TuijinJishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No.4 (2023)

Conceptual Design of Loiter Munition UAV

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Abstract. The concept of UAV is popping out of the box in defense technology. The use of Loitering Munitions has given the military a cutting edge in warfare tactics. From the most advanced nations to the least emerged nations, all have employed the services of the UAV/UCAV. Today, India is actively buying this technology from developed nations like the US and advanced technologies of UAVs from Israel. This indicates the lack of indigenous technology or very limited research centers looking into the development of the concept of UAV for the military. This is because the largest workforce of minds in the nation- the students and researchers are not entirely looking into this concept. Thus, this work is an attempt to fill the gap of such necessities through the conceptualdesign of an LM-UAV using variousdesign calculations and verifying the design by CFD analysis. A Loitering Munition is a type of UAV that itself acts as a weapon and hits the target when the target is in sight,after waiting passively or loitering in the area nearby. The first estimates obtained from the literature review, are used as initial design parameters once the discussions regarding the design in OpenVSP software aretaken into context. The Fluent flow analysis using Ansys for cruise flight at a particular altitude is done to obtain the lift force generation on the designed UAV and compare it with the theoretically calculated lift force. This work can be used as a source of reliable information for the development of UAVs or other works related to the design and development of UAVs.

Keywords: *Unmanned Aerial Vehicle (UAV), Loitering Munitions (LM), Unmanned Combat Aerial Vehicle (UCAV), Open Vehicle Sketch Pad (OpenVSP), Computational Fluid Dynamics (CFD), Ansys Fluent.*

1. Introduction

This work involves the following procedures starting with a little introduction to the concept of UAV and Loitering munitions followed by the definition of the problem statement and objectives. Then, the literature survey is carried out and the related sources were identified. The sources include research works on design calculations, research works on UAV designing, and comparative studies of various UAVs in the market. Once the initial estimates from the literature survey are obtained, the design calculations are drafted for the required mission condition. With the design calculations in mind, a JAVA program is constructed. With the output values of the JAVA program, the designing is carried out in OpenVSP software. The CAD files are then imported into Ansys for meshing and flow analysis to find the lift and drag force generated on the UAV.

As we know from general understanding the UAV is the most advanced aircraft of the 21st century. They are the modified form of aeronautical and Artificial Intelligence technology. Thus, Loitering Munitions are that category of UAVs used mainly in defense as suicide drones or airplanes. They loiter at a particular place and then the aircraft itself hits when the target is in sight.

Mark Voskuijl has developed a huge database of information available from the public domain which includes the dimension, weights, and performance parameters like endurance and range of the UAV. He has also created six categories of loiter munitions based on the data collected [1].Vincent Spada has enumerated a unique methodology that calculates various flight design variables like wing loading, power loading, thrust loading aspect ratio ad cruise altitude for the conceptual design phase of medium altitude long endurance (MALE) UAVs[2].Landolfo has studied the overall air vehicle performance of a multiple lifting surface configuration concerning both structural and aerodynamic considerations for a candidate mission similar to that of the AeroVironment Raven[3]. Shiva Sharma et.al have made a report on the entire design cycle for the production of a minimal cost fixed wing, commercial monitoring UAV using a fixed-wing camera[4]. Miller A. Rocha et.al in their article, have provided the conceptual design for a model UAV based on similar data available based on surveillance and reconnaissance based on flight type and stability for a particular topography of the earth[5].

Thus, all the pieces of literature are regarding the conceptual designs of various types of UAVs, similarly, this work is also related to conceptual design and verification of design by fluid flow analysis of the LM UAV in Ansys fluent.

The OpenVSP design software which is an open-source tool used for designing aircraft is used for the design of the LM UAV.

Once the design is complete the CAAD model is imported into Ansys for meshing and CFD analysis in Fluent.

2. Experimental setup

The calculations used for designing the UAV are similar to those used for designing the engine-propelled aircraft. The design of a subsonic propeller-driven airplane requires theknowledge of the history of the evolution of airplanes as the first step and all the way to understanding the performance equations of the airplane. The most basic approach is considering 7 pivot points around which the entire design process is anchored.

Before proceeding into the first design calculation there are some initial estimates or assumptions to be made for some of the design parameters. These are called the first estimates of the design procedure in a conceptual design. These first estimates are very cruicial besause they act as the pillars for the next design steps and final design of the vehicle. The firs estimates are those values or assumptions which are considered as the known values to start solving the equations and can be obtained from the vehicle requirements as per the mission and also from literature review. The values from the review process can be sometimes exactly as required for the mission requirements and sometimes they can be considered as the one best available for the required estimate. The equations (1) to (39) show the design parameter formulas.

Now for this work, the first estimates assumed and obtained from the literature survey are as follows,

3. Results and Discussion

3.1 The overall weight of the UAV - W_o

$$W_o = W_{WH} + W_B + W_{PR} + W_e \quad (1)$$

$W_P = 4$ kg

$W_B = 1$ kg (approx. 10000 mAh)

$W_{PR} + W_e = 25$ kg

$W_o = 4 + 1 + 25 = 30 * 9.81 = \underline{294\ N}$

3.2 Estimation of critical performance parameters

3.2.1 $C_{L\,max}$ Estimation

Airfoil selected 5 series – Root = NACA 23018 ($C_{L\,max}$ = 1.6)

Tip = NACA 23012 ($C_{L\,max}$ = 1.8)

Average $C_{L\,max}$ = 1.7

NOTE: the $C_{L\,max}$ of the wing is 1.7, but to aid landing and takeoff, high lift devices are used. In this case, $C_{L\,max}$ changes.

$C_{l\,max}$ = 0.9 (for 45° flap deflection)

Sototal, $\Delta C_{L\,max} = 0.9 + 1.7 = 2.6$

But due to 3D effects on the wing and other bodies and assuming the wing aspect ratio to be more than 5, we rewrite it as,

$(C_{L\,max})_{overall} = 0.9 * \Delta C_{L\,max}$ (2)

$= 0.9 * 2.6$

$C_{L\,max} = 2.34$

3.3 Wing loading W/S

$$V_{Stall} = \sqrt{\frac{2\, W/S}{(\rho * CL\ max)}}$$

$W/S = ½\, \rho * V^2_{Stall} * C_{L\,max}$ (3)

From the Literature review and opensource information V_{Stall} = 70 m/s

$W/S = ½ * 1.29 * 20^2 * 2.34$

$W/S = 603\ N/m^2$

3.3.1 Wing Surface area S

$S = W_o / (W/S)$ (4)

$= (30 * 9.81) / (603)$

S = $0.488\ m^2$

Note: We can find S using stall speed and also rolling distance. In our case we stick to stall speed method as it is more important than rolling distance method.

3.3.2 Calculating Wing Span

We know from Literature review

AR= 8

$C_{Do} = 0.03$

We know

$S = b * c$ (5)

$AR = b/c$ (6)

Solving, b = 1.97 m

c = 0.256

3.3.3 Lift to drag ratio L/D

$C_D = C_{Do} + k\, C^2_L$

$$C_D = C_{Do} + \frac{C_L^2}{\pi e AR} \quad (7)$$

$C_D = 0.173$

$$\frac{L}{D} = \frac{C_L}{C_D} = \frac{1.7}{0.173} = 9.78 \quad (8)$$

3.3.4 Power required for ROC_{max}

$$\frac{P_R}{W} = \sqrt{\frac{2}{\rho_\infty}\sqrt{\frac{k}{3.C_{Do}}} * \frac{W}{S}} * \frac{1.55}{L/D_{max}} \quad (9)$$

Substituting the values,

$P_R/W = 0.842$

$P_R = 294 * 0.842$

$\underline{P_R = 247.78\ \text{Watt}}$

3.3.5 $T_{R\,max}$ at V_{max}

$$\frac{T_{max}}{W} = \frac{1}{2}\rho_\infty V^2_{max}\frac{C_{Do}}{W/S} + \frac{2\,k}{\rho_\infty V^2_{max}}\frac{W}{S} \quad (10)$$

Assuming $V_{max} = 110$ m/s,

$T_{R\,max} = 78.115$ N

Hence,

$$P_{R\,max} = T_{R\,max} * V_{max} \quad (11)$$

$\underline{P_{R\,max} = 8592.65\ \text{Watt}}$

This means that the UAV must be able to produce 8.5 kW or more power to overcome V_{max} constraint. If you have other motor and prop combo in mind and if it is not able to produce the specified thrust then V_{max} of UAV will be less.

$P_R/W = \frac{8.6\ \text{kW}}{294\ \text{N}} = 0.0292\ \text{kW}/\text{N}$

Power loading (W/P) = 10.0292 = 34.186 N/kW

3.4 Design Calculations

Now we know the AR and wing span. We need to decide the chord of the wing.

$$c_r = \frac{2S}{b(1+\lambda)} \quad (12)$$

$c_r = 0.32945$ m

$$\lambda * c_r = c_t \quad (13)$$

$c_t = 0.16472$ m

The semi wing span area is given as b/2 = 0.9879 m^2

3.4.1 Location of mean aerodynamic chord

$$\bar{y} = \frac{b}{6}\frac{1+2\lambda}{1+\lambda} \quad (14)$$

$\bar{C}$ = 2/3 c_r ($\frac{1+\lambda+\lambda^2}{1+\lambda}$) (15)

$\bar{y}$ = 0.48333 m; $\bar{C}$ = 0.2562388 m

3.4.2 The length of fuselage

Usually L_f = 4- 6 of $\bar{c}$ (16)

= 4 * 0.25623 = 1.02492 m

3.4.3 C_g of airplaneFirst estimate

Note: Length of each component from nose of the airplane

$$\bar{x} = \frac{W_{WR}L_{WR}+W_{BA}L_{BA}+W_E L_E+W_{Wing}L_W}{W_{WR}+W_{BA}+W_E+W_{Wing}} \quad (17)$$

$\bar{x}$ = 0.672698 m

3.4.4 Tail section Initial estimate

We Know volume ratio of horizontal and vertical tail are,

$$S_{HT} = \frac{V_{HT}\bar{C}S}{L_{HT}} \quad (18)$$

L_{HT} = 90% L_f is the distance of aerodynamic centre of horizontal tail from airplane c_g. (Assumed from Literature review)

And V_{HT} = 0.4 to 0.8is also assumed from Literature Review

$$S_{VT} = \frac{V_{HT}bS}{L_{VT}} \quad (19)$$

L_{VT} = 85.5% L_f is the distance of aerodynamic centre of vertical tail from airplane c_g and V_{VT} = 0.04is also assumed from Literature Review.

3.4.5 Span b_{HT} of horizontal tail

Say AR_{HT} = 4 and λ = 0.5 (from literature review)

$$b_t = \sqrt{AR_t S_{HT}} \quad (20)$$

- Chord of horizontal tail:

$$c_{r\,HT} = \frac{2S_{HT}}{b_{HT}(1+\lambda)} \quad (21)$$

$$\lambda c_{r\,HT} = c_{t\,HT} \quad (22)$$

- Location and length of mean aerodynamic chord of horizontal tail:

$$\bar{y}_{HT} = \frac{b_{HT}}{6}\frac{1+2\lambda}{1+\lambda} \quad (23)$$

$$\bar{C}_{HT} = 2/3\ c_{r\,HT}\left(\frac{1+\lambda+\lambda^2}{1+\lambda}\right) \quad (24)$$

3.4.6 Span h_{VT} of horizontal tail

Say AR_{VT} = 2 and λ = 0.5

$$h_{VT} = \sqrt{AR_{VT}S_{VT}} \quad (25)$$

- Chord of vertical tail:

$$c_{rvt} = \frac{2S_{HT}}{b_{HT}(1+\lambda)} \quad (26)$$

$\lambda c_{r\,VT} = c_{t\,VT}$ (27)

- Location and length of mean aerodynamic chord of vertical tail:

$$\bar{y}_{VT} = \frac{2h_{VT}}{6}\frac{1+2\lambda}{1+\lambda} \quad (28)$$

$$\bar{C}_{VT} = 2/3\, c_{r\,VT}\left(\frac{1+\lambda+\lambda^2}{1+\lambda}\right) \quad (29)$$

3.5 Better weight estimate

3.5.1 Fuselage

This requires battery dimensions (say) = 158mm x 59mm x 161mm; 3.370 kg; 11000 mAh; 16S.

The weight of the fuselage is given as $W_F = 1.4(S_{wetted\ area})$

Surface area of cuboid shaped fuselage

$$S_{wetted\ Area} = 2(lw + wh + lh) \quad (30)$$

Length of fuselage l = 1024.952 m; w = 59 mm; h = 158 mm

3.5.2 Wing

$$W_{Wing} = 2.5(S_{exposed\ planform}) \quad (31)$$

$$S_{exposed\ planform} = (c_{r\,fw} + c_t)\left(\frac{b_{wing} - \frac{width\ of\ fuselage}{2}}{2}\right) \quad (32)$$

Note: $c_{r\,fw}$ is the chord at wing fuselage interaction and is obtained after design

3.5.3 Horizontal tail

$$W_{HT} = 2\, S_{exposed\ HT\ planform} \quad (33)$$

$$S_{exposed\ HT\ planform} = (c_{r\,fHT} + c_{t\,HT})\left(\frac{b_{HT} - \frac{width\ of\ fuselage}{2}}{2}\right) \quad (34)$$

Note: $c_{r\,fHT}$ is the chord at horizontal tail and fuselage interaction and is obtained after design.

3.5.4 Vertical tail

$$W_{VT} = 2\, S_{exposed\ VT\ planform} \quad (35)$$

$$S_{exposed\ VT\ planform} = (c_{r\,fVT} + c_{t\,HT})\left(\frac{h_{VT} - \frac{height\ of\ fuselage}{2}}{2}\right) \quad (36)$$

Note: $c_{r\,fVT}$ is the chord at horizontal tail and fuselage interaction and is obtained after design.

3.5.5 All else empty weight

$$W_{e\ all\ else} = 0.1\, W_o \quad (37)$$

Note: W_o is our first gross weight estimate.

3.5.6 Total empty weight

$$W_{e\ total} = W_F + W_{Wing} + W_{HT} + W_{VT} + W_{e\ all\ else} \quad (38)$$

3.5.7 New Gross weight

$$W_{o\ new} = W_{WH} + W_B + W_{PR} + W_{e\ total} \quad (39)$$

3.6 Iteration for weight estimate convergence

3.6.1 Iteration 1

For new all else empty weight, calculations can be done as per eq^n (37)

$W_{e\ all\ else\ 1} = 0.1\ W_{o\ new}$

Total empty weight 1st iteration can be calculated using eqn (38), as

$W_{e\ total\ 1} = W_F + W_{Wing} + W_{HT} + W_{VT} + W_{e\ all\ else\ 1}$

New Gross weight 1st iteration can be calculated using eqn (39), as

$W_{o\ new\ 1} = W_{WH} + W_B + W_{PR} + W_{e\ total\ 1}$

3.6.2 Iteration 2:

Similar to iteration 1 the values can be calculated as follows

For new all else empty weight as per eqn (37)

$W_{e\ all\ else\ 2} = 0.1\ W_{o\ new\ 1}$

For total empty weight as per eqn (38)

$W_{e\ total\ 2} = W_F + W_{Wing} + W_{HT} + W_{VT} + W_{e\ all\ else\ 2}$

For new Gross weight as per eqn (39)

$W_{o\ new\ 2} = W_{WH} + W_B + W_{PR} + W_{e\ total\ 2}$

3.6.3 N^{th} iteration

Thus, to obtain convergence for new gross weight there will be n number of iterations and the initial value for n^{th} iteration is taken from the result of the previous iteration ie. $(n-1)^{th}$ iteration

- Thus, at the end of each iteration, there is new value of total empty and gross weight.
- End the iterations when successive iterations give same values of gross weight.
- The values obtained in the last iteration is taken as the gross take-off weight for our UAV in pounds.

But to calculate the results manually on paper is very tedious task and during the process there can be chances of data mismatch due to handling of huge data set. There is very good room for human errors to happen, which exactly is not expected in calculations done to design an aircraft.

Hence to eliminate the human errors and to cut time and costs there is considerations for machine calculations. With this thought, the method employed is programming. Here the calculations are done using JAVA programming as explained in detail in consecutive chapter.

3.8 Design in OpenVSP

The above-mentioned calculations are now used as the design parameters for designing the UAV. The design of the UAV is shown in Fig 3 and 4 below.

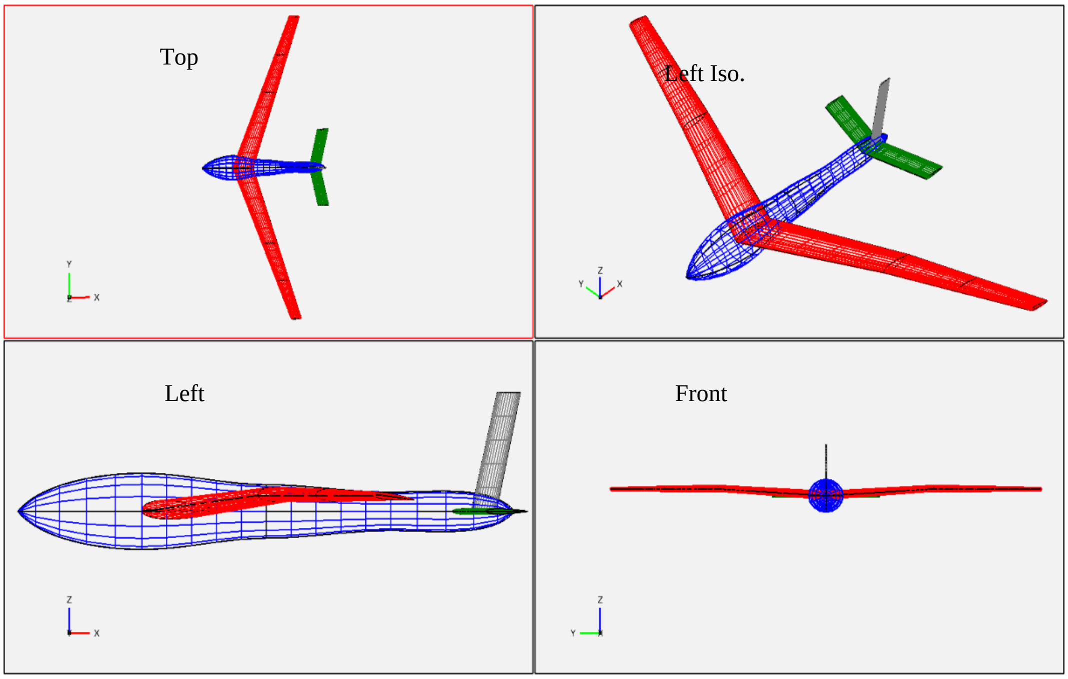

Fig.1: Four views of the UAV

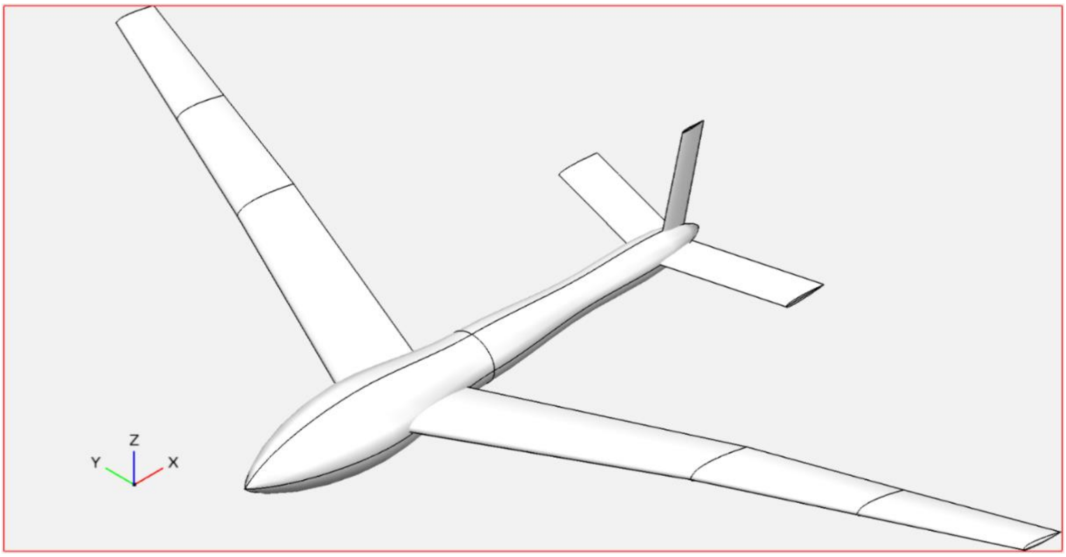

Fig.2: Isometric View of the UAV with skin (shaded).

3.9Analysis in Ansys

The analysis of the UAV is done by creating the flow field around it. This is done in design modeler geometry by creating an enclosure around the UAV of size 4 m x 2 m x 1 m (box type) as shown in Fig.2 below.

Once the enclosure is created the next part is meshing of the flow region. The mesh needs to be uniform with triangular elements for better mesh quality and analysis results. Optimize the mesh size where ever required. The mesh statistics are mentioned in the Table 1 below and mesh is shown in Fig.3.

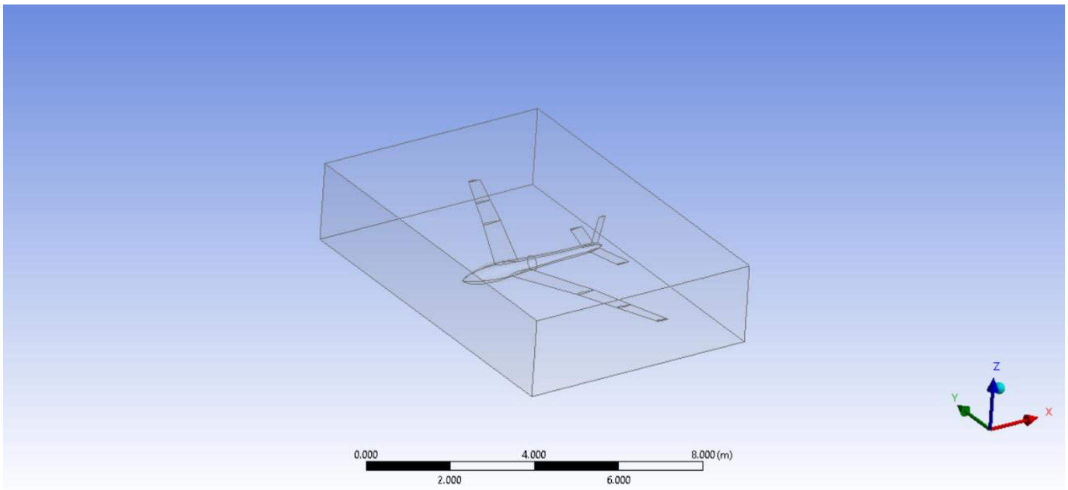

Fig.3: Enclosure around the UAV

Table 1: Mesh statistics

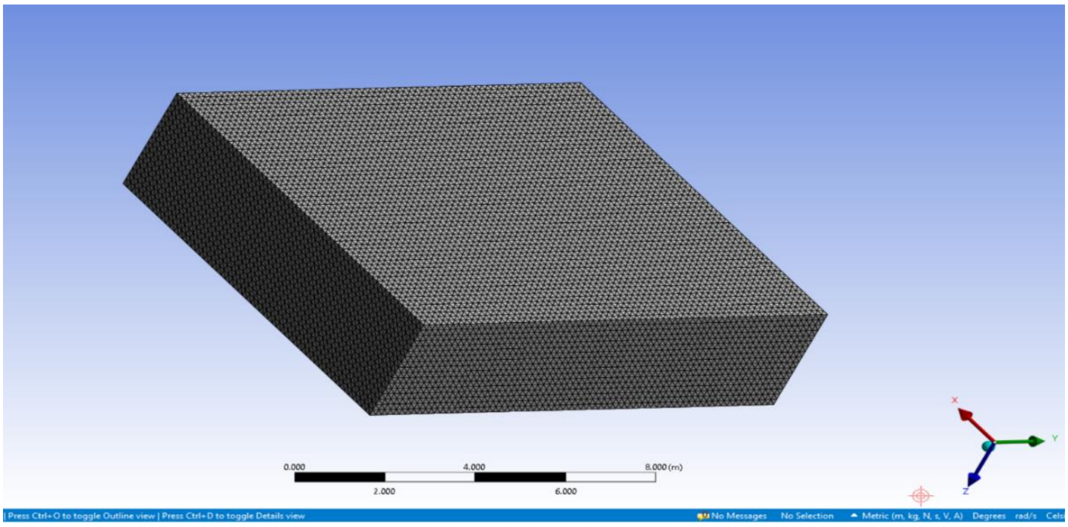

Fig.4: Uniform Triangular Mesh

After meshing the next step is the solution setup. This step requires the values of the atmospheric parameters like pressure and temperature, beforehand. The solution setup followed in this work are mentioned below

4. Results and discussion

After the calculations are run the residual plot is shown in Fig. 5.

The lift force and drag force plots are shown in fig 6 and 7 respectively. It is to be noted that the solver is nearing convergence at 400th iteration itself.

Thus, the lift and drag force values displayed in console are

It is to be noted that there is enough lift as required for the mission. But the value of drag force generated should be overrun by the thrust produced by the propulsion system and is the factor which is to be dealt later on in a separate work.

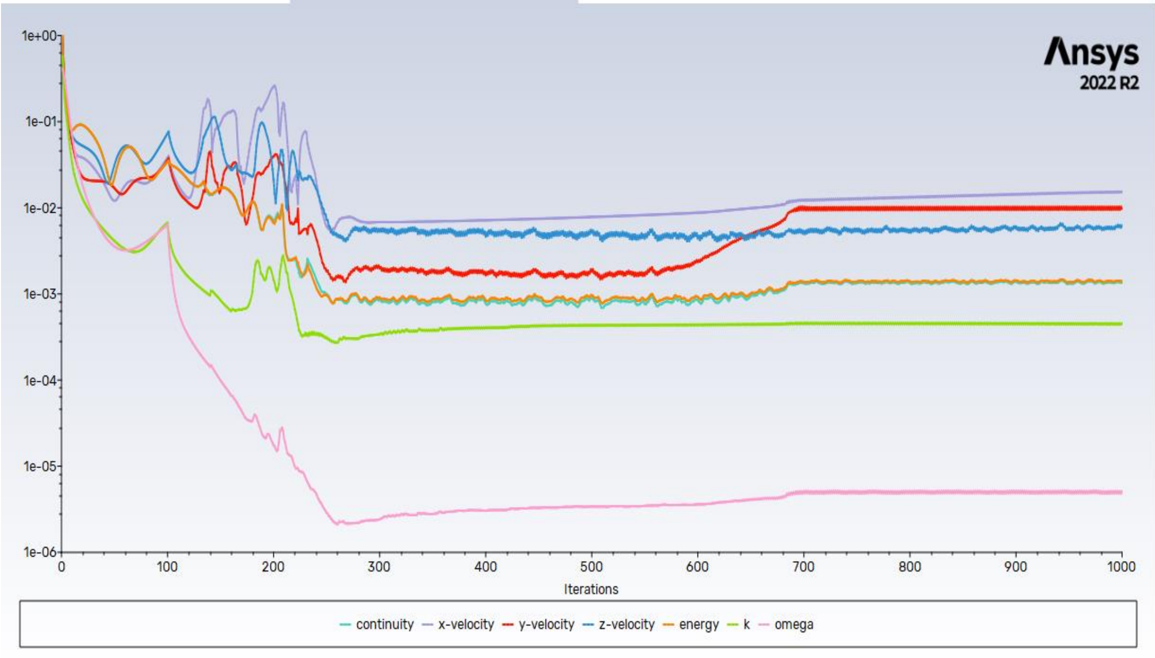

Fig.5: Residual plot

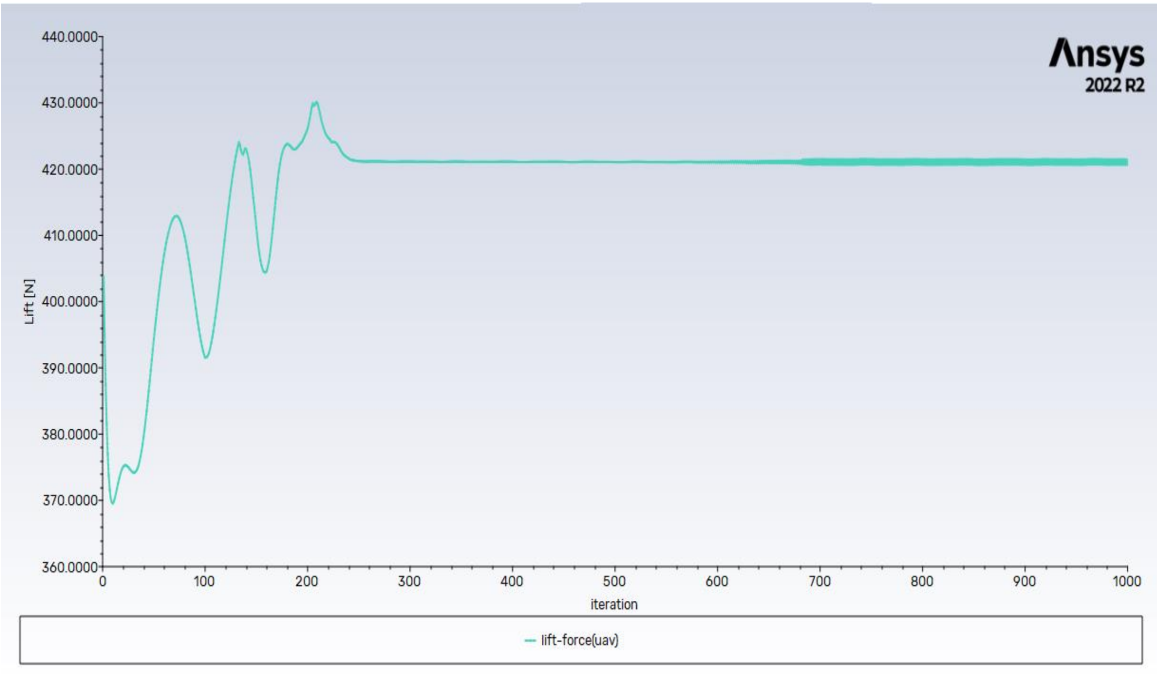

Fig 6: Lift Force

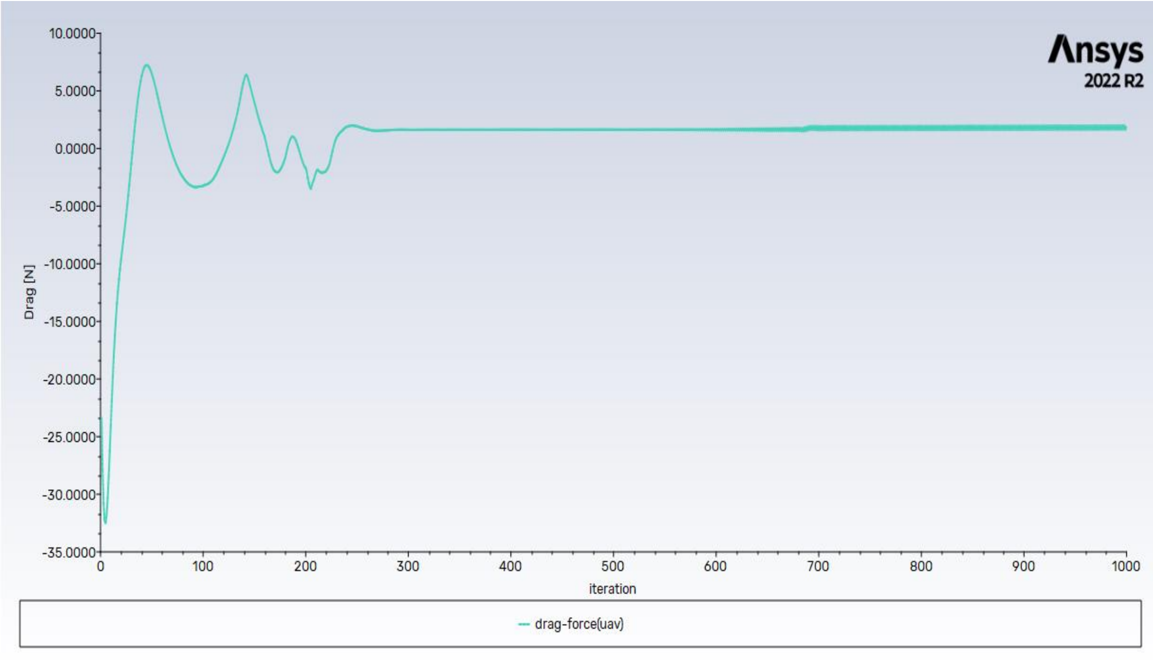

Fig 7: Drag Force

This is not the best result as far as design part is concerned but it is fairly good to understand the conceptual design procedure since the results are obtained on basis of good first estimates and design calculations.

The fig. 6 shows the velocity profile in the flow region. The velocity profile in flow region is depicted in three different regions using three different planes. It is to be noted that the velocity at the tip of the UAV is decreasing (depicted by green contour) compared to the surroundings. This is because of the following possible reasons,

- The design at the fuselage nose is not sharp or blunt enough to ease the flow of air towards rear.
- The design at this point is giving rise to normal shocks which in-turn is affecting the study parameters in the near vicinity.

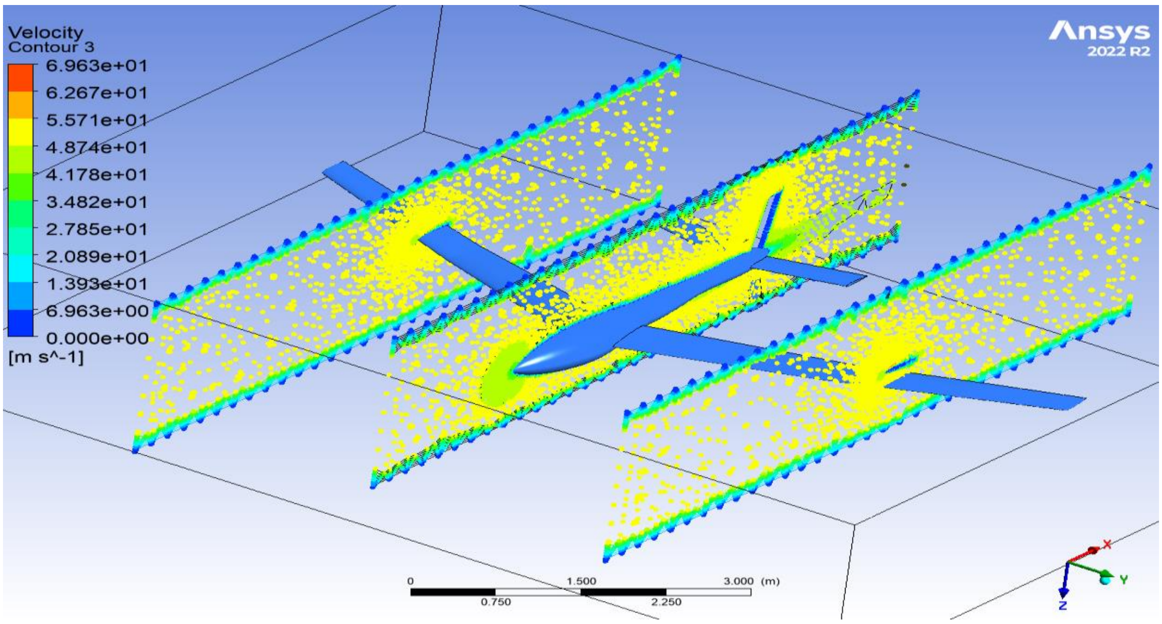

Fig. 8: Velocity Contour

The solution shows the lift force magnitude as 420.665 N which is 42.88 kg. The initial estimate was to design an LM UAV for a 30 kg take-off weight. So, the flow analysis is very satisfactory and the work can be pushed to the preliminary design phase of the development.

4.1. Future Scope

The successful lift and drag force analysis on the UAV are just the first milestone in the development of a UAV. The next major hurdles are the analysis of the UAV with the propulsion system and stability analysis which is carried out in the preliminary design phase. After the preliminary design phase, the detailed design phase gives the detailed CAD model of the UAV. Since this work is only a conceptual design phase, it serves as the fundamental basement for the preliminary design and detailed phase. This work also serves as information to all those who are looking into the design of an LM UAV. It is very critical to push this development into the preliminary and detailed design phase, to ensure that the LM-UAV is finally ready as a product and pushed to manufacturing. It is only at this time the void in the industry is filled and the problem is provided with a solution.

5. Conclusion

Thus, from the results of the design analysis in Fluent, it can be concluded that the lift force of 420.665 N and drag force of 2 N forces generated is clearly more than the lift force required to lift a 30 kg take-off weight (First estimate) as estimated earlier. Since simulation results are obtained by numerical calculations within the software it can be certified that the design employed can be moved to the next stage of design process i.e., the preliminary design phase where the further development of LM with the propulsion system requirements are dealt with. As mentioned earlier, this work does not ensure that the design of the LM-UAV is the best, thus there is always room for becoming more and more precise in calculations which in turn leads to more precise and better designs than the previous ones.

References

[1] M. Voskuijl, "Performance analysis and design of loitering munitions: A comprehensive technical survey of recent developments", Defence Technology, vol. 18, no. 3, pp. 325-343, (2021).

[2] V. Spada, "Conceptual Design of MALE UAVs," West Virginia University, (2019).

[3] G. Landolfo, "Aerodynamic and Structural Design of a Small Non-planar Wing UAV," University of Dayton, Dayton, Ohio, (May 2008).

[4] Shiva Sharma, Umran Sharieff, Ankit Singh, Dr. R. S. Tarnacha, "Design and Fabrication of Fixed-Wing UAV for Commercial Monitoring," International Research Journal of Engineering and Technology, vol. 08, no. 08, pp. 1153-1177, (August 2021).

[5] Miller A. Rocha, Leonardo E. Solaque, "Concept Design for an Unmanned Aerial Vehicle that will perform Exploration Missions in Colombia," in 2nd IFAC Workshop on Research, Education, and Development of Unmanned Aerial Vehicle Systems, Compiegne, France, (2013).

[6] John D. Anderson Jr,Aircraft Performance,Mc Graw-Hill International 1999 ed.,Aerospace Science/ Technology Series, Part 3, Chapter 7, pg 387.