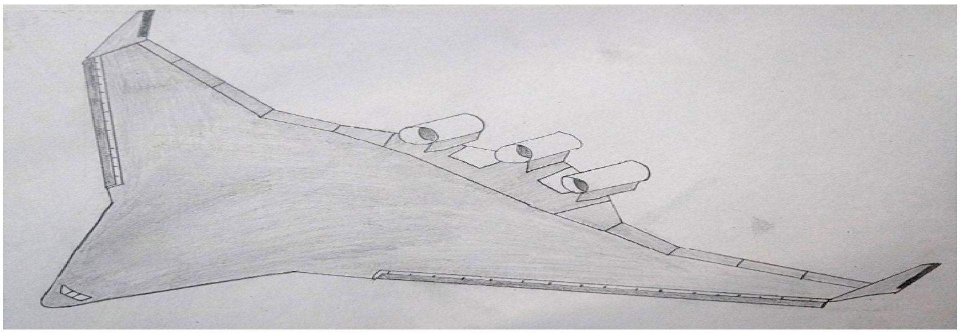

Fig. 1(a): Boeing X-48B(*X-48B*, n.d.)

Specialties of the new Blended Wing Body:

- 27% less fuel
- 15% weight reduction
- 20% higher lift to drag ratio
- 27% less thrust required

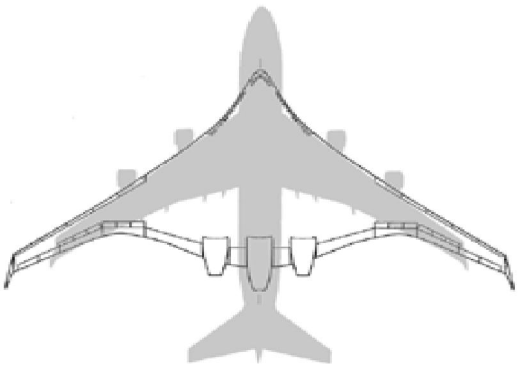

Fig.1(b):Blended wing body structure vs conventional structure (*The Blended Wing Body Concept*, n.d.)

As the primary benefit of the blended wing body design comes from the large aerodynamic gain, there are structural advantages due to the integration of the wing structure with the thick central body. The main drawback to the blended wing body concept is that it lacks control surfaces and conventional stabilizing surfaces such as a tail making it unstable and difficult to control. Most importantly the international aviation operation contributes 2-3% to the global warming phenomena (Lee, Fahey et al. 2009). If aviation remains on its current path with no significant operational changes, its contribution to global warming is predicted to increase to 10-15% by 2050 due to the forecasted demand (Maurice and Lee 2009) hence the BWB aircraft can significantly help the aviation industry to fight with the global warming with its unique features combined to single mainframe body.

The advantage of a BWB design is the lower wetted area to volume ratio, and a lower interference drag when compared to a conventional aircraft. As a result the L/D ratio is approximated to increase by 20% relative to conventional aircraft (Liebeck, 2004). According to the researchers the BWB aircraft was estimated to have an advantageous operational efficiency over current airliners of similar capacity.

Ref.	Name of Aircraft	Nation of origin and date	Class	Technical Characteristics	Remarks
1	Lockheed Martin RQ-3 Darkstar	USA, 1996	UAV	Stealthy and highly advanced reconnaissance UAV using satellite digital link it was intended to be fully autonomous as well as provide information across the Earth	Department of Defence ended the program due to cost and instability
2	Boeing X-45C	USA, 2004	UAV	Could carry precision guided munition with larger payload at longer range	Under Development
3	Northrop Grumann X-47 Pegasus	USA, 2003	UAV	Autonomous aerial vehicle whose stealth feature was intended to perform sea missions which may be surveillance as well as strike	Under Development
4	Boeing X-48	USA, 2007	UAV	Intended for the low-noise Blended wing body aircraft, longer range and environment friendly	Under Development
5	Lockheed Martin RQ-170 Sentinel	USA, 2007	UAV	Highly stealth, Low-observable, tailless configuration with advanced electronics and sensors for deep mission, reconnaissance, intelligence for long endurance and high altitude	Operational
6	AVIC 601-S	China, 2008	UAV	Stealthy deign hypersonic UAV consisting of low observable feature	Under Development
7	NASA BWB-450	USA	UAV	Quiet Green Aircraft for fuel efficient	Under Development

8	NASA N-3X	USA	Subsonic Transport Aircraft	Hybrid propulsion system aerodynamically and structurally efficient with reduced fuel consumption operating at longer range	Under Development
9	UK based APH	UK	Airliner	Hybrid electric plane to go greener and environmental responsible with reduced noise levels.	Under Development
10	Cambridge MIT silent Aircraft	UK and USA, 2004	Airliner	Ultra-low noise, fuel efficient incorporating ultra-high bypass ratio turbofans	Under Development
11	The PAK-TA (The Prospective Aviation Complex Transport Aviation)	Russia	Military Transport Aircraft	New generation Strategic transport aircraft incorporating hybrid engines contributing to low noise, fuel efficient with greater payload at longer ranges	Under Development
12	Tu-404	Russia in 1991	Airliner	New airliner aircraft designed to carry 1,200 passenger to 12,000 to 13,000 km, more cargo with six engines	Under Development

The known benefits of the BWB concept created several organizations into researches on various aspects of the aircraft. Notable among the researches is the European Union (EU) 5 - tiered project to develop innovative, efficient, long - range, large - capacity, passenger transport and cargo aircraft (*MKozek and A Schirrer, Editors. Modelling and Control. - Google Scholar*, n.d.). The project comprised 3 wholly funded EU framework Programs and a program jointly funded by the EU and the United States(Okonkwo, 2016).

The 3 EU Framework Programs are the 5th, 6th and 7th EU Framework Programs respectively. The 5th EU Framework Program consists of the Multidisciplinary Optimization of a Blended Wing Body (MOB) and the Very Efficient Large Aircraft (VELA) projects. The VELA project was set up to develop the necessary skills set, capabilities and methodologies appropriate to the design and optimization of Very Efficient Large Aircraft concepts (Okonkwo, 2016).

The VELA project, which ran from 2002 - 2005, investigated 2 extremes of a BWB configuration, in terms of the placement and blending of the outboard wing. This gave rise to the 2 baseline concepts VELA 1 and VELA 2 shown in Figures 2 and 3 respectively.

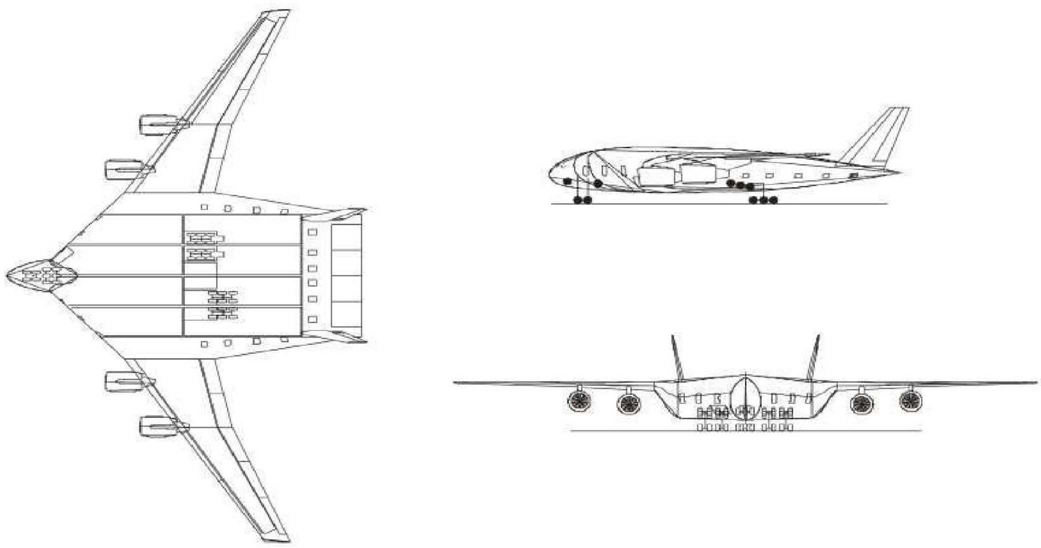

Fig.2: VELA 1 Baseline Concept (Source: DLR, Martin Hepperle 2005)

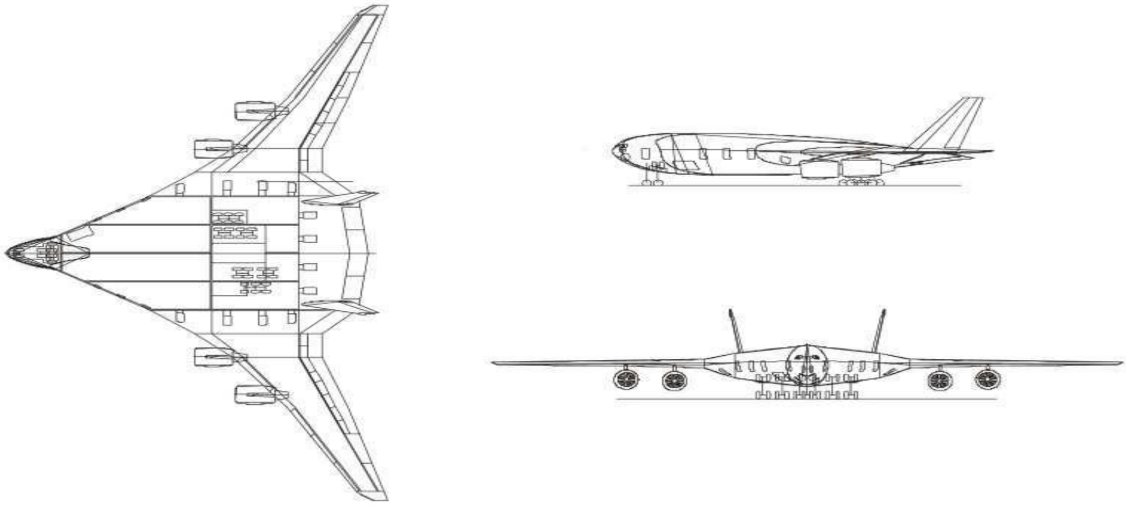

Fig.3: VELA 2 Baseline Concept (Source: DLR, Martin Hepperle 2005)

Similarly Russian researchers also started development and design on Blended Wing Body Aircraft. The project was known as The TsAGI Project. The TsAGI project was undertaken by Russia, in conjunction with Airbus and Boeing, to compare 4 new large aircraft configurations based on the VELA configuration. The study identified 3 candidate concepts for analysis. These are the Integrated Wing Body (IWB), lifting body configuration and a pure flying wing. With a 750 passenger capacity, a range of 13700 km and a cruise M0.85, these concepts were compared with a similarly designed conventional configuration in terms of the aerodynamics, weight and fuel efficiency. The results found the IWB as the most optimal configuration with a L/D ratio of 25 at a Mach 0.85(Y.-Y. A. Ko, 2003a).

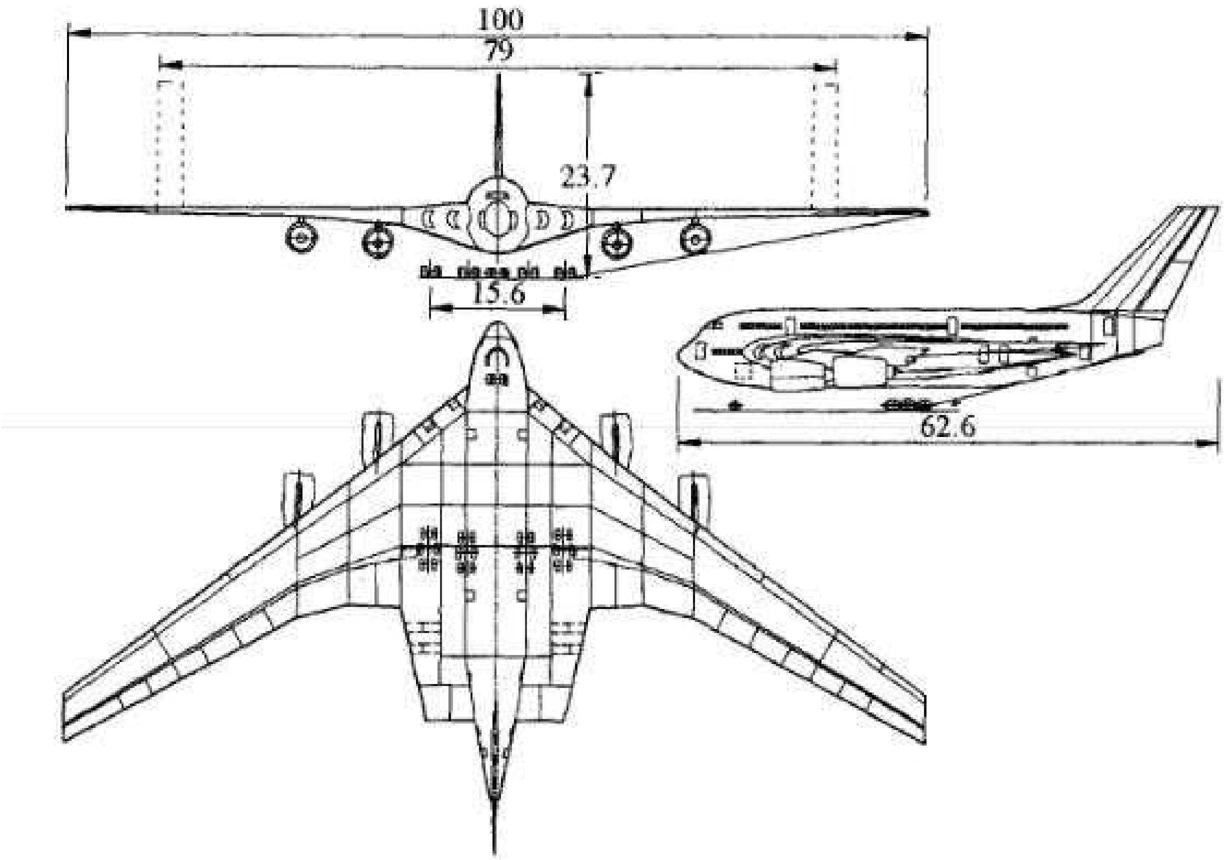

Fig.4: - View Diagram of the Russian TsAGI Integrated Wing Body Aircraft

Challenges on the Blended Wing Body Design

As we all know that the BWB aircraft is in its testing phase it requires a lot of time and hard work for researchers and the technician as well as aeronautical engineer to finally mark as a safe and sound aircraft. There are several aspects and fundamental things required for its entry in commercial airliners for prescribed roles either passenger or as a cargo aircraft because as we know the BWB aircraft having its unique configurational benefits is well adapted for the role of environmental friendly, long-range, high capacity airliner. Cabin pressurization will pose a problem in the flying wing's much larger cabin. It will require the development of a new pressurization system. Control and stability and aircraft handling qualities amongst others need to be known as well as addressed. So here are the few of these potential challenges to this unique aircraft designing as well as production. The BWB aircraft also possess challenges for emergency and evacuation procedures have not been extensively studied. The large cabin and small exterior surface area could also cause an issue in emergency evacuation situations. Most passengers won't have a window, so the aircraft may have to introduce more entertainment on board or implement a system which allows passengers time to see out of the aircraft.

i. Aerodynamics

The Blended Wing Body aircraft is designed to have low wetted surface area to volume ratio and reduced interference drag (Okonkwo, 2016; Wan & Yang, 2010). This lowers total drag and provides higher L/D ratio compared to conventional configuration (Staelens et al., 2007; Wan & Yang, 2010). However, the BWB fuselage has a low aspect ratio. The Blended Wing Body generates a near perfect elliptic span-wise lift distribution by combining reflexed center-body airfoil for pitch-trim stability with outboard supercritical airfoils in wash-out arrangement (Liebeck, 2004). This results in a rapid increase in induced drag with lift coefficient thus generating a very low optimum lift coefficient (*MKozek and A Schirrer, Editors. Modelling and Control... - Google Scholar*, n.d.).

ii. Propulsion Airframe Integration

As proposed design the engine or the power plant of the BWB aircraft is to be installed aft of the aircraft center body over the wing which helps to offset the weight of payload and several other systems achieving a balanced aircraft (Diedrich et al., 2006; Y.-Y. A. Ko, 2003b). We have much more advantages of installing the engines over the wings, the aircraft will possess no any disturbance in ground clearance limits, have the advantage of Coanda effect to increase lift and improve shot take-off and landing performances well as it also helps in reducing the risk of damage by foreign objects which are less prone to sucking the debris. However, having the engine over the wing distorts lift distribution creating poor cruise aerodynamics(Hill & Thomas, 2004; Okonkwo, 2016). But the distortion could be minimized through Embedded Propulsion System which enables better integration of the propulsion system with the airframe minimizing ram drag and decreasing the wettedarea. This improves cruise performance and lowers structural weight compared with apodded system(Kok et al., 2010). Embedded systems have various advantages, such as drag reduction and reduced overall system complexity however there are operation, safety and design challenges with the design. But Top mounted and embedded engine systems pose maintenance complications due to their location on the aircraft(*Numerical Methods for Engine-Airframe Integration|INIS*, n.d.).

The distributed propulsion concept is also assumed to increase levels of engine failure redundancy. Some studies have shown configurations using more than 6 engines on the top surface of the BWB structure. The failure of an engine may reduce the thrusting capability and safe operation of the BWB however the loss is less compared to the 2 or 4 engine designs (A. Ko et al., 2003).

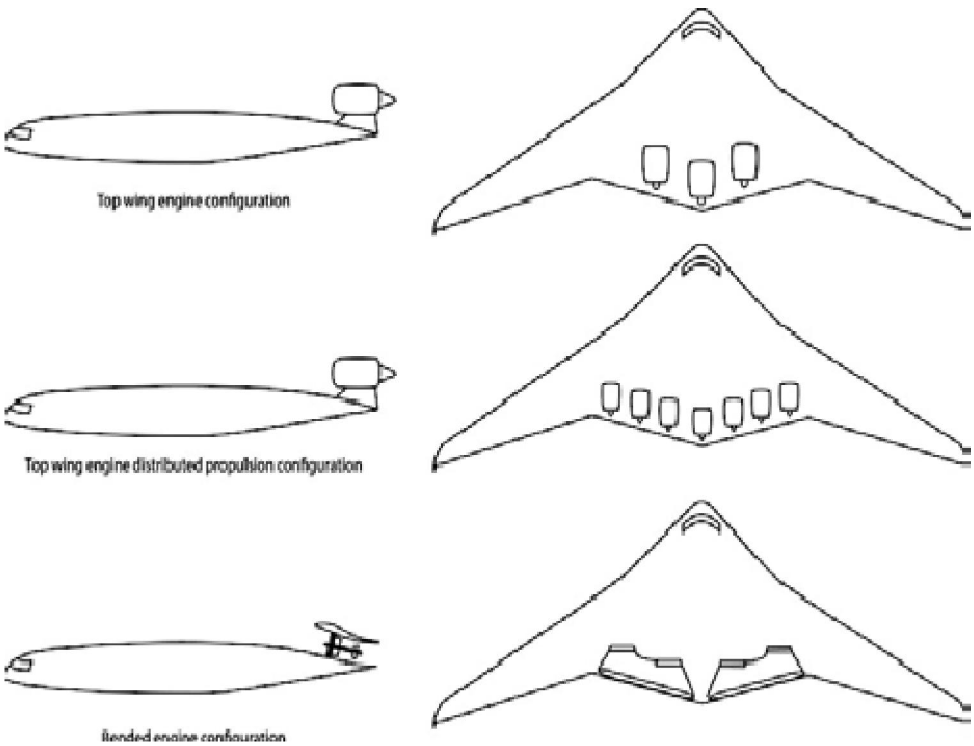

Fig.5: Possible engines installation on BWB Aircraft

iii. Aero-structures

The BWB provides efficient payload distribution and permits over the wing engine placement. Additionally, the BWB center - body generates lift due to its low aspect ratio thereby reducing the wing load. These features minimize wing bending moment and shear force, thus creating favorable inertia relief and hence reduced structural weight (Ikeda, 2006; Murthy & Paynter, 1986; Okonkwo, 2016). The box - shape nature of the BWB center - body presents a structural design challenge. Because passengers are accommodated within the center-body, the cabin is subjected to both pressure and span - wise bending loads(Cho et al., 2008; Okonkwo, 2016). The combined pressure and bending loads create very high non - linear stresses. The non-linear stress arises because the BWB resists pressure loads by bending stresses unlike the uniform stretching or hoop stress that occurs in the cylindrical pressure vessels used in conventional aircraft. Under extreme maneuvers or gusts, these non – linear stresses produce severe deformations and increased stress levels that are difficult to predict(Cho et al., 2008; Okonkwo, 2016). Several structural concepts have been proposed to handle the high, non - linear stresses on BWB cabins. Among these concepts are the separate pressure shell (Also known as the double - skin vaulted shell) and the integrated skin and shell concepts (sometimes referred to as the thick flat sandwich shell) (Liebeck, 2004; Martínez-Val et al., 2007; Okonkwo, 2016).The separate pressure shell concept consists of a thin arched pressure vessel above and below each cabin creating an inner and outer skins together with Inter-cabin walls(Liebeck, 2004). The inner skin carries the pressure load in tension, the cabin walls support the weight of the structure above the cabin bay while the outer panel takes the bending loads and shear force due to aerodynamic loads acting on the aircraft (Liebeck, 2004; Okonkwo, 2016).The use of separate pressure vessel permits seamless integration of laminar flow control. Additionally, separate pressure shell prevents fatigue crack propagation and increases bulking rigidity. Over the wing distributed propulsion system increases the threat of rotor burst due to proximity of engines to one another.

Uncontained engine blade burst could thus have severe impact on adjacent engines (Hill & Thomas, 2004; Okonkwo, 2016). Similarly, frequent pressurization and de - pressurization could lead to structural fatigue. In view of this, Liebeck recommends the use of composites for the center-body structure due to its immunity to fatigue and weight advantage (Liebeck, 2004).

iv. Flight Control and Stability

The BWB is subject to high yaw rates and auto - rotation tumble. This calls for an effective means of providing sufficient yaw control and stability without a vertical tail. Wilds check et al demonstrated that simple winglet flaps are insufficient for yaw control especially in the one engine in - operative case because of their limited height and total winglet area. Thus, they recommend the use of crocodile flaps as effective yaw stabilization device. This view is shared by Lie beck who proposes the use of winglet rudders as primary directional stability and control surface while split outboard elevons are deployed in the low-speed engine - out condition. The BWB has low pitch and yaw control authority due to its short moment arm. Hence, multiple, rapidly moving control surfaces are required to provide sufficient control force for longitudinal and lateral control Furthermore, excessive power is required to actuate large multi-functional control surfaces with high hinge moments. This feature of the BWB increases the challenge of improving lateral and longitudinal stability.

Similarly other challenges such as marketing and manufacturing potential, handling quality, regarding maintenance are prior to figure out by the working researchers and the technical aerospace engineer to eliminate the problem and make this aircraft a real flying machine with all its potential advantages regarding the safety of the passenger and the crew as well.

Conclusions

As discussed earlier the new and efficient BWB aircraft configuration possess a new design that more environmentally sustainable due to the significant performance advantages over current airliners. The world is already fighting the climate change and the global warming as well as increasing price on fossil fuel used on airline industry is usually higher hence a unique aircraft must be taken in account which not only consume less fuel than earlier aircraft but also cut down the carbon emissions must be addressed for a sustainable aviation future. Hence introduction and implementation after several research must be carried out on its performance and must be brought down operational. According to researchers it is one monumental challenge due to the cost and certification process involved in introducing a new aircraft configuration. The BWB aircraft is known to be a promising technology that allows reduced fuel burn, less carbon emissions, less noise and increasing airport capacity. Hence induction of such an aircraft not only lower operating costs, production costs and reduced airport/airspace congestion but also keens to provide lower fares, reduced environmental impact and improved safety.

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