ESTIMATION OF BASE DRAG ON SUPERSONIC CRUISE MISSILE

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Abstract - ***Drag is the main drawback for flight and cost consideration. Among several forms of drag, one usually studied category is the base drag. This paper focuses on an improved method for base pressure and drag prediction under rocket motor-on conditions called Brazzel's drag prediction model. Also, a major modification done in this method is, to extend its range of applicability to high values of thrust coefficient(Ct) and to Mach number less than 1.5(transonic) at zero angel-of-attack.***

Simulating the problem using CFD analysis, which best describes the physics behind the flow is done. For numerically predicting the base drag, codes are generated for the classical (Brazzel's) model and modified model to validate the results. The results are compared and were found to be synonymous with each other. It can be noted that the improved method will prove to be a better and faster method in determining the base drag of a cruise missile at supersonic mach numbers.

Key Words: *Drag, Aerodynamic forces, Mach number.*

1. INTRODUCTION

Accurate prediction of drag is very important from aerodynamic configuration design point view. Initial off-prediction can lead to oversize or undersize propulsion system and intern it will affect the flying vehicle performance. It may increase the weight or may reduce the range. An initial accurate prediction of drag brings down the design time and leads to optimum configuration design. Especially, in the case of cruise missile, it is essential to predict the drag component. Prediction of power-on base drag is very critical part of overall drag. For proper and accurate design, it is important to bring out the power on base drag component for given geometry, propulsion unit and trajectory.

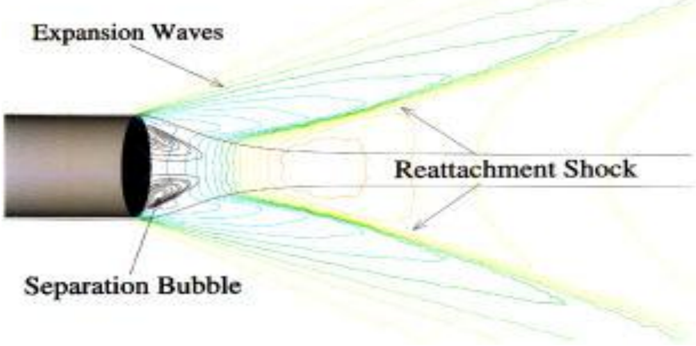
With above as objective, a project has been carried out to estimate the power-on base drag using multiple methods. Based on literature survey, a method is selected which reasonably predicts the base drag component in power-on condition. Based on given methodology, a computer code has been developed and used for evaluating the power-on base drag for given geometry, flight conditions.

2. EQUATION USED

$$F_D = \frac{1}{2}\rho A C_D v^2$$

3. DRAG CLASSIFICATION

Drag force is the summation of all forces that resist against aircraft motion. The calculation of the drag of a complete aircraft is a difficult and challenging task, even for the simplest configurations. We will consider the separate sources of drag that contribute to the total drag of an aircraft. The variation of drag force as a function of airspeed looks like a graph of parabola. This indicates that the drag initially reduces with airspeed, and then increases as the airspeed increases. It demonstrates that there are some parameters that will decrease drag as the velocity increases; and there are some other parameters that will increase drag as the velocity increases. This observation shows us a nice direction for drag classification. Although the drag and the drag coefficient can be expressed in a number of ways, for reasons of simplicity and clarity, the parabolic drag polar will be used in all main analyses. Different references and textbooks use different terminology, so it may confuse students and engineers. In this section, a list of definitions of various types of drag is presented, and then a classification of all of these drag forces is described.



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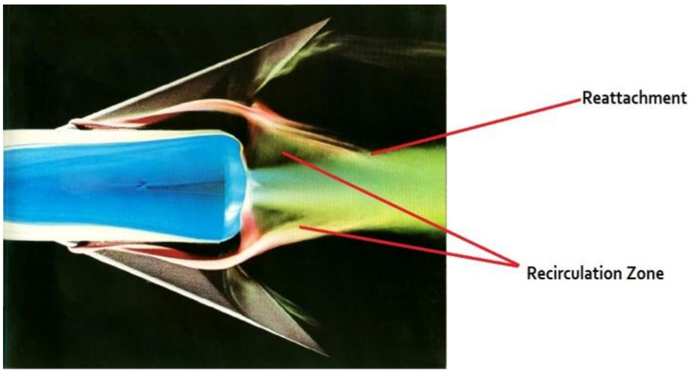


4. THE BRAZZEL'S METHOD

The Brazzel's method was built around two fundamental assumptions that, he was able to develop based on analysis of experimental data for jet exit Mach numbers 1.0 to 3.8. The first assumption is that, the free-stream Mach number and the nozzle diameter are accounted for by the momentum flux (RMF). The second assumption is that, jet exit Mach number could be described by the ratio of the jet- static temperature for a given jet Mach number to that at exit jet Mach number of 1.0.

In reality Brazzel's method was geared primarily to account for base drag for sustainer rocket motors that typically have values of thrust coefficient of 0.2 to about 3.0 and fly supersonically. However, as the mass- flow ratio as thrust coefficient get high or the free-stream Mach number is transonic, the Brazzel's method produces increasingly erroneous results for many cases.

Brazzel's technique had little data for high thrust ratios to use in the method development. The other methods, uses the Brazzel's method for RMF up to 1.5. It was found that for higher values of C_T, P_B/P was primarily dependent on free-stream Mach number with a little dependence on jet exit Mach number or jet diameter. Apparently, for high thrust levels such as would occur in sustainer or booster rocket motor, one of the main correlation parameters for P_B/P is free-stream Mach number.

M_∞	$C_1(C_T, M_\infty)$					$C_2(M_\infty, C_T)$	
	C_T					C_T	
	≤1.0	2.0	20	40	≥70	≤1.0	≥2.0
≤0.9	0.19	0.16	-0.06	0.02	0.0	1.24	1.24
1.0	0.19	-0.085	-0.06	0.02	0.0	1.28	1.37
1.25	0.19	-0.085	-0.01	0.02	0.0	1.28	1.47
1.65	0.19	-0.175	-0.06	0.04	0.0	1.28	1.70
2.0	0.19	-0.30	-0.20	0.02	0.0	1.28	1.90
2.5	0.19	-0.45	-0.23	0.01	0.0	1.28	2.30
3.0	0.19	-0.55	-0.22	-0.03	0.0	1.28	2.50
≥4.0	0.19	-0.65	-0.10	-0.04	0.0	1.28	2.7

5. THE APPROACH

The advancement through the problem in each sub-step is briefed as follows. Firstly, a MATLAB code is written in order to find the value for base drag coefficient. Then after, based on a simple geometry of a missile (without fins or any lift producing device) an axi-symmetric model is created in GAMBIT software simulating the throat, nozzle and other flow conditions as in the MATLAB code.

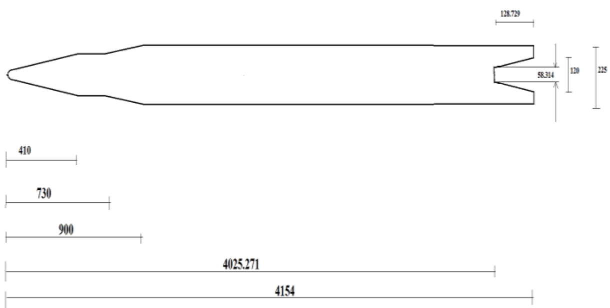
After this is done, the meshed model from GAMBIT is exported to FLUENT 13 to simulate the flow analysis by defining the boundary conditions and flow parameters. To run the flow analysis, a journal file was created and pasted in the command window of FLUENT to constantly and iteratively vary the flow parameters and other conditions at different altitudes(at MSL, 5kms above MSL and 10kms above MSL).

Finally, the results obtained from FLUENT were compared to that of the MATLAB results and checked for correctness with low percentage of error. Corresponding graphs and contour maps were taken to visually analyze the flow.

6. METHOD (GRID GENERATION)

The next step in the process is to model a simple axi-symmetric 2-D missile geometry without any lift producing surfaces like wings or canards or even any external launch lugs.

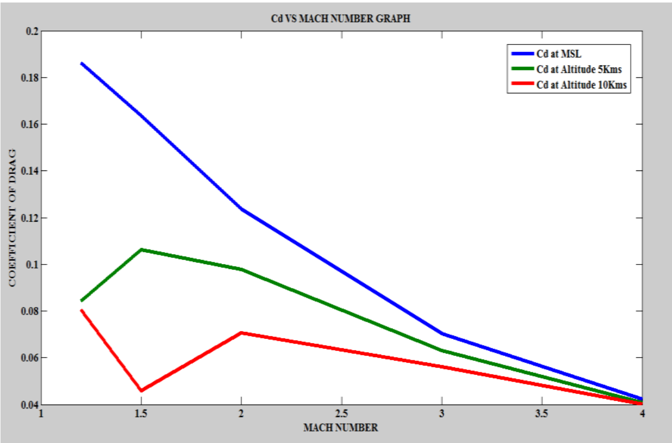
In using this software in the present methodology, we model simple 2-D axi-symmetric missile geometry with known co-ordinates and also the domain surrounding the model to accommodate the flow. Even though we are more interested in the base section of the missile, however, the aerodynamics at the fore-sections(nose-cone and the body) affect the physics at the base region. The following sketch shows the simple 2-D missile model.



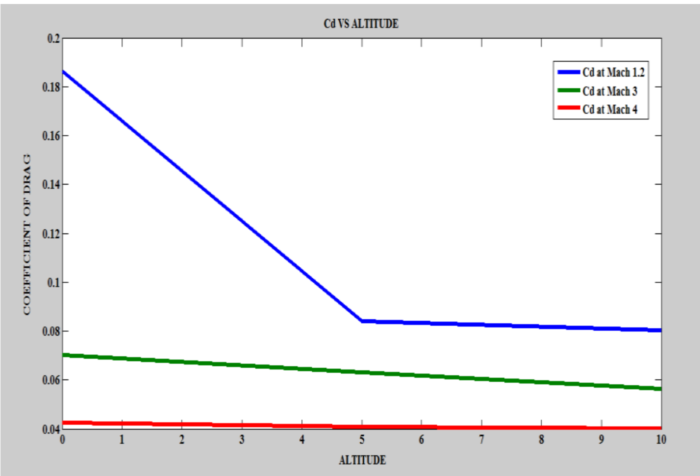
7. THE EXPECTATIONS FROM THE RESULTS

As the modeling, meshing and the analysis is done alongside the MATLAB code generated, the intension is to get a similar output from the both (FLUENT and MATLAB) thus, demonstrating validation of the FLUENT results. Moreover, the results should lie in the valid range of values for base drag coefficient with power-on conditions. Usually, the base drag coefficient for power-off condition varies in the range of 0.180-0.195, hence it is apparent that a nozzle that has almost fifty percent of the base occupied will contribute to about fifty percent or less value of the coefficient of base drag i.e, the base drag coefficient for power-on condition may lie between 0.05 to 0.09. This is checked for every altitude variation along with the jet exit Mach number variation which are; at MSL, 5kms above MSL and 10Kms above MSL with five Mach numbers 1.2, 1.5, 2.0, 3.0 and 4.0.

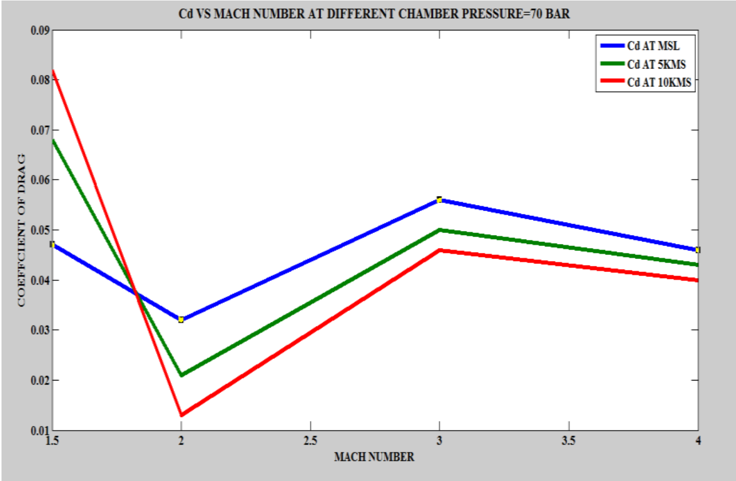
Effect of Mach number



Effect of altitude

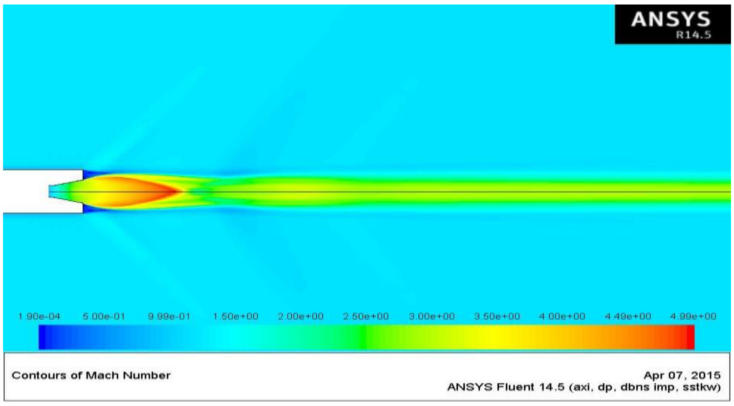


At chamber pressure=70 bar

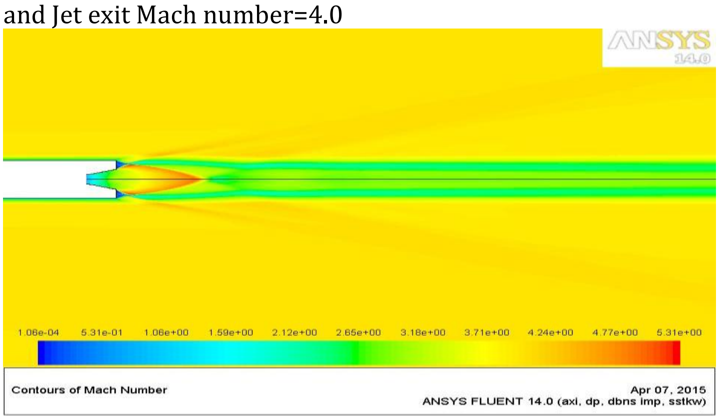


CONTOUR PLOTS FROM METHOD-2

Contour plot of Velocity as Mach number at Mean Sea-level and Jet exit Mach number=1.2



Contour plot of Velocity as Mach number at Mean Sea-level and Jet exit Mach number=4.0

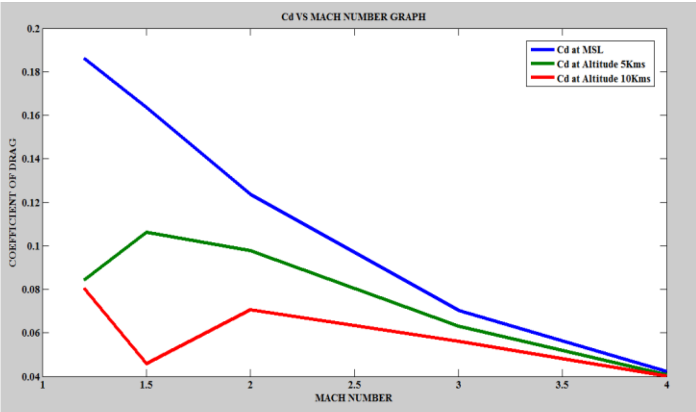


8. RESULTS COMPARISON

As shown above the results of FLUENT and MATLAB, the following structured table showing all the obtained values for Exit Mach number, Altitude, obtained Coefficient of Drag(C_D) from MATLAB and FLUENT and the percentage error in the values.

9. COMPARISON THROUGH PLOTS:

Comparison of the plots of "Mach number vs Cd" from MATLAB and FLUENT is as shown:



Power on brag from method-1(Ref.1) and method-2(CFD)

Exit Mach number	Altitude (Kms)	C_D (From MATLAB)	C_D (from FLUENT)	Percentage Error (%)
1.2	MSL	0.1864	0.1863	**0.0536**
1.2	5	0.0842	0.0870	**3.3254**
1.2	10	0.0805	0.0727	**9.6894**
1.5	MSL	0.1635	0.1734	**6.055**
1.5	5	0.1062	0.1046	**1.5066**
1.5	10	0.0460	0.0451	**1.9565**
2.0	MSL	0.1238	0.1269	**2.504**
2.0	5	0.0978	0.0886	**9.407**
2.0	10	0.0705	0.0770	**9.2199**
3.0	MSL	0.0703	0.0743	**5.6899**
3.0	5	0.0632	0.0590	**6.6456**
3.0	10	0.0563	0.0597	**6.0391**

10.CONCLUSION

The intention of finding the base drag on a supersonic cruise missile was to study the variation of aerodynamic parameters which change with altitude, also to make sure that the coefficient of drag on the base through the Brazzel's technique, which used a MATLAB code, is analogous to the results from a CFD analysis through FLUENT.

It has been found that the results in both the methods are more or less equal to each other with an average of 5.3% as the percentage error while comparing both the methods. Hence, it can be concluded that, based on the results and comparisons, the Base drag coefficient(C_{Ab}) decreases with increase in altitude and Mach number and that the missile's performance is increased during cruise at a higher exit Mach number and a higher altitude where ambient pressure is reduced relieving the jet's plume to expand more and reduce air recirculation at the base.

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