FUSELAGE AERODYNAMICS ANALYSIS THROUGH SEMI EMPIRICAL METHOD AND COMPUTATIONAL AERODYNAMICS

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ABSTRACT

To fulfil the need of civilian and military purposes, there may be more than millions of aircrafts that had been built so far. In year of 2010, The Federal Aviation Administration (FAA) recorded that there were 223,370 aircraft under the category of General Aviation Aircraft is in operation around the world. This type of aircraft serves in the unscheduled flight for various reasons. Other aircrafts which are designed to support scheduled flight used by airlines such as the aircraft produced by aircraft manufacturer such as Boeing, McDonnell Douglas, Airbus, Fokker, Lockheed etc, may already contributed more than 100,000 aircrafts. Strictly speaking hundred thousand aircrafts have already built and each having its own fuselage shape and most of them had been tested under wind tunnel test. Unfortunately, their aerodynamics data kept in a confidential manner by the most aircraft manufacturers. The present work focused on the development of computer code for allowing one to carry out the aerodynamic characteristics over an arbitrary fuselage geometry. The computer code was developed by using semi empirical aerodynamics method in obtaining the overall aerodynamic characteristics and using Three Dimensional Panel Method for their pressure distribution over the fuselage surface. The aerodynamic characteristics analysis was carried out over various shape models and compared with the results provided by DATCOM software. In term of lift and pitching moment coefficient for various angle of attacks, the result of the developed software is in a good agreement with DATCOM software, but totally differ with DATCOM software is in term of drag coefficient. However if the component of base drag is ignored both two computer codes give close results. The effect of cambered fuselage was investigated by modelling the fuselage geometry developed based on NACA series. The result indicates that the maximum camber and the position of the maximum camber give strong influence to the pitching moment. The result of pressure distribution over the fuselage surface indicates that there are significant pressure variation over the body surface due to angle of attack. In addition to this, the research also found that the fuselage nose, fuselage camber line, and fuselage cross section give a strong influence to the overall aerodynamic characteristics.

ABSTRAK

Bagi memenuhi keperluan awam dan tentera, lebih berjuta-juta pesawat telah dibina. Pada tahun 2010, Pentadbiran Penerbangan Persekutuan (FAA), mencatatkan bahawa terdapat 223,370 pesawat udara di bawah kategori Penerbangan Pesawat Umum telah beroperasi di seluruh dunia. Pesawat-pesawat ini dibina mempunyai pelbagai fungsi. Untuk memenuhi permintaan penerbangan, syarikat-syarikat penerbangan seperti Boeing, McDonnell Douglas, Airbus, Fokker, Lockheed dan lain-lain, sudah boleh membina lebih daripada 100,000 pesawat. Terdapat beratus ribu pesawat telah dibangunkan dan setiap satunya mempunyai bentuk fiuslaj yang tersendiri dan kebanyakannya telah diuji dengan ujian terowong angin. Malangnya, data aerodinamik disimpan secara sulit oleh setiap pengeluar pesawat. Penyelidikan terkini memberi tumpuan kepada membangunkan kod komputer untuk membolehkan penyelidik lain untuk menjalankan ujian aerodinamik ke atas pelbagai bentuk geometri fiuslaj. Kod komputer dibangunkan dengan menggunakan kaedah separuh empirikal aerodinamik bagi mendapatkan ciri-ciri aerodinamik serta menggunakan kaedah Panel Tiga Dimensi untuk mendapatkan taburan tekanan ke atas permukaan fiuslaj. Analisis aerodinamik yang dijalankan ke atas pelbagai bentuk model dan hasil kajian tersebut dibandingkan dengan hasil kajian yang diberikan oleh perisian DATCOM. Dalam istilah pekali daya angkat dan momen dalam pelbagai sudut serangan, hasil yang diperolehi amat menghampiri dengan hasil kajian perisian DATCOM, tetapi dari segi pekali seretan, hasil kajiannya memberi perbezaan yang amat ketara. Walaubagaimanapun, jika komponen asas seretan diabaikan, kedua-dua kod komputer memberikan hasil yang hampir antara satu sama yang lain. Kesan fiuslaj yang melengkung dikaji dengan kaedah pemodelan geometri fiuslaj berasaskan dari NACA. Hasil dari kajian menunjukkan bahawa lengkungan maksimum dan kedudukan maksimum lengkungan memberikan pengaruh yang kuat kepada pekali momen. Hasil taburan tekanan di permukaan badan pesawat menunjukkan bahawa terdapat perubahan tekanan di permukaan badan yang disebabkan oleh sudut serangan amat ketara. Sebagai tambahan, hasil-hasil penyelidikan juga mendapati muncung fiuslaj, garis lengkungan fiuslaj dan keratan rentas fiuslaj memberikan pengaruh yang kuat secara keseluruhan terhadap ciri-ciri aerodinamik.

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CHAPTER I

INTRODUCTION

1.1 Introduction

The fuselage, or body of the airplane represents a long hollow tube which holds all the pieces of aircraft components together. The fuselage is designed as a hollow tube to reduce weight. Conventionally the role of fuselage is carrying passengers. Besides that, fuselages are also designed to accommodate antennas, outsized cargo, and any sort of devices according to what the aircraft is intended to. The aircraft fuselage is basically responsible for 25-50 percent of the overall drag for most airplanes. Fuselages generates the following types of drag; profile drag, compressibility drag, and induced drag. A fuselage contributes to induced drag primarily because its adverse effect on wings span load distribution. When the fuselage is integrated into the wing (and with nacelles and the empennage), extra drag, the so called interference drag is produced. Many aerospace design teams frequently treat fuselage aerodynamic design as a matter of secondary importance during the aircraft development phases. Understandably, aerodynamicists prefer to focus their efforts on wing design employing inverse or optimization methods in order to obtain, for example, transonic wings with minimum wave drag. Usually, fuselage aerodynamic design is scheduled for the last stage of the development phase. At this point, time is a major issue and as far as the multidisciplinary aspects of fuselage aerodynamics is concerned, a less elaborated work is then performed. It is worth mentioning that the drag creep of a well-designed wing should be under 10 drag counts (CD = 0.001) at maximum cruise condition. Drag resulting from a poor fuselage design is likely to overcome such figure 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 arising at wing-fuselage junction or fuselage regions has a similar behaviour to 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. Considering that it is desirable to have as little drag as possible, the fuselage should be sized and shaped accordingly. Basically there are some factors need to be accounted in designing the fuselage, such as [48]:

- Low aerodynamic drag.
- Minimum aerodynamic instability.
- Comfort and attractiveness in terms of seat design, placement, and storage space.
- Safety during emergencies such as fires, cabin depressurization, ditching, and proper placement of emergency exits, oxygen systems, etc.
- Ease of cargo handling in loading and unloading, safe and robust cargo hatches and doors.
- Structural support for wing and tail forces acting in flight, as well as for landing and ground operation forces.
- Structural optimization to save weight while incorporating protection against corrosion and fatigue.
- Flight deck optimization to reduce pilot workload and protect against crew fatigue and intrusion by passengers.
- Convenience, size, and placement of galleys, lavatories, and coat racks.
- Minimization of noise and control of all sounds so as to provide a comfortable and secure environment.
- Climate control within the fuselage including air conditioning, heating, and ventilation.

- Provision for housing a number of different sub-systems required by the aircraft, including auxiliary power units, hydraulic system, air conditioning system, etc.

Most aircrafts were designed with the combination of above factors and they were built with the use of unsymmetrical fuselage shape. This situation was also applied to the aircraft which was designed to be a platform for unmanned aerial vehicles. The unsymmetrical fuselage made the zero lift angle of attack will not occur at zero angle of attack, but at any angle of attack depending on the shape of fuselage camber line. The aerodynamics analysis method applied to the case of a symmetrical fuselage can be adopted for the analysis of unsymmetrical fuselage as far as the zero lift angle of attack for the corresponding fuselage is known. Unfortunately the manner in how to define this zero lift angle of attack was not yet established. Wolowicz et.al. used graphical approach in order to define the zero lift angle of attack $\alpha_{L=0}$ as reported in Ref. 3. While the DATCOM book [1, 2] did not discuss the way to determine the angle, but their software provide the ability to predict the aerodynamics characteristics for unsymmetrical fuselage.

1.2 Research Background

In parallel of the advancement of computer technology, material, propulsion system and better understanding on the aircraft stability had made the development of autonomous flying vehicle becomes an attracted matter. This type of flying vehicle called Autonomous Aerial Vehicle (UAV) offers various useful applications both in military point of view as well as in civilian's activity.

In view of military application, the UAV can be used as:

1. Reconnaissance surveillance and Target acquisition (RSTA).
2. Surveillance for peacetime and combat synthetic aperture radar (SAR).
3. Deception operations.

4. Maritime operations (Naval fire support, over the horizon targeting, anti-ship missile deference, ship classification).
5. Electronic warfare (EW) and SIGNT (SIGnals INTTelligence).
6. Special and psyops.
7. Meteorology missions.

UAV is designed as an aircraft without pilot which gives it relatively smaller size compared to the size of ordinary manned flying vehicles. The airframe UAV was designed just to fulfil the required payload, fuel and its onboard flight control system. To fulfil such requirements, the UAV's fuselage was not as a symmetrical body but slightly in the form of arbitrary shape. Unfortunately, for every flying vehicle designed to fly on its own flight control system required a precise aerodynamics characteristics data. For UAV, fuselage may give a strong aerodynamics influence to the overall aerodynamics characteristics of the aircraft. Hence, an accurate fuselage aerodynamics analysis is needed for the success of designing a flight control system of the UAV. The present work focused on the development of aerodynamics analysis computer code based on semi empirical aerodynamic method for an arbitrary fuselage shape.

1.3 Problem Statements

Fuselage plays an important role in any type of aircraft. This aircraft component represent the part which all other aircraft components will be attached. The size and shape of fuselage may depend on the payload and also the aircraft engine placements. As a result, the fuselage may contribute around 25 % to 50 % [37] of the total drag force on the airplane depending on the shape and size of the fuselage. The best fuselage design contributes the smallest drag without an excessive pitching moment. In addition to this one might expect the presence of lift although the angle of attack is zero. Such condition can be achieved if the fuselage designed as cambered fuselage. To obtain the most suitable fuselage one need an appropriate fuselage aerodynamics analysis software capable for predicting the aerodynamics characteristics of symmetrical as well as unsymmetrical fuselage shape.

1.4 Research Objectives

To develop the aerodynamic capability in predicting the fuselage aerodynamic characteristics which may useful for designing flying vehicle such as light aircraft, UAV or missile, the research objectives will be carried out involve :

1. Creating the data base for various symmetrical fuselage models based on their shapes defined by a single component or two components consist of nose and mid body.
2. Developing computer code which allow one to visualize the fuselage shape in three dimensional view by using Tecplot software
3. Developing computer code based on given fuselage geometry to generate set of data needed in carrying out the aerodynamic analysis by using DATCOM software.
4. Developing computer code to analyse various fuselage geometry with better fuselage representations compared to the DATCOM software.
5. To investigate the aerodynamic characteristics of various fuselage shapes by using the developed computer code.
6. Developing computer code for predicting the pressure distribution over a symmetrical fuselage model by using Three Dimensional Panel Method.

1.5 Scope of Study

As mentioned in the previous sub chapter, the contribution of the fuselage aerodynamics characteristics to the overall aerodynamics characteristics of the aircraft need to be estimated precisely in the aircraft design work. An accurate aerodynamics characteristics prediction result becoming more important if one want to success in the development of flight control system. There are three approaches which can be done to estimate the fuselage aerodynamics. They are namely by using of (1) aerodynamics semi empirical method such as DATCOM, (2) Computational Aerodynamics/ Computational Fluid Dynamics and (3) Experimental aerodynamics by using wind tunnel. The present work will deal with the first two approaches and in context with the objectives of the research work as mentioned above, the scope of study in this research work involves:

1. The study on various fuselage geometry from fuselage consist as a single to multi components.
2. Study on various fuselage nose models commonly use in the designing flying vehicles.
3. Study on the use of post processing software for three dimensional plotting fuselage geometry by use Tecplot and DATCOM software for their aerodynamics analysis.
4. Study on the aerodynamics analysis for symmetrical and unsymmetrical fuselage based on semi empirical aerodynamics method.
5. Study on the implementation of Panel Method for Fuselage aerodynamics analysis.

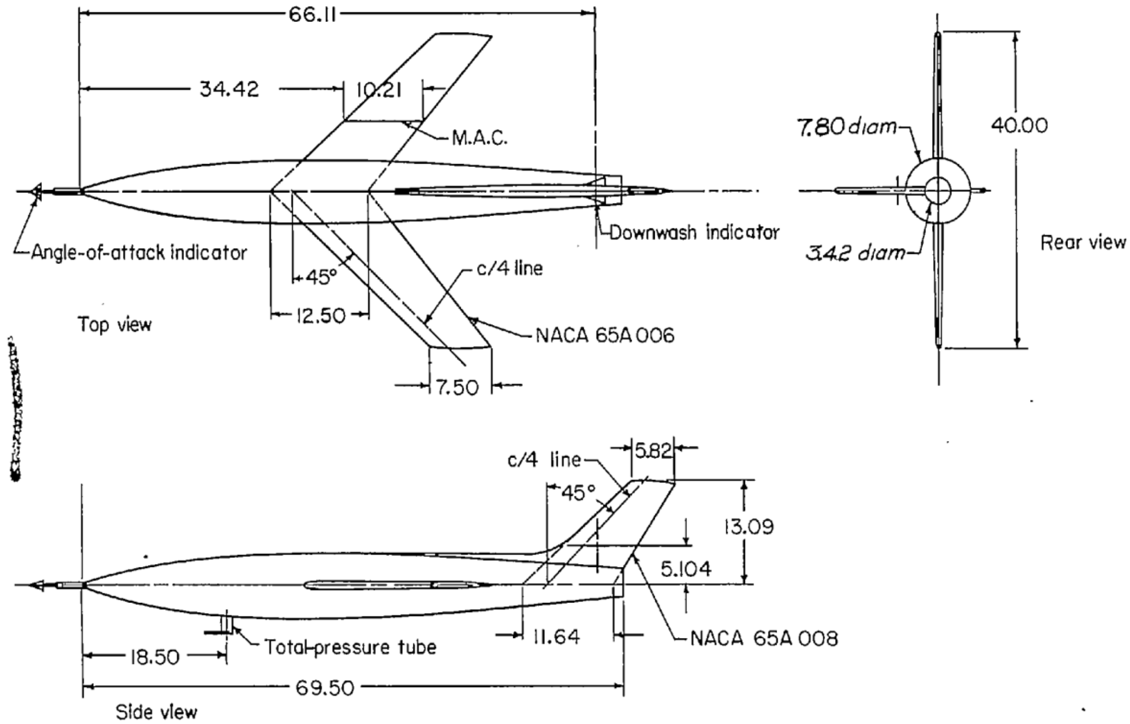
CHAPTER II

LITERATURE REVIEW

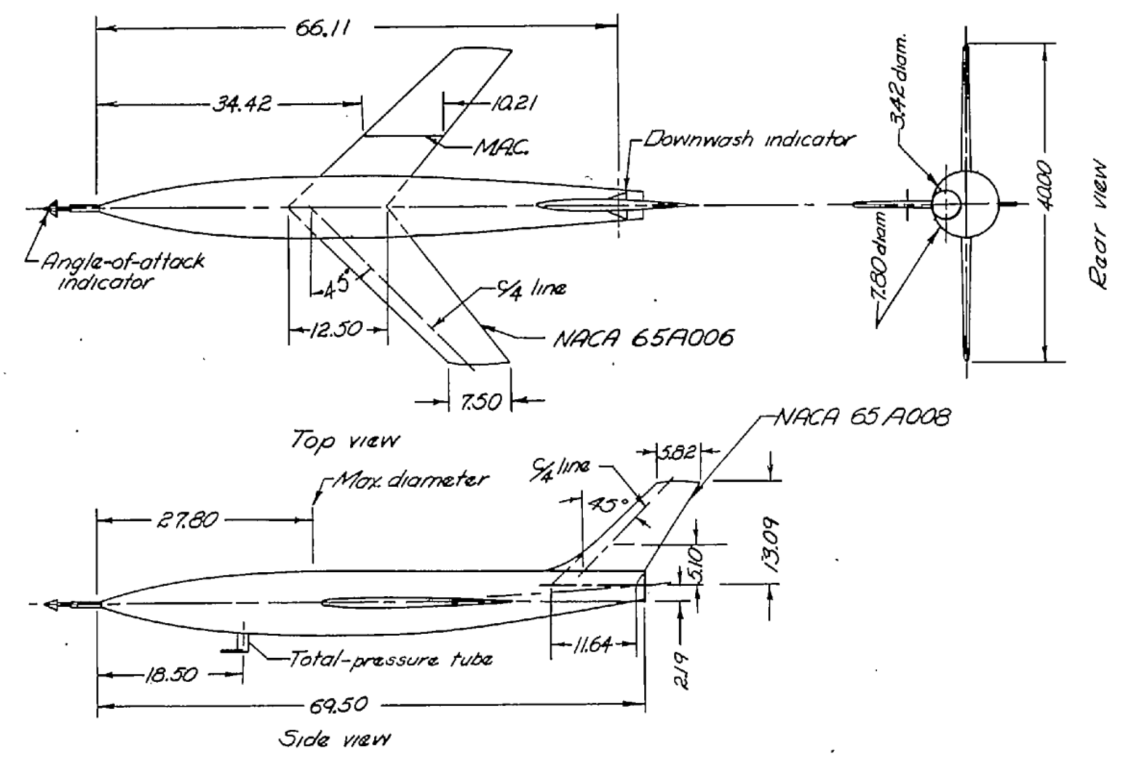
2.1 Introduction

The success of two Wright brothers making the first flight in 1903, had open up the opportunity for various countries to develop the aircraft technology. As a result, more than million aircrafts had been built and flown. Various type of aircraft had been introduced and the aircraft can be classified into several manners. The aircraft can be classified for instance according to the method how the aerodynamic lift force created. This point of view give the aircraft can be classified as a fixed wing aircraft and rotary wing aircraft.

Other classification of the aircraft may be from the point of view of their flight characteristic. From the range capability, the aircraft can be classified as a short, medium or long range aircraft. From the capability in takeoff and landing, the aircraft can be classified as a vertical takeoff and landing (VTOL) aircraft, or a short takeoff and landing (STOL) aircraft as opposed to the aircraft which having a normal takeoff and landing capability.The further aircraft classification may be derived from the type and the number of engine used or based on the shape of wing plan form or also according to how the arrangement of the aircraft components. So, here one can recognize the presence of the type of aircraft belong to the class of low wing aircraft, high wing or mid wing aircraft. While from the aircraft tail configuration one can identify the aircraft belong to the T tail aircraft or V tail aircraft. Every class or category of the aircraft will give influence to the fuselage shape of the corresponding aircraft. As result, there are variety of fuselage shape. The number of fuselage variety may have the same number of variety aircraft that had been built so far. However for stand point aerodynamics characteristics, the fuselage shape can be grouped into two. They are namely a symmetrical and unsymmetrical fuselage. To distinguish between them, the present work uses the definition according to Parks [4]. In the three dimensional views for a given aircraft drawing in top view, side view and rear view as depicted in the Figure 2.1. The fuselage shown in this figure has a circular cross section uniformly distributed along the longitudinal axis. The center of cross section at each fuselage station coincided with longitudinal axis resulted the aircraft seen from a rear side, the center of cross section at each fuselage station looks as a single points. Such fuselage shape is called as a symmetrical fuselage. In defining the unsymmetrical fuselage, Parks made a modification to the symmetrical fuselage. He made the part of upper fuselage surface rearward of the maximum diameter station parallel to the original fuselage center line and retaining the original fuselage coordinates in planes normal to it. This approach gives the unsymmetrical fuselage in three dimensional views as shown in the Figure 2.2.



(a) Symmetric fuselage model.



(b) Unsymmetric fuselage model.

Figure 2.1: The definition of symmetrical and unsymmetrical fuselage shape [4]

The symmetrical fuselage as presented in Figure 2.1 represents a parabolic body of revolution of fineness ratio 8.91 with maximum thickness at 40 % of the length. Fuselage ordinates are given in tabulated form as in Table 2.1

Table 2.1: Distribution of fuselage diameter of the fuselage NACA RM L54KL2 [4]

No	Fuselage Station x (inch)	Fuselage diameter D (inch)
1	0	0.0
2	3	1.60
3	6	3.00
4	9	4.24
5	12	5.28
6	15	6.14
7	18	6.84
8	21	7.34
9	24	7.66
10	27.8	7.80
11	30	7.78
12	33	7.74
13	36	7.64
14	39	7.48
15	42	7.30
16	45	7.06
17	48	6.78
18	51	6.44
19	54	6.08
20	57	5.66
21	60	5.18
22	63	4.68
23	66	4.12
24	69.5	3.42

As result of the aircraft technology requirement and development, there are various type of fuselage that had been introduced and implemented in designing a new flying vehicle. The required fuselage may represent a fuselage with three sections: nose, fuselage mid section and the fuselage tail cone. While other may came in the form of fuselage with two sections: fuselage nose and the fuselage mid section. In addition to this, there are some fuselages without clear partition in respect of those parts.

Several example of mathematical models can be used to generate a symmetrical fuselage in the form of single segment for instances:

2.1.1 Symmetrical Fuselage Model NACA RM L9I30 [5]

This report provide wind tunnel test over several symmetrical fuselage models. The fuselage has a uniform cross section in the form of circular cross section. If the fuselage length denoted as L and the fuselage diameter at any fuselage station x denoted as D(x). This NACA report introduced that the distribution of fuselage diameter in the longitudinal axis D(x) is given as [6]:

$$\mathbf{D}(\mathbf{x}) = \begin{cases} D_m - 2a\left(x_m - \mathbf{x}\right)^2 & \text{for} \quad 0 \le x \le x_m \\ D_m - 2b\left(x_m - \mathbf{x}\right)^2 & \text{for} \quad x_m \le x \le L \end{cases} \tag{2.1}$$

In above equation, the variable a, b and x_m are called as shape parameter. There are 12 fuselage models that had been generated and tested in the wind tunnel. All 12 fuselages have common frontal area $\left(\frac{\boldsymbol{\pi}}{4}\mathbf{D}_{\mathbf{m}}^2\right)$ that was equal to 0.307 square foot and base area was 0.0586 square foot. In addition to this, the fineness ratio F_N which represent the ratio of length L to the maximum diameter D had been set for 12.5, 8.91 and 6.04. The fineness ratio F_N = 12.5 will correspond with the fuselage length L = 93.72 inch, and for F_N = 8.91 with fuselage length L = 66.81 inch while for F_N = 6.04 with fuselage length L = 45.32 inch. The shape parameters a, b and $x_m$for those 12 fuselages are shown in the Table 2.2 below

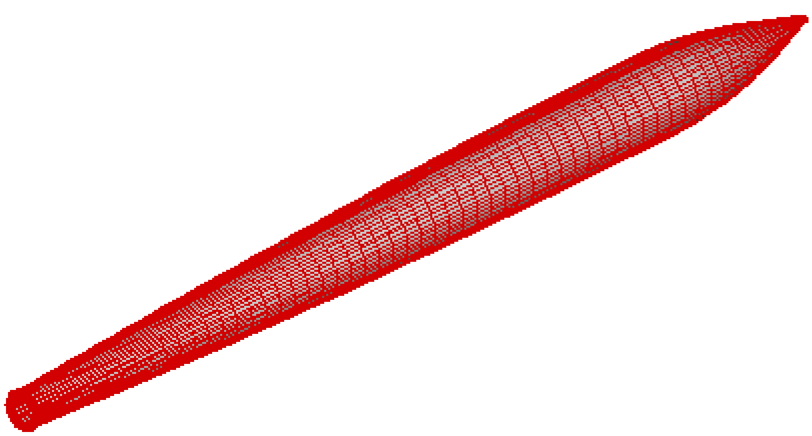
Table 2.2: Parameter fuselage geometry of fuselage model NACA RM l9I30

The body-shape parameters, a and b, have the values given below

Configuration	Fineness ratio	K	a	b
1	12.5	0.20	0.010673	0.000375
2	12.5	.40	.002668	.000667
3	12.5	.60	.001186	.001501
4	12.5	.80	.000667	.006006
5	8.91	.20	.021004	.000739
6	8.91	.40	.005251	.001313
7	8.91	.60	.002334	.002954
8	8.91	.80	.001313	.011818
[a]9	6.04	.20	.04564	.00161
[a]10	6.04	.40	.01141	.00285
[a]11	6.04	.60	.00507	.00642
12	6.04	.80	.00285	.02563

[a]Configuration taken from reference 1.

To distinguish with others fuselage shape, the fuselage which developed by use of mathematical expression as given in the Report NACA RM L9I30 denoted as Fuselage RML39I30-J, J=1,2,3,...,12. Here J=1 means that the fuselage generated based on the use of fuselage shape parameter as given in the j^{th} row of the Table 2.2. The shape of fuselage created by use of Eq.2.1, for a given a fixed fineness ratio F_N = 12.5 with different location maximum fuselage diameter x_M = 0.2L, 0.4L , 0.6L and 0.8L are shown in the Figure 2.2 respectively. While in view for different value of fineness ratio but having the same position of the maximum fuselage diameter for those three value of fineness ratio F_N = 12.5, 8.91 and F_N = 6.04 are shown in the Figure 2.3 respectively.



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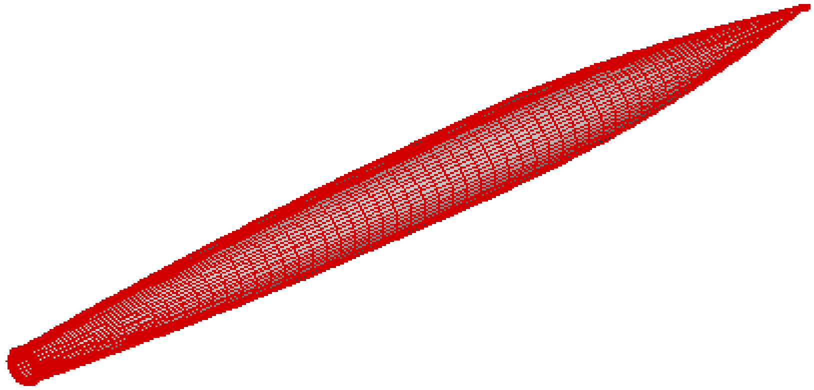

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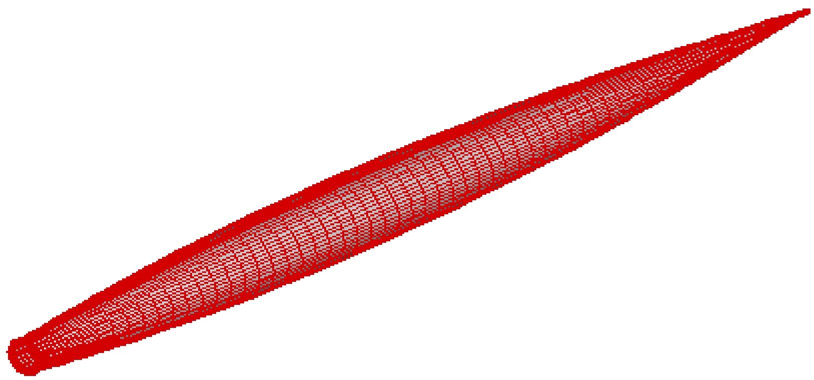

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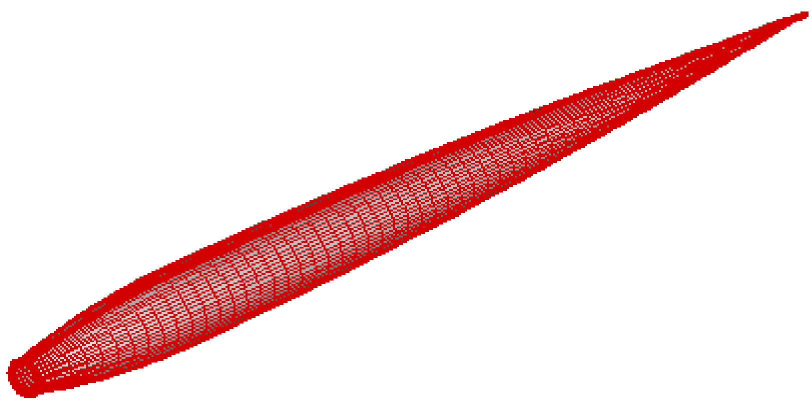
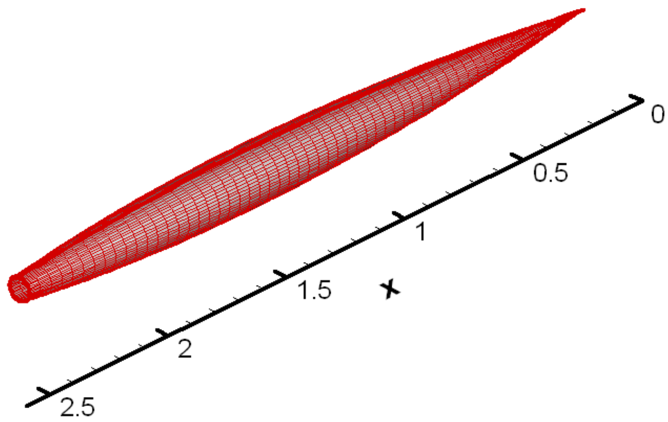
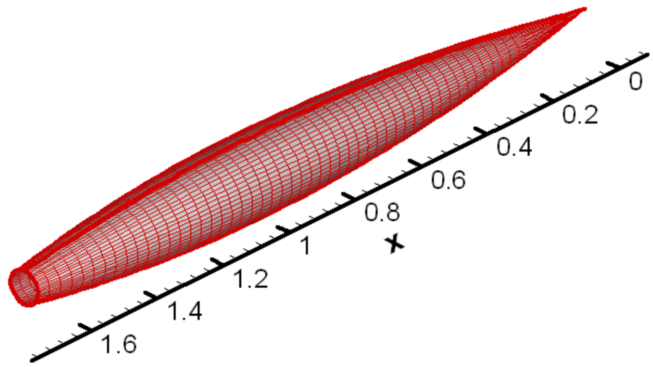


(d)

Figure 2.2: Fuselage model RML9I30-1 Fineness ratio F_N = 12.5, with (a) X_M = 0.2L. (b) X_M = 0.4L, (c) X_M = 0.6L and (d) X_M = 0.8L



(a)



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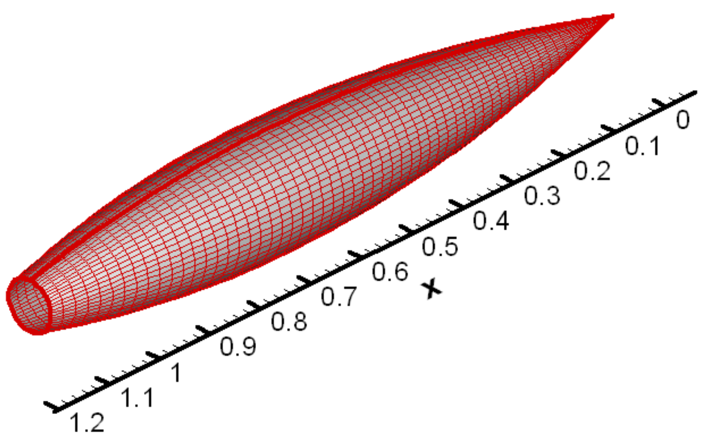


(c)

Figure 2.3: Fuselage RML9I30-1 with position maximum diameter $X_M = 0.6L$ and different Fineness ratio. (a) $F_N = 12.5$, (b) $F_N = 8.91$ and (c) $F_N = 6.04$

2.1.2 Symmetrical Fuselage Geometry Model NACA RM A50K24b [6]

The fuselage geometry was taken from NACA Report RM A50K24b [7]. This NACA report represent the experimental aerodynamics works on wing body configuration models. The wing plan form is in the form of triangular wing which known as delta wing. The fuselage model having circular cross section, with the distribution of the fuselage radius of the cross section r(x) is given as:

$$\mathbf{r(x)} = \mathbf{r_0}\left[\mathbf{1.0} - \left(\mathbf{1.0} - \frac{\mathbf{2x}}{\mathbf{L}}\right)^2\right]^{3/4}, \qquad \mathbf{0.0} \le \mathbf{x} \le \mathbf{L_B} \tag{2.2}$$

In above equation r_o is the maximum fuselage radius cross section, L_B is the actual fuselage length and L is the mathematical fuselage length. Similar equation as given by Eq. 2.2 is also used by other researchers but with different fuselage shape parameters. Table 2.3 shows the value of fuselage shape parameters had been used to generate fuselage as reported in the NACA report.

Table 2.3: The List of NACA Report adopted Fuselage Model RM A50K24b

No	Source	R_0 (inch)	L_B (inch)	L(inch)
1	NACA RM A50K24b[6,7,8]	2.17	45.38	54.13
2	NACA RM A50K20[9]	3.06	60.44	76.50
3	NACA RM A50K21[10]	3.06	60.44	76.50
4	NACA RM A9D25[11]	3.06	60.44	76.50

The top view of the technical drawing of wing body configuration which using Eq. 2.2 for defining the fuselage shape adopted from the Report NACA RM A50K24b as shown in the Figure 2.4

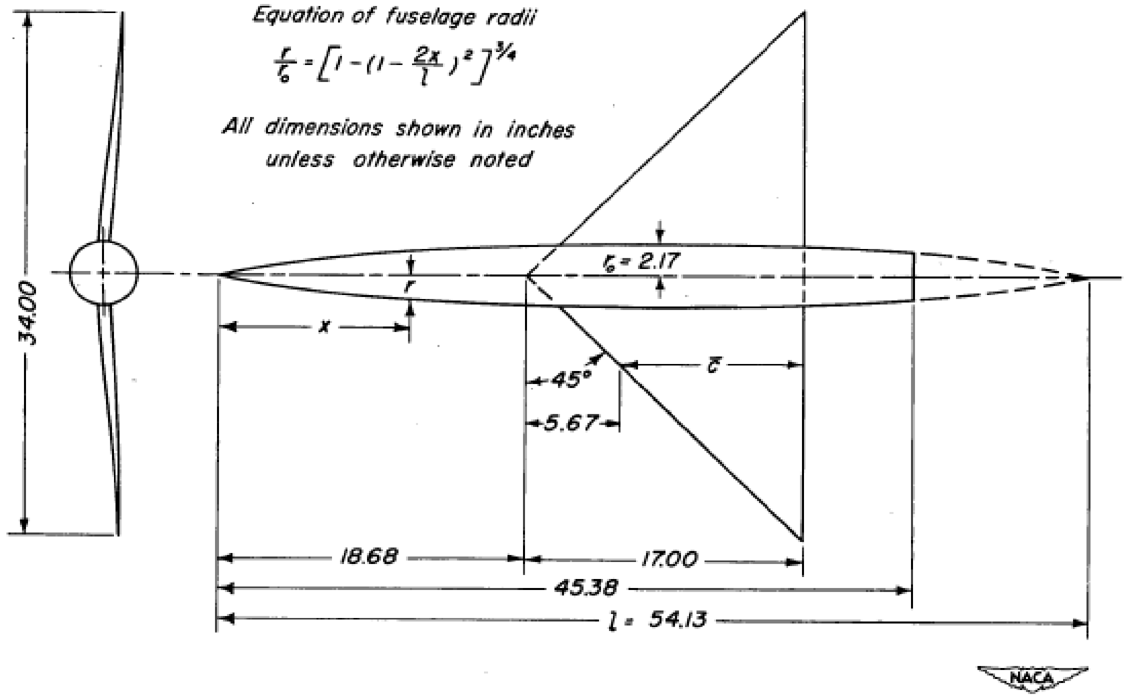
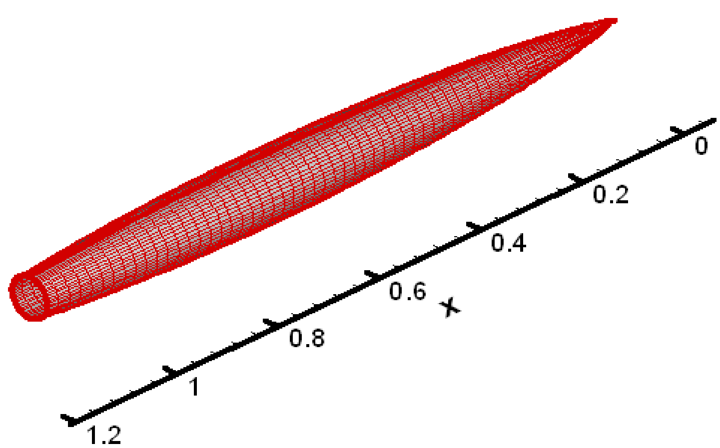


Figure 2.4: The top view of wing body configuration with fuselage shape according to Eq. 2.2[7]

Three dimensional view for those three type of fuselage due to different value of fuselage shape factors as defining their values in the Table 2.3 are shown in the Figure 2.5.



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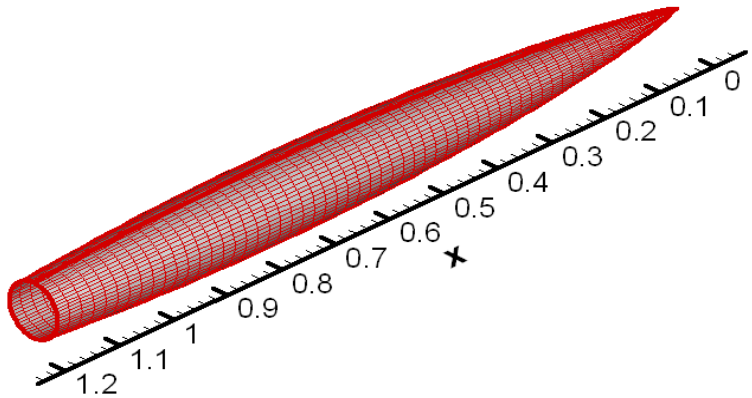

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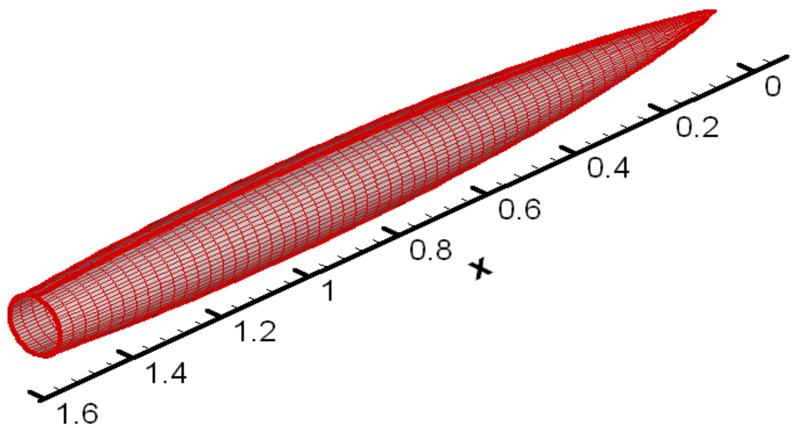


(c)

Figure 2.5: Fuselage Model RM A50K24b

2.1.3 Symmetrical Fuselage: Agard's Model – 1 [12]

Another mathematical expression to define fuselage shape is using a mathematical model introduced by AGARD [12]. For the purpose of wind tunnel calibration, AGARD, tested a body tail configuration as depicted in the Figure 2.6 below:

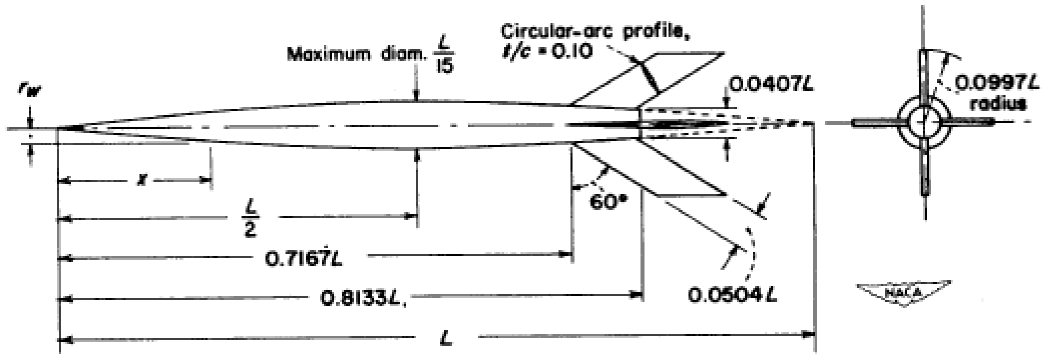


Figure 2.6: The Tail Body Configuration of AGARD Model [12]

This AGARD model have a circular cross section with the fuselage radius distribution**r(x)** is defined as:

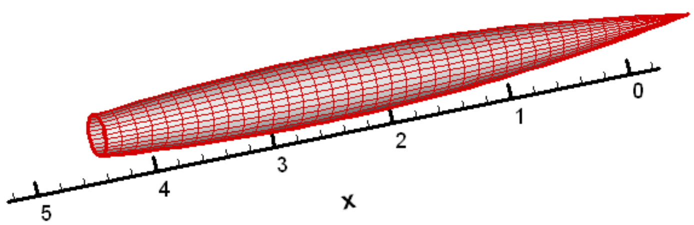
$$\mathbf{r(x) = \frac{x}{7.5}\, r_0 \left(1 - \frac{x}{L}\right) \; ; \quad 0.0 \leq x \leq L_B} \qquad (2.3)$$

Fuselage shape parameters in above equation are the actual fuselage length L_B and the mathematical fuselage length L. Unfortunately in their report, the value for those two shape parameters were not mentioned. However above equation is similar with the equation that hadbeen used to define the NACA RM-10 missile [13], which the actual fuselage length L_B is set equal to 81.33% of the mathematical fuselage length L. The NACA RM -10 M had been tested in various size of wind tunnel, as result there are various size of RM-10 that had been built. The table 2.4 shows the two fuselage shape parameter that were used to define and built NACA RM-10 missiles in relation with the size of wind tunnel test section where the aerodynamic experiment was conducted.

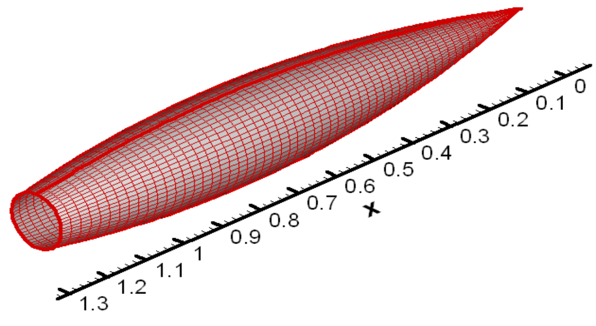
Table 2.4: The actual fuselage length of RM-10 missile related with the size of wind tunnel test section[13,14,15,16,17]

No	Wind Tunnel Size of Test Section	L_B (inch)	L
1	8 x 6 foot	73	89.76
2	8 x 6 foot	50	61.48
		42.05	51.70
3	1 x 3 foot	12.208	15.01
4	9 inch	9	11.06
		7.325	9.006
5	Flight	146.5	180.13

Figure 2.7(a) shows a three dimensional fuselage shape generated by using Eq. 2.3 for a given L_B = 0.8133 L = 50 inches and Figure 2.7(b) for the actual fuselage length L_B = 7.325 inches.



(a)



(b)

Figure 2.7: Agard Fuselage Model (a) Fuselage length L_B = 50 inches and (b) L_B = 7.325 inches

2.1.4 Symmetrical Fuselage: Parabolic Spindle Fuselage model [17]

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

$$\frac{\mathbf{r(x)}}{\mathbf{L}} = 4\frac{\mathbf{r_{mid}}}{\mathbf{L}}\frac{\mathbf{x}}{\mathbf{L}}\left(1-\frac{\mathbf{x}}{\mathbf{L}}\right) \qquad (2.4)$$

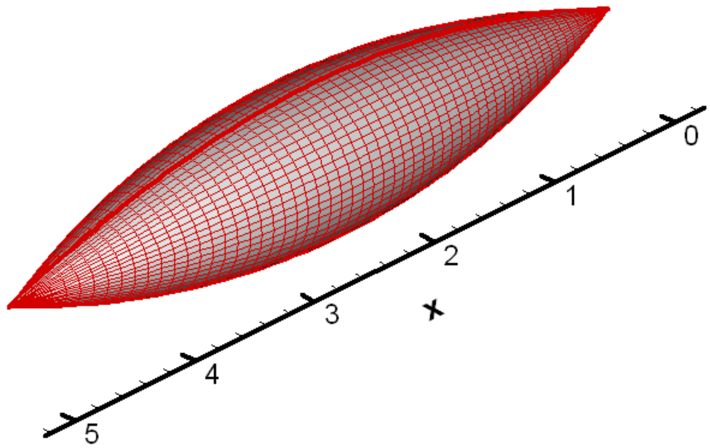
In above equation r_{mid} represents the fuselage radius cross section at the mid fuselage length. It also represents the maximum value of fuselage radius cross section. By definition, fuselage fineness ratio is defined as:

$$\mathbf{F_N} = \frac{L}{D_{max}} = \frac{L}{2\ r_{max}} = \frac{L}{2\ r_{mid}}$$

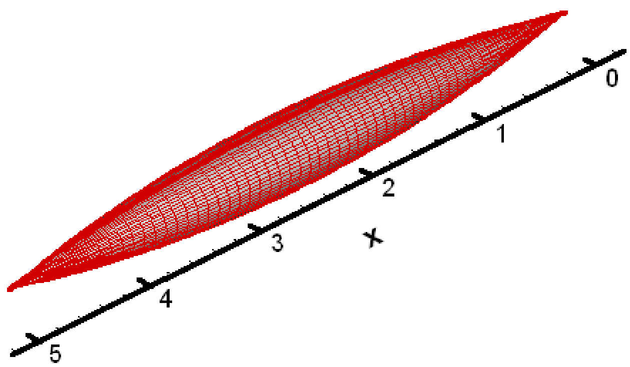
So in term of Fineness ratio F_N above equation, Eq. 2.4, can be written as:

$$\frac{\mathbf{r(x)}}{\mathbf{L}} = 4\frac{\mathbf{r_{mid}}}{\mathbf{L}}\frac{\mathbf{x}}{\mathbf{L}}\left(1-\frac{\mathbf{x}}{\mathbf{L}}\right) = \frac{2}{L/(2r_{mid})}\frac{\mathbf{x}}{\mathbf{L}}\left(1-\frac{\mathbf{x}}{\mathbf{L}}\right)$$
$$= \frac{2}{\mathbf{F_N}}\frac{\mathbf{x}}{\mathbf{L}}\left(1-\frac{\mathbf{x}}{\mathbf{L}}\right) \qquad (2.5)$$

Figure 2.8 shows the three dimensional view of two fuselage models generated by using Eq. 2.5, with the same fuselage length of 5 unit length but differ in term of their fineness ratio. The first figure describes the fuselage geometry for fineness ratio $F_N = 5$, while the second figure for the fineness ratio of 10.



(a)



(b)

Figure 2.8:Parabolic Spindle Fuselage Model (a) Fineness ratio $F_N = 5$, (b) $F_N = 10$

2.1.5 Symmetrical Fuselage: Ellipsoid of revolution [17]

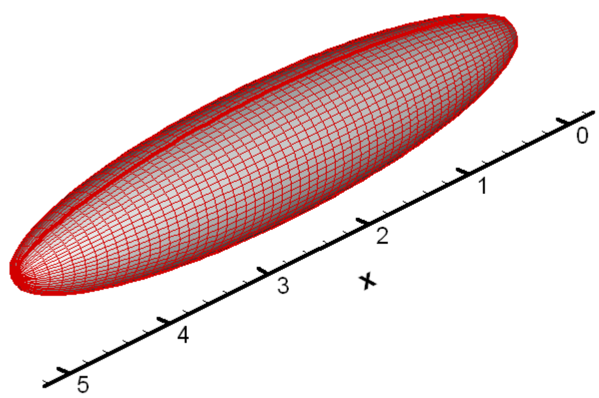
The radius of fuselage cross section r(x) for this type of fuselage as:

$$\frac{r(x)}{L} = 2\frac{r_{mid}}{L}\sqrt{\frac{x}{L}\left(1-\frac{x}{L}\right)} \quad (2.6)$$

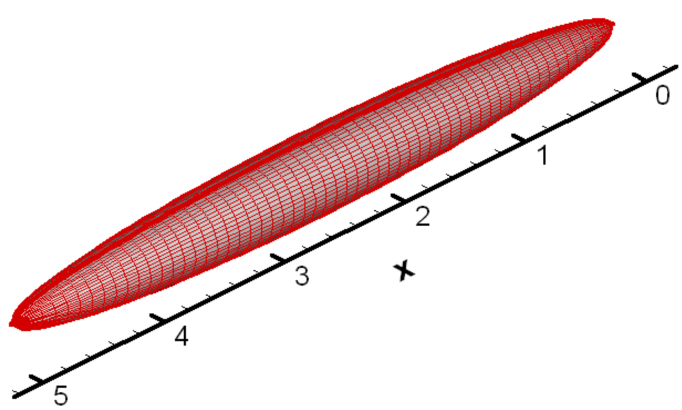
Here r_{mid} represent the radius of fuselage cross section at the mid length of fuselage. The radius of fuselage cross section at this position is maximum. Hence the fuselage fineness ratio is determined by the r_{mid}. For a given fuselage length L and the fuselage fineness ratio F_N,the radius of fuselage cross section at the mid of fuselage length is

$$\mathbf{r}_{\mathbf{mid}} = \frac{L}{2F_N}$$

Figure 2.9 shows two fuselage models created by use of Eq. 2.6. Both fuselages have the same fuselage length L equal to 5 unit length. The first figure correspond to the fuselage with fineness ratio 5 while the second one with F_N = 10.



(a)



(b)

Figure 2.9:Ellipsoidal Fuselage Model (a) Fineness ratio F_N = 5, (b) F_N = 10

2.2 Mathematical Model for Generating Symmetrical Fuselages: Multi Segments

Due to payload requirements or due to pilot visual ability over the outside environment of the cockpit, the fuselage need to be designed with fuselage partition. The fuselage need to be divided into nose part, fuselage mid section and with addition of fuselage boat tail.

An example of fuselage model which consist of two section, nose part and the fuselage mid section is AGARD model 2[12]. Other name of Agard model 2 is AGARD model B[20, 21]. This model actually consist of a wing and body combination. The wing is a delta in the form of an equilateral triangle with a span four times of the body diameter. The body is a cylindrical body of revolution with an Ogive nose. Figure 2.10 is a sketch of the model with the pertinent dimensions given in terms of the body diameter *D*.This fuselage model had been used for model of wind tunnel calibrations.

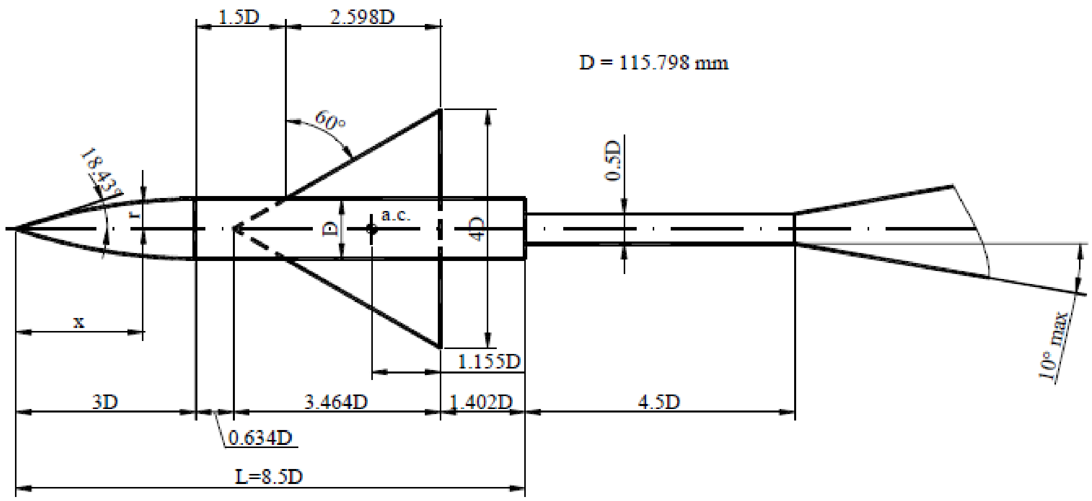


Figure 2.10: Basic Dimension of AGARD Model – B [12]

The distribution of fuselage radius of cross section for this AGARD model B can be given as:

$$\mathbf{r(x)} = \begin{cases} \dfrac{\mathbf{x}}{\ell_{\mathbf{N}}}\left(\mathbf{1} - \dfrac{\mathbf{1}}{(\ell_{\mathbf{N}})^2}\left(\dfrac{\mathbf{x}}{\mathbf{D}}\right)^2 + \dfrac{\mathbf{1}}{2(\ell_{\mathbf{N}})^3}\left(\dfrac{\mathbf{x}}{\mathbf{D}}\right)^3\right); & \mathbf{x} \le \ell_{\mathbf{N}}\mathbf{D} \\ \dfrac{\mathbf{1}}{\mathbf{2}}\mathbf{D}; & \ell_{\mathbf{N}}\mathbf{D} < \mathbf{x} \le \mathbf{L} \end{cases} \qquad (2.7)$$

In above equation, $\ell_{\mathbf{N}}$ is nose length factor. Figure 2.10 shows the case of AGARD model – B with nose length factor $\ell_{\mathbf{N}}$ = 3D and the fuselage diameter at the mid section D = 115.798 mm. While for a given Fuselage diameter D = 1.25 inch, the distribution of fuselage radius cross section of the nose part as given in the Table 2.5 below:

Table 2.5: Nose ordinates of AGARD Model 2[12]

Nose ordinates	
x, in.	r, in.
0	0
.188	.063
.375	.124
.563	.184
.750	.241
.938	.296
1.125	.343
1.313	.394
1.500	.436
1.688	.475
1.875	.508
2.063	.537
2.250	.561
2.438	.580
2.625	.599
2.813	.608
3.000	.616
3.188	.621
3.375	.623
3.563	.624
3.750	.625

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