AERODYNAMICS ANALYSIS FOR SEVERAL FUSELAGE GEOMETRIES USING FLUENT SOFTWARE AND AERODYNAMICS SEMI EMPIRICAL METHOD

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A thesis submitted in fulfillment of the requirement for the award of the

Degree of Master of Engineering

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April 2011

ABSTRACT

This study presents aerodynamics analysis over several generic fuselage geometries. The aerodynamics analysis carried out by use of DATCOM Software, Fluent and own developed computer code. The own developed computer code is computer code which developed based on semi empirical aerodynamics method adopted according to Roskam[1,2] and Datcom Handbook[3,4]. There are various possible fuselage shapes. Basically the size and fuselage shape determined by payload requirement, and also the related design objectives of that flying vehicle. However the present work focuses on symmetrical fuselage having uniform cross sections may in the form: circular, elliptic or rectangular cross section which suit for missiles. It had been known that a missile design goes through several steps, where the aerodynamic calculation one of the most important stage in missile design. Missiles as flying vehicles which are usually expendable and uninhabited, have provided an opportunity for designers to increase the ranges of speed, altitude, and maneuvering accelerations. Unfortunately such opportunity has created new aerodynamic problems and represent a challenge for the designers in order to maintain the flight path of the missile. In respect to the aerodynamics analysis on fuselage suited for missile. Here the pertinent fuselage geometry data had been chosen is in accordance to typical missile currently used in military operation, such as AGM – 129, AGM-86 , BGM – 109 and Exocet cruise. Such kind missiles have a fineness ratio around 10. The fuselage geometry defined according to several fuselage model available from various model such as Fuselage Agard Model 1, Agard Model 2, Parabolic Spindle, Ellipsoid of revolution ect. The aerodynamics analysis carried out at different Mach number in the range below Mach number 0.6 from angle of attack $\alpha = -5^0$ to $\alpha = 20^0$. The comparison result in term of lift and pitching moment coefficients for various angles of attack between DATCOM and The Developed computer code are in a good agreement. Through this study it had been found that the DATCOM software provided drag

calculation exclude the base drag component. Comparison Fluent and DATCOM can be done if some correction in defining the aerodynamics coefficient in Fluent is needed to be corrected. Through this analysis, data base of fuselage's aerodynamics characteristics is available and it will be very useful for supporting the flying vehicle design work.

CHAPTER 1

1.1 Introduction

The fuselage is the main body of the airplanes and rockets. There are many different shapes of the fuselages depending on the mission of the Flying vehicle designed. The flying vehicle designers have been trying to fabricate the most suitable configuration of flying vehicle to achieve the design objectives since the Bryan Wright brothers invented the first airplane. In addition to this, there is highly competition among various countries in the field of weaponry system in order to get the most appropriate missiles for military purposes.

It had been realized, that the fuselage whether it will be a part of aircraft or missile, it plays important role in determining the overall performance of flying vehicle. Payload requirement had made that fuselage geometry need to be defined first in any design process of flying vehicles. The aerodynamics characteristics fuselage becomes apparently significant if the flying vehicles are in the form of missile or rocket, since the most of aerodynamics characteristics for such flying vehicles is came from the fuselage. As result, the performance and the flight stability for such kind flying vehicle are dependent on the aerodynamics characteristic of the fuselage. There are various possible fuselage geometries can be purposed and defined. The fuselage sizing is normally carried out through firstly a volume specification in order to fulfill the payload requirements. Secondly surface contouring in order to obtain the overall fuselage geometry in the form of streamline body. There are several generic fuselage geometries which can be used as a basic plan form in defining the fuselage geometry for a particular flying vehicle. The present research will conduct aerodynamics analysis over various forms of generic fuselage geometries by using Fluent Software and Aerodynamics semi analytical method. The fuselage geometry will be investigated can be categorized into four groups:

1. Symmetrical fuselage developed base as a single expression for their radius cross section along main fuselage axis.
2. Symmetrical fuselage with super elliptic cross section (two mathematical expressions for width and height fuselage distribution).
3. Fuselage geometry which consist more than one fuselage component (fuselage nose, fuselage mid section and boat tail).
4. Unsymmetrical fuselage.

The aerodynamics analysis will be carried out at different Mach number in the range below Mach number 0.6 from angle of attack from minus 5^0 to positive 20^0. Through this will give an aerodynamics data base which will be very useful in supporting work on the flying vehicle design.

1.2 Research Background

Design requirements may made a particular flying vehicle having a fuselage with relative significant size compared to other components of flying vehicles. The fuselage becomes clearly dominant part for missile. The size of wing or controls surface for such flying vehicle normally relative smaller compared to the size of fuselage. As result the aerodynamics characteristics of the fuselage may play important role in determining the overall aerodynamics characteristics of missile. It is therefore the ability to predict the aerodynamics characteristics is important part in design missile.

1.3 Problem Statement

A missile design goes through several steps, where the aerodynamic calculation one of the most important stage to build a missile. Missiles are usually expendable and uninhabited flying vehicles. Such characteristics, expendable and uninhabitat, give an opportunity for designers to increase the ranges of speed, altitude, and maneuvering accelerations. All of these opportunities will, of course, created new aerodynamic problems. These aerodynamic problems are challenge for the designers, since the designers require to know the aerodynamic forces and moments which use to maintain the flight path of the missile at various flight conditions. Hence understanding fuselage aerodynamics is required for a better missile design.

1.4 Research Objectives

The major objectives of this study can be stated as follows:

- To obtain the aerodynamics characteristics over various forms of generic fuselage geometries.
- To carry out a comparative study on the fuselage aerodynamics prediction method among DATCOM software, Fluent software and the in house developed computer code.

1.5 Scope of Study

The scopes of this project are:

1. Define a generic fuselage geometry through literature study.
2. Define the fuselage geometry belong to: the first, second, third and fourth categories as mentioned above.

3. Use the first fuselage category carried out Fluent's comparative study in respect to the influence of mesh model and type of solver had been used.
4. Based on the result of step 3, carried out aerodynamics analysis for other fuselage geometries (Fuselage geometry category: 2, 3 and 4).
5. Aerodynamics analysis by using a semi empirical method
6. Comparing between the semi empirical method and Fluent results.

CHAPTER 2

2.1 The Fuselage

The fuselage is the main part of the airplanes and missiles; there are various forms of fuselages which their geometries are depended on their design objectives of that the Flying vehicle. For example, a passenger airplane will has a fuselage which is completely different from the body of a military aircrafts. The following figures illustrate some fuselage geometries of airplanes for typical passenger airplanes. Figure 2.1 shows the fuselage shape of Airbus 330 which designed to be able to accommodate 253-293 Passengers. Figure 2.2 shows typical of fuselage of small passenger airplane for four passengers, while figure 2.3 shows typical of fuselage for helicopter.

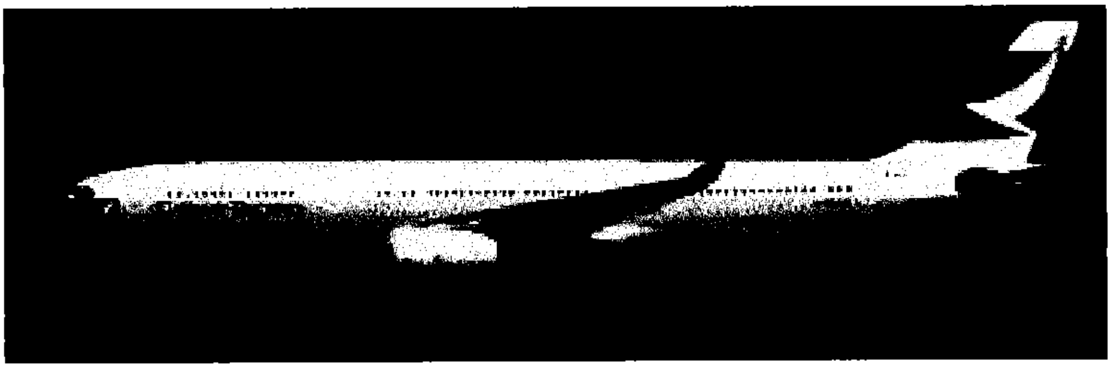

Figure2.1. The fuselage shape of Airbus 330*[www.aerofiles.com]*

Figure2.2. Typical of fuselage of small passenger airplane *[www.aerofiles.com]*

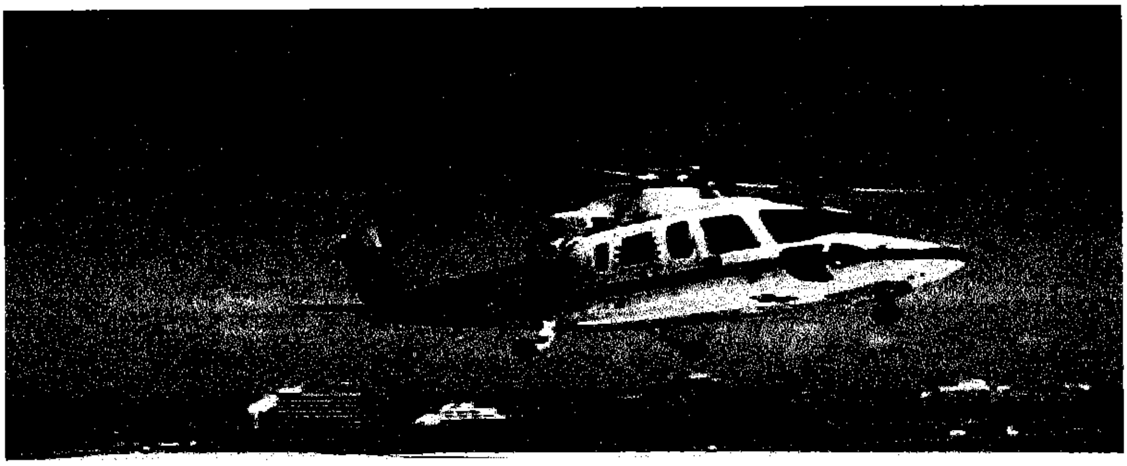

Figure2.3. Typical helicopter's fuselage. *[www.aerofiles.com]*

The present works is more focusing in the aerodynamics study for missile. It is there, discussion about missile given more further explantion in the present work. The shape difference between fuselage's missiles and other flying vehicles may due to difference in their design objectives. The missle's design objective may to bring explosive material to particular target and exploded. Speed and endurance may finally determine the shape and size of the missile. However, in response to fulfill the modern military requirement, there are various type of missile had been developed. As result no single manner to classify type of missile. The classification of missile may according to : points of launching and impact, type of guidance system, trajectory, propulsive system.

From the point of view shape and geometry, figure 1.4 below shows some of the missiles which have different cross-section area.

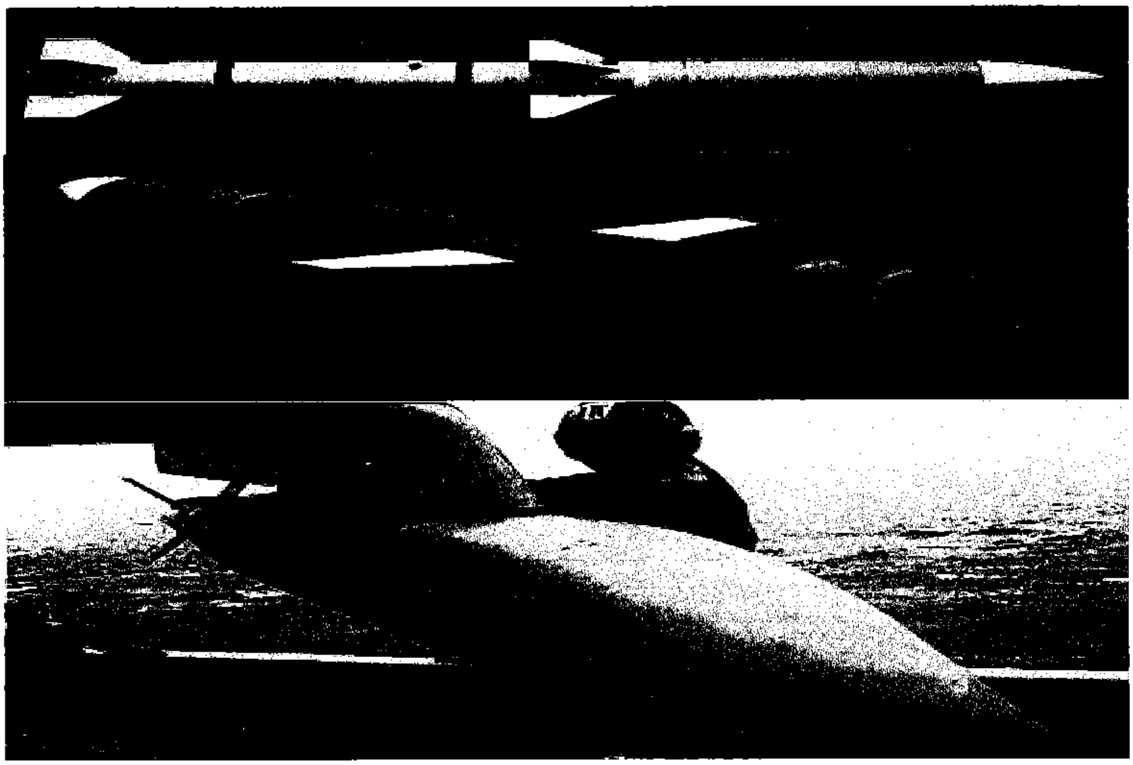

Figure.2.4. Missiles with different cross-section area *[www.wikipedia.org]*

2.2. Missiles

The word missile comes from the Latin verb “mittere”, meaning "to send". In military parlance the missile is a weapon system propelled by internal combustion mechanism toward its target with some form of guidance mechanism.

2.3. History of Missiles

The first rocket was almost certainly constructed in China, but the date of that invention is not known. There is evidence that the Chinese knew about black gunpowder at least two centuries before the birth of Christ, but the explosive was probably used exclusively for ceremonial purposes. The concept of using gunpowder to
propel an object through space probably did not arise for more than a thousand years, perhaps during the thirteenth century. Records of the time indicate that gunpowder was attached to sticks for use as offensive weapons during battle. The birth of rocketry was, therefore, intimately associated with their first use as missiles.

For a short period of time, rockets were a reasonably effective weapon in warfare. For example, French troops under Joan of Arc apparently used simple rockets to defend the city of Orleans in 1429 *[www.aerofiles.com]*. Military strategists of the time devised imaginative and sometimes bizarre variations on the rocket for use in battles, but such concepts were apparently seldom put into practice.

Figure .2.5. Early Chinese rocket

Airborne missiles were experimented with in World War I and used extensively in World War II. Since then a wide variety of airborne missiles have been tested in combat many times till now. Their performance has continuously improved because of technological advances in aerodynamics, guidance, propulsion, and warheads.

2.4. Missile Aerodynamics Versus Airplane Aerodynamics:

There are some differences between the missiles and the airplanes, the first difference that the missiles are usually expendable and uninhabited. That provides an opportunity for designers to increase the ranges of speed, altitude, and maneuvering accelerations. However it may created new aerodynamics problems. For instance, the higher allowable altitudes and maneuvering acceleration permit operation in the nonlinear range of high angles of attack. Wherefore, a large longitudinal acceleration will be a logical result whether the missile is ground-launched or air-launched, can utilize very high wing loadings, and can dispense with landing gear. In the absence of a pilot, the missile can sometimes be permitted to roll and thereby to introduce new dynamic stability phenomena. The flying of missiles without a pilot have brought problems into the missile guidance system, in additional to the problem of guidance system also the acting of air frame introduce very complicated problems. The present work will more focused to the aerodynamic analysis of fuselage related to the missile, hence further detail of missile will be discussed in the following sub chapter.

2.5. Classification of Missiles

Missiles can be classified on the basis of points of launching and impact, type of guidance system, trajectory, propulsive system. Trim and control device, etc. An important classification on the basis of points of launching device and impact is given in table 2.1.

Another source of distinction among missiles is the guidance system. In a command system the missile and the target are continuously tracked from one or more

Vantage points, and the necessary for the missile to intercept the target is computed and relayed to the missile by some means such as radio (Jack n. Nielsen)

TABLE 2.1. CLASSIFICATION OF MISSILES (Jack n. Nielsen)

AAM	Air-to-air missile
ASM	Air-to-surface missile
AUM	Air-to-underwater missile
SAM	Surface-to-air missile
SSM	Surface-to-surface missile
UUM	Underwater-to-underwater missile

Another method of classifying missiles is with regard to the type of trajectory taken by the missile. A ballistic missile is launched at a steep angle to an altitude depending on the range, and then glides down on the target. A skip missile is launched to an altitude where the atmosphere is very rare, and then skips on the atmospheric shell.

On the basis of propulsive systems missiles recieves a short burst of power that rapidly accelerates it to top speed and then glides to its target, it is a boos-glide missile.

Sometimes a missile is termed single-stage, double-stage, etc., depending on the numbers of stages of its propulsive system.

Further differentiation among missiles can be made on the basis of trim and control devices, A canard missile has a small forward lifting surface that can be used for either trim or control similar to a tail-first airplane.

A missile controlled by deflecting the wing surface is termed a wing-control missile, and one controlled by deflecting the tail surface is termed a tail-control missile. It is to be noted that these definitions depend on which set of lifting surface is taken as the wing and which is taken as the tail. For missile with two sets of lifting surface, we will specify the wing to be the main lifting surfaces and the tail to be the balancing surfaces, a distinction maintained throughout the book. In a cruciform missile, sets of controls at right angels permit the missile to turn immediately in any plane without the necessary of its banking. On the ather hand a bank-to-turn missile, like an airplane, banks into the turn bring the normal acceleration vector as close to the vertical plane of symmetry as possible.

Considering that missile technology development had been progressing rapidly, as result there are thousands type of missiles around the world had been built. Table 2.2 shows a comparison pertinent performance and size for well known missile belong to class of air to air missile. While for surface to air missile as given Table 2.3. Figure 2.6a, b, c, d and e and Figure 2.7a, b, c, d, and e show the shape and configuration of missiles are shown in the Tables 2.2 and 2.3 respectively.

Table 2.2. Some examples of surface to air missiles (www.aerofiles.com)

Code Name	**Manufacturer**	**Length**	**Diamater**	**Operational range**	**Flight altitude**
V-750	Soviet Union	10.6 m	0.7 m	45 Km	20 Km
RIM-161	Raytheon, Aerojet	6.55 m	0.34 m	>500 Km	>160 Km
Akash	India	5.78 m	0.35 m	30 Km	18 Km
RIM-7	United States	3.64 m	0.203 m	19 Km	-
Crotale	France	2.4 m	0.16 m	16 Km	9,000 m

Table 2.3. Some examples of air to air missiles (www.aerofiles.com)

Code Name	**Manufacturer**	**Length**	**Diamater**	**Weight**	**Operational range**
AIM-120	United States	3.7 m	0.18 m	152 Kg	48 Km
IRIS-T	Germany	2.936 m	0.127 m	87.4 Kg	~25 Km
AIM-132 ASRAAM	United Kingdom	2.90 m	0.166 m	88 Kg	18 Km
K-5	NATO	2.5 m	0.2 m	82.7 Kg	6 Km
K-100-1	Russia & India	6.01 m	0.4 m	748 kg	300–400 km

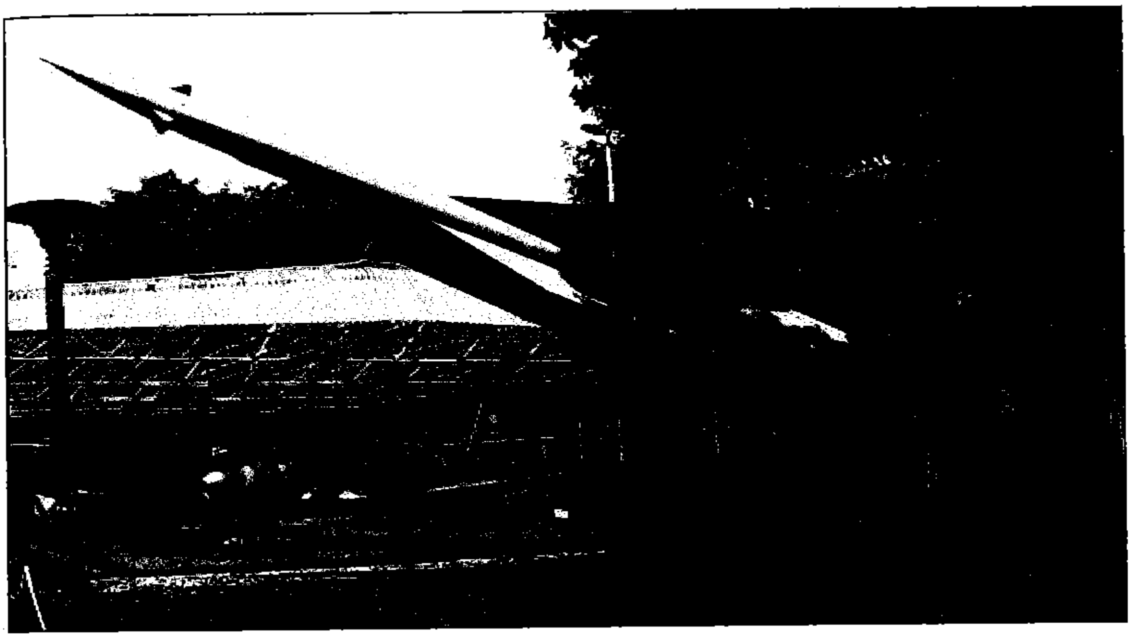

Figure 2.6a. V-750, a Surface-to-air missile *[www.wikipedia.org]*

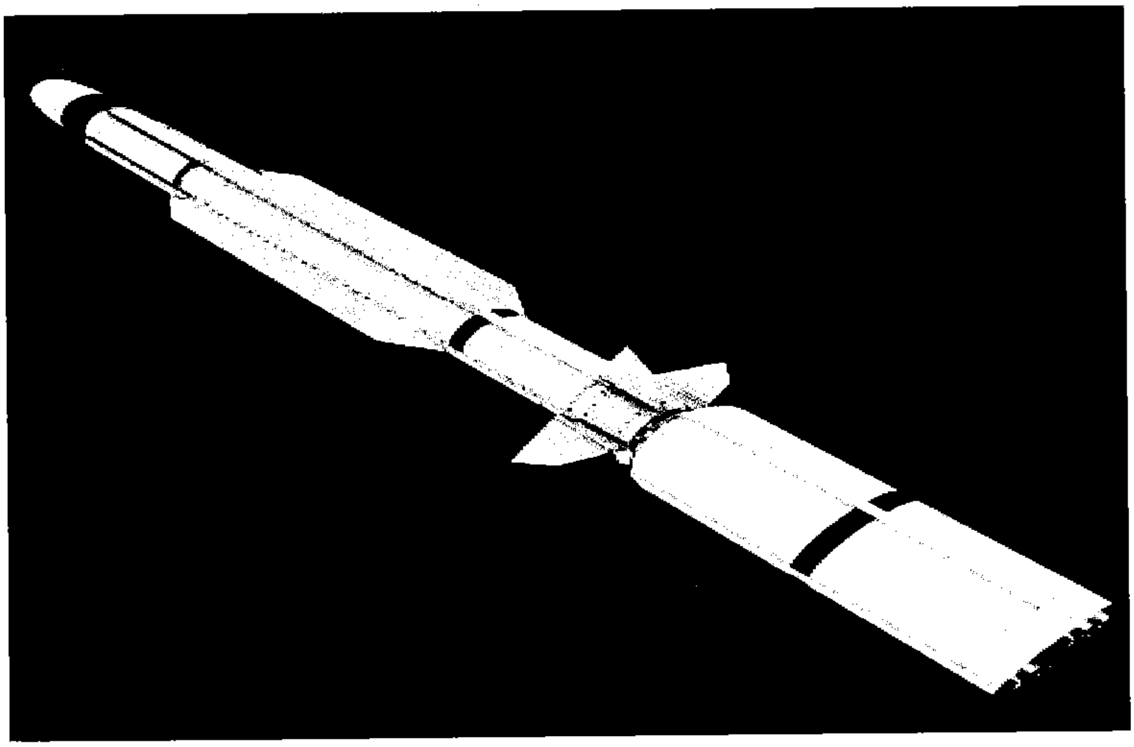

Figure2.6b. RIM-161, a Surface-to-air missile *[www.wikipedia.org]*

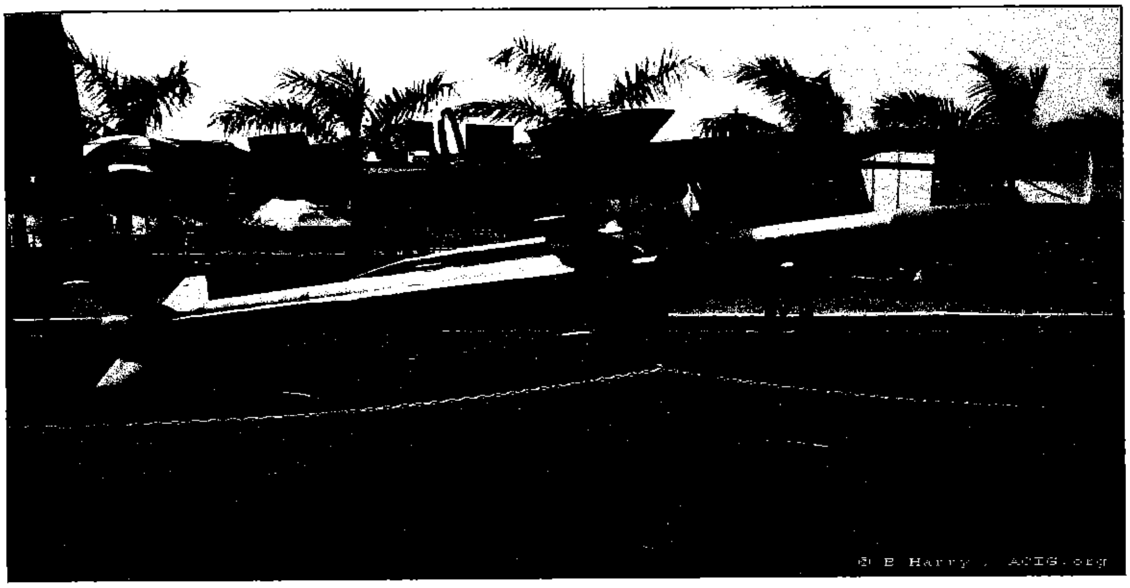

Figure 2.6c. AKASH, a Surface-to-air missile *[www.wikipedia.org]*

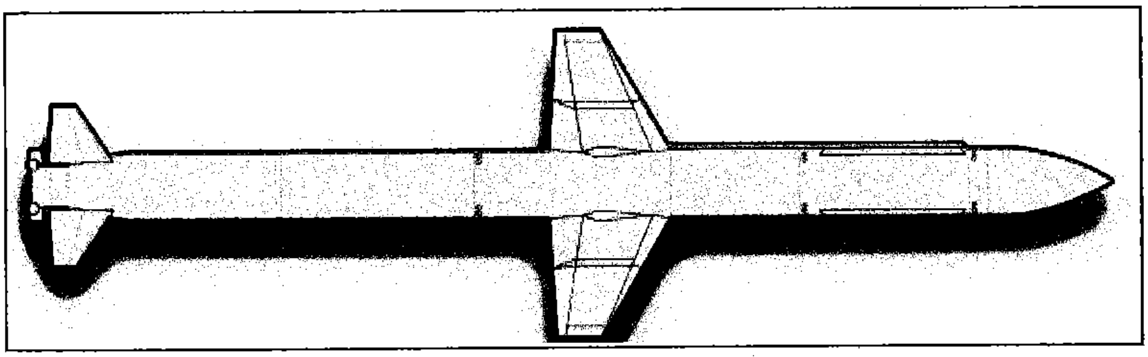

Figure 2.6d. RIM-7, a Surface-to-air missile *[www.wikipedia.org]*

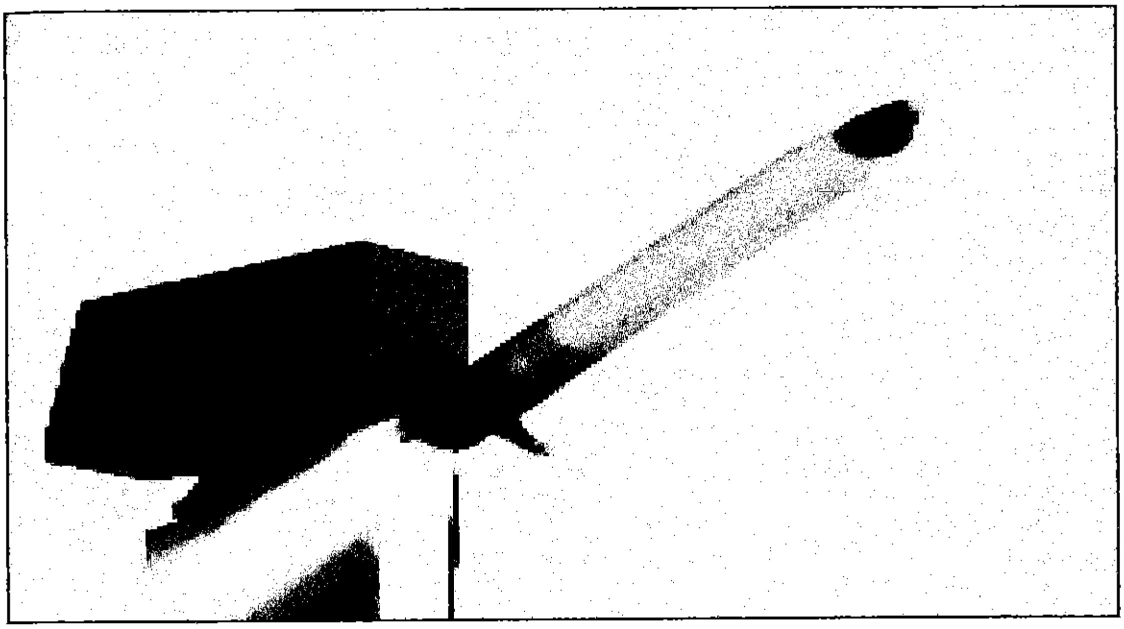

Figure 2.6e. Crotale, a Surface-to-air missile *[www.wikipedia.org]*

Figure 2.7a. AIM-120, an air to air missile *[www.wikipedia.org]*

Figure 2.7b. IRIS-T, an air to air missile *[www.wikipedia.org]*

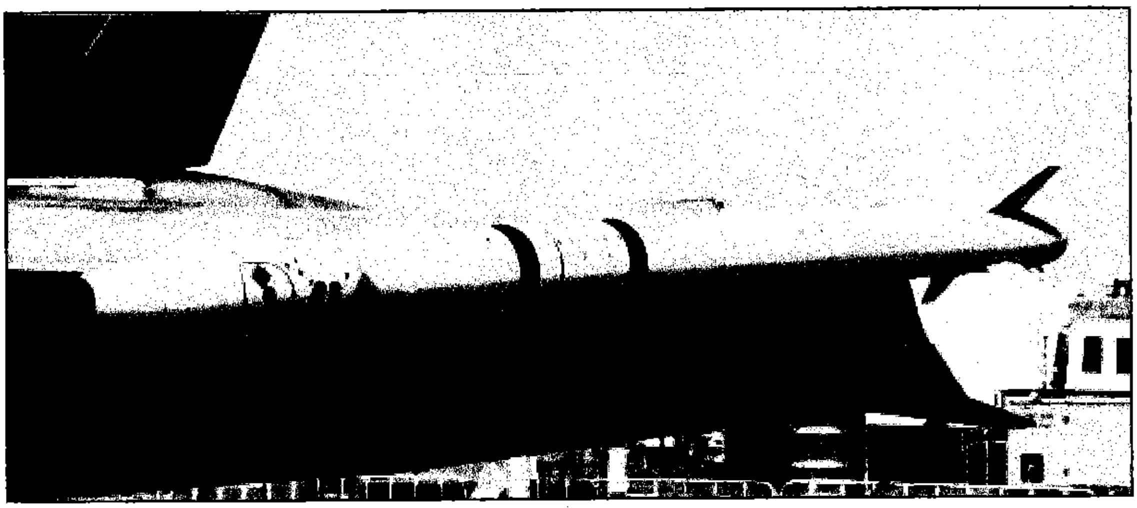

Figure 2.7c. AIM-132 ASRAAM, an air to air missile *[www.wikipedia.org]*

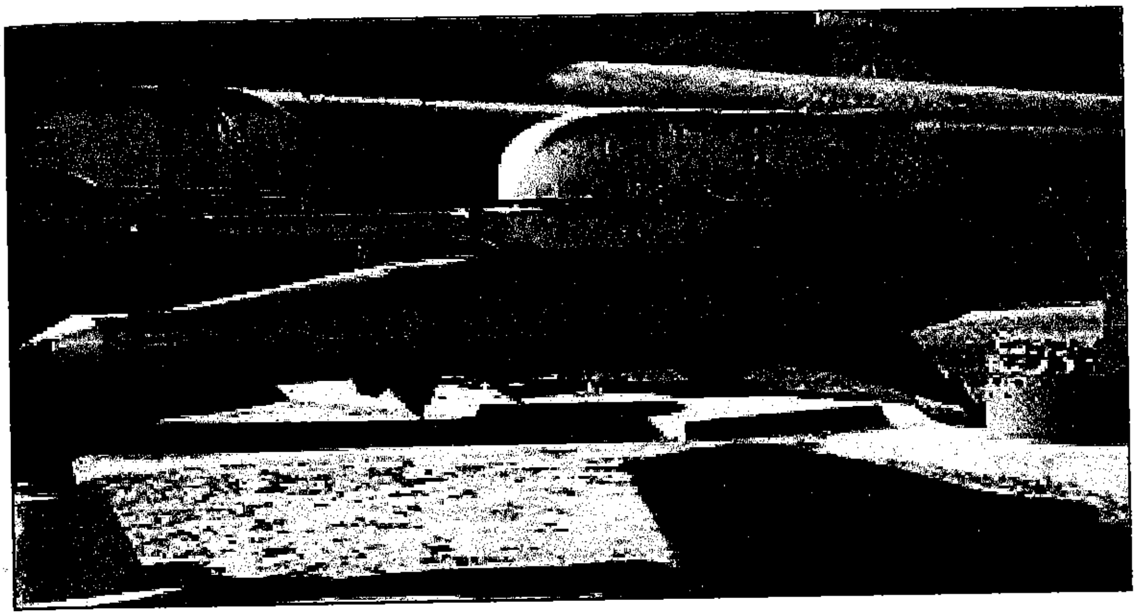

Figure 2.7d. K-5, an air to air missile *[www.wikipedia.org]*

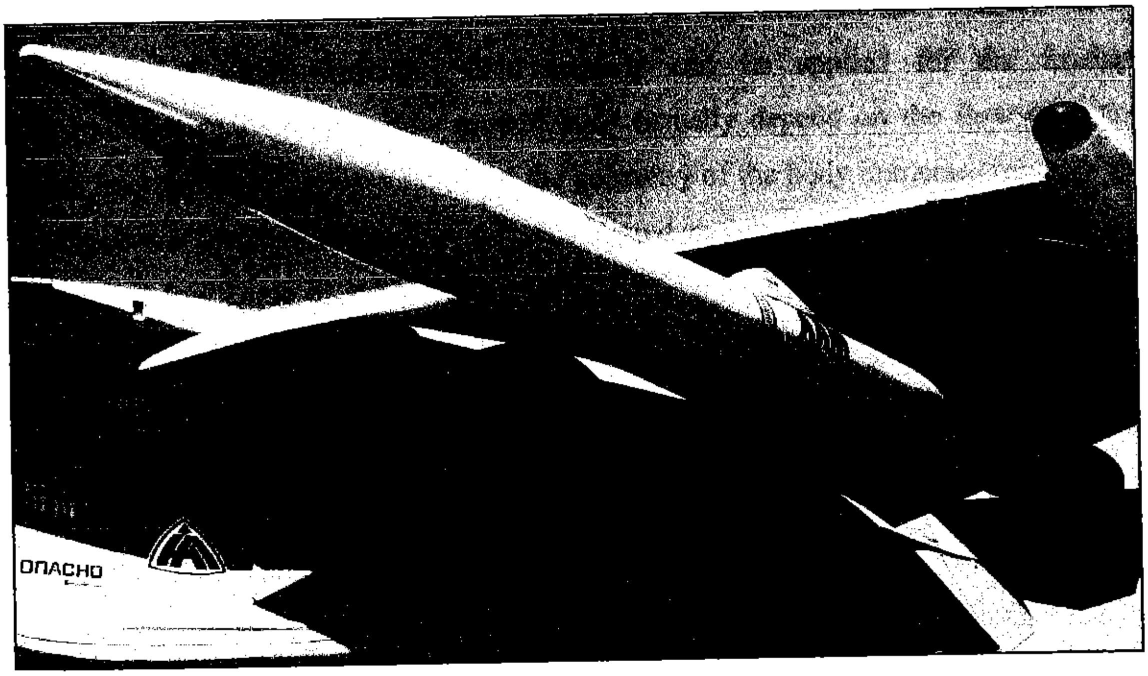

Figure 2.7e. K-100-1, an air to air missile *[www.wikipedia.org]*

CHAPTER 3

3. Methodology

3.1.1 The Overview Of The Development Fuselage Aerodynamics Analysis.

The way how to estimate the fuselage's aerodynamics characteristics can be said are similar to the way one solve the fluid dynamic flow problems. The numerical method applicable for solving the fluid problems such well known numerical schemes in the Computational Fluid Dynamics field actually can be applied for the fuselage aerodynamics analysis. The flow around body actually depend on the flow condition which may appear in the flow field and the geometry of the body immersed on it. If the fuselage has a special form and it can be considered as a streamline body and operated at relatively a low angle of attack and low Mach number, then the flow problem can be treated as Potential Flow problem. Here one can use a singularities method such as Panel method to predict the aerodynamics problem. In other hand, if such the fuselage operated at high Mach number which the compressible effect can be ignored, so such flow problem can be considered to be governed by the Compressible Euler Equations. Hence one can use the method which can be applied for solving such type equation, such as one may use MacCormack Scheme, Steger Warming Scheme, Beam Warming Scheme, TVD Scheme (Hoffman,2000 and Hirsch, 2007) etc. All mentioned methods are relatively complicated and a computer time consuming. The panel method requires a paneling geometry over the surface, while solving the Euler equation require an appropriate meshing over the flow field domain.

To do a fuselage aerodynamics performance analysis, the present work uses a semi empirical method developed by group researcher of US air force known as

DATCOM Semi Aerodynamic Analysis Approach (D. E. Hoak ,1960). In addition of the use Fluent software for a comparison result purposes. The aerodynamic problem is very sensitive to the geometry of the body under consideration, it is, therefore, the fuselage geometry will be discussed first in the following sub chapter.

3.1.2 Basic Fuselage Geometry Flying Vehicles

In most cases the geometry of fuselage flying vehicle sees from top view or side view can be divided into three sections: (a) nose section, (b) mid section and (c) tail section. The total length of fuselage L would be the sum of nose length, cabin length and tail cone length. Figure 3.1 shows the typical of fuselage shape for the airplane which is also applicable for the winged missile.

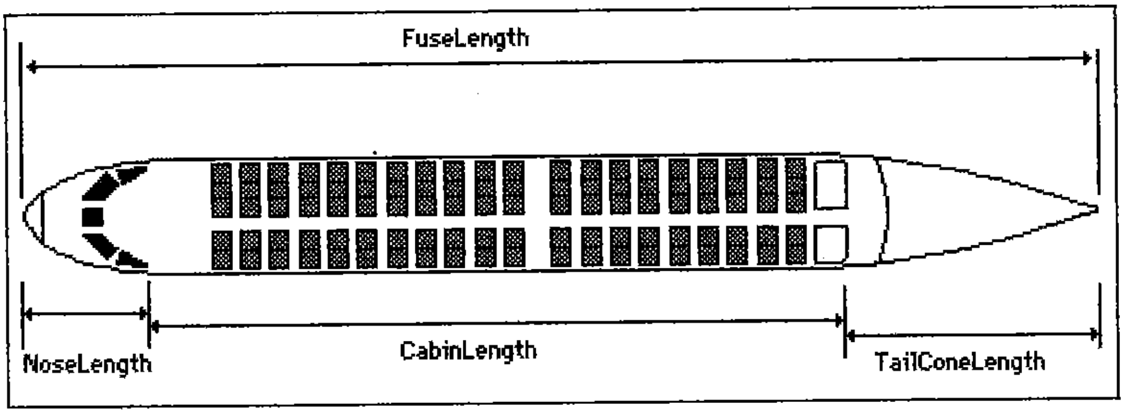

Figure 3.1. Fuselage shape for transport aircraft

For the case of missile, there are three basic configurations of missile geometries from side view. They are namely :

- The missile configuration expressible with single mathematical expression.
- Missile which consist of two segments: nose and mid body missile
- Missile which consist of three segments: nose, mid body missile and boat tail segment.

An example of missile which its geometry can be expressed in a single mathematical expression as shown in the Figure 3.2 .

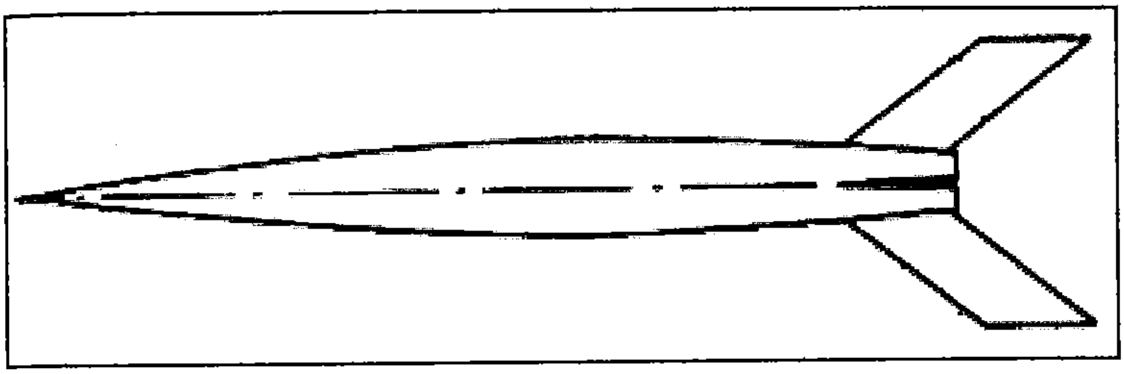

Figure 3.2. A missile with single mathematical experession

The second fuselage model of missiles that has two segement nose and mid body as shown in the next figure.

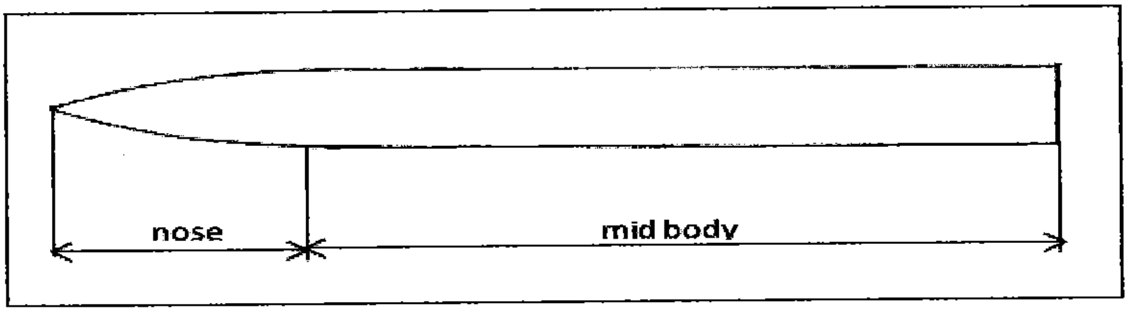

Figure 3.3. A missile with two segments nose and mid body

Fuselage model with three segments which has nose , mid body and tail as shown in the figure 3.4.

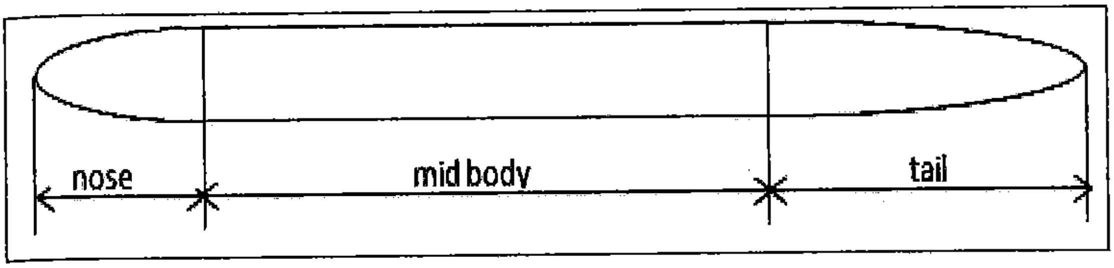

Figure 3.4. A missile with two segments nose, mid body and tail

In addition, the difference between one flying vehicles to other might come from their difference in shape of fuselage cross section. There are various shape of fuselage cross section had been developed as shown in the Figure 3.5.

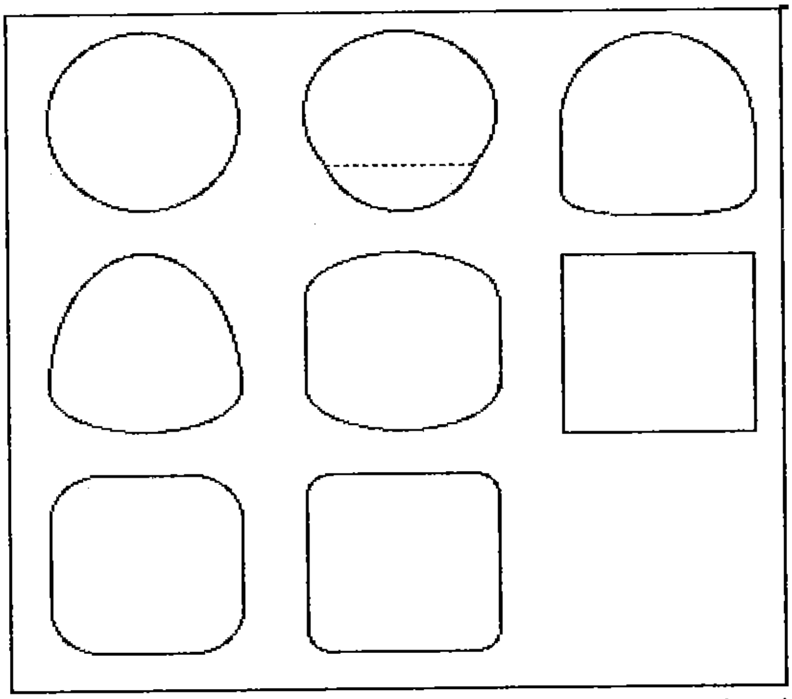

Figure 3.5. The fuselage geometry from the fuselage cross section point view.

3.2 Mathematical model of Fuselage Geometry of Missile.

Figure 3.6 had shown a typical shape of fuselage from side view drawing. For a such typical shape one could generate their geometry data since some of them had their own analytical formulation. The following subchapter presents some of fuselage shapes which can be generated by using a mathematical model.

3.2.1 Agard Model -1[1]

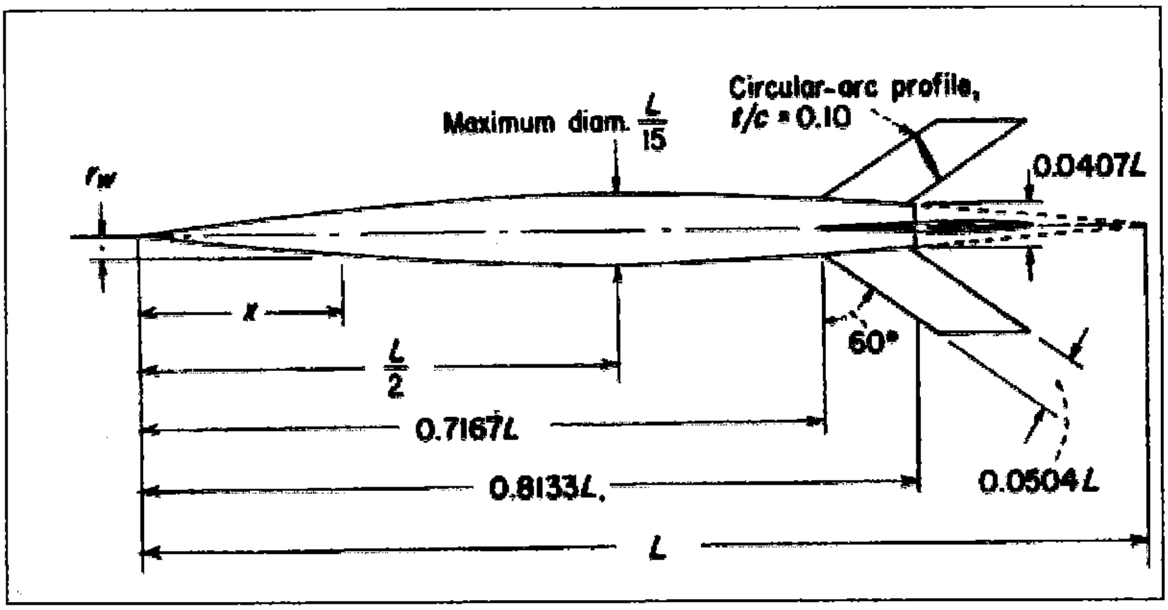

Figure 3.6 The fuselage shape : Agard Model -1

Figure 3.6 as mentioned above shows the side view of the fuselage model which can be generated by using a distribution function for the local radius of fuselage cross section $r(x)$ defined as:

$$r(x) = \frac{x}{7.5}\left(1 - \frac{x}{L}\right) \qquad (3\text{-}1)$$

Above equation could be generalized to have a form as:

$$r(x) = \frac{x}{A}\left(1 - \frac{x}{L}\right) \qquad (3\text{-}2)$$

Hence for different value of A for a Fixed L, one can create a various shape of fuselages. There is no fuselage division into three sections for this model.

3.2.2 Agard Model – 2[1]

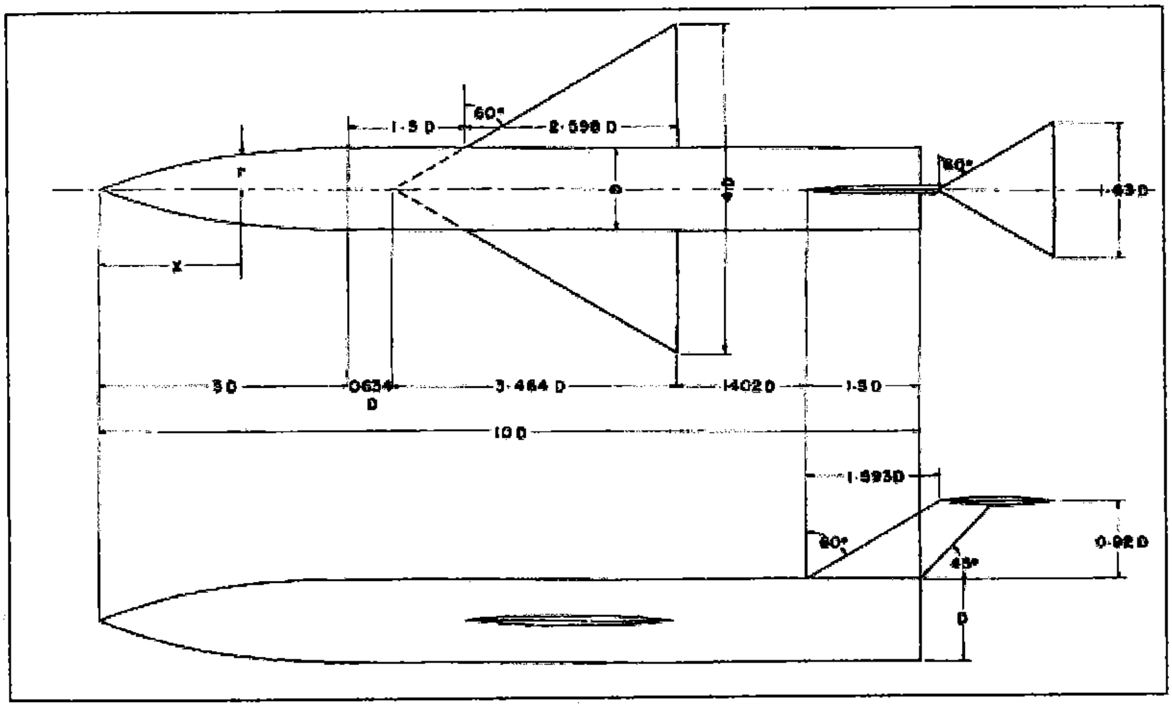

Figure 3.7 Side View Drawing : Agard Model – 2

The fuselage shape , Fig. 3.7, can be created by using a distribution function for the local radius $r(x)$, in form as:

$$r(x) = \frac{x}{3.0}\left(1 - \frac{1}{9}\left(\frac{x}{D}\right)^2 + \frac{1}{54}\left(\frac{x}{D}\right)^3\right) \qquad (3\text{-}5)$$

In above equation, the variable D represents the fuselage diameter. If the variable dependent x is set to be $x = 3D$ and substitute into Eq. 3.5 one would get :

$$r(x) = \frac{x}{3.0}\left(1 - \frac{1}{9}\left(\frac{x}{D}\right)^2 + \frac{1}{54}\left(\frac{x}{D}\right)^3\right)$$

$$= \frac{3D}{3.0}\left(1 - \frac{1}{9}\left(\frac{3D}{D}\right)^2 + \frac{1}{54}\left(\frac{3D}{D}\right)^3\right) = D\left(1 - \frac{1}{9}(3)^2 + \frac{1}{54}(3)^3\right) = \frac{1}{2}D$$

While if one is set $x = 6D$, for instance, one would get $r(x = 6D) = 2D$. However, Fig.3.6 shows that $r(x) = (1/2)D$, namely constant for $x > 3D$, Hence this fuselage model introduced that the fuselage was divided into two section: Nose section and mid fuse section. In other word, the equation 3.5 should be represented as:

$$r(x) = \frac{x}{3.0}\left(1 - \frac{1}{9}\left(\frac{x}{D}\right)^2 + \frac{1}{54}\left(\frac{x}{D}\right)^3\right) \qquad x \leq 3D$$

$$= \frac{1}{2}D \qquad x > 3D \qquad (3\text{-}6)$$

The nose length $LN = 3\,D$, The different length of nose can be used, let say, the nose length denoted as: $L_N = l_N D$,for any a given value l_N, then Eq. 3-6 would be written as :

$$r(x) = \frac{x}{l_N}\left(1 - \frac{1}{(l_N)^2}\left(\frac{x}{l_N}\right)^2 + \frac{1}{2(l_N)^3}\left(\frac{x}{D}\right)^3\right) \qquad x \leq l_N D$$

$$= \frac{1}{2}D \qquad x > l_N D \qquad (3\text{-}7)$$

3.2.3 Parabolic Spindle Fuselage (Jan Roskam, Chuan-Tau Edward Lan).

The radius distribution along $x-axis$, $r(x)$, for this fuselage shape can be defined as:

$$\frac{r(x)}{L} = 4\frac{r_{mid}}{L}\frac{X}{L}\left(1-\frac{X}{L}\right) \qquad (3-8)$$

This shape would not distinguish between nose part, mid fuse part or tail part. The maximum fuselage radius would occurred at $x = 0.5\,L$. Above equation would give zero fuselage radius at the both end of fuselage namely at $x = 0$ and $x = L$. However, in practice, the fuselage which is derived from this equation for the fuselage defined over the whole fuselage length L, but would be the fuselage with fuselage length just 0.8 L. If the term $4\frac{r_{mid}}{L}$ is set equal to 1. Then, eq. 3-8 became:

$$\frac{r(x)}{L} = 4\frac{X}{L}\left(1-\frac{X}{L}\right) \qquad (3-9)$$

Hence at $\frac{X}{L} = 0.5$, represent the position of maximum fuselage radius r_{max} according to eq. 3-9 would be equal to 0.25. Hence it is clear that in the Parabolic spindle model , eq. 3-8, where the multiplication factor 4 was introduced on it in order to make the maximum radius without $\frac{r_{mid}}{L}$ is equal to 1. Hence this term $\frac{r_{mid}}{L}$ can be considered as the order of magnitude of the fuselage slenderness.

3.2.4 Ellipsoid of revolution (Jan Roskam, Chuan-Tau Edward Lan).

In order to increase the local fuselage radius, it can be obtained by putting a square root into the term $4\frac{X}{L}\left(1-\frac{X}{L}\right)$, hence equation 3-8 can be written as: