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Aerodynamic Design of Rocket Launchers To Reduce Drag

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Abstract

The main aim of this work was to modify and then investigate the effect of the modified Rocket Launcher's design on the Drag force produced due to it, so as to get an optimal design that finally leads to reduction of drag. To achieve the desired goal we tested the effect for the Hemi-spherical nose shape as compared to the Blunt shaped conventional Rocket Launcher. We used FLUENT as the CFD software for getting the drag values for the different nose shapes at different operating conditions. M261, Hydra-70 Light Weight Launcher, reusable, 19-tube, electrically fired 2.75-inch folding fin aircraft rocket (FFAR) launcher, was used as the basis for our investigation. While calculating the Coefficient of Parasite Drag in the forward flight, during Preliminary Helicopter Design process, it is a general practice that while calculating Coefficient of Parasite Drag for external loads, and additional 15% is added to the usual value of Coefficient of Parasite Drag for external loads. Now if somehow this 15% value be reduced, this will lead to reduction of drag. This Thesis work is one step in this direction.

1. Introduction

Drag force resists the motion of the vehicle through the air and opposes thrust. Drag is due primarily to friction between the surface of the vehicle and the fluid through which it travels, that fluid being air in this case. Drag results because, as an object moves through a fluid, the molecules of the fluid must be moved aside. This process takes energy, and the energy needed to move the fluid aside reduces the remaining energy available to move the object forward. Drag is minimized when the air flowing past a flying object is smooth, because less energy is imparted to the airflow when it is smooth than when it is turbulent.

Very narrow gains (1 % or less) can translate into a change of technology. It is widely assumed that the fuel crisis of the 1970s created the need to invest in drag reduction technology. The reduction of 10 % drag on a large military transport aircraft would save over 10 million gallons of fuel over the life time of the aircraft. A 15 % drag reduction on the Airbus A340-300B would yield a 12 % fuel saving, other parameters being constant.

1.1 Thesis Scope

Each and every countries army has got a large fleet of Helicopters and fighter Aircrafts, and all of these vehicles have got a service life and after which they are dumped. So, if we can refurbish these aircraft in such a way that they are made compatible with the modern technology, and hence our goal of extending their service life be achieved. This would save a lot of money for the country and the country may invest that money in some other development work.

This thesis work is one such small part of the redevelopment of the existing Helicopters, or in other words one can say that this work is in general dedicated to all the existing and coming Helicopters and aircrafts. Whenever an aircraft designer starts the design process for the aircraft the main problems that he face are the Payload and Drag, both of these variables are important for their respective reasons.

In this work we tried to investigate the effect of the change of the nose shapes of the M261 Rocket Launcher, just for our goal to reduce drag. The conventional M261 Rocket launcher has a blunt nose, and we in this thesis tried to modify the nose shape to Hemispherical, just to see the effect on the drag produced.

1.2 Rocket Launcher (M261 19-Tube) []

M261 Light Weight Launcher is a 19-tube 2.75 inch rocket launcher used on the Army Helicopters. The M261 is reusable, but not repairable. Empty weight of the Rocket Launcher being 82lbs.

This system fires a 2.75" FFAR with a variety of special purpose warheads, including: 10lb. and 17lb. high explosive (HE) warheads for light armor and bunker penetration (bursting radius of 8-10 meters for a 10 lb. warhead, 12-15 meters for the 17 lb. warhead), with either proximity or contact fuse; the anti-personnel flechettes warhead, filled with 2,200 flechettes; white phosphorous; white and IR illumination warheads, providing up to 120 seconds of overt light or 180 seconds of IR light; the Multi-Purpose Sub-Munitions (MPSM) warhead, containing 9 sub-munitions which are effective against light armor and personnel; and a warhead containing the CS riot control agent. The 2.75" FFAR can be used as a point target weapon at ranges from 100 to 750 meters and an area fire weapon at ranges up to 7000 meters. The aircraft can carry an additional load of rockets internally allowing the crew to reload the rocket pod without having to return to a rearm site. The reload can be accomplished in under 15 minutes.

1.3 Hydra 70 Rocket System []

Unguided, 2.75 inch (70 mm) diameter FFAR (Folding Fin Aircraft Rocket) were originally developed in the late 1940s by the Naval Ordnance Test Station at China Lake as an air- to-air weapon. The rockets were to be used as more powerful supplements and/or replacements for guns in both air-to-air and air-to-ground applications such as interceptors against heavy bombers.

The current 2.75-inch (70 mm) rockets are known as *Hydra 70* rocket system, and use the **MK66** rocket motor. The latter was developed by the U.S. Army as a common replacement of the MK4 and MK40 for both fixed-wing aircraft and helicopters. The MK 66 is longer than the MK4/MK40, uses an improved smoke-less propellant and has a completely new fin and nozzle assembly. The three fins are of the wrap-around type, and fit around the circumference of the rocket nozzle. Therefore the MK66 is sometimes called a Wrap-Around Fin Aerial Rocket instead of an FFAR. The MK 66 has a higher thrust and spin rate than the MK 4/40, increasing effective range and accuracy.

2. Drag Prediction (Theoretical Approach)

2.1 Equivalent Flat Plate Area Approach:

Usually, it is not a simple matter to directly calculate the parasite drag. However, years and years of experiments, computation, and flight tests have provided us with a very large pool of data from which it is possible to make excellent predictions of parasite drag for most shapes. The parasite drag coefficient is defined as:

$$C_{DP} = \frac{D_P}{\left(\frac{1}{2} \times \rho \times v^2 \times S\right)}$$

A more useful measure of the parasite drag is the equivalent flat-plate drag area, *f*. The equivalent flat plate area, *f*, is the size of a flat plate held normal or perpendicular to the air stream which has the same parasite drag as the object under consideration. Thus, the total parasite drag is just:

$$D_p = f \times q$$

One can find *f* by doing a component drag buildup. Each exterior component of the Rocket Launcher is considered separately, and the *f* of each is found. Then the total *f* is determined by summing the component drag areas. In general, the equivalent flat-plate area of the i^{th} component can be computed from:

$$f_i = C_{f\_body\_i} \times S_{wet\_body\_i}$$

2.2 Body Skin Friction

The friction coefficient depends on Reynolds number and surface roughness, and is most affected by whether the flow is laminar, turbulent or transitional. Reynolds number is given by:

$$R_e = \frac{\rho \times v \times L}{\mu}$$

2.2.1 Skin Friction Coefficient for Laminar Boundary Layer

Derived from the viscosity μ (in $kg.sec/m^2$) of the flowing medium, a theoretical solution (Blasius, Zeitschr. Mathematic Physik 1908 p.l.), indicates the total drag coefficient (based upon wetted surface area):

$$C_{f\_lam} = \frac{1.328}{(R_e)^{1/2}}$$

2.2.1 Skin Friction Coefficient for Turbulent Boundary Layer

The theoretical analysis of the turbulent skin-friction drag is complex, and an exact solution has not been established. The available solutions are basically the generalizations of experimentally determined velocity distributions across the boundary layer. Prandtl and vonKármán utilizing velocity distributions determined in pipes, found for smooth and plane surfaces:

$$C_{f\_turb} = \frac{0.074}{(R_e)^{1/5}}$$

2.2.1 Skin Friction Coefficient for Mixed or Transition Boundary Layer

The best estimate of the coefficient of friction in the case of transition boundary layer is given by the equation:

$$C_{f\_trans} = C_{f\_turb} - \left(\frac{1700}{R_e}\right)$$

2.3 Pressure Drag

This type of drag is mainly because of the first impact of the flowing air with the body, and is mainly concerned with the nose shape of the body. In our case the first contact is with the Warheads nose and hence we have to calculate the pressure drag because of the 19 Warheads, and then come the Rocket Launcher, which has a blunt shape, and the interference area is the difference of the total cross-sectional area of the Rocket Launcher minus the cross-sectional areas of the 19 Rockets.

2.4 Base Drag

Base drag occurs when the air (boundary layer) flowing over the rocket-pod becomes separated from it when the flat base is reached, so it creates a vacuum region behind the rocket-pod. This low pressure region tries to suck the rocket-pod rearward. This rearward force causes "drag." In this particular case, it is called "base drag".

The base drag of projectiles is found to depend largely upon the length of the forebody, its surface conditions and the ratio of base – to – body diameter. The Skin friction drag for the forebody (C_{fB}) is given by:

$$C_{fB} = \frac{D_{fore}}{q \times S_B} = \frac{C_f \times S_{wet}}{S_B}$$

The above analysis primarily applies to the subsonic flow. From the available experiments on projectiles and fuselages *(Sighard F. Hoerner, Fluid Dynamic Drag,)*, for the three-dimensional bodies, the total base drag is given by:

$$C_{DB} = \frac{D}{q \times S_B} = \frac{0.029}{\sqrt{C_{fB}}}$$

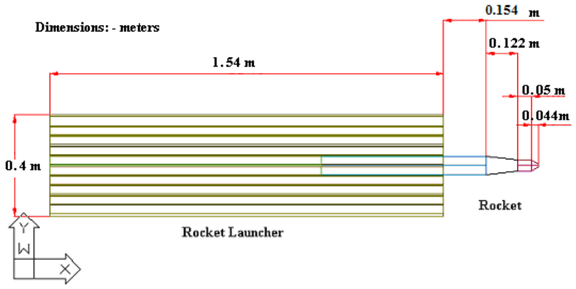
3. Calculations

3.1 Operating Conditions:

Average velocity of Helicopter, $V_{avg} = 60\ ms^{-1}$
Acceleration due to gravity, $g_0 = 9.807\ m/s^2$
Universal gas constant for, $R_{air} = 286.59\ m^2s^{-2}K^{-1}$
Ratio of specific heats for air, $\gamma_{air} = 1.4$

At sea level conditions:
Temperature, $T_0 = 288.16$ K
Density of Air, $\rho_0 = 1.225\ kg\ m^{-3}$
Viscosity, $\mu_0 = 1.7894 \times 10^{-5}\ kg\ m^{-1}\ s^{-1}$

3.2 Conventional M261 (19-tube) Hydra-70 Light weight Launcher



Length of Rocket Launcher,
$L_{RL} = 1.54$ m
Diameter of Rocket Launcher,
$d_{RL} = 0.40$ m
Cross-sectional area of Rocket Launcher,
$A_{RL} = \{(\pi \times d_{RL}^2) / 4\} = 0.1257\ m^2$
Length of Warhead outside Rocket Launcher,
$L_W = 0.37$ m
Diameter of the warhead,
$d_W = 0.07$ m
Cross-sectional area of the Warhead,
$A_W = \{(\pi \times d_W^2) / 4\}$
$= 3.85 \times 10^{-3}\ m^2$

3.2.1 Body Skin Friction

Equivalent Flat Plate area due to the body friction of all the 19 warheads extending from the Launcher comes out to be:

$$f_{W\_skin} = 4.14 \times 10^{-3}\ m^2$$

Equivalent Flat Plate area due to the body friction of the Rocket Launcher comes out to be:

$$f_{RL\_skin} = 5.7276 \times 10^{-3}\ m^2$$

Now, Total Equivalent Flat Plate area due to the Body Friction of all the 19 warheads extending from the Launcher and the Rocket Launcher is given by:

$$f_{SF\_Total} = f_{RL\_skin} + f_{W\_skin}$$

$$\mathbf{f_{SF\_Total} = 9.87 \times 10^{-3}\ m^2}$$

3.2.2 Pressure Drag

The Warhead has a Blunt Conical nose shape, from "Fluid Dynamic Drag, Hoerner (page 3-12)", the drag coefficient for the Blunt Conical nose shape ($C_{D\_W\_nose}$) is 0.4. Equivalent Flat Plate area due to the nose pressure for 19 warheads is given by:

$$f_{n\_PD\_19W} = 19 \times C_{D\_W\_nose} \times A_W$$

$$f_{n\_PD\_19W} = 29.25 \times 10^{-3}\ m^2$$

The Rocket Launcher has a Blunt nose shape, from "Fluid Dynamic Drag, Hoerner (page 3-12)", the drag coefficient for the Blunt nose shape ($C_{D\_RL\_nose}$) is 0.8. Equivalent Flat Plate area due to the nose pressure for Rocket Launcher is given by:

Reference Area, $A_R = A_{RL} - A_W$

$$f_{n\_PD\_RL} = C_{D\_RL\_nose} \times A_R$$

$$f_{n\_PD\_RL} = 42.4 \times 10^{-3}\ m^2$$

Now, Total Equivalent Flat Plate Area due to the Pressure Drag of all the 19 warheads extending from the Launcher and the Rocket Launcher is given by:

$$f_{PD\_Total} = f_{n\_PD\_19W} + f_{n\_PD\_RL}$$

$$\mathbf{f_{PD\_Total} = 71.65 \times 10^{-3}\ m^2}$$

3.2.3 Base Drag

Equivalent Flat Plate area due to the Base Drag for Rocket Launcher is given by:

$$f_{base} = C_{DB} \times A_{RL}$$

$$\mathbf{f_{base} = 17.095 \times 10^{-3}\ m^2}$$

3.2.4 Total Drag Calculations

Total Equivalent Flat Plate Area is given by:

$$f = (f_{SF\_Total} + f_{PD\_Total} + f_{base})\ m^2$$

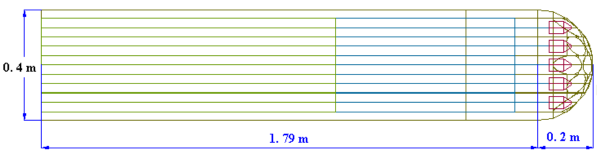
$$\mathbf{f = 98.615 \times 10^{-3}\ m^2}$$

Total coefficient of drag for the whole system is given by:

$$C_D = f / A_{RL}$$

$\mathbf{C_D = 0.7845}$ ***(Conventional M261 Blunt nose Rocket Launcher)***

3.3 Modified M261 (19-tube) Hydra-70 Light weight Hemi-spherical Nose Rocket Launcher



Cross-sectional Area,

$$A_t = \pi r^2 = 0.1257 \text{ m}^2$$

Total length of the pod,

$$L_{t+n} = L_t + L_n$$
$$L_{t+n} = (1.79 + 0.2) \text{ m}$$
$$\mathbf{L_{t+n} = 1.99 \text{ m}}$$

Wetted area of Hemi-spherical Nose,

$$S_{Wet\_nose} = 2 \pi r^2 = 0.25133 \text{ m}^2$$

Wetted area of Tube part,

$$S_{Wet\_tube} = 2 \pi r L_t = 2.2494 \text{ m}^2$$

Total Wetted area Rocket Launcher,

$$\mathbf{S_{Wet\_RL} = S_{Wet\_nose} + S_{Wet\_tube} = 2.501 \text{ m}^2}$$

Reynolds number for Nose-Tube junction,

$$Re_{\_Ln} = (\rho_0 \times V_{avg} \times L_n) / \mu_0$$
$$\mathbf{Re_{\_Ln} = 8.215 \times 10^5}$$

Reynolds number for complete Nose + Tube,

$$Re_{\_L} = (\rho_0 \times V_{avg} \times L_{t+n}) / \mu_0$$
$$\mathbf{Re_{\_L} = 8.174 \times 10^6}$$

3.3.1 Body Skin Friction

Now, the average skin friction coefficient for the modified Rocket Launcher's Nose and Tube combined is given by the formulae:

$$C_{f\_body} = \left\{\frac{L_n}{L} \times C_{flam}\left(Re_{\ Ln}\right)\right\} + \left[C_{f\_turb}\left(Re_L\right) - \left\{\frac{L_n}{L} \times C_{f\_turb}\left(Re_{Ln}\right)\right\}\right]$$

$$\mathbf{C_{f\_Body} = 2.7262 \times 10^{-3}}$$

Now, Equivalent Flat Plate area due to the body friction for the whole Launcher is given by:

$$f_{RL\_skin} = C_{f\_Body} \times S_{Wet\_RL}$$

$$\mathbf{f_{RL\_skin} = 6.818 \times 10^{-3}}$$

3.3.2 Nose Pressure Drag

From "Fluid Dynamic Drag, Hoerner (page 3-12)", the drag coefficient for the Hemi-spherical nose shape (C_{D_nose}) is 0.04.

Hence, Equivalent Flat Plate area due to the nose pressure is given by:

$$f_{nose\_PD} = C_{D\_nose} \times A_t$$
$$\mathbf{f_{nose\_PD} = 5.0265 \times 10^{-3} \text{ m}^2}$$

3.3.3 Base Drag

Now, Equivalent Flat Plate area due to the Base Drag for the Rocket Launcher is given by:

$$f_{base} = C_{DB} \times A_t$$
$$\mathbf{f_{base} = 15.5868 \times 10^{-3} \text{ m}^2}$$

3.3.4 Total Drag Calculations

$$f = (f_{RL\_skin} + f_{nose\_PD} + f_{base}) \text{ m}^2$$
$$\mathbf{f = 27.43 \times 10^{-3} \text{ m}^2}$$

Total coefficient of drag for the whole system is given by:

$$C_D = f / A_t$$

$\mathbf{C_D = 0.218}$ ***(Modified M261 Hemi-Spherical nose Rocket Launcher)***

4. Computational Fluid Dynamics (CFD) Analysis

The Mathematical method used above for estimating the value for Drag coefficient, does not reflect the current industry practice. Aircraft companies now-a-days are using CAD softwares like CATIA or ProEngineer, for the modeling purposes and Computational Fluid Dynamic (CFD), software like FLUENT for getting the first estimates for the Drag, Lift and Momentum coefficients. Using these CFD softwares saves a lot of time as it gives us the first estimate of the Drag and Lift for the body, without the hassle of making the prototype and then testing it again and again in the wind tunnel by modifying the prototype. Wind tunnel testing offers a powerful tool for aircraft development, but unfortunately, the costs associated with detailed wind tunnel testing tend to preclude an exhaustive evaluation of all possible designs.

4.1 FLUENT

FLUENT is a suite of programs that model systems in computational fluid dynamics (CFD). This includes flows in two- and three-dimensional geometries, and under a variety of conditions: compressible and incompressible; inviscid, laminar and turbulent; Newtonian and non-Newtonian. The analysis can be steady-state or transient. The FLUENT package consists of several programs: "FLUENT", the solver; "prePDF", a preprocessor for modeling combustion; "GAMBIT", a preprocessor for modeling geometries and generating meshes; "TGrid", creating volume meshes from boundary meshes; several filters to import meshes from other CAD packages.

4.2 GAMBIT

GAMBIT is a software package designed to help analysts and designers build and mesh models for computational fluid dynamics (CFD) and other scientific applications. The GAMBIT GUI makes the basic steps of building, meshing, and assigning zone types to a model simple and intuitive, yet it is versatile enough to accommodate a wide range of modeling applications.

Before any numerical solution can be computed, the physical domain must be filled with a computational grid. The two major categories of grid construction are structured grids and unstructured grids. Structured grids are easier to handle computationally because their connectivity information is stored block to block. Unstructured grids are more difficult to handle computationally because their connectivity is stored for each node. Unstructured grids, however, tend to be easier to construct and do not waste memory in far field cell resolution. Unstructured solvers often result in simpler computer codes too, which means they are easier to maintain and modify. In our analysis we are also using the unstructured mesh for the conventional and the modified Rocket Launcher models.

5. Modeling

A two dimensional model for both the conventional and the modified hemispherical nose rocket launcher's were modeled in GAMBIT. The drawings for both of the above mentioned launcher's are as under:

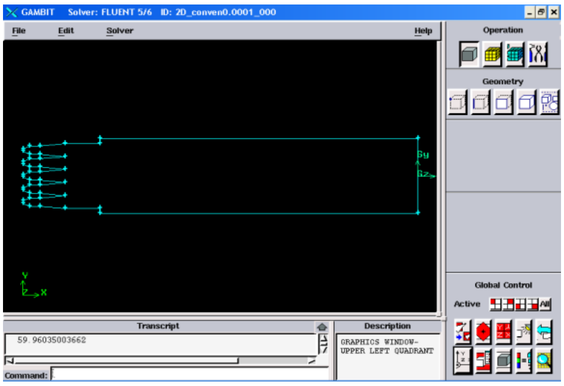


Fig. 5.1: Conventional Launcher

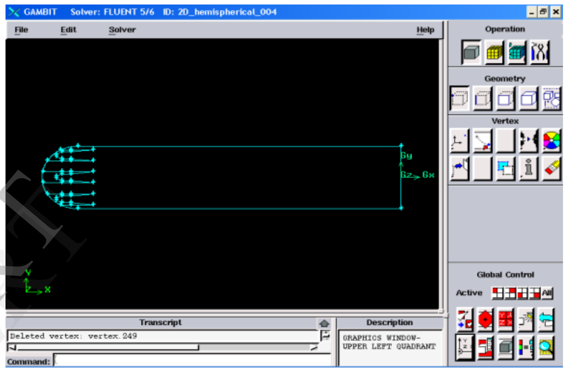


Fig. 5.2: Hemispherical Nose shape Launcher

6. Meshing

After the modeling part, it was time for making a domain around the model that would represent the environment around it. A rectangular environment was made with dimensions around 20 times that of the Launcher drawing. After that the launcher body was subtracted from the environment, the remaining part represents the fluid or air around the launcher. It is just like imagining a model to be tested in a wind tunnel.

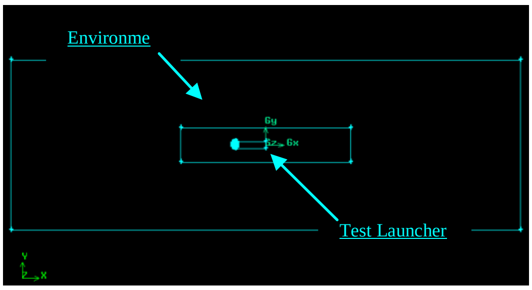


Fig. 6.1: Diagram showing the test launcher and the environment around it

Fixed Size-function was used to generate the tetrahedral mesh around the test object. Size functions allow you to control the size of mesh-element edges for geometric edge entities and for faces or volumes that are meshed using triangular or tetrahedral elements, respectively.

The diagrams below show the mesh generated using the above schemes in GAMBIT.

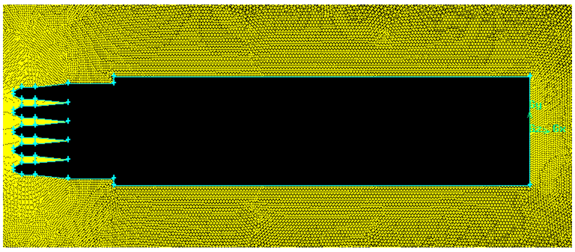


Fig. 6.2: Diagram showing the Meshing around the Conventional launcher

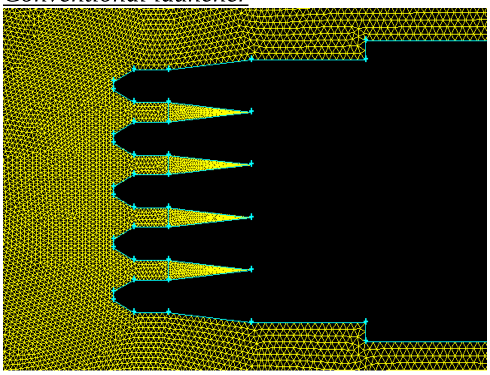


Fig. 6.3: Diagram showing the meshing in the vicinity of the nose of the Conventional launcher

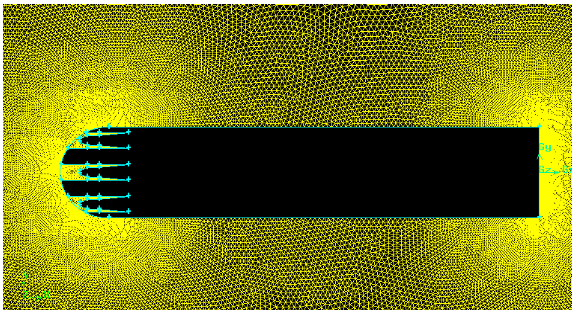


Fig. 6.4: Diagram showing the meshing around the Hemispherical Nose launcher

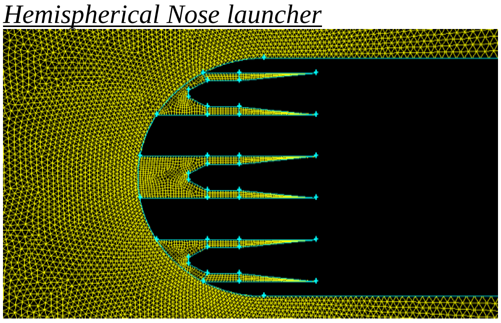


Fig. 6.5: Diagram showing the meshing in the vicinity of the nose of the Hemispherical Nose launcher

7. CFD Results

7.1. Conventional Blunt Nose Rocket Launcher

Iterating the solution until the convergence of the results achieved, we got the values of coefficient of friction for the Conventional Launcher Model,

The Coefficient of Friction comes out to be **0.31462** for the conventional Blunt nose shape of the Rocket Launcher.

The figure below shows the convergence history for the coefficient of friction for the conventional launcher:

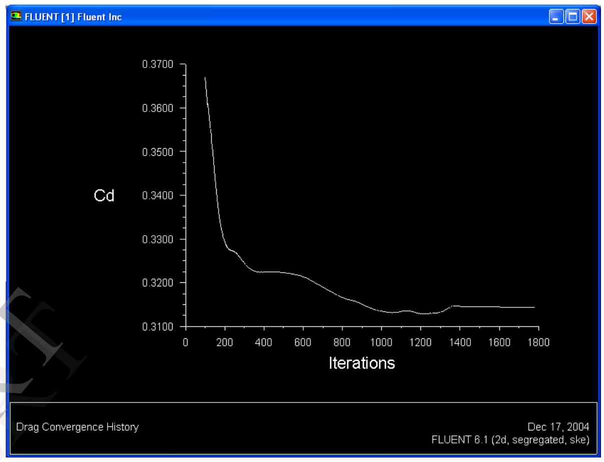


Fig. 7.1: Drag Coefficient History for the Conventional Rocket Launcher

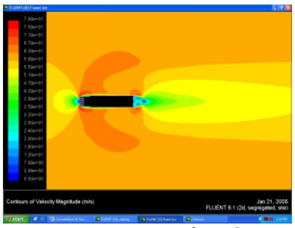


Fig.7.2: Contours of Velocity Magnitude

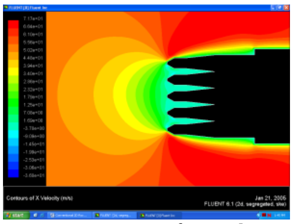


Fig.7.3: Contours of X Velocity (Front)

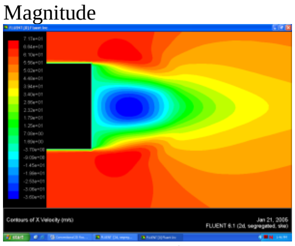


Fig.7.4: Contours of X Velocity (Aft)

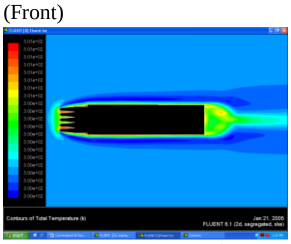


Fig. 7.5: Contours of Total Temperature

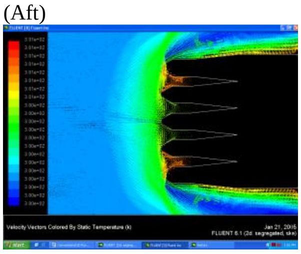


Fig. 7.6: Velocity Vectors colored by Static Temperature

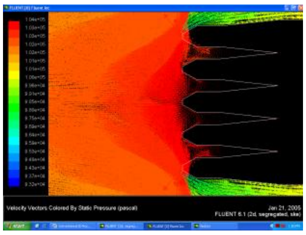


Fig. 7.7: Velocity Vectors colored by Static Pressure

7.2 Hemispherical Nose Shape Rocket Launcher

Iterating the solution until the convergence of the results achieved, we got the values of coefficient of friction for the Hemispherical Nose Shape Launcher Model.

The Coefficient of Friction comes out to be **0.2449** for the Hemispherical Nose Shape of the Rocket Launcher.

The figure below shows the convergence history for the coefficient of friction for the Hemispherical Nose Shape Launcher:

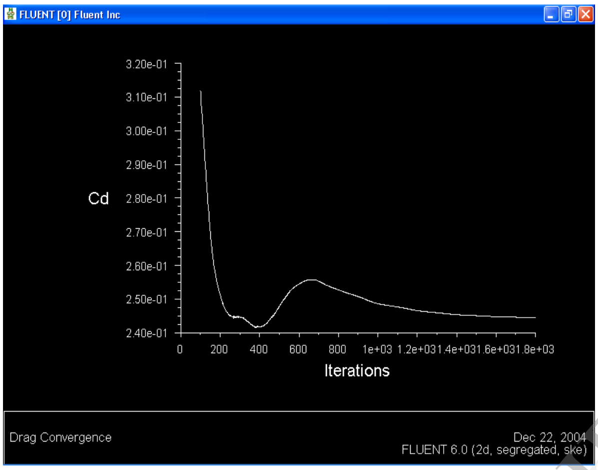


Fig. 7.8: Drag Convergence History for the Hemispherical Nose Launcher

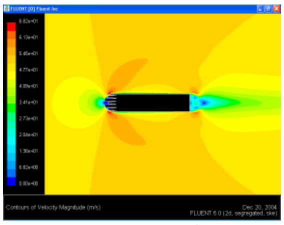


Fig. 7.9: Contours of Velocity Magnitude

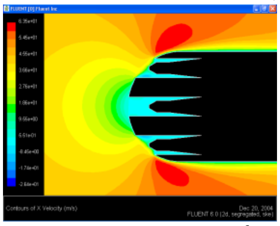


Fig. 7.10: Contours of X Velocity (Front)

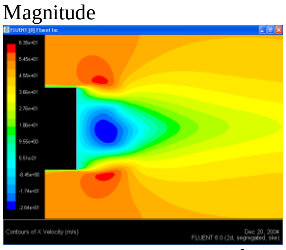


Fig. 7.11: Contours of X Velocity (Aft)

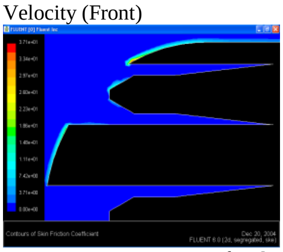


Fig. 7.12: Contours of Skin Friction Coefficient

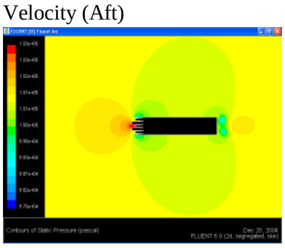


Fig. 7.13: Contours of Static Pressure

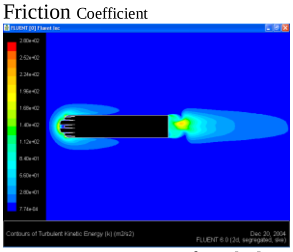


Fig. 7.14: Contours of Turbulent Kinetic Energy

8. Conclusion

We used M261 Rocket Launcher that is mainly used by the Military Helicopters, as the basis of our investigation. We tried to modify the design of the conventional Rocket Launcher by modifying the shape of the nose, and giving it a Hemi-spherical nose shape. Using FLUENT as the CFD software we calculated the coefficients of Drags for both the cases, and tried to get the rough estimate of the difference of the Drag forces that we can achieve after modifying the nose shape of the Conventional Rocket Launcher, though a penalty had to be paid in the shape of the weight, in the course of modifying the design there was a approximate increase of the weight of the Rocket Launcher by 6-10 Kg, but this weight increase can be consolidated using smarter and lighter material.

Now from the simulation results of the FLUENT we got the values of the coefficient of Drag values for both the conventional and the modified versions of the Rocket Launchers, these are summed up as under:

For Conventional Rocket Launcher design, $C_{d(conven)} = 0.31462$

For Hemi-spherical Nose Rocket Launcher design, $C_{d(hemi\text{-}spherical)} = 0.2449$

Drag (D) is given by:

$$D = (\frac{1}{2} \times \rho \times V^2 \times S_{wet} \times C_d)\ N$$

Case I: Conventional Blunt Nose Launcher

$D_{conven} = 2011.84$ N

Case II: Hemi-spherical Nose Launcher

$D_{hemi\text{-}spherical} = 1357.19$ N

Now the difference between them is:

$$\mathbf{D_{conven} - D_{hemi\text{-}spherical} = 654.65\ N}$$

This implies percentage decrease in the Drag is = **32.54 %**

Hence the results show a **32.54 %** decrease in the Drag Force, the main reason being the wetted area of the Launcher and the Rocket system.

9. Future Work

Due to the shortage of time, we had confined our work only to the analysis for the 2–dimensional models of the Launchers for both the cases. It is desired to simulate the results for the 3-dimensional models of the launchers, to get more accurate results. Meshing of the 3-D, model take a lot of time as in the case of the conventional launcher the gap between the rockets is too small, and Gambit only allows a maximum of 1 million elements in the case of the tetrahedral meshing scheme for the unstructured meshing.

After this has been achieved a further step would be to test the various nose shapes possible, i.e. Cone, Blunt Cone, Parabolic and Elliptical, and then comparing the results of all to get the optimum design.

Further work can be done by actually modeling the Rocket Launcher and perform the wind tunnel tests and then testing the different nose shapes to get the optimum design.

10. References

[1] Anatol Roshko, *The Drag and Shedding Frequency of Two-Dimensional Bluff Bodies,* NACA TN – 3169, 1954.

[2] Andreas Parsch, *2.75 – Inch Rockets, Air Launched 2.75 – Inch Rockets,* Appendix – 4 Undesignated Vehicles, Directory of US Military Rockets and Missiles, 2003.

[3] Armaments that Apache can carry, *http://www.voodoo.cz/ah64/arm.html.*

[4] Bruce R. Munson, Donald F. Young, and Theodore H. Okiishi, *Fundamentals of Fluid Mechanics,* John Wiley and Sons, 1990.

[5] E.L. Houghton and P.W. Carpenter, *Aerodynamics for Engineering Students,* Edward Arnold, 1993.

[6] Eric Hawley, *MK66 Rocket Motor / Helicopter Compatibility Program,* Indian Head Division, Naval Surface Warfare Center, March 2003.

[7] Eugene E. Covert – Editor, C.R. James, William F. Kimzey, George K. Richey, and Eugene C. Rooney – Associate Editors, *Thrust and Drag: Its Prediction and Verification,* Volume-98, Progress in Astronautics and Aeronautics, American Institute of Aeronautics and Astronautics, 1985.

[8] Federation of American Scientists (FAS), Website, *http://www.fas.org/man/dod-101/sys/ac/equip/lau-hydra-7.htm.*

[9] George E. Solomon, *Transonic Flow Past Cone Cylinders,* NACA Report – 1242.

[10] Glen Goodwin, Mercus O. Creager, and Ernest L. Winkler, *Investigation of Local Heat-Transfer and Pressure Drag Characteristics of a Yawed Circular Cylinder at Supersonic Speeds,* NACA RM – A55H31, 1956.

[11] John Pike, *Advanced Precision Kill Weapon System (APKWS), http://www.globalsecurity.org/military/systems/munitions/apkws.htm*, 2002.

[12] Joni Johnson, *Improved Insensitive Munitions Performance of an HE Rocket Warhead,* NDIA Rockets and Missiles Symposium, San Antonio, TX, 2001.

[13] Michael A. Park, *Adjoint-Based, Three-Dimensional Error Prediction and Grid Adaptation,* NASA Langley Research Centre, AIAA 2002 – 3286, 32nd Fluid Dynamics Conference 24 – 27 June 2002.

[14] Michael J. Hemsch and Jack N. Nielsen – Editors, *Tactical Missile Aerodynamics,* Volume-104, Progress in Astronautics and Aeronautics, American Institute of Aeronautics and Astronautics, 1986.

[15] Noel K. Delany and Norman E. Sorensen, *Low – Speed Drag of Cylinders of Various Shapes,* National Advisory Committee for Aeronautics – Technical Note 3038, NACA, 1953.

[16] Roy Braybrook, Dough Richardson, and Brian Walters, *Bolt from The Blue, The Grey and The Black – The General Dynamics APKWS on Hyda-70 Rockets,* Armada International, Volume – 28, March 2004.

[17] Sighard F. Hoerner, *Fluid Dynamic Drag,* Practical information on Aerodynamic Drag and Hydrodynamic Resistance, Hoerner Fluid Dynamics, Vancouver, WA, 1965.

[18] Tuncer Cebeci and A.M.O. Smith, *Analysis of Turbulent Boundary Layers,* Academic Press, 1974.