

AUTOMATIC MESH GENERATOR INTEGRATED MISSILE DESIGN SOFTWARE DEVELOPMENT

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ABSTRACT

In this study, a software that is utilized after the pre-design phase of the missile design is presented. This software consists of computational domain modeller and multi-block structured mesh generator. Geometrical design variables of the missile used in the software are based on Missile DATCOM and the presented software eliminates the time consumed between the preliminary design and the CFD analysis by automating the computational domain generation. In order to model the different orientations of the fins during the flight, fins and the body of the missile are brought together by the use of overset mesh method which eliminates the time for modifying and deforming the mesh during the solution time. Mesh generation is automated and the user only need to enter the basic geometric variables of the missile which can be obtained from Missile DATCOM software.

INTRODUCTION

Computational fluid dynamics analyses become the main part of the design process of missiles as well as the other aerospace structures. Shape of the nose, geometric dimensions of the body, orientation and types of the fins are few of the parameters that determine the aerodynamic performance of the missile. In order to design a missile with a good aerodynamic performance, all of these parameters should be studied and the design should be carried out based on these studies. In the preliminary design phase, these parameters are used to determine the general performance characteristic of the missile by using empirical, semi-empirical correlations or with the help of reduced order 1D analysis. However, in order to investigate the flow around the body and the wings in more detail, especially for the separation and the stall characteristics, CFD analysis should be performed. In order to perform a CFD analysis, the computational domain of the problem should be generated and a proper mesh should be created on the domain, since the external aerodynamic problems require a mesh quality at a certain level to fully resolve the boundary layer or to let the wall functions to be used, which is quite time consuming job. However, the mesh generation is one of the key parameters that determines the quality of the CFD analysis. Therefore, it is required that the high quality mesh should be generated for different combinations of the design parameters to ensure that the analysis reflects only the design parameter effects, not the mesh and the discretization errors and problems.

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In the literature, there exist several works for the automated geometry and the mesh creation for the missiles and the aerospace structures. In one of the works, a tool for structural design of missiles is developed [Jixing, Tao, Ping and Tian, 2016]. In this tool, the geometrical modelling is based on the parametric variables and completed in a third party CAD software. Then the mesh is created using an integrated mesh generator. In addition, this work is limited with structural design of the missiles, it does not include the aerodynamic analysis. In another work, a design optimization study is performed using a machine learning algorithm and the design is based on the DATCOM software [Yan, Zhu, Kuang and Wang, 2019]. In this study, design modifications are compared autonomously in the pre-design phase which does not include mesh generation or CFD analysis. A knowledge-based design environment for the general purpose aircraft structures is developed to easily implement different configurations [Haocheng, Mingqiang, Hu and Zhe, 2011]. However, this study is not autonomous and is not specific for the missiles. In the mesh generation, a multi-block structured mesh generator for the boundary layer mesh of arbitrary aerospace structures is developed by Lu et. al. [Lu, Pang, Jiang, Sun, Huang, Wang and Ju, 2018]. In this study, the boundary layer mesh generation is automated and validated for the convex and concave geometries. However, three dimensional modelling is not included and the surface mesh is needed to perform meshing. Therefore, it is not fully automated and the need of a preprocessing of the mesh still exists. For the last example, an interactive and automated design environment for the turbomachinery design is created which includes the geometry generation, the mesh generation and the flow solver within the context of the thesis [Kundes, 2017]. This study is an example work for automated aerodynamic design which includes preliminary design, mesh generation and the solver. Therefore, as an ultimate goal, a design environment should contain these three properties.

In this work, an automated software for aerodynamic design of missiles which includes computational domain and multi-block structured mesh generation is presented. It is expected that in the phase of preliminary design to CFD analysis, user interruption is going to be minimized and the high quality mesh is generated for each configuration. With this work, speed of aerodynamic design of missiles is going to be shortened significantly since the time consumed to create high quality mesh is reduced. This study covers only the first two parts of the previously mentioned full design environment which are the preliminary design and the geometry and mesh generation.

METHOD

In this work, the geometrical data that is needed to create the three dimensional model and the computational domain is taken from the Missile DATCOM, which is a semi-empirical preliminary design tool for missiles. The computational domain and the mesh is generated by extending and modifying the C++ code of Dener's studies [Dener, 1992]. This code was developed as an interactive geometry and grid generation environment. Using and extending the code segments and objects, a standalone missile design and mesh generation platform is developed.

Missile design consists of two main parts when the geometrical properties are considered, which are the body design and the fin design [DATCOM, 2008].

Body Design

The body consists of three components which are nose, center and aft. In this software, the notation for these parameters is same as the notation of Missile DATCOM which is presented in the Figure 1. Necessary inputs to create the body are

- Nose shape, diameter (D) and length of the nose (L)
- Center diameter (D) and length of the body center (L)
- Aft shape, diameter (D) and length of the body (L)

In addition to them, nose and aft can be modelled as truncated, which is a common design concept, which requires the input for truncation diameter.

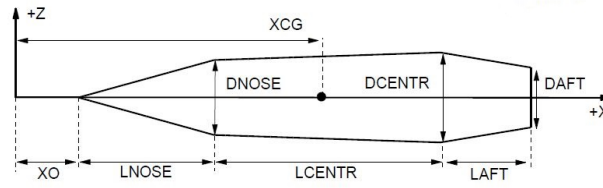


Figure 1: Missile body notation

In this tool, widely used nose geometries are defined which are cone, ogive, power series, Haack and von Karman type. For aft shape ogive and cone shapes are defined preliminarily.

Cone:

The simplest nose shape is the cone, which can be mathematically described as

$$y = \frac{xR}{L}$$

The problem with the cone shape is that it is hard to create a mesh around sharp point since it creates discontinuity. In the software, use of truncated nose is dictated which can be good assumption due to the manufacturing problems.

Tangent Ogive:

Due to its simplicity to create and manufacture, tangent ogive profile is one of the most popular nose cone shapes. The mathematical formula is given as

$$y = \sqrt{\rho^2 - (L - x)^2} + R - \rho$$

where ρ being ogive radius and is given as

$$\frac{R^2 + L^2}{2R}$$

Power Series:

Power series type nose cones are generally characterized with blunt nose that depends on the power constant. Shape is given by

$$y = R\left(\frac{x}{L}\right)^n$$

where

$$0 \leq n \leq 1$$

Haack Series:

The Haack Series nose cones are not geometrically constructed, but they are derived from mathematical and aerodynamic equations to minimize the drag. The shape of the nose is given as

$$y = \frac{R}{\sqrt{\pi}} \sqrt{\theta - \frac{\sin 2\theta}{2} + C \sin^3 \theta}$$

where θ is defined as

$$\theta = \arccos\left(1 - \frac{2x}{L}\right)$$

The constant C determines the drag coefficient and the discontinuity in the body. For given nose length and nose diameter, $C = 0$ gives the minimum drag coefficient while for given nose length and nose volume

$C = 1/3$ gives minimum drag coefficient.

von Karman:

If the $C = 0$, the Haack Series type is called as von Karman type.

Based on the input dimensions and the given shape, a set of points are created and they are connected with a B-Spline curve.

Body geometry is created as axisymmetric for both nose, center and aft. Each of the parts are defined as different blocks to eliminate the discontinuities in the boundaries and preventing them to propagating into the domain, especially to the boundary layer mesh. For the truncated front and back, diamond mesh is created since it is easy to implement and do not decrease the quality of the mesh in the circular domain significantly when compared to the four boundary structured mesh of circular domain.

Due to the modularity of the code architecture, custom designs for nose and aft shapes. Therefore, applicable nose and aft cone shapes are not limited with the pre-defined shapes.

Fin Design

For the fin design, hexagonal shaped airfoil is taken as the default configuration. A finset consists of identical fins at prescribed distance from the nose tip. The fins can be designed as single segment or multi-segment fins. Each segment is defined with spans which is the sweep from the surface with of the body with a certain angle and the distance from the nose tip of the missile. Geometric representations for finsets and the hexagonal airfoil is presented in the figures 2 and 3 respectively. Necessary geometric inputs for the finsets are:

- Number of finsets
- Number of fins in each finset
- Leading and trailing edge lengths of the hexagonal airfoil
- Center length of the hexagonal airfoil
- Span distances from the center line of the body
- Distances of each fin from the nose of the body

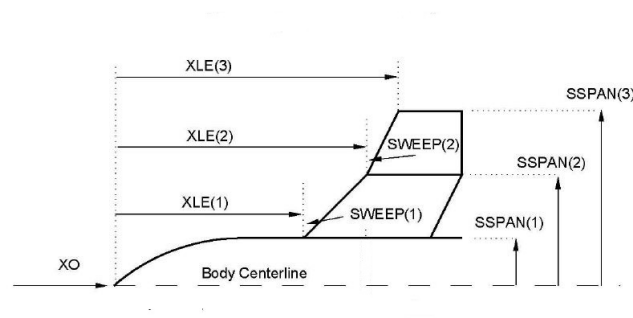


Figure 2: Fin arrangement in the body

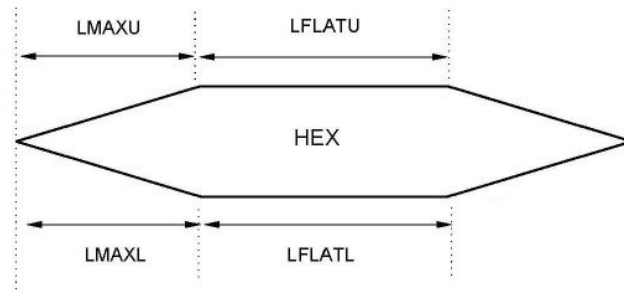


Figure 3: Hexagonal airfoil

Each fin may consist of several segments, generally 1 to 2, and each segment consists of six block of structured mesh which covers the whole domain around the fin. Since the hexagonal geometry consists of discontinuity and sharp corners in the boundary, creating different blocks for each part eliminates the propagation of boundary discontinuities into the domain. This is extremely critical for the boundary layer mesh around the fin which governs the separation and the possible shock wave-boundary layer interactions. In addition to that, a tip mesh is needed for the upper surface of the fins, which is generated autonomously with the given geometric parameters. Mesh of finsets and body is brought together using overset mesh method. This approach brings two major advantages which are ease of meshing process and possibility to implement different fin orientations, such as different angle of attack during the flight conditions, without modifying the generated mesh.

Structured mesh for each block is generated using transfinite interpolation method which requires 4 boundaries in 2-dimensional space and 6 boundaries in 3-dimensional space. Since the generated domains are simplified due to the use of multi-block strategy, transfinite interpolation creates high quality grids fast. Smoothing is applied using elliptic mesh generation which eliminates the non-smooth cells in the domain. For the elliptic grid generation successive line over-relaxation (SLOR) algorithm is used which converges faster than successive over-relaxation method [Dener, 1992]. Using multi-block strategy, discontinuities in the boundaries are eliminated which guarantees the convergence of the elliptic smoother.

The summary of the grid generation and design process is given in the flow chart below.

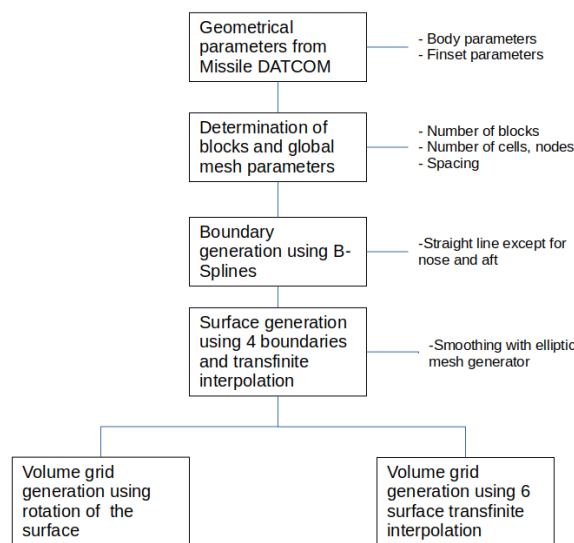
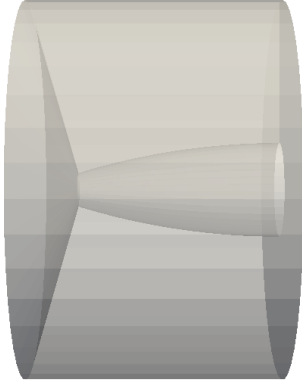


Figure 4: Methodology implemented in the software

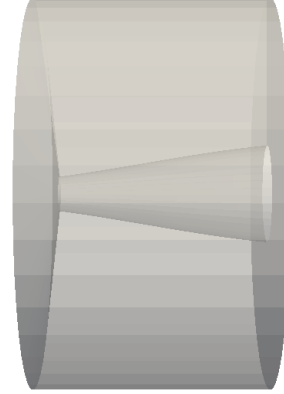
RESULTS AND DISCUSSION

Nose Cone Design

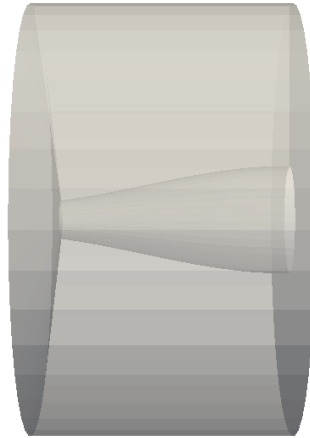
As described above, different configurations for the nose cones can implemented with the software with one input. In order to demonstrate the geometry and mesh generation capability of the software, the ratio of the nose diameter to nose length is selected to be 0.5 and Ogive, power law and Haack types of the nose geometry presented in the figures below.



(a) Ogive nose



(b) Power nose, $n = 0.5$



(c) Haack nose, $C = 1/3$

Figure 5: Nose cone options

These are the most common types of the nose shapes and in order to implement them only one more input in addition to the dimensions of the body is enough. The corresponding points for the B-Spline curve is generated automatically and the desired geometry is represented with high quality.

Full Missile Domain

A missile body is created with this software to show the overall computational domain. Missile body consists of an ogive shaped nose and cone shaped aft, 1 finset and 4 fins for this finset. In the figure, generated domain for body, butterfly mesh for the tip of the nose and the tip of the aft, generated domain for the fins and their tips are presented.

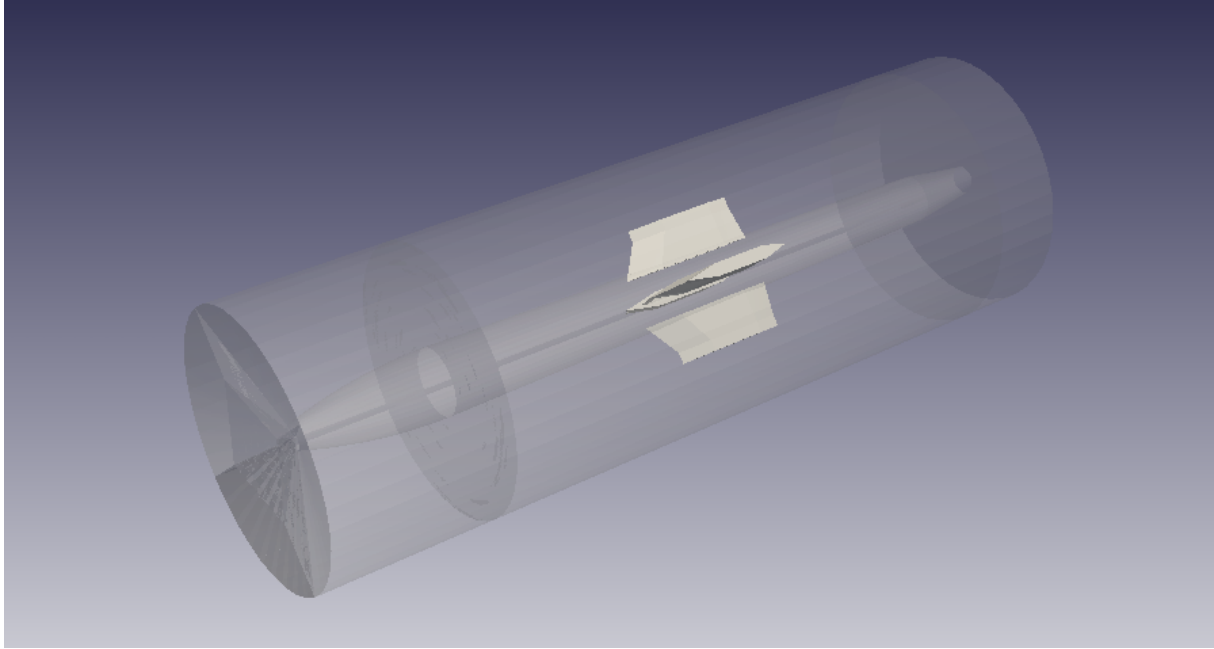


Figure 6: Full scale missile body

Generated overall mesh for this full scale geometry is presented in the figure below. Finset mesh is shown separately from the full scale model to see the details more clearly. In the domain, blocks can be identified for the nose, center and the aft regions.

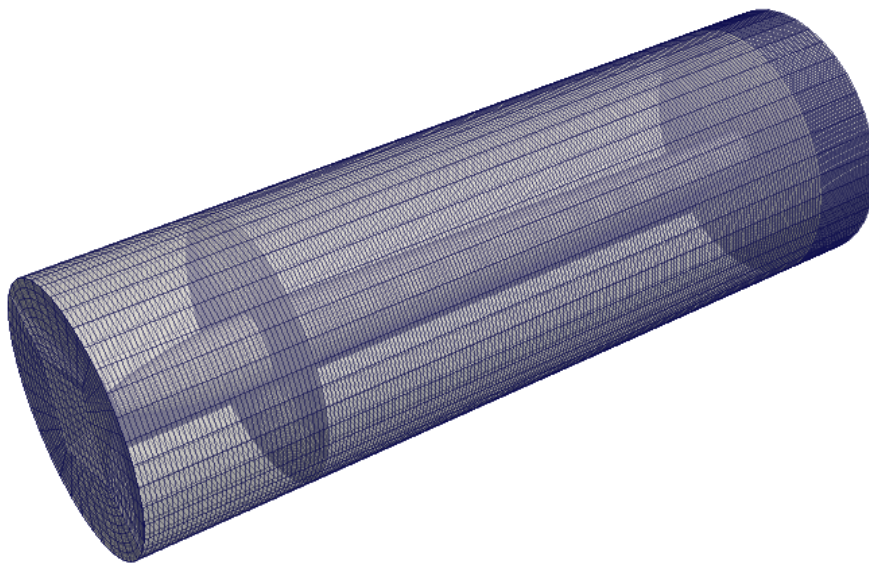


Figure 7: Full scale missile body mesh

Butterfly mesh for the nose and aft tip is presented below. In order to represent more clearly number of cells is decreased for the demonstration purposes. Mesh quality can be increased by adjusting central diamond size.

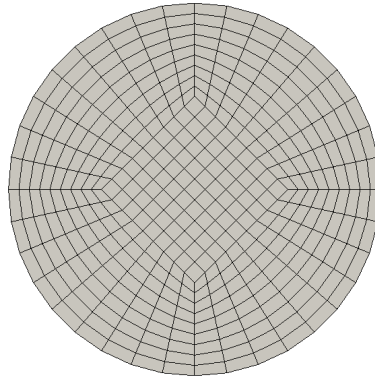
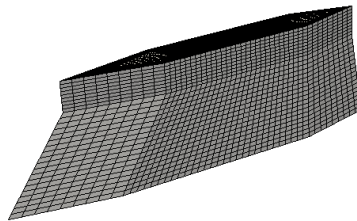


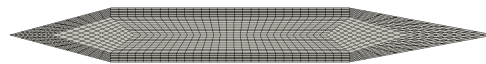
Figure 8: Circular surface mesh

Fin Mesh

For the hexagonal fins generated mesh including the tip surface is presented in the figure below. The discontinuity between the tip and the boundary layer mesh can be reduced further by pre-evaluating the sweep angle, however it may reduce the mesh quality.



(a) Overall fin mesh



(b) Tip mesh

Figure 9: Fin Mesh

While generating the geometry and the mesh, user interaction is limited with the input parameters and the rest of the process is automated. Geometry and mesh whose cell number is nearly 2 million is created under 5 seconds.

CONCLUSIONS

In the presented work, automated design software for missiles is presented. In the software, multi-block structured grid generation is implemented and based on the geometry parameters from Missile DATCOM software, the domain and the mesh is generated autonomously. Different types of the nose cone geometries are implemented in accordance with the Missile DATCOM to develop preliminary designs more accurately and without concerning about the 3D geometry generation. With this tool, CFD mesh for preliminary designed missile body in the Missile DATCOM can be created rapidly and the design decision based on 1D analysis can be tested in higher dimensional analyses. For the finsets, with the implementation of the overset mesh method, it becomes easy and reliable to test the different orientations of the fins without concerning about the generation and deformation of the mesh.

In the future work, this software is going to be implemented to the Missile DATCOM and to the $k-\omega$ SST-LES hybrid compressible solver to create a full design environment to minimize the user interaction which improves the usage of the design time. Based on the results that will be obtained in the next phase, mesh spacing and clustering will be optimized.

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