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Aerodynamic Design of Wing for Supersonic Flight Vehicle

Mr.K.Veeranjaneyulu
Assistant Professor,
Dept of Aeronautical Engineering,
MLR Institute of Technology.

Karupalli Anvesh
M.Tech Student,
Dept of Aeronautical Engineering,
MLR Institute of Technology.

Dr.M.Satyanarayana Gupta
Professor & HOD,
Dept of Aeronautical Engineering,
MLR Institute of Technology.

ABSTRACT:

The aim of the present project is to design a wing for the given missile body-control tail surface configuration meeting the design objectives. A detailed literature survey for the related problem yielded a nominal wing loading required for this design. With this input the wing area has been selected and sized based on the design constraints.
The tool for design is DATCOM semi-empirical methodology, which is based on component buildup approach and mostly used by the aerodynamic designers across globe for preliminary designs.It has been found that the configuration is able to generate enough lift at alpha less than 10° due to the fact that the huge body contribution. But the configuration was unstable by more than 1d which indicates that it cannot be controlled. The final configuration thus designed has been characterized for its operating M.A regime and analyzed resulting in a performance validation for the design and off-design requirements.

INTRODUCTION
DESIGN OBJECTIVES

The aim of this project is to design a wing for an available body-tail configuration meeting the following objectives, 1) to pull an 8g maneuver at an altitude of 15km while flying in a supersonic Mach number, 2.0 at a reasonable angle of attack, 2) to have a stable static margin of within 0.5d.

DESIGN CONSTRAINTS:

The constraints in carrying out the design are,1) use of available missile body-tail configuration to reduce the overall design cycle by avoiding additional cycles of rocket motor design and tail actuator design, 2) the rocket motor is so heavy such that the center of gravity of the missile is almost at 65% of body length from nose, making it difficult to achieve the desired stability margins.

DESIGN TOOL

The tool used for carrying out this design is DATCOM semi-empirical method (Ref.--). This method is based on component buildup approach implementing the slender body theory and thin airfoil theory. It is a formulation based on a wide variety of test data compilation considering different test models. The other tools utilized in this project are: Solid works for CAD modeling, ANSYS-ICEMCFD 12.0.1 for mesh generation and Microsoft Excel for tabulation and plotting of results.

LITERATURE SURVEY:

For commencing any technical project, it is required to carry out the literature survey for the benefit of better understanding of the work to be carried out. This chapter will describe in detail the articles published and papers presented related to the present work – Aerodynamic Design of Wing for Supersonic Flight Vehicle.

HISTORY: THE ORIGINS OF SUPERSONIC WING CONCEPTS:

Falling back to late 1940's, Heavy research into aircraft techniques during World War II led to the creation of the first rocket and jet aircraft. Subsequently the first claims of breaking the sound barrier were made during the war. The first recognized flight exceeding the speed of sound for the first time by a manned aircraft in controlled level flight was on October 14, 1947 in an American research project, using the experimental Bell X-1 research rocket plane, piloted by Charles Chuck Yeager. As jet propulsion opened the prospects of flight in the high-subsonic, transonic, and supersonic flight regimes, however, these and other time-honored tenets of airplane wing design were to undergo radical change. The classic shape of the airplane wing of the 1940's had to be fundamentally altered to permit efficient and safe operation in these new speed ranges.

R.T. JONES CONTRIBUTION

For many years, reducing the airfoil thickness ratio was the only known method of increasing the wing critical Mach number by any significant amount. Then in 1945, Robert T.Jones of NACA offered a fundamental breakthrough when he proposed the use of wing sweep as a means for increasing critical Mach number. The use of wing sweep to increase the efficiency of aircraft intended for flight at supersonic speed was first suggested by Busemann in 1935. As compared with a straight wing, the swept wing offers significant increase in cruising Mach number and, at the same time, permits the use of wings of sufficient thickness to allow aspect ratios high enough for good values of the maximum lift-drag ratio. The aspect ratio, sweep angle, airfoil thickness ratio, and wing weight necessary for adequate wing strength and stiffness are all related and require a complex series of trade-off studies to arrive at an optimum design for a given set of requirements.

RICHARD T. WHITCOMB

Both aerodynamic theory for Supersonic speed range and early experimental results obtained from tests in the slotted-throat transonic wind tunnel indicated that the wave drag of a wing-fuselage combination would be significantly higher than the sum of the drag of these two elements measured separately. In the early 1950's, Richard T. Whitcomb of the NACA Langley Memorial Aeronautical Laboratory first experimentally demonstrated an aerodynamic principle that has had a profound and far-reaching effect on the entire process of airplane configuration synthesis, known as the Transonic Area rule. According to Donlan, "the basic tenet of the area rule ... states that the wave drag of an airplane configuration depends primarily on the longitudinal distribution of the total cross-sectional area. This concept results in the proposition that the wave drag of a simple equivalent body of revolution (that is, a body having the same longitudinal distribution of total cross-sectional area) would be the same as that of the more complex wing-body arrangement."

CONCORDE:

In the late 1950s, France, the United Kingdom, United States, and Soviet Union were considering developing supersonic transport. The British design was for a thin-winged delta shape. The design work was supported by a preceding research programme studying the flight characteristics of low ratio delta wings. The supersonic BAC 221 was modified for flight tests of the high speed flight envelope, the Handley Page HP.115 also provided valuable information on low speed performance.

R.M. SNOW AND E.A. BENNY

The papers dealing with practical aspects of theoretical work done at the applied physics laboratory on the subject of the aerodynamic characteristics of wings in the supersonic flow are presented in this report. The first paper derives lift coefficients and centre of pressure, cp location for flat plates of polygonal plan form from fundamental considerations, using Busemanns conical field method. The other papers utilize Busemanns second order approximation formula to determine the aerodynamic characteristics of certain type of wings having finite thickness.

RICHARD M. WOOD, JAMES E. BYRD, and GARY F. WESSELMANN

A review of the Langley wing leading edge vertex flow research at the supersonic speeds has been presented along with source from a recent experimental study in which the influence of wing airfoil shape on wing leading edge vortex flow was assessed.

SHIGERU OBAYASHI AND YUKIHIRO TAKEGUCHI

This paper describes the design optimization of a plan form shape for a supersonic transport wing using Multiple Objective Genetic Algorithm (MOGA). The objective functions are to minimize the drag for a supersonic cruise, the drag for transonic cruise and the bending moment at the wing root for supersonic cruise.

STEVEN E. SKARE

In this paper, an Inverse design method utilizing the class shape transformation technique is presented. This method was shown to provide an accurate and efficient design technique for various geometries in supersonic flow. Specially, cases were run for thin airfoils, supercritical airfoils, simple wedge geometries, and a sears- hack body.

NACA TECHNICAL REPORT

In this report, an investigation has been conducted at subsonic mach numbers in the Langley rectangular high speed tunnel on five supersonic airfoils and, for comparison on two subsonic airfoils. Two-Dimensional data were obtained by pressure measurements at angles of attack from 0 to 4 for mach numbers between 0.30 and 0.90 for these 6% thick symmetrical airfoils.

HARRY W. CARLSON AND DAVID S. MILLER

In his paper, rather extensive employment of numerical methods for the design and

analysis of arbitrary- plan form wings at supersonic speeds, certain deficiencies have been revealed, particularly in application to wings with subsonic leading edges. These improvements, in combination with more compatible summation methods in the design and analysis mode, have reduced small but disturbing discrepancies which sometimes arose between wing loadings and forces calculated for that same shape upon submittal to the evaluation program.

DESIGN METHODOLOGY

Introduction

Any design has to be carried out in a systematic method to achieve its requirements. The process of design starts with the requirement analysis, design constraints, design conditions and system analysis.

Problem definition

The present project is to design a wing for a given missile body-control surface layout to achieve the design requirements of stability and maneuverability. The missile body constitutes a conical nose of fineness ratio 2d (d-base diameter of body) followed by a straight cylinder of fineness ratio 10d.

Design Requirements& Conditions

The design requirements are evolved from the simulation model to meet the mission requirements which is to kill an enemy air threat. The missile has to maneuver at 8g latax at an altitude of 15km with speed of Mach 2.0 at a reasonable angle of attack. The final configuration has to be stable with a stability margin of 1.0d. The mass of the total configuration is 600kg.

Design Constraints

The design has to be carried out with the available missile body, control surfaces as the available rocket motor and the control actuator have to be used to reduce the overall design cycle time. Also the missile launch has to canisterised and the whole configuration has to fit in a square container of 1.6m. This restricts the semi span of the wing and tail by 0.5m otherwise it complicates to folding mechanisms in wing.

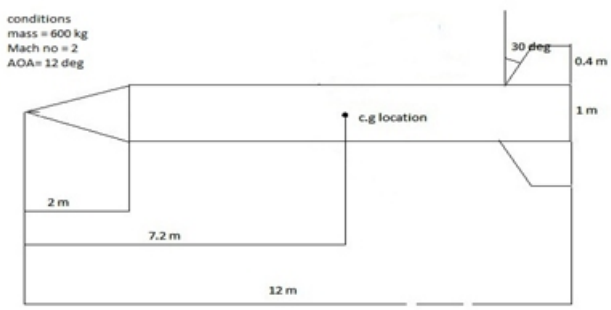


fig.1.Missile body layout.

Wing Design

The missile must satisfy the latax value (acceleration in g's) = 8g. so that the normal force of the missile at an altitude of 15 km will be

Normal force = mass x latax

= 600 kg x 8g

= 4800 kg

The overall normal force generated by the complete configuration including the body, wing and tail at reasonable ($<15^0$) should be atleast 4800 kg to achieve this design condition.

To design a wing for the given configuration and design conditions, the following steps are followed.

1.Selection of airfoil

2.Planformsizing

3.Location of wing

Selection Of Airfoil:

For a supersonic flight vehicle to acquire high Mach numbers of speed, double wedge and biconvex airfoils are mostly used, because they are designed with thin and sharp leading and trailing edges to handle the strong shock waves.

Planform Sizing

The planform of the wing has to size to meet the design objectives. The following processes are followed for sizing of the wing.

a. Wing loading

The source of this parameter is mainly from the literature survey where the wing loading parameter are compared among various missiles developed globally meeting the same design objectives. The weight and wing span of the missiles are tabulated and shown in Table below.

Table No.1

SL.NO	MISSILE NAME	SPEED (M)	SPAN (m)	Mass (kg)	WING LOADING (kg/m^2)
1	Aphid	2	0.49	54	110.2
2	R-13	2.5	0.63	90	142.85
3	Atoll	2.5	0.46	70	152.47
4	Shrike	2	0.91	181	200
5	Aspide	2.5	1	220	220
6	Pl-5b	2.5	0.65	148	227.69
7	Pl-2	2.5	0.6	152	253.33
8	***Umkhonto***	***2***	***0.5***	***130***	***260***
9	Side Winder	2.5	0.3	85.3	287.3
10	Gecko	2	0.61	181.43	297.42
11	Kingfish	2.5	2.5	850.3	332.75
12	Rapier	2.5	0.13	45	346.15
13	Acrid	2.2	2.23	850	373.6
14	Mim-23 Hawk	2.4	1.1	590	495.7
15	See Dart	2	0.9	550	611.11
16	Kangaroo	1.8	9.1	10999	1176.3

The median of this data is project missile "Umkhonto", whose details are given below.

Missile "Umkhonto":
Missile weight :130 kg
Wing span : 0.5 m
Aspect ratio : 3
Using this three parameters wing area of the Umkhonto missile is calculated
i.e aspect ratio = b^2/S
b = span of the wing
S= wing area
S=0.08333 m^2
As we know that, Wing loading = Mass /wing area
So that wing loading = 130/0.0833 kg/m^2
= 1560.62 kg/m^2
This wing loading of the Umkhonto missile is used to calculate wing area of the present configuration the missile.
At aspect ratio = 3
Mass of the missile is 600 kg
Wing area of the missileis =Mass of the missile / wing loading of the Umkhonto missile
= 600/1,560.62 m2
S = 0.384 m2
Aspect ratio = 3
b2= 3 x 0.384
b = 1.073 m

Using the value of the wing total exposed span (b)= 1.073 m
The values of the root chord and tip chord are calculated.
.
Location of the Wing:
The location of wing is selected with reference to the Centre of gravity location.
The C.G. of the total configuration is matched with the 1/4th of the MAC of the wing from the leading edge to start with the design.

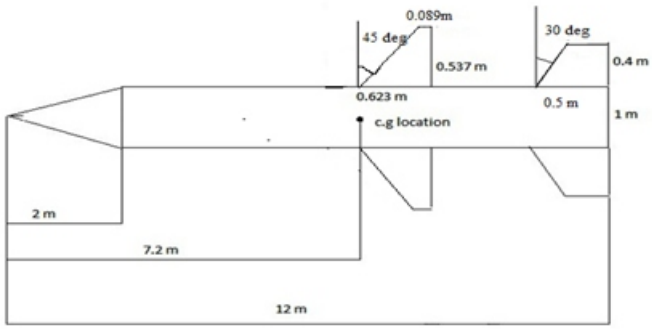


fig.2 Body-Wing-Tail Configuration

RESULTS AND DISCUSSIONS

The configuration which has been finalized in the earlier chapter has been characterized by DATCOM method by evaluating the longitudinal aerodynamic characteristics with the confidence of its validation by CFD data. The complete flight domain covering the M, spectrum has been considered for characterization whose details are given below.

Mach range: 1.0 to 4.0 (1.0, 2.0, 3.0, 4.0)
range: 4^0 to 16^0 (4^0, 8^0, 12^0, 16^0)

Here it is fairly assumed that the M 0.6 data is valid for the lower speeds and for the domain it is assumed that intermediate data are linearly varying. The results are thus tabulated.

Table no.2 : M=1

alpha	C_N	C_M	C_A	X_{cp}/d
4	0.694	-5.444	0.299	7844
8	1.547	-12.021	0.297	7771
12	2.523	-19.415	0.292	7695
16	3.628	-27.609	0.276	7610

Table no.3 : M=2

alpha	C_N	C_M	C_A	X_{cp}/d
4	0.667	-4.798	0.273	7193
8	1.496	-10.685	0.268	7142
12	2.558	-18.104	0.259	7077
16	3.88	-26.988	0.248	6956

Table no.4 :M=3

alpha	C_N	C_M	C_A	X_{cp}/d
4	0.514	-3.633	0.227	7068
8	1.233	-8.621	0.228	6992
12	2.264	-15.625	0.23	6902
16	3.327	-22.778	0.232	6846

Table no.5 :M=4

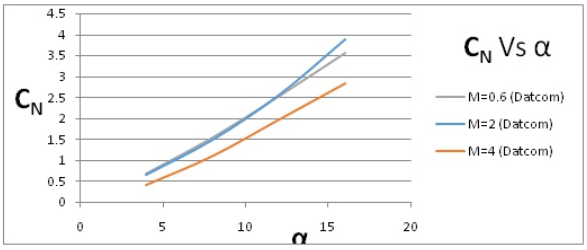
alpha	C_N	CM	C_A	Xcp
4	0.419	-2.895	0.2	6909
8	1.104	-7.559	0.204	6847
12	1.964	-13.38	0.21	6813
16	2.824	-19.243	0.219	6814

Aerodynamic Data Analysis:

The above processed data are analyzed as f(M,) to bring out the aerodynamic behavior of this flight configuration in its operating domain.

EFFECT OF ANGLE OF ATTACK CNVs:

The trend of CN with alpha is linear in low range and nonlinear in high range due to the effect of body contribution at high which are highly non-linear. But at high supersonic M, the nonlinearity at high 's come down due to the strong shock over the nose region which reduces the non-linear trend. These points can be clearly seen in Fig.6.1 below.



Cm (about nose) Vs:

In Fig. below, The Cm trend with looks similar to the CN trend. The values are negative due to the reason that it has been considered pitch down moment about nose is positive and it is a pitch up moment for the configuration considered about the nose.

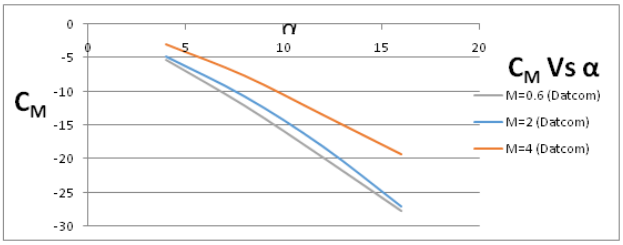


Fig.4 CM vs. , DATCOM

CAVs:

In Fig, The axial force coefficient , CA is plotted as f() for select M of 0.6, 2.0 and 4.0. Here we can observe that the trend of CA is increasing with for subsonic and high supersonic M but for M 2.0 the trend is reverse with a decreasing trend with .

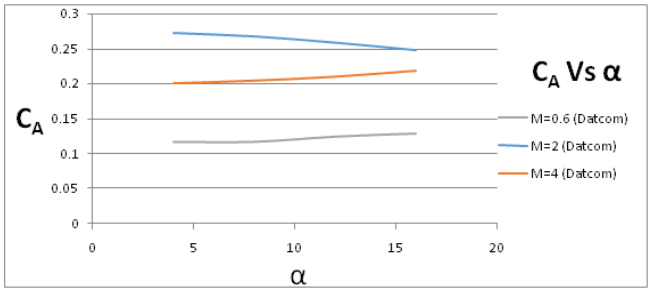


Fig.5 CA vs. , DATCOM

XCP/d Vs:

From Fig, it can be seen that the subsonic M has the center of pressure very much rearward by about 7.8d whereas for supersonic flows, the center of pressure shifted forward to around 7d. This indicates that the presence of shock waves in nose cone plays a major contribution of lift generation thus proving that the flow over the configuration is body dominant.

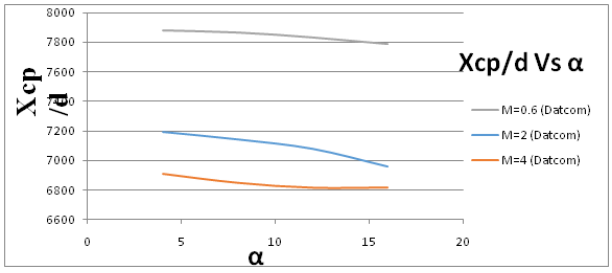


Fig.6 Xcp/d vs. , DATCOM

EFFECT OF MACH NUMBER CNVs M:

The Fig. shows that the CN follows the expected trend with Mach number. At low , it is seen that the body is completely dominant to the surfaces whereas at high 's the surfaces try to pick up momentum over body as the trend follows that of a isolated surface.

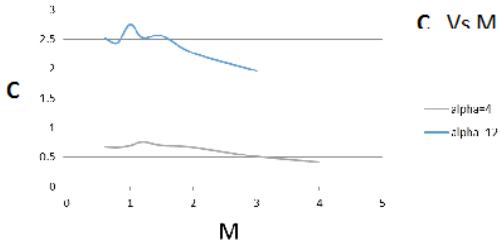


Fig.7CN vs. M, DATCOM

Cm Vs M:

In Fig. below, pitching moment coefficient about nose, Cm, is plotted against M for 4 and 12.It again follows similar trend that of CN Vs M and the same comments are valid for this coefficient too.

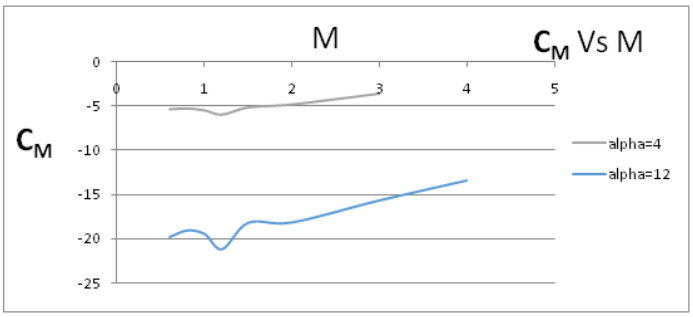


Fig.8 CM vs. M, DATCOM

CAVs M:

In Fig.below, the axial force trend is as expected and it can be seen that its variation with is very less compared to M.

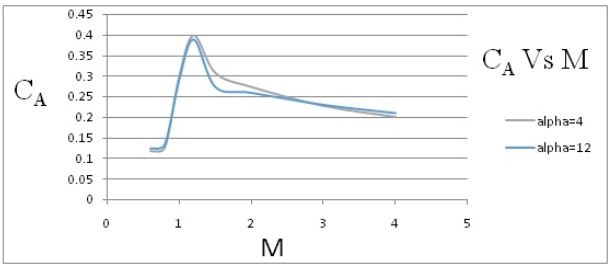


Fig.9CA vs. M, DATCOM

XCP/d Vs M:

The center of pressure location is clearly shifting from rearward to forward by about 1d when the missile accelerates from subsonic to supersonic M.

The dispersion with Mach number is little higher but for supersonic m, the variation in XCP along with variation is just 0.4d which will help in tuning the control laws at supersonic M.

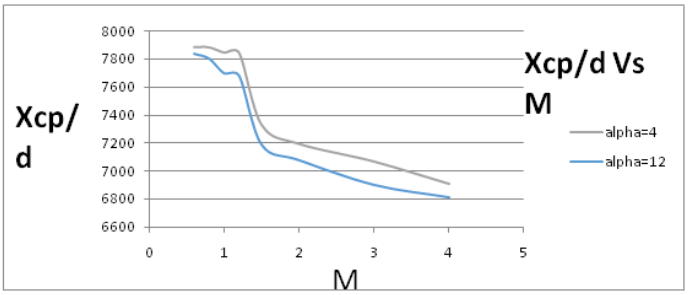


Fig.10 Xcp vs. M, DATCOM

CONCLUSION:

From the above analysis it could be concluded that the aerodynamic characteristics of the selected configuration follows the expected trend. Also it is once again confirming the flow over the configuration to be body dominant and the addition of wing surface is mainly for the purpose of stability management only.

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