Aerodynamic Configuration Design of a Missile

P. Sethunathan
Asst.Professor,
Department of Aeronautical Engineering
Paavaai Group of Institutions
Namakkal, India.

R. N Sugendran, T. Anbarasan
UG Students
Department of Aeronautical Engineering
Paavaai Group of Institutions
Namakkal, India.

***Abstract*—In this proposed paper the aerodynamic characteristics of various sections such as body, wing and tail of an anti-aircraft missile were computed using analytical methods. Generally predicting the aerodynamic characteristics is mandatory in case of performance analysis. Drag characterization is carried out at different Mach number varying from subsonic to supersonic for different altitudes. It is found that at 15km the drag is reduced to about 23% of that on 5km while considering supersonic Mach numbers. To predict the normal force coefficient values linear wing theory, Newtonian impact theory and slender wing theory is used. Normal force coefficients were calculated at different angle of attacks (1, 5 & 10). This paper also includes predicting of centre of pressure and sizing the tail, which helps in maintaining the missile at static neutral stability. The predicted aerodynamic characteristics were in good agreement with the results in the literature.**

Keywords— Missile, Drag, Normal force, Tail area sizing.

I. INTRODUCTION

Generally a missile is nothing but any object that is thrown on a target with the motive of hitting it. For example, an arrow delivered from a bow to hit a target can also be said to be a missile. If the thrown object is provided with some intelligence and quick response to track the path of target which moves are known as guided missile.

In modern military usage a missile or a guided missile is a self-propelled guided weapon system. The technologies of a guided missile are propulsion, guidance and control which helps in making a missile specific to a target, i.e., they determine the size, range and state of motion of a missile.

One distinction between a missile and an airplane is that, unlike an airplane a missile is usually expandable in the accomplishment of its mission. From the configurational point of view, the distinction is frequently made that a missile is more slender than an airplane and tends to possess smaller wings in proportion to its body. These distinctions are, however, subject to many exceptions. In fact configurational distinctions between missile and airplane seem to narrow as the operational speeds increases. Therefore much of the missile aerodynamics contained herein will be directly applicable to airplanes.

II. LITERATURE REVIEW

Guided missiles can be broadly classified based on their features such as type of target, range, mode of launching, system adopted for control, propulsion, guidance, aerodynamics, etc. Among these classifications general and most popular is based on method of launching surface to surface (SSM), surface to air (SAM), air to air (AAM), air to surface (ASM), air to underwater (AUM) and underwater to underwater (UUM)

A. On the basis of guidance system

There are various types Command guidance, Beam-riding guidance, homing guidance, and inertial navigation guidance.

In a command system the missile and the target air continuously tracked from one or more vantage points and the necessary path for the missile to intercept target is computed and relayed to missile by some means such as ratio. A beam-riding missile contains a guidance system to constrain it to a beam. The beam is usually a radar illuminating the target so that, if the missile stays in the beam, it will move towards the target. A homing missile has a seeker, which sees the target and gives the necessary direction to the missile to intercept the target. The homing missile can be sub divided into classes having active, semi active, and passive guidance systems. In the active class the missile illuminates the target and receives the reflected signals. In the semi active class the missile receives reflected signals from a target illuminated by means of external to the missile. The passive type of guidance system depends on the receiver in the missile sensitive to the radiation of the target itself.

B. On the basis of trajectory

They are of three types Ballistic missiles, Glide missiles, and Skip missiles.

A ballistic missile follows the usual ballistics trajectory of a hurled object. By definition a ballistic missile is the one which covers a major part of its range outside the atmosphere where the only external force acting on the missile is the gravitational force of the earth, while the cruise missile is the one which travels its entire range in the atmosphere at a nearly constant height and speed. However, a missile could have a combination of the two also where a missile could cover part of the flight in ballistics mode and later a terminal portion in cruising mode. A glide 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 along on the atmospheric shell.

C. On the basis of range

- Short range missiles – 50 to 100 km;

- Medium range ballistic missiles (MRBM) – 100 to 1500 km;
- Intermediate range ballistic missiles (IRBM) – up to 5000 km;
- Intercontinental or long range ballistic missile (ICBM) – 12000 km;

D. *On the basis of target*

There are various types Anti-tank/anti-armor, Anti-personnel, Anti-aircraft/helicopter, Anti-ship/anti-submarine, Anti-satellite, or Anti-missiles.

The missile Milan manufactured in India is an anti-tank missile. Roland, Rapier, etc., are examples of anti-aircraft missiles and the much talked-about Patriot missile belongs to anti-missile class.

E. *On the basis of launch platform*

Shoulder fired/tripod launched, Land/mobile (wheeled vehicle or tracked vehicle), Aircraft/helicopter-borne, Ship/submarine-launched, Silo-based, or Space-based (star wars concept).

F. *On the basis of aerodynamic control*

Wing controlled, Tail controlled, or Canard controlled.

G. *Based on propulsion system*

They are of three types Solid propulsion, Liquid propulsion, and Hybrid propulsion.

III. DESIGN CONSIDERATION OF GENERAL AERODYNAMICS

The design of missile configurations is one of the most interesting and challenging fields and perhaps the most complex for the aeronautical design engineers since it requires a broad knowledge of the fundamentals of many technical specialties such as aerodynamics, thermodynamics, kinematics, propulsion, structural design, etc.

A. *Sections of a missile*

The body of a missile may be divided into three major sections

- The forebody or the nose,
- The mid-section and
- The boat-tail section.

1) *The forebody or the nose section*

Forebodies may have many varieties of shapes, most common of which are conical, ogival, power series or hemispherical. These shapes are used primarily on the missiles of supersonic speeds and are generally selected on the basis of combined aerodynamic, guidance and structural considerations. Since the pressure or wave drag may be several times that due to friction at supersonic speeds, careful selection of the nose shape needs attention to assure satisfactory performance of the overall system.

2) *Mid-section*

The mid-section in most missile configurations is cylindrical in shape. This shape is advantageous from the stand point of drag, ease of manufacturing and load carrying capability. It is known that the total reaction of the missile at any instant has two components, the lift and drag. These may be positive or negative. It becomes desirable to have a greater lift than the drag and this can be done by using a curved surface. Angle of attack is the direction of the reaction force with respect to the free stream direction. Even at zero angle of attack, some lift can be obtained by using airfoil sections.

The effect of mid-section or after body extension on the aerodynamic characteristics of the conical and ogival nose bodies have been investigated and it is seen that the effect of after body extension is to increase the lift coefficient and move the centre of pressure toward aft end as a result of body carry over and viscous cross-flow effects.

3) *Boat-tail section*

Boat-tail is the tapered portion of the aft section of a body. The purpose of the boat-tail is to decrease the drag of a body which has a 'squared off' base. By 'boat-tailing' the rear portion of the body, the base area is reduced and thus a decrease in base drag may be partially nullified by the boat-tail.

B. *Missile configurations*

The anti-aircraft missile with the following dimension is taken

Length of the missile = 7.32m
Wing surface area S_w = $0.21m^2$
Reference area S_{Ref} = $0.13m^2$
Aspect ratio A_w = 3.59
Mean aerodynamic chord = 0.53m
Mach number M = 3
Diameter d = 0.42m
Centre of gravity from nose = 4.5m
Nose fineness ratio = 2.8
Body fineness ratio = 17.42
Nozzle exit area = $0.07m^2$
Reference area = $0.1385m^2$
Number of wings = 2(fixed)
Specific heat ratio = 1.4
$\delta le_{(wing)}$ = 5 deg
Λ_{LE} (wing) = 39.64deg
t_{mac} = 0.01m
span = 0.88m
$\delta le_{(tail)}$ = 3.8 deg
Λ_{LE} (tail) =49.38 deg

IV. MISSILE AERODYNAMICS

When a missile travels through air it is affected due to some forces and the direction air flow passing through it. The study of these characteristics is known as missile aerodynamics. The forces acting on it may be classified into two general types, they are

- Forces generated due to air friction and
- Those due to pressure.

In the first type the force (drag), is created by the shearing action of the air due to its viscosity and the latter by differences in surface pressures which result in creation of both lift and drag forces. In supersonic missile design studies it is more convenient to consider normal forces, i.e., forces perpendicular to the missile axis, in the place of lift forces.

The reason for this is that the component section and aerodynamic lifting surfaces are generally symmetrical about the longitudinal axis or chord wise centre line, the resultant aerodynamic pressure forces on these symmetrical sections are thus normal to the longitudinal axis or wing chord.

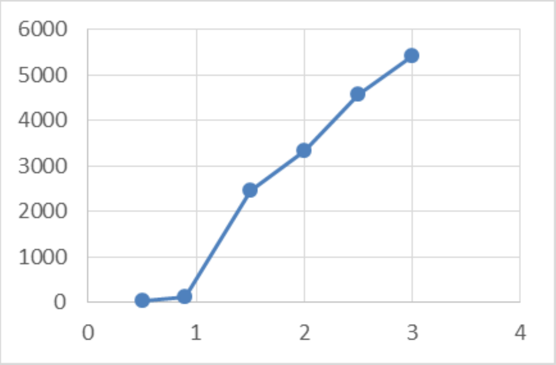
A. *Drag prediction*

Drag is the opposing force acting on a missile which reduces the speed of the missile. It acts on every components of the missile such as nose, wing, etc. here we are about o calculate the co-efficient of drag by splitting the missile into three sections and finally summing it. The sections are the body, the wing and the tail.

Total drag is calculated for different Mach number with the altitudes 5km, 10km and 15km. Drag increases with increase in Mach number. At 15km the drag is reduced to about 75 percent of drag obtained at 5km. The following table and graph provides the total drag obtained at 15km for various Mach numbers.

Table 1: Total drag at 15000m

Mach number	**Dynamic pressure**	**Total coefficient of drag**	**Drag**
0.5	$2.1*10^3$	0.1437	41.795
0.9	$6.86*10^3$	0.1249	118.76
1.5	$1.9*10^4$	0.9302	$2.447*10^3$
2	$3.3*10^4$	0.7261	$3.318*10^3$
2.5	$5.2*10^4$	0.6333	$4.561*10^3$
3	$7.6*10^4$	0.5150	$5.42*10^3$



Graph 1: Total drag Vs Mach number

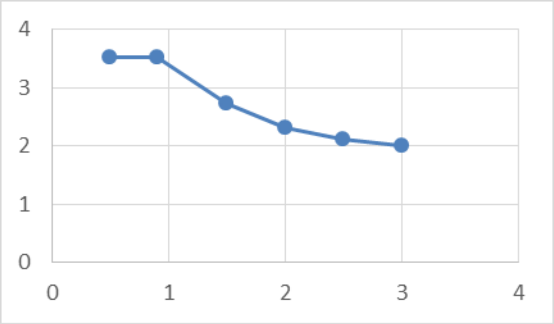
B. *Normal force prediction*

A missile surface planforms include wing, tail, and canard surfaces. These may be fixed or movable. The wing surface normal force coefficient is a function of Mach number, local angle of attack, aspect ratio, and the wing surface planform area. $(C_N)_{Wing}$ based on the missile reference area, decreases with increasing supersonic Mach number and increases with angle of attack and the wing surface area. The prediction is based on the linear wing theory plus Newtonian impact theory are applied at high supersonic Mach number. , with $M^2>1+[8/(\pi A)]^2$. Slender wing theory plus Newtonian impact theory is more applicable at subsonic and low supersonic Mach number with $M^2<1+[8/(\pi A)]^2$.

Coefficient of normal force calculated at different mach numbers with angle of attack 1, 5 and 10 degrees. The result shows that on increasing Mach number coefficient of normal force decreases and increases with increase in α. The following table and graph provides the total coefficient of normal force obtained at angle of attack 10^0 for various Mach numbers.

Table 2: Normal force coefficient at an angle 10 degree

Mach no	**Conditions**	$(C_N)_{Total}$
0.5	0.25<1.5012	3.5247
0.9	0.81<1.5012	3.5247
1.5	1.00<1.5012	2.7351
2.0	4.00>1.5012	2.3016
2.5	6.25>1.5012	2.1089
3.0	9.00>1.5012	1.9955



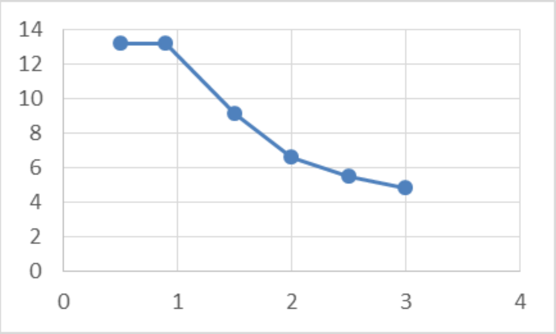
Graph 2: $(C_N)_{Total}$ Vs Mach number

A similar approach can be used to determine the wing normal force curve slope due to angle of attack. Determination of the normal force due to angle of attack is used in sizing the tail to meet the static stability requirement.

The total normal force curve slope due to angle of attack for various Mach number is calculated and tabulated. The graph represents the variation of normal force coefficient due to angle of attack from Mach number 0.5 to 3.

Table 3: Normal force coefficient due to angle of attack

Mach no	Conditions	$(C_{N\alpha})_{Total}$
0.5	0.25<1.354	13.1918
0.9	0.81<1.354	13.1918
1.5	1.00<1.354	9.1499
2.0	4.00>1.354	6.6152
2.5	6.25>1.354	5.4886
3.0	9.00>1.354	4.8262



Graph 3: $(C_{N\alpha})_{Total}$ Vs Mach number

C. *Tail area sizing*

Much of the conceptual design configuration sizing process is oriented toward tail sizing. Because missiles are usually volume limited and the subsystems are of comparable density, the center-of-gravity location is usually near 50% of the length of the missile, because the nose and any forward surfaces (strakes/canards) are destabilizing, the tail must be sized to provide static stability. The tail contribution to pitching moment stability, provided by the tail normal force effectiveness $(C_{N\alpha})_T(S_T/S_{Ref})$ times its moment arm to the center of gravity $[x_{CG} – (x_{CP})_T]$, must balance the contributions to pitching moment from the nose and wing. The equation for finding the required tail area is given below,

$$S_T / S_{Ref} = \{(C_{N\alpha})_B[X_{CG}-(X_{CP})_B]/d +(C_{N\alpha})_W\{[X_{CG} – (X_{CP})_W]/d\}(S_W/S_{Ref})\} / \{[(X_{CP})_T – (X_{CG})]/d\} (C_{N\alpha})_T$$

Note that for a small tail area the wing Centre of pressure should be located near the Centre of gravity $[(X_{CP})_W – X_{CG}]\approx 0]$.

The required tail area for neutral static margin is a function of Mach number and wing location. Note that the required tail area for neutral static stability must be larger as the Mach number increases toward hypersonic. The tail loses its aerodynamic efficiency as Mach number increases. Also note that placing the wing such that its aerodynamic center is forward of the Centre-of-gravity location is destabilizing, requiring a larger tail area for compensation. The rocket baseline wing aerodynamic center is forward of the Centre of gravity, and therefore the rocker baseline has a large tail. Placing the wing aft of the Centre of gravity is stabilizing, allowing a smaller tail area to meet the static margin requirement. It is noted that for a typical missile wing without camber, the location of the wing aerodynamic center is the same as the wing Centre-of-pressure location.

For Mach number 3, the required tail area is can be calculated for the data given below as,

Centre of pressure location can be predicted as,

$(X_{CP})_{Body} \approx d$, from slender body theory

$(X_{CP})_{Body}= 0.42$

$(X_{CP}/ C_{MAC})_W = [A_W (M^2-1)^{1/2}- 0.67] / [2A_W (M^2 -1)^{1/2} -1]$, from linear wing theory

$= [3.59 (9-1)^{0.5}-0.67] / [2*3.59 (9-1)^{0.5}-1]$

$= 0.4912$

$(X_{CP})_W= 0.4912*(C_{MAC})_W$

$= 0.4912*0.5353$

$= 0.2639$m from leading edge of MAC

$= 0.2639 + 5.663$ (location of wing from nose)

$(X_{CP})_W = 5.9239$m from nose

$(X_{CP})_{Tail} \approx l – d$

$= 7.32 – 0.42$

$= 6.9$m

Now the required tail area is,

$$S_T / S_{Ref} = \{(C_{N\alpha})_B[X_{CG}-(X_{CP})_B]/d +(C_{N\alpha})_W\{[X_{CG} – (X_{CP})_W]/d\} (S_W/S_{Ref})\} / \{[(X_{CP})_T – (X_{CG})]/d\} (C_{N\alpha})_T$$

$$= \{2*[4.5-0.42]/0.42 + [1.4142(4.5-5.92)/0.42]*(0.2153/0.1385)\} / [(6.9-4.5)/0.42]*1.4142$$

$$= 1.4789$$

$$S_T = 1.4789*S_{Ref}$$

$$= 1.4789*0.1385$$

$$= 0.2048 m^2$$

For this anti-aircraft missile at Mach number 3, the required tail area must be 0.2048 square meter for neutral static stability.

V. CONCLUSION

From this report we have concluded that, an Anti-aircraft missiles performance can be increased by decreasing the drag. The result showed that on increasing the nose fineness ratio and decreasing the diameter of the missile, drag is considerably reduced. It also provides a clear image, that as Mach number increases drag also increases and also drag decreases with increase in altitude. The normal force coefficient decreases with increasing supersonic Mach number and increases with increasing angle of attack and the surface area. By sizing the tail area the static neutral stability can be achieved easily and as x_{CP} of wing moves behind the X_{CG}, the required tail area is reduced.

REFERENCES

[1] Missile configuration design by S.S.CHIN

[2] Guided missiles by T.V. Karthikeyan, A.K. Kapoor Scientists at (Defence Research & Development Laboratory- Hyderabad)

[3] Missile aerodynamics by Jack N. Nielsen.

[4] Prediction of aerodynamic characteristics of missiles with circular and non-circular cross sections by HabibAsan and Mehmet Akcay.

[5] Jorgensen, L.H., "Prediction of Aerodynamic Characteristics for Slender Bodies Alone and Width Lifting Surfaces to High Angles of Attack," AGARD-CP-247, 1978.

[6] Barth, H., "Aerodynamic characteristics of complete configurations," AGARD LS., NO. 98, 1979.

[7] Sigal, A., Lapidot, E.; "Aerodynamic characteristics of configurations having bodies with Square, Rectangular, and Circular Cross sections," Journal of Spacecraft, Vol. 26, No.2, March, April 1989.

[8] Kidd, J., "An Investigation of Drag Reduction using Stepped Afterbodies," AIAA paper presented at the 27th Aerospace Sciences Meeting January 1989.

[9] Thomas J. Sooy and Rebecca Z. Schmidt.: "Aerodynamic Predictions, Comparisons, and Validations Using Missile DATCOM (97) and Aeroprediction 98 (AP98)", Journal of Spacecraft and Rockets, Vol. 42, No. 2, March–April 2005.

[10] Nhu-Van NGUYEN, Jae-Woo LEE, and Yung-Hwan BYUN; "Investigation on Short and Medium Range Missile Aerodynamic Characteristics For Flight Simulation and Design"

[11] Lesieutre, D.J., Dillenius, M.F.E., and Lesieutre, T.O., "Optimal Aerodynamic Design of Advanced Missile Configurations With Geometric and Structural Constraints," NEAR TR 520, September 1997.