CONCEPTUAL AERODYNAMIC STUDIES OF A SMALL TAILLESS UNMANNED AIR VEHICLE

by

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LIST OF SYMBOLS

Roman Symbols

a	General coefficent	-
AR	Aspect ratio	-
C_{Do}	Drag Coefficient at zero lift	-
C_{fe}	Skin friction coefficient	-
C_{Lmax}	Maximum lift coefficient	-
$C_{Lmax,root}$	Maximum lift coefficient at root	-
$C_{Lmax,tip}$	Maximum lift coefficient at tip	-
C_{Mo}	Moment Coefficient	-
G	Climb gradient	-
K	Coefficient for the drag polar	-
q	Dynamic pressure	-
q_{SSL}	Dynamic pressure at standard sea level	-
Re	Reynolds number	-
W	Weight	kg
W_{crew}	Crew weight	kg
W_{empty}	Empty weight	kg
W_{fuel}	Fuel weight	kg
W_{PL}	Payload weight	kg
W_{TO}	Take off weight	kg
T	Thrust	kN
c	chord	m
C_{MAC}	The position of mean aerodynamic center (vertical)	m
C_r	Chord at root	m

C_t	Chord at tip	m
E	Endurance	m
l	Reference length	m
L_{ref}	Reference Length of the aircraft	m
x_{ac}	The location of aerodynamic centre	m
x_{cg}	The location of center of gravity	m
Y_{MAC}	The position of mean aerodynamic center (horizontal)	m
u	velocity	m/s
V	Speed	m/s
V_{cruise}	Cruise Velocity	m/s
v_{end}	The end speed	m/s
V_{max}	Maximum Velocity	m/s
V_{stall}	Stall velocity	m/s
v_{thrust}	The velocity added by the engine thrust	m/s
v_{wod}	The wind over the deck	m/s
S	Reference Area	m^2
S_{ref}	Reference area	m^2
S_{wet}	Wetted area	m^2

Greek Symbols

α	Angle of attacks
e	Oswald's efficiency factor
π	Pi
η	Propeller efficiency
ρ	Air density

g	gravity
λ	Taper ratio
Λ	Sweep angle
n_p	Propeller efficiency
∂	Partial differential
∂V	Boundary of control volume
k	Turbulent kinetic energy
ε	Dissipation rate of k
ρ	Fluid density
ω	Specific rate of dissipation of k
Γ	Diffusion Coefficient
S_ϕ	Source term
ϕ	General scalar

Abbreviations

BWB	Blended Wing Body
UAV	Unmanned Air Vehicles
CFD	Computational Fluid Dynamics
L/D	Lift to Drag ratio
NACA	(U.S) National Advisory Committee for Aeronautics
RANS	Reynolds-Average Navier Stokes
EUROUVS	European Association of Unmanned Vehicles Systems
SACCON	Stability And Control Configuration
T/W	Thrust to weight ratio

W/S	Wing loading
P/W	Power loading
R/C	Rate of Climb
SSL	Standard sea level
SM	Static margin
MAC	Mean Aerodynamic centre
SA	Spallart All Maras
2D	Two Dimensional
3D	Three Dimensional

KAJIAN AERODINAMIK BAGI KONSEP REKA BENTUK PESAWAT KECIL TANPA PEMANDU TANPA EKOR

ABSTRAK

Secara prinsip, model pesawat tanpa ekor boleh dilengkapi dengan mana-mana aerofoil selagi reka bentuk tersebut direka dengan kombinasi parameter yang betul seperti nisbah bidang, sudut sapu, piuhan sayap dan lain-lain. Tesis ini membentangkan kajian berparameter konsep reka bentuk pesawat tanpa ekor bagi pesawat ringan tanpa pemandu (UAV) berkelajuan subsonik dengan mengambil kira beberapa parameter rekabentuk di dalam sistem permodelannya. Penggunaan tiga jenis aerofoil iaitu aerofoil terkamber (konvensional), aerofoil refleks dan aerofoil simetrik dalam rekabentuk pesawat tanpa ekor telah dikaji. Kajian rekabentuk ini dibahagikan kepada tiga kes iaitu kes 1 (aerofoil konvensional), kes 2 (aerofoil simetrik) dan kes 3 (aerofoil refleks). Semua kes direka bentuk untuk memenuhi keperluan spesifikasi misi yang sama. Analisis ciri-ciri aerodinamik bagi ketiga-tiga tiga kes dijalankan pada kelajuan 18m/s menggunakan aplikasi simulasi Pengiraan Dinamik Bendalir (CFD) dengan model gelora Spalart-Allmaras. Penjanaan grid adalah berstruktur penuh. Grid yang digunakan telah diuji untuk ketidakbergantungan dan data yang diperolehi dari penyelesaian berangka diuji kesahihannya dan dibandingkan dengan kajian jurnal. Gambarajah pekali angkat, pekali seret, pekali momen dan nisbah daya angkat dan daya seret diplot dan dibandingkan serta dianalisa pada nombor Reynolds yang berbeza. Secara umumnya, keputusan tiga kes ini adalah konsisten dengan konfigurasi pesawat tanpa ekor yang lain yang mana ia menunjukkan persamaan-persamaan dalam ciri-ciri aerodinamiknya. Walaupun menyedari bahawa aerofoil konvensional mempunyai momen anggul negatif, tetapi dengan pemilihan jumlah momen anggul yang rendah dan dengan pemilihan parameter yang sesuai seperti jidar statik, sudut sapu, nisbah bidang, piuhan sayap dan lain-lain, ia akan membolehkan rekebentuk pesawat tanpa ekor ini mampu memiliki nilai C_{mo} yang mencukupi . Maka, dengan itu, satu kajian berkaitan sudut sapu dan bentuk badan pesawat turut dianalisa bagi kes 1. Keputusan menunjukkan satu kemajuan yang ketara bagi kes 1. Kontur tekanan dan magnitud turut dikaji. Pesawat tanpa ekor ini boleh mencapai kecekapan aerodinamik yang lebih tinggi jika sesetengah pengoptimuman dari pelbagai disiplin dijalankan.

CONCEPTUAL AERODYNAMIC STUDIES OF A SMALL TAILLESS UNMANNED AIR VEHICLE

ABSTRACT

In principle, the tailless model configuration can be equipped with any airfoil as long as the design is compensated with an appropriate combination of some parameter such as aspect ratio, sweep angle and twist. This thesis presents a parametric study of subsonic Tailless UAV conceptual design with some parameter trade off. The usages of three types of airfoils of which are the conventional airfoil, reflex airfoil and symmetrical airfoil in tailless configuration have been studied. The design is divided into three cases which are case 1 (conventional airfoil), case 2 (symmetrical airfoil) and case 3 (reflexed airfoil). All cases are designed to meet the same mission requirement. Analyses of aerodynamic characteristics of three cases have been carried out primarily at cruising speed ($18 m.s^{-1}$) using Computational Fluid Dynamic (CFD) simulation with Spalart-Allmaras turbulence model. The fully structured mesh is employed and grid dependency check had been carried out. The results numerically iterated had been verified and compared to the published data. The lift coefficient, drag coefficient, moment coefficient and lift to drag ratio are plotted, compared and analyzed at different Reynolds number. Generally, by comparison the results of these three cases are consistent with other tailless configurations where it shows similarities in their aerodynamic trends. Though it is realized that conventional airfoil have negative pitching moment, but a moderate amount of pitching moment with proper selections of parameters such as static margin, sweep angle, aspect ratio, and twist will enable the design to obtained a sufficient C_{mo}. Thus, the sweep angle and the body shape at the center body for case 1 are varied. The results showed a significant improvement in aerodynamic characteristic. The pressure contours and velocity magnitude over tailless configuration were also observed. It may achieve higher aerodynamic efficiency if some multidisciplinary optimization is carried out.

Chapter 1

INTRODUCTION

1.1 Overview

The conventional aircraft is the most pervasive aircraft design in history. It existed since the Wright Flyer was invented in 1903. In this configuration, the fuselage and wing serve different role. The fuselage carries the payload while wing generates lift. However, it is a fact that for conventional aircraft the fuselage and the empennage caused a significant amount of drag. As the wing is optimized to produce the best efficiency as possible, and less drag, when connecting to fuselage afterwards it will create the interference drag which is quite high. Due to this, the designers think of integrating all parts and optimized them for a common purpose. This led the designers to design an aircraft consist with only of a wing which called tailless aircraft or flying wing.

The idea of combining of several aircraft functions in just a wing is not new and it has been resurgence in past years. There have been several attempts throughout all the time to integrate the functions in just one surface by omitting tail component. Either for commercial aircraft or unmanned aircraft, the research and interest toward the tailless design keeps in increasing as the configuration offer many advantages [2][16].

The tailless configuration had shown promises in its aerodynamic efficiency. This configuration had single lifting surfaces which mean it is an aerodynamically clean configuration. It offers many advantages such as performance improvement, fuel efficiency, reduction in noise and stealth characteristics [2] [5] [16]. In addition, it also produced less drag. Due to this benefit, another valuable characteristic is its long endurance mission capability which is important in reconnaissance.

Recently, development of UAV had increasing in varieties of designs and tailless is the emerging class of vehicles in the family of UAV. The designs principles for tailless UAV are generally similar to the principles developed over the years with some exceptions and some design considerations. Raymer [47], Anderson [46], Torrenbeck [48] and Roskam [50] provided standard guidelines for the aircraft design. The designs of this tailless UAV face new challenges as a result of new requirement, requires several recent works.

1.2 Problem Statement

The interest toward tailless aircraft began since 1903 until nowadays. Started via assumptions and trials on its design, now tailless had been investigated using high technology in proving the capability of its performance compared to conventional one. The proof is nowadays the tailless design had drawn major attentions of researcher from various university and industries due to its advantages. To date, Boeing Company showed their interest toward this design. They have recently exploring, investigating and developing on blended wing body (BWB) concept. Most of the literatures on this subject suggested that the tailless configuration had great potential to be the next generation of aircraft especially UAV. There are however many issues to be addressed before the tailless configuration to become reality.

This configuration can be defined as a new class of aircraft, and thus, the statistical data of some important design parameters are not available for the design evolution. Though there were still numbers of tailless design exist, there were non-available data that can be obtained and most were very limited. The main problem toward the data collection was due to the data accessibility where some of the project was confidential and thus the data cannot be easily access. Due to this shortcoming, first, the research will explore the tailless configuration via conceptual design. Second, it is also questioned, what are the design parameters that must be take into account in order to utilize this configuration. Then only further aerodynamic analyses could be done. It is a need to develop an analytical baseline of Tailless UAV which would permit the future evaluation and analysis of tailless configuration using wind tunnel, in where the configuration changed and trade studies can be further compared.

1.3 Aims and objectives

The objectives of this research are as follow:

- To provide a conceptual design of tailless configuration for a new requirement by performing a parametrical studies of tailless conceptual design.
- To perform aerodynamic analysis of tailless configuration by using CFD simulation.
- To identify the influence of some importance parameters which are airfoil type, sweep angle and the shape of center body.

1.4 Scope of Work

The research scope of this thesis involves:

- The review on tailless design.
- Conceptually design an airframe of Mini Tailless UAV that is compatible with the existing UAVs in Malaysia market.
- Simulating the Tailless UAV using CFD in turbulent flow conditions with different type of airfoil at various angles of attack, variable airspeed to obtain the aerodynamic characteristics and investigating the geometry parameters influences on the aerodynamic characteristics.

1.5 Thesis Organization

There will be five chapters presented for this thesis. The organizations of the thesis are as follows:

- <u>Chapter 1: Introduction</u>

  This section presents a brief introduction on Tailless UAV design, problem statement and the objectives of the project.

- <u>Chapter 2: Literature review</u>

  This section presents the literature review regarding the tailless configuration

  This will provide the information about tailless configuration which comprises such history of tailless aircraft, the advantages of tailless aircraft and the related studies regarding tailless design.

- Chapter 3: Methodology

  This section describes methodologies used for the completion of this project. The methodologies cover the parametrical studies of Tailless UAV design for a new design, the computational phase to obtain the aerodynamic characteristics at different flight condition and performance parameters.

  Chapter 4: Results and discussions

  This section presents the results from the parametrical studies, CFD simulations which also includes the validation of CFD simulations setting.

- Chapter 5: Conclusions and recommendations

  This section presents the conclusion of this work and also recommendations necessary for future works.

Chapter 2

LITERATURE REVIEW

In this chapter, a review of the work related to tailless configuration is presented. This begins with a brief review of evolution of tailless aircraft in flight history. A review of advantages and disadvantages of tailless configuration is also being addressed. The feasible studies pertaining tailless configuration also has been reviewed. The studies pertaining to aircraft conceptual design and the use of Computational Fluid Dynamics in aircraft design are presented.

2.1 Definition of tailless

It is important to define what is meant by tailless aircraft before going further with the main subject of this research. According to Lippisch [1], an aircraft can be classified by its planform shape. This is shown in Figure 2.1.

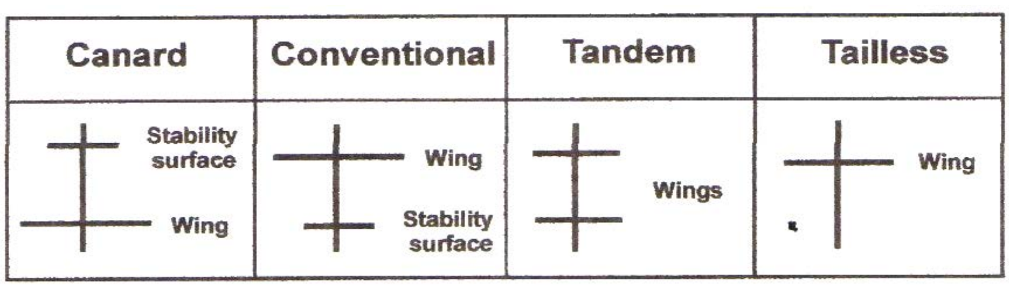


Fig.2.1: Lippisch's aircraft classification [1].

Lippisch defined tailless aircraft as an aircraft without tail although no particular reference exists to define the addition of a vertical tail or fin.

Nickel defined tailless aircraft as an aircraft with a single wing [2]. Adding to this, the terms of tailless aircraft, flying wing aircraft, blended wing bodies and all wing aircraft have all the same meaning. However, the term flying wing is only used when there is no fuselage and no vertical and horizontal tail. In other words, it only consists of just a wing and nothing else. There are three possible configurations of tailless aircraft as described by Nickel. Each configuration is classified according to their wing planform. These include swept back wing, straight wing, forward swept wing and delta wing [2].

Some authors use tailless as a generic term for any aircraft without a horizontal tail surface [3]. The presence of a vertical fin for tailless aircraft is not always well defined. In general, the tailless definition still allows for one or more vertical surfaces, somewhere attached to the fuselage or wing. Throughout this thesis, the term tailless aircraft will be used to describe those aircraft that are designed with only one main lifting surface that is responsible to produce lift as well as contains all the control surfaces that provides static and dynamic stability.

2.2 The History and Evolution of Tailless Aircraft.

Large varieties of tailless aircraft had been built in the past. They had been used in some applications such as supersonic airliners, re-entry vehicles, bombardier, light airplanes, unmanned aerial vehicles (UAV), sailplanes and glider [107]. Wood and Bauer [5] also documented the previous history on the flying wing.

Agenbag [107], in his thesis about tailless swept gull wing configuration, provided a study on tailless history. The information was appreciable in Table 2.1 below.

Table 2.1: The evolution of tailless aircraft

1930 Reimar Horten	• The aircraft had a triangular planform with high taper ratio. Several improvement and modification were made in the series of Horten flying wing by taking into account of some design parameters such as aspect ratio, taper ratio, various CG position and the location of control surface and the combination of the function of elevators and aileron. • High taper ratio will lead to undesirable design characteristics since this can lead to tip stalling and also seems to produce an unavoidable loss in performance (unfavorable spin characteristic, flutter problem).
(After WorldWarII) Northrop	• Developed tailless aircraft before and after World War II. Examples: XB-35, YB-49 (see Figure 2.3). With high lift and low drag characteristics, the design can transport more cargo, faster and farther than the conventional aircraft. Northrop mentioned that structurally, the tailless is simpler to manufacture. For military purpose, it offered smaller cross-section for radar detection • On Northrop YB-49 flight test programmed, the configurations displayed pitch and yaw problems that made it very slow in settling to the initial point for the bombing run [3][107]. An autopilot was decided to be used in order to fix the problems. However, the project was stopped before further modification done.
1980's	• Shows the more modern low tapered ratio tailless aircraft. Examples: Flair 30, SB-13, SWIFT. Most designs showed a better handling characteristic. There are some improvements in its efficiency.
1990's	• B-2 Spirit Stealth Bomber was introduced with the basis of previous design. It was equipped with modern computer control system and thus solved the inherent problems experienced by YB-49. This design was proved to be the most successful tailless aircraft and had been produced. It performed it mission on 1999 successfully [3] [7].
2000's	• The latest designs of modern tailless aircraft are Boeing ScanEagle, X-36, X-43 X-45 and X-48 (see Figure 2.4). Boeing ScanEagle was developed to be a low cost, long endurance autonomous air vehicle, used for reconnaissance. The X-43 is an example of hypersonic tailless aircraft, travelled at the speed of Mach number and used scramjet technology. The X-45 is designed to perform a combat mission autonomously.

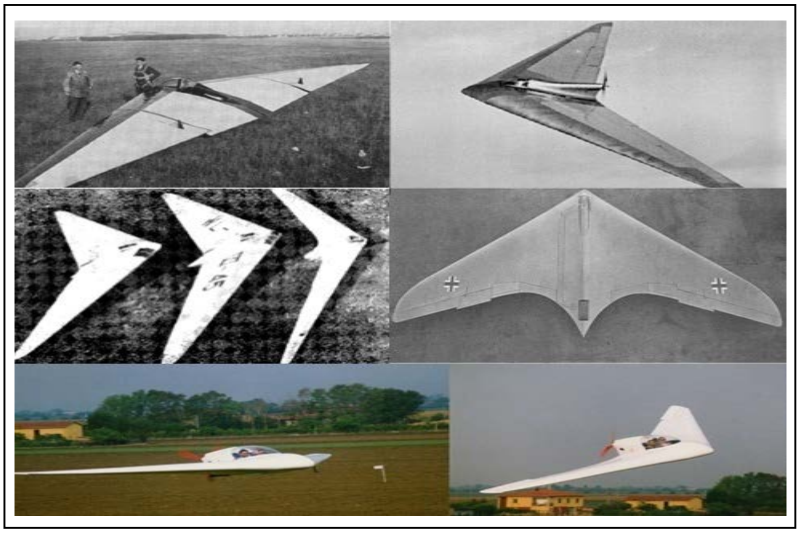


Fig. 2.2: Photo of Horten aircraft [2]

Fig. 2.3: Northrop YB49, B2 Spirit Stealth Bomber (Northrop image courtesy) [99]

Fig 2.4: Boeing image courtesy [108]

The latest design of tailless aircraft is the Blended Wing Body (BWB) concept. This passenger airliner is currently being investigated and developed [16-22]. Due to the absence of tail, this airliner will be more efficient in carrying the passenger and also can reduce noise. Figure 2.5 show the concept of Blended Wing Body X-36 is the prototype of this concept for flight testing.

The Boeing Company has recently exploring a blended wing body (BWB) concept and currently having it flight test. In comparison to similar tailed aircraft, Boeing studies showed 15% reduction in takeoff weight and 12% lower operating empty weight. Besides, there was improvement in lift to drag ratio by 20%. The fuel consumption is reduced by 27% and thus allows for lower thrust of 27% as well [16-22] (See Figure 2.5).

In conclusion, tailless aircraft had drawn attention in last two decades and yet has not been lost by the designers of today, as in the recent years, major aeronautical industries and universities have been researching and developing the tailless concept. Either for commercial aircraft or unmanned aircraft, the research and interest toward the design keeps in increasing as the configuration offers many advantages such as stealth, performance improvement, fuel efficiency and structural efficiency.

Moreover, the advent of unmanned air vehicles (UAV), improved control systems, and the importance of stealth has made the tailless configuration become popular among designers especially for UAV and military applications [107]. In addition, commercial airline industries also showed an interest on this configuration to be utilized in the future [16].

According to literature review of historical background of tailless aircraft, in the early year, it showed that tailless configurations were design basically based on trial and error in term of design parameters that been selected. Further modification had been made to the design with different design parameters for a better performance. What is the exact value of design parameters that had been used was not clearly stated. However, some of the data were very helpful as guidance in conceptual design stage.

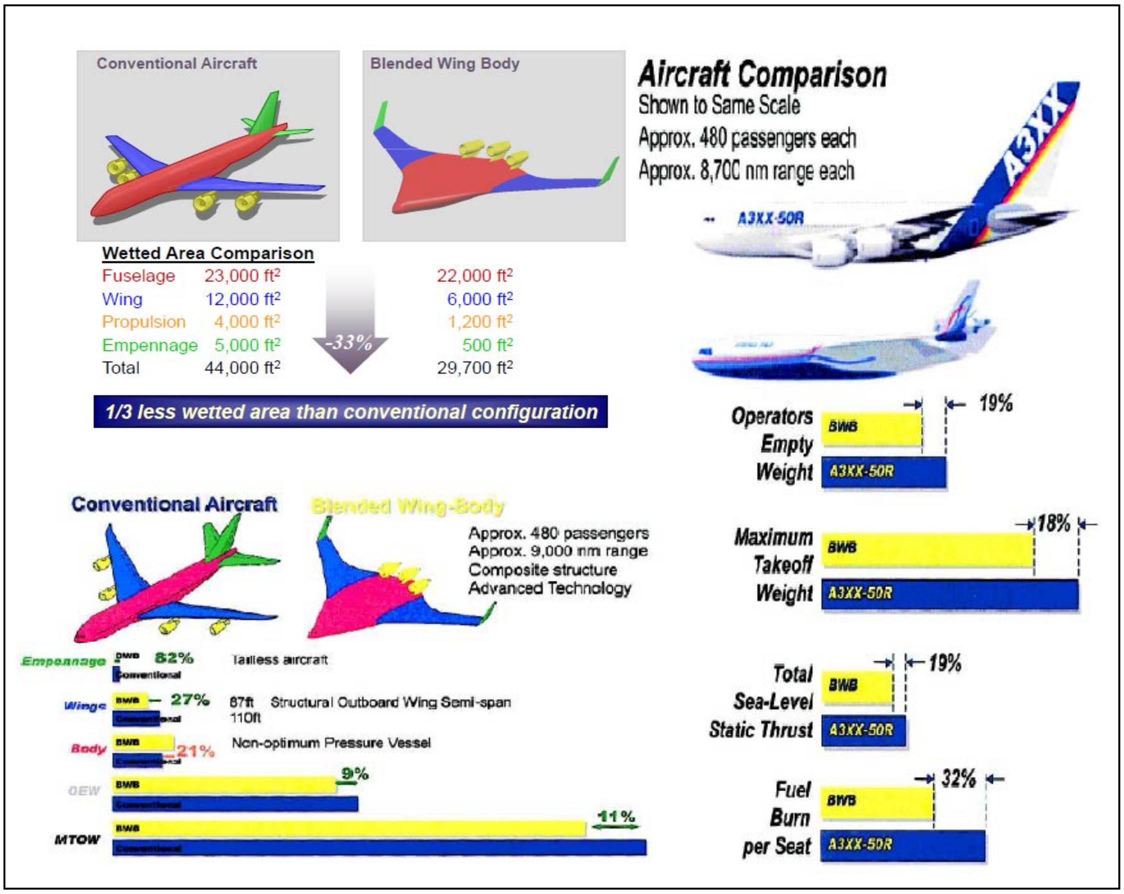


Fig. 2.5: Comparison of wetted area, structural weight fraction and performance. (BWB-450 and A380-700) [16].

2.3 Advantages and Disadvantages of Tailless Configuration

2.3.1 Advantages

2.3.1.2 Aerodynamics

Tailless configuration become more interesting in the BWB concept because the leading motivation of BWB is its lift generating center body which improves the aerodynamic performance by reducing the wing loading [29][35][75]. Hence, this configuration provides more lift compared to conventional one. In addition, due to the removal of the empennage and the use of smaller outer wing for BWB concept, the configuration had a reduction in wetted area [16-17] [21]. By referring to blended wing body concept [16], due to elimination of tail and the compact design, this configuration had a reduction in wetted surface area of 33%.

Furthermore, the total drag is reduced due to the elimination and reduction of junctions which exists between the wing and fuselage and results in more streamline shape. This configuration will benefit it term of lift to drag ratio [29-30] [35]. Yet again, by referring to blended wing body concept, the initial testing on it shows that it can have up to 27% reduction in fuel burn during flight [16]. Roman et al. [21] mentioned that there will be decreased in wave drag due to more favorable area-ruling, the BWB cross sectional area distribution is closer to Sears-Haack distribution for minimum wave drag.

Liebeck et al. [16] suggested the implementation of engine embedded partially in the BWB aft body, known as Boundary Layer Ingestion (BLI). This approach also does not only balance the airframe and counterbalance the weight of payload but also ensures that this technology has greatest effect since the boundary layer is fully developed towards the rear of the wing [8]. This technology also can improve the propulsive efficiency as well as reduced the required thrust and fuel burn [16-17]. This proved that the tailless configuration by way of BWB concept is well suited for such technology.

Kroo [8][10] in his analysis with similar conventional aircraft, shows that with the absence of tail, there are reductions in fuel consumption, low direct operating cost as well as the gross weight. These also can be a best sense of the potential that future tailless design can hold. First, as there is only one lifting surface is used; it has been known that there will be a reduction in drag. Thus, theoretically, in aerodynamic terms efficiency could be increased and in term of structure it provides a uniform distribution of the load. Besides, it can minimize fuel consumption and thus can maximize the range and allow for a long period of flight.

In addition, Kroo state that removal of tail can reduce aircraft gross weight, and fuel consumption [10]. Boeing study also showed the similar rewards [16] [20].

2.3.1.2 Noise

The tailless configuration is proved to have low noise. Mistry in his paper states that with the tailless configuration, the noise can be reducing by 15% [14] and friendly environmental [16-17] [20]. On 1991, NASA built a BWB model which had three engine nacelles on the aft of the top surface. The airframe has no tail, smooth lifting surfaces and had a minimum exposed edges and cavity. It is noticed that the noise reduced from 25dB to 10dB or less at the lower frequencies [13-14]. These gave a good sense for the reconnaissance mission.

2.3.1.3 Structures

Liebeck et al. [17] mentioned that for the BWB passenger aircraft configuration the lift and payload are in line with each other. Essentially, the passenger cabin which also called inner wing is used as a bending structure. As a result, the cantilever span of the outer wing is reduced and the weight is distributed optimally along the span. Qin et al. [32] explained that the integration of the thick center body with the outer wing translates into reduced bending moments and thus reduced structural weight. The result shows that besides aerodynamically efficient it also structurally efficient.

2.3.1.4 High payload capacity

The space of fuselage for this configuration now is more wide compared to conventional tube fuselage. Thus, it allows for greater volume and larger payload capacity [16].

2.3.1.5 Stability

This configuration can get a higher C_{Lmax} from a relaxed static stability. This is proved from research done by Kroo [8] [10], Liebeck [16-20], Qin et al. [31-36] and many researchers. Liebeck noted that a complicated high lift system is not required for the Boeing BWB transport due to the low effective wing loading of the configuration [16]. Without the need of complicated high lift devices, it offers a shorter take-off field length.

2.3.1.6 Stealth

Tailless configuration has low cross sectional profile and it has a few rounded shapes which is good for low observe ability and thus it is suitable for UAV and military purpose [16].

2.3.2 Disadvantages

Despite these positives, the elimination of empennage also brings problems. This configuration tends to be difficult to stabilize and control without using techniques that substantially increase the airplane’s drag and fuel consumption. Some disadvantages are outlined as below:

2.3.2.1 Stability and control

Base on the past design history, this type of aircraft present difficulties in achieving longitudinal stability and trim [53][57-59]. This configuration has a major problem on its longitudinal stability as the result of eliminated stabilizer. The moment arm becomes smaller. Thus, large or more control surfaces are needed for pitch control. Some coupling controls (lateral-directional control) are needed and this control coupling might cause non-conventional spin recovery [16] [64].

Liebeck pointed that the integrated nature of body and wing alone with the elimination of tail by means the interactions between internal forces, aerodynamic loads, elastic deformations and the flight control systems responses may have great impact on the performance and stability of the aircraft [16]. This also mentioned by other researchers. Wakayama and Kroo [37-38] stated that whilst to ensure that the aircraft is balanced, it is importance to make sure that control deflections do not adversely affect the span load and drag. Although there are problems with tailless design in term of its stability and control, it is believed that with current advanced technology such as feedback control system and fly-by-wire technology, good flying qualities might be achieved.

2.3.2.2 Aerodynamics

There will be a significant increase in induced drag when wash out is used for stability. This configuration also will create a thick section at the center and this thick section will create high drag if it is operated at transonic speed. The use of transonic airfoil with high thickness to chord ratio at inboard invites problems in maintaining low drag. This ratio must be maintained along a considerable portion of the chord length [16] [22]. The high thickness is required in order to accommodate passengers' cargo, as well as landing gear.

Potsdam et al. [22] mentioned that the supersonic flow on the lower surface of the BWB is one of the challenges in the design which is not characterized by the conventional configuration. In addition, Tjoetjoek [75] pointed that the benefits of low wetted area may not hold for the case of medium-sized BWB aircraft which was in fact it was found to have a higher wetted area compared to conventional aircraft. Roman et al. [21] stated that, in the aerodynamic design of the aircraft, manufacturing constraints must also be factored in complex, three dimensional shapes which might be expensive and difficult to manufacture must be avoided with smooth, simply curved surfaced being favored.

2.3.2.3 Propulsion

The engine provides a thrust moment and his thrust moment might interrupt pitch stability of tailless design during takeoff and landing [92]. Additionally, Wakayama and Kroo [37] mentioned that there will be additional difficulties of aft-mounted engines and propulsion with airframe integration as the engine integration affects several disciplines more directly than the case for conventional configuration. The interaction between the wing, control surfaces and engines increase the complexity of the design of this region [67]. This also pointed by Liebeck in his paper [17] and then explored the solutions for this issue.

2.3.2.4 Structural

According to Mukhopadhyay et al. [26-28], regarding the structural analysis of the BWB concept, the stress level in the pressurized fuselage is high. The internal pressure results in the blending stress instead of skin stress [96]. This is due the non cylindrical shape of fuselage. The increased stresses in the pressure vessel lead to increased structural weight. [17] [98]. The similar behavior also experienced by X-33 type space aircraft as written by Mukhopadhyay [26]. Velicki et al. and Mukhopadhyay et al. discussed the concepts in order to determine the optimal fuselage configuration for the tailless configuration especially BWB in their paper [26-27] [67].

2.4 Feasible Studies Pertaining Tailless Configuration

In this section, a brief review of the researches and studies related to current studies are presented. These will include research studies and works done by Canfield University, Sheffield University, NATO-AVT-161 group (German Department of Defense and Technical University Braunschweig, Germany) and UiTM and some other researcher. A total of four designs will be investigated in further detail as guidance in the development of the tailless aircraft conceptual design methodology.

2.4.1 Cranfield College of Aeronautic, Cranfield University

Some extensive studies had been carried out at Cranfield University. The interest towards BWB layout was due to the fact that the configuration may offer compensation when applied to high-capacity transport aircraft. BW-98 is one of the research projects which is similar to the Boeing concept and also represent the UK National project [43][70][96]. The design requirements are similar to the specifications of Airbus A380 with 656 seats in three class layout and compatible with the existing airports and facilities. The design is carrying payload of 656 passengers and baggage, cruising at Mach 0.85. The design rage is 7650 nm.

The alternative structural designs of the centre fuselage were discussed in paper [96] by Smith. The centre wing-body is planned to have aluminum alloy and structure members which are frames and stringers. The inner and the outer fuselage were designed as a conventional fuselage in which, the skin is supported by stringers. The frames were used in order to stabilize the aircraft structures Composite materials were used to limit the number of parts. This also will reduce the weight to lowest possible. The outer skin gets the pressurization loads without the help of additional structures. The used of vaulted double-skin ribbed shell configuration was found to be superior due the weight saving and the load diffusion. Thus, a multi-bubble circular section was chosen.

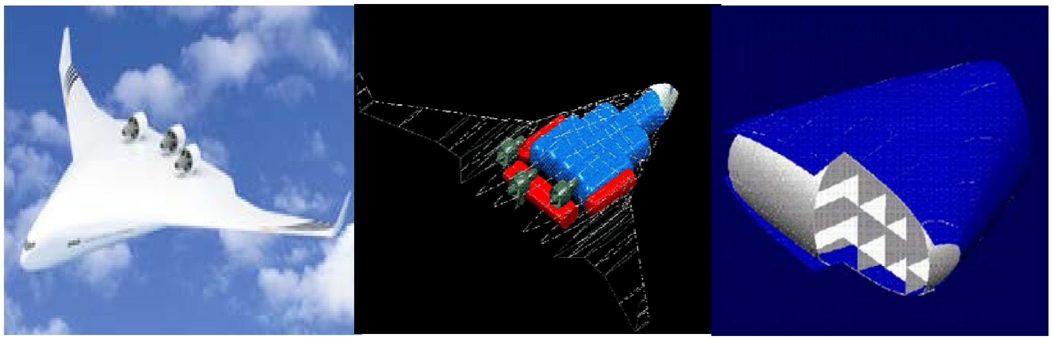


Fig. 2.6: The design of fuselage for BWB from Cranfield University [96].

Prior to the previous design, a novel airframe design for silent aircraft also been analyzed. Mistry [13] in his research investigated the design of four tailless concepts which are Broad Delta, Slender Delta, and Blended Wing Body and Innovative Wing variations. The main purposes were to identify novel airframe configurations and engine technologies, integrate the design, and determine an ideal configuration solution for a silent aircraft. The expected outcome of this Cranfield study is to assess which novel aircraft design is a competitive solution to meet legislative and operator requirements and is an economically viable solution for entry into services [97]. The integrated airframe engine designs would then be compared to the SAI noise target of 60dB.

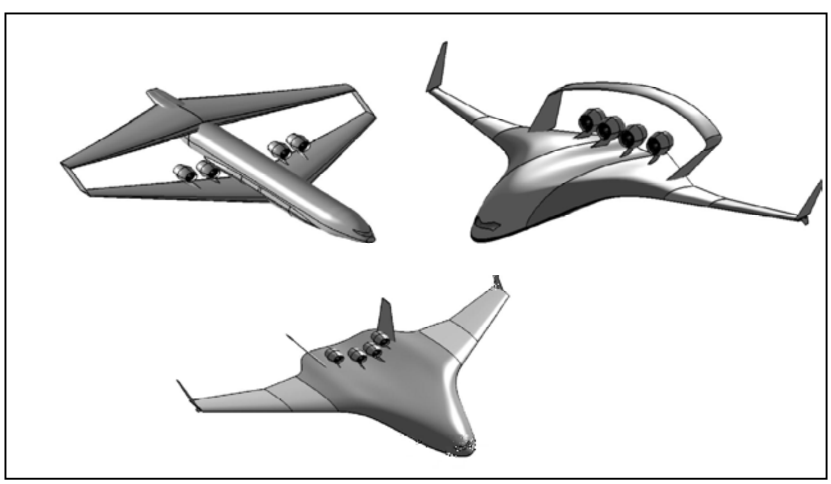
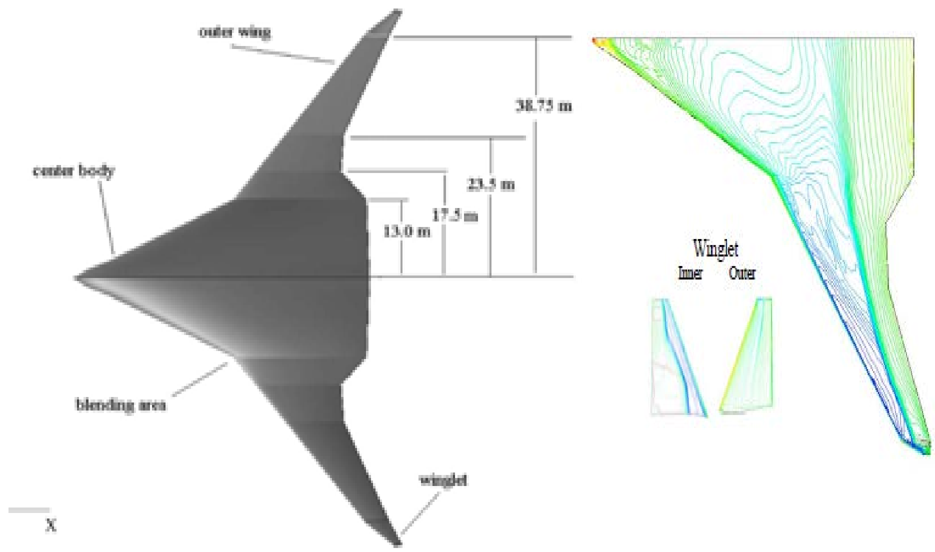


Fig. 2.7: Initial design layout to conduct a preliminary noise analysis [13].

2.4.2 University of Sheffield

The University of Sheffield has presented a progressive an aerodynamic study of BWB configuration. Qin et al. [30-36] present a multidisciplinary optimization of BWB configuration. He investigated an aerodynamic performance of the various BWB design projects. With the theoretical view of the ideal aerodynamic performance for the baseline design, viscous flow simulation was applied to investigate the aerodynamic performance of BWB configuration. The BWB was mapped to an airfoil optimization program. It was projected back to the wing for further investigation in the performance.

In this research work, the span loading distribution, the importance of wave drag, the airfoil section design and three dimensional shaping for BWB performance are highlighted by Qin. In regards to the aerodynamic performance of BWB configuration, the L/D is similar to conventional aircraft but parasite drag is excessively lower than cylindrical body aircraft. The resulting geometry had 20% increases in lift to drag ratio compared to the baseline. However, the high sweep and three dimensionality of BWB shape implied 2D optimization cannot fully capture the potential of shape optimization. Further studies dome by Qin et al. was by implementing forward swept wing to the BWB configuration [36]. The lift to drag ratio was low and create intense shocks at the intersection between the body and wing. The behavior of the baseline model was defined as transonic cruise condition.



Mach Number	0.85	Aspect Ratio	4.26
Altitude	11,500 m	Sweep Angle (centre)	63.8 deg.
Reynolds Number	5.41×10^6	Sweep Angle (wing)	38 deg.
Design C_L	0.41	C.G. Position	29.3 m
Length of Centre Chord	50.8 m	Centre Body	0 - 13.0 m span
Reference Area	842 m^2	Inner Wing Location	13.0 - 23.5 m span
Wetted Area	3,079 m^2	Outer Wing Location	23.5 - 38.75 m span

Fig.2.8: The BWB model [36].

2.4.3 Stability and Control Configuration (SACCON)-Collaborative work through Department of Defense, German.

A generic tailless design which is for UCAV model was developed specifically for NATO-AVT-161 group supported by German Department of Defense. The initial design was made by DLR and EADS together with Technical University Braunschweig, Germany. The CFD simulation and wind tunnel experiment on typical UCAV geometry called SACCON configuration have been performed collaboratively involving various partners in. The results are described in detail in the paper [78-82]. Computational analyses were carried out on tailless configuration, SACCON to study the effects of turbulence model as well as the influence of wing profile on pressure distribution and vortex formation along the leading edge. Besides, several analyses also be done to investigate and to understand the physics of the vertical flow.

The SACCON geometry represents a configuration regarding most of the stealth requirements. The preliminary design resulted in the final design shown in Figure 2.10. The design features a lambda type of wing with a leading edge sweep of 53 degrees. One advantage of using a delta wing planform is that, the leading edge of the wing is generating a vortex. This vortex remains attached to the upper surface of the wing. This keeps increasing as the angle- of-attack increases. This phenomenon gave a delta wing a very high stall angle and thus maintaining lift at high angle of attack. This vortex reduces upper surface pressure by inducing high velocities on the upper surface.

The flow over delta wings is dominated by leading edge vortices and other vortical structures. UCAV relies on lift generated by the vortex flow to enhance its stability and control. At a high angle-of-attack, strong vortices are generated along the leading edge of the highly swept delta wing. These leading-edge vortices have a dominant effect on the flow and aerodynamic loads. At such high angle-of-attack, a phenomenon known as “vortex breakdown” occurs in the vortices above the wing. When breakdown occurs over a wing surface, it causes a sudden lift loss and a severe non-linearity in the aerodynamic loads.

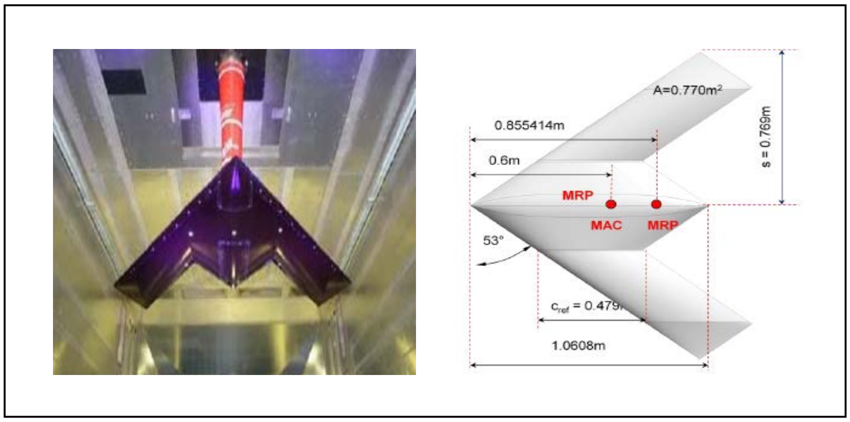
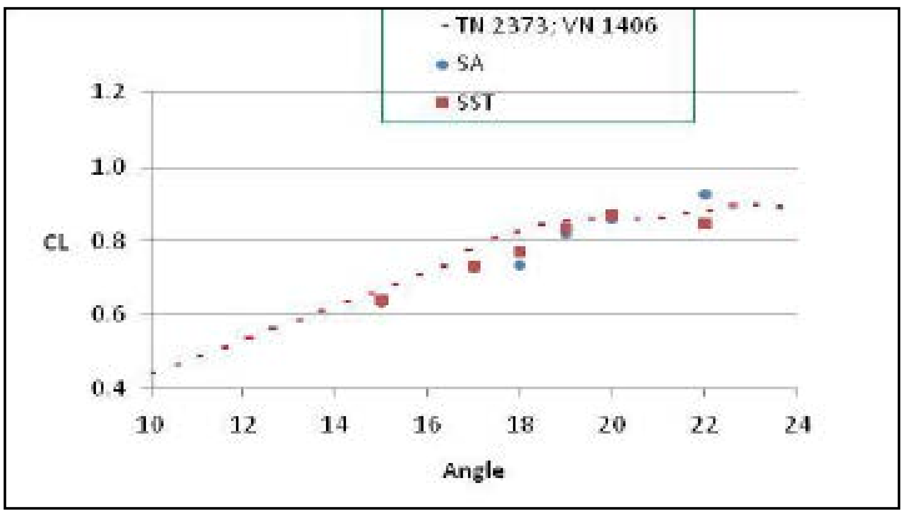
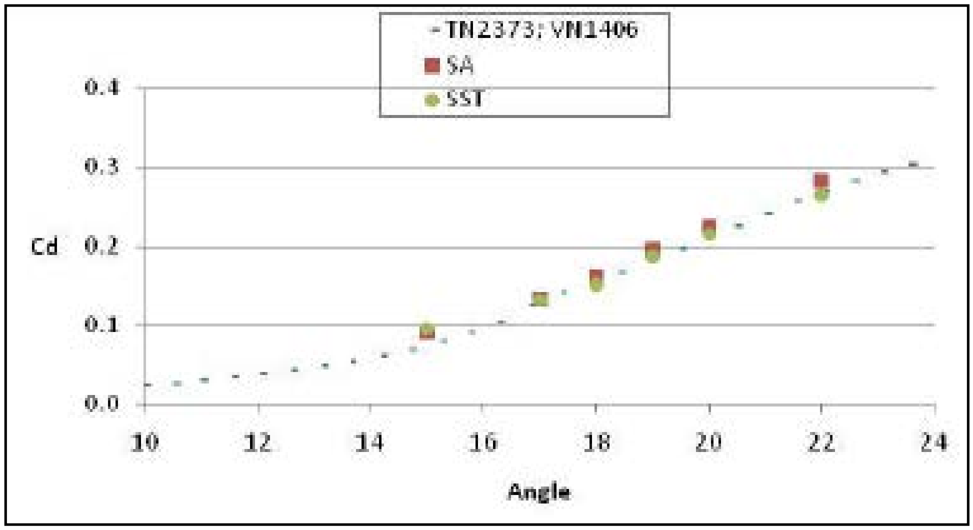


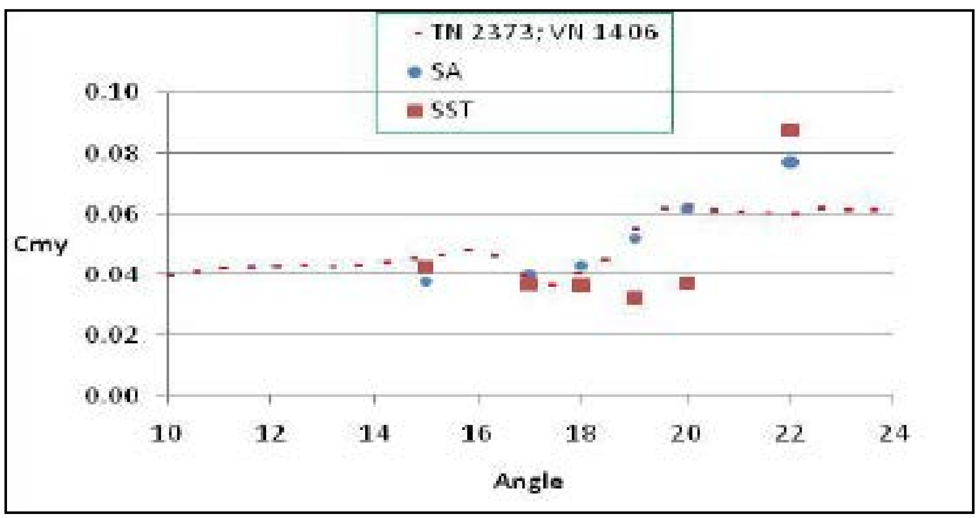
Fig.2.9: Planform and geometric parameters of the UCAV SACCON [78]



(a) Lift Coefficient versus AoA.



(b) Moment Coefficient versus AoA.



(c) Pitching moment Coefficient Versus AoA

Fig. 2.10: Comparison between CFD (SA, SST) and Wind tunnel experiment. [82]