ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

DESIGNING OF FUSELAGE CROSS-SECTION PARAMETERS AND STUDY OF THEIR EFFECTS ON aERODYNAMIC DRAG

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ABSTRACT

In present study, different fuselage shapes and designs obtained through using various empirical equations defined by NACA had been reviewed. The shape and planform of the fuselage plays a vital role in defining the overall drag by the aircraft. Due to this, it becomes extremely essential to explore new, unsymmetrical and unconventional shapes which may deliver better aerodynamic performance. Such unconventional and cambered fuselage shapes may also contribute to the generation of lift even at zero and some negative angles of attacks. Such of the few shapes and planforms have been reviewed based on their governing empirical relations and their inherent aerodynamic performances.

Keywords: *Fuselage, Circular, Non circular, Zero lift Drag, Lifting Drag, Base Drag, Interference Factor.*

I. INTRODUCTION

Fuselage plays a vital role in enhancing the overall performance of any aircraft. The importance of lift and drag for an aircraft are substantial to the overall flight performance. The most ideal condition in the design process in terms of aerodynamics is that the fuselage should have maximum production of lift and minimum production of drag to increase the efficiency. The size and shape of fuselage is governed by the payload and also by the aircraft's engine placement locations. As a result, the fuselage tends to contribute around 25% to 50% of the overall drag force on the aircraft depending on the form and size of the fuselage. The optimum fuselage design experiences the smallest drag force without an excessive pitching moment. In addition to this, it is expected that the presence of lift is positive even if the angle of attack is zero. Such condition can be achieved if the fuselage is designed as a cambered fuselage. To obtain the most suitable fuselage, appropriate fuselage aerodynamics analysis software capable for predicting the aerodynamics characteristics of symmetrical as well as unsymmetrical fuselage shapes should be used.

Nicolosi et.al developed a CFD-based method to predict aerodynamic coefficients of aircraft and observed that about 30% of the aircraft's zero lift drag source is attributed to the fuselage. Welstead used vortex lattice method to approximate lift distribution, induced drag, and the moments for a given planform. Walter and David conducted the study on the static longitudinal and lateral stability characteristics at low subsonic speed of unsweep midwing with models of different Aspect Ratios. Hall had reported the results obtained from wind tunnel tests experimenting on the thin, low aspect ratio wings in combination with a body at subsonic and supersonic speeds. The data obtained are lift, drag and pitching moment coefficients for various Mach number ranging from 0.25 to 1.9. Additionally, he performed a study on a series of wing with different planforms, aspect ratios, thicknesses, thickness distributions, wing cambers and twists in combination with the fuselage. His research showed that wings with a sharp leading edge had lesser values of minimum drag at supersonic speed.

Drag originating from a poorly designed fuselage design is likely to hamper aircraft performance and lift generation due to small separations, shock waves, or excess wetted area. There is also a significant impact on other aircraft regions because disturbed airflow can contribute to lower efficiency of engine inlets and tail surfaces. Separated airflow rising at wing-fuselage junctions or fuselage regions has a similar performance of vortex shedding from wings. Thus, the disturbed air pattern is prone to cause earlier-than-anticipated fatigue on tail surface structural parts. Frequently, this phenomenon is difficult to diagnose. It is desirable to have as little drag as possible and thus the fuselage should be sized and shaped accordingly. Thus, designing a fuselage is neither easy nor simple task, especially for civil aircrafts as the passengers comfort must also be taken into account while sizing it. The fuselage covers a large area of an aircraft which most likely contributes to most of the drag. To minimize the effect of this problem, fuselage is usually designed of having a streamlined shape to minimize the form drag.

The main objective of this study is to review various profiles of fuselage and the various empirical and fundamental equations governing their design and aerodynamic performance.

II. DESIGNING

Fuselage has to be designed to offer minimum drag, great structural support for wing and tail forces acting in flight and maximum comfort and attractiveness to the passengers in terms of seat design, placement, and storage space. As a result, the fuselage's cross-section may not be symmetrical and have a circular cross-section.

NACA RM L9I30

The cross-section of this type of fuselage is uniform and circular where L is the length of fuselage, x is the fuselage station, D (x) is the diameter of fuselage at x and a, b and x_m are the shape parameters. The distribution of fuselage diameter in the longitudinal axis is given as:

$$\mathbf{D}(\mathbf{x}) = \begin{cases} D_m - 2a(x_m - \mathbf{x})^2 & \text{for } 0 \le x \le x_m \\ D_m - 2b(x_m - \mathbf{x})^2 & \text{for } x_m \le x \le L \end{cases} \quad (1)$$

Using Eq. 1, the cross section of fuselage would be represented as shown in Figure 1.

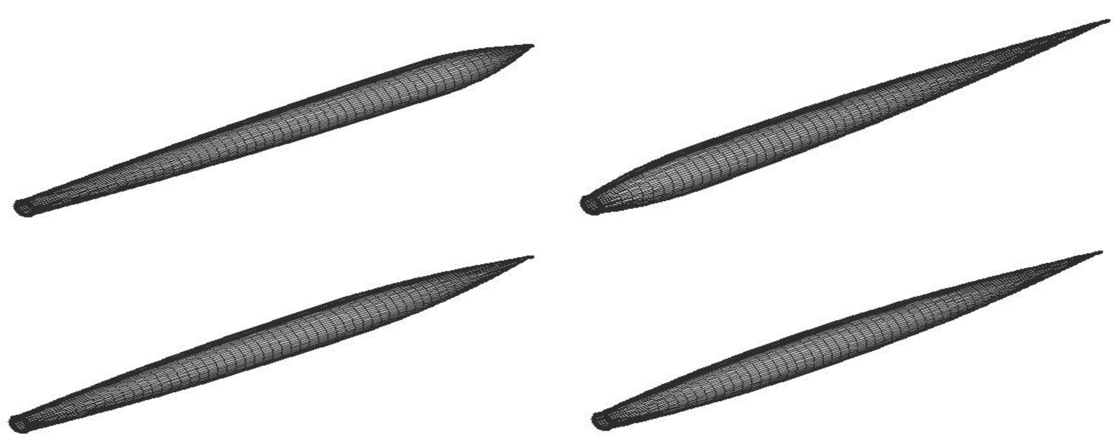


Figure 1: Fuselage at Fineness ratio 12.5, (a) XM = 0.2L. (b) XM = 0.4L, (c) XM = 0.6L and (d) XM = 0.8L

ISSN 2348 – 8034
Impact Factor- 5.070

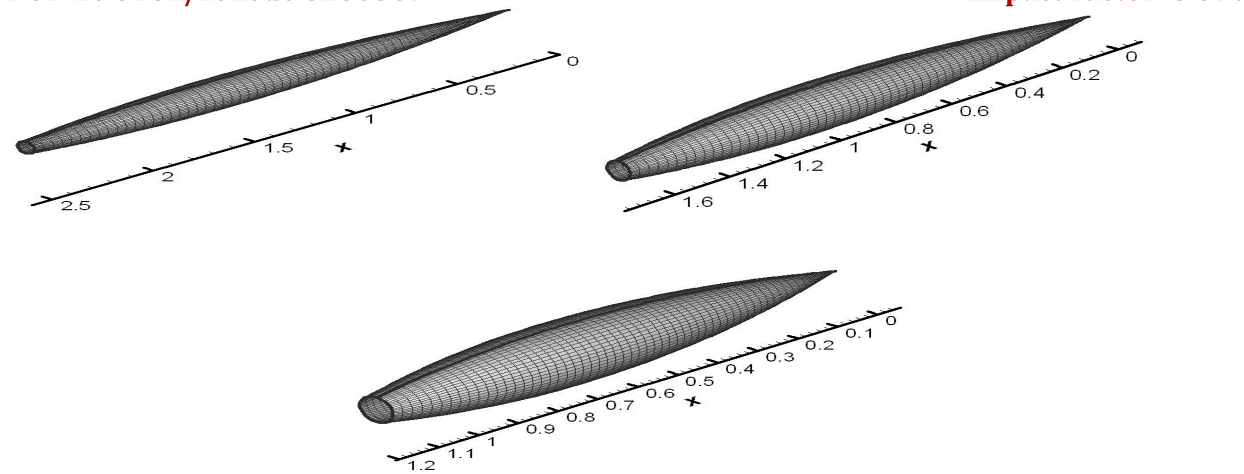


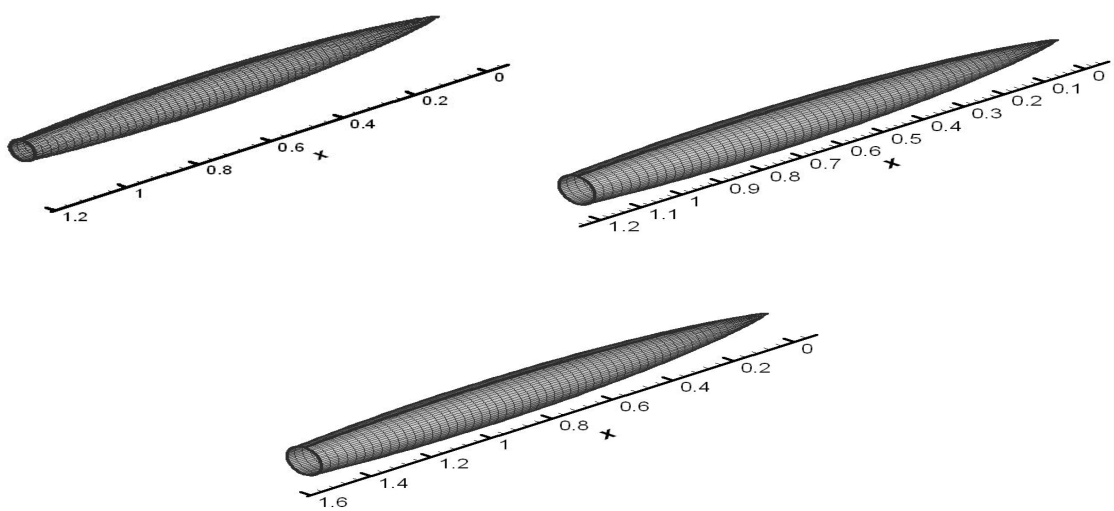
Figure 2: Fuselage maximum diameter 0.6L a. (a) Fineness ratio = 12.5, (b) Fineness ratio = 8.91 and (c) Fineness ratio = 6.04

NACA RM A50K24b

The distribution of the fuselage radius of the cross section r(x) is given as:

$$r(x) = r_0 \left[1.0 - \left(1.0 - \frac{2x}{L} \right)^2 \right]^{3/4}, \qquad 0.0 \le x \le L_B \tag{2}$$

Here, r_0 is the maximum fuselage radius cross-section, L_B is the actual fuselage length and L is the mathematical fuselage length. Three dimensional views for those three types of fuselage due to different value of fuselage shape factors are shown in the Figure 3.



[Chalia, 6(4): April 2019] ISSN 2348 – 8034
DOI- 10.5281/zenodo.3250367 Impact Factor- 5.070

Figure 3: Fuselage Model RM A50K24b

Agard's Model – 1

The AGARD model has a circular cross section with the fuselage radius distribution(x) is defined as:

$$\mathbf{r(x)} = \frac{\mathbf{x}}{\mathbf{7.5}}\,\mathbf{r_0}\left(\mathbf{1} - \frac{\mathbf{x}}{\mathbf{L}}\right) \;; \qquad \mathbf{0.0} \le \mathbf{x} \le \mathbf{L_B} \tag{3}$$

Figure 4 shows three dimensional fuselage shapes generated by using Eq .3.

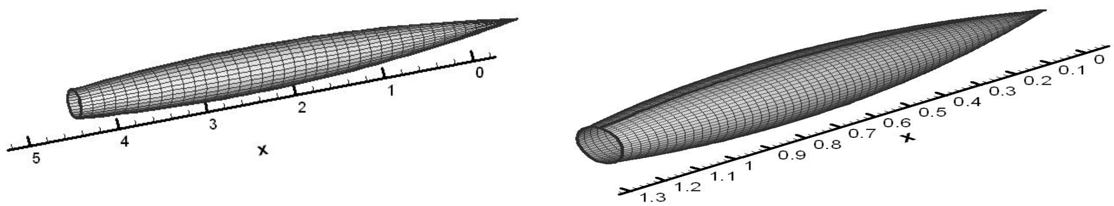


Figure 4: Agard Fuselage Model (a) Fuselage length L_B = 50 inches and (b) L_B = 7.325 inches

Parabolic Spindle Fuselage Model

A parabolic spindle Fuselage model having a distribution fuselage radius cross section along the main axis is given as:

$$\frac{\mathbf{r(x)}}{\mathbf{L}} = 4\frac{\mathbf{r_{mid}}}{\mathbf{L}}\frac{\mathbf{x}}{\mathbf{L}}\left(\mathbf{1} - \frac{\mathbf{x}}{\mathbf{L}}\right) \tag{4}$$

In above equation, r_{mid} represents the fuselage radius cross section at the mid fuselage length. It also represents the maximum value of fuselage radius cross section.

Figure 5 shows the three dimensional view of two fuselage models generated by using Eq. 4, with the same fuselage length of 5 unit length but differ in term of their fineness ratio.

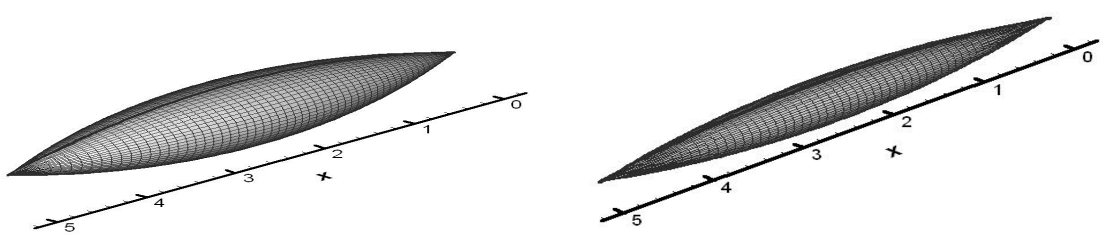


Figure 5:Parabolic Spindle Fuselage Model (a) Fineness ratio FN = 5, (b) FN = 10

Ellipsoid of revolution

The radius of fuselage cross section r(x) for this type of fuselage as:

$$\frac{r(x)}{L} = 2\frac{r_{mid}}{L}\sqrt{\frac{x}{L}\left(1-\frac{x}{L}\right)}$$ (5)

Figure 6 shows two fuselage models created by use of Eq. 5. Both fuselages have the same fuselage length L equal to 5 unit lengths. The first figure correspond to the fuselage with fineness ratio 5 while the second one with FN = 10.

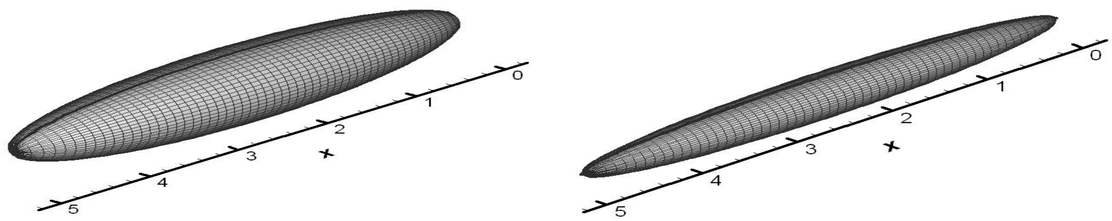


Figure 6: Ellipsoidal Fuselage Model (a) Fineness ratio FN = 5, (b) FN = 1

III. AERODYNAMIC CHARACTERISTICS

The fuselage contributes a large amount of drag to the entire wing-body combination. Flow separation due the geometry of the fuselage is one of the sources of drag. Fuselage will contribute few types of drag which includes friction drag, interference drag, form drag, base drag and induced drag.

There are several methods that are capable to compute the drag of the fuselage. The most common method used is the Roskam's Drag Prediction method where it suggest that the fuselage drag coefficient is the summation of the fuselage zero-lift drag and drag due to lift. Zero-lift drag represented by C_{Dof} and lift induced drag is represented by $C_{DLf.}$

As the fuselage drag is highly dependent on the fuselage geometry, its diameter and length will be the main parameters that influence the fuselage drag. Hence, the equation below shows the equation that used to model the zero-lift drag which is also the function of the fuselage geometry. Where, Rwf is Wing-fuselage interference factor, C_{ff} is the turbulent flat plate skin-friction factor as a function of Mach number and the Re, df is Maximum fuselage diameter, S_{wet} is the Wetted area of the fuselage, l_f is Fuselage length and C_{Dbf} is Fuselage base drag coefficient.

$$C_{D_{0_f}} = R_{wf}C_{f_f}\left[1+\frac{60}{\left(l_f/d_f\right)^3}+0.0025\left(\frac{l_f}{d_f}\right)\right]\frac{S_{wet}}{S}+C_{D_{b_f}}$$ (7)

Based on Equation (7), in order to obtain a minimal fuselage zero-lift drag coefficient, its wetted area should be minimized and fuselage fineness ratio should be maximized. Another term that will affect the fuselage zero-lift drag coefficient is the base drag which is produce due to the presence of base area of the fuselage. Figure 1 show the fuselage without base area and with base area. The presence of base will leads to flow separation, where the larger the base area, the greater the base drag.

The base drag coefficient of the fuselage can be determined by using the equation below, where d_b is Fuselage-base diameter, S_{fus} is Fuselage maximum frontal area, $C_{Dofus\text{-}base}$ is the Zero-lift drag coefficient of fuselage exclusive of the base.

$$C_{D_{b_f}} = \left\{ \frac{0.029 (d_b/d_f)^3}{C_{D0_{fus-base}} (S/S_{fus})^{1/2}} \right\} \{S_{fus}/S\} \quad (8)$$

From equation (8), the higher base diameter will leads to a greater base drag coefficient as it yields a higher base area.

The drag due to lift can be computed using the following equation where α is the Fuselage angle of attack in radian and η is the Ratio of the drag of a finite cylinder to the drag of an infinite cylinder.

$$C_{D_{L_f}} = \frac{(2\alpha^2 S_{b_{fuse}})}{S} + \frac{(\eta C_{d_C} \alpha^3 S_{plf_{fuse}})}{S} \quad (9)$$

Fuselage drag due to lift coefficient is relatively very small compare to the fuselage zero-lift drag. Thus, in some cases, it is neglected as its value is not significant to the total drag of the fuselage. However, it is taken into account for this project to achieve a more accurate computational result. Although the individual lift of the fuselage is not calculated as its value is very small, the lift generated by the entire wing-body is still been calculated. The lift curve slope of the wing-body combination can be obtained by the equation below:

$$C_{L_{a_{wf}}} = K_{wf} C_{L_{a_w}} \quad (10)$$

The wing-fuselage interference factor depends upon diameter of fuselage and wing span as shown by equation

$$K_{wf} = 1 + 0.025 \left(\frac{d_f}{b}\right) - 0.25 \left(\frac{d_f}{b}\right)^2 \quad (11)$$

IV. CONCLUSION

Various profiles of fuselage such as circular, triangular, parabolic and elliptical have been designed by taking reference from NACA reports. It has been showed that fuselage profiles largely depends upon distribution of diameter across longitudinal axis, length of fuselage and fineness ratio. Fuselage contributes 25-30% in overall drag of an aircraft therefore careful designing of a fuselage is must to increase performance of an aircraft. Radius and length of fuselage are the main parameters in base drag, skin friction drag and interference drag and those drags greatly affects aircraft's performance. Empirical expressions are generated to calculate various parts of drag with varying parameters of fuselage geometry.

ISSN 2348 – 8034
Impact Factor- 5.070

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