Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 6 (2023)

Statistical Design and Numerical Simulation of an Unmanned Aerial Vehicle with Delta Wings

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Abstract:- The present study is a conceptual design of a delta wing unmanned aerial vehicle (UAV) based on the requirements of its mission and then conducting a parameter study that can relate the changes in aerodynamic and geometric parameters to the UAV's performance. Regarding the characteristics of this manuscript, it can be mentioned that by having the results of a quantitative study in the field of geometry and aerodynamics, then it is possible to move towards optimization and reduction of construction costs. In addition, the aerodynamic of delta wing is considered and the modeling of delta wing is done using simple algebraic equations that presents lift and drag forces quantity generally. This UAV designed in such a dimension that 2 people can carry, initialize, guide and recover themselves. In addition, the maximum speed of 280 km/h is suggested during the flight. The minimum flight altitude of the present UAV while carrying out a mission is more than 2000 meters. The power required for flight increases with increasing flight speed, but decreases with increasing altitude. Finally the numerical study was performed using Ansys Fluent 19 software to investigate more parameters such as pressure and Mach number distributions around the present UAV.

Keywords: *Statistical design, Numerical simulation, Unmanned aerial vehicle, Delta wing, Aerodynamic parameters.*

1. Introduction

Since a very early age in the History of Aviation, mankind has shown notorious insight regarding the unmanned aerial vehicle (UAV) main philosophy - the absence of pilot in an aircraft. UAV settling in the daily routine environment could not possibly happen as fast. It is a fact that unmanned systems latent potential for civil applications has been perceived throughout the years, technically enabling missions involving Earth science research, land management, delivery tasks, amongst some other social and customer services. However, usage progress is far from being steadily established because, unlike in the defense sector, where aerospace is properly prepared and the completion of the mission is supra to the economics of the vehicle, for civilian procedures cost sustainability and operational complexity are still major barriers [1].

The research done on delta UAVs are addressed in this section of the text. Each of the important papers that have been read is briefly described below.

A delta wing UAV's guidance and control:

This study was conducted using a small, lightweight UAV with a main wing that has a delta shape. This article also describes the characteristic of this UAV that makes it excellent for ground observation because it can fly at a low speed because of its small weight and broad main wing. Under the effect of a control command or a wind disturbance, this aircraft may be severely deviated. This work discusses a "rolling circle" strategy for route following control based on nonlinear state control to address this issue. The roll angle is modified in order to follow the intended path, and stability analysis is also used to create the reference signal [2].

Numerical study on the delta wing and riversed delta wing:

This study aims to provide a preliminary theory and knowledge of passive tornado sinking by delta wing and reverse delta wing. This study separated the wings from the airplane for its initial calculations in order to clearly see how tornadoes would form behind just the wing. The RANS turbulence model has been used in the simulations. Better conditions for aerodynamic forces for inverted delta wings are evident from a comparison of numerical and experimental results. While taking into account the drag coefficient, the comparison is not favorable for the delta wing. Additionally, the simulation documents the development of tornadoes, but the turbulence model fails to accurately estimate the size of the tornado. Overall, the findings show that at an angle of attack between 20 and 30 degrees, the delta wing-produced tornadoes offer greater tangential velocity and spin than the inverted delta wing. [3]

Numerical static simulation of fluid dynamics on a specific delta wing:

This paper's main objective is to define an appropriate model for computational fluid dynamics' entire static angle of attack. This makes CFD an effective technique for developing aircraft, decreasing reliance on wind tunnel research and thereby cutting costs. The research's model is built around a modified delta wing. In this work, the discretization type, time step size, turbulence and transfer models, meshing precision, and the order of the integral operator were all modified. The German Aerospace Agency's (DLR) flow simulation software (TAU), a specialized meshing program, is used for this modeling. The results demonstrate that the existing CFD can successfully model the flying envelope of this arrangement. The results also highlight the challenges a CFD model has when simulating a variety of attack angles. [4]

A numerical investigation of the aerodynamics of a delta wing under the influence of the ground effect:

During takeoff and landing, ground effect has an impact on an aircraft's aerodynamics that has a delta wing. In this article, the unstable compressible Navier-Stokes-Reynolds-mean equivalent, transitional shear stress (SST), and TurbulenceK model are used to analyze the ground effect of a delta wing with sharp leading edges and a sweep angle of 65 degrees. did a check. The flight height fluctuates from the height with L to virtually touching the ground, with the angle of attack fixed at 20 degrees. With a reduction in altitude, the lift and drag forces as well as the moment that lowers the nose rise. The principal source of changes in aerodynamic forces is the side of the wing that faces the direction of the wind. Due to the ramping effect, the pressure beneath the delta wing rises in ground effect. The intensity of tornadoes at the front of the attack grows before they break, and by accelerating the reverse pressure gradient, the disintegration of tornadoes is sped up. [5]

Delta wing flow study with high sweep angle:

This work used experimental and numerical analysis to determine the properties of a 5.74 degree delta wing, such as lift and drag forces. The emergence of tornadoes on the delta wing is caused by the negative pressure distribution on the wing, which reaches the maximum absolute value in the tornado cone. Experiments were conducted in the low speed wind tunnel of Hanoi University and numerical analysis tests were conducted using the commercial software FLUENT ANSYS. The characteristics of the wing with swept wing at a speed of 10 m/s and the angle of attack of 20 degrees was investigated in the roll angle varying from 0 to 20 degrees [6]

The influence of the wing back angle on the eddy flow on the delta wing at the angle of attack of 10 degrees:

The eddy flow on delta wings with sharp edges and varying sweep angles in subsonic flow and at a 10 degree angle of attack has been examined using CFD models. The experimental data for a 65° rollback angle with a flat cross-section was used to confirm the RANS simulations. A range of the back angle, from 65° to 43°, is simulated to assess its impact on the flow field. The primary tornado is seen to split from the leading edge at moderate angles, creating a "shadow" tornado. A shadow tornado is observed for the backward angles of 50 degrees and less, which results in a decrease in the productive force near the wing tip. [7]

Enhanced performance of delta wings at low angle of attack and subsonic speed:

At the same angle of attack, delta wings typically produce less downforce than conventional wings. An experimental study was done to see if a new shape could increase a delta wing's ability to produce thrust at low angles of attack and subsonic speeds. The answer is to switch the wing surfaces from their default delta configuration to an X-shaped arrangement, which can produce a lot of lift by encasing vortices in the high aspect ratio wings. The discussion of non-comparable effects was made possible by the use of load cell and static pressure measurements in both studies. The X-shaped configuration offers an increase in lift at low angles of attack in comparison to a basic delta wing, but it also increases drag. An overall improvement in performance compared to leading edge tornado flaps (LEVFs) was demonstrated. [8]

Aerodynamic analysis of damaged delta wings based on numerical fluid dynamics:

In this paper, steady numerical fluid dynamics simulations are used to assess the aerodynamic response of damaged delta wings. A High Speed Civilian Transport (HSCT) wing and an F-16 Wing Block 40 are the two types of wings that are being looked into. These analyses are used to forecast how long damaged wings will remain airworthy (during engagement). are necessary. The CFD model of both wings simulates the damage as a hole. Investigated are the variations in the holes' dimensions, configurations, positions, and rotations. The obtained numerical results demonstrate that the location of the hole has a significant impact on the performance of the wing, and that holes with smooth edges compared to holes with cylindrical edges seem to have a greater effect on aerodynamics. in order to make the shape of the hole as close to reality as possible, a lesion above the surface of the wing was defined. [9]

Experimental and computational research of delta wing aerodynamics:

Both computational and experimental techniques have been used to investigate the delta wing's aerodynamic behavior. A delta wing model with a 70 degree sweep angle, sharp leading edges, and sharp trailing edges has been put through a force measurement test at various angles of attack. Using the CFD code of the commercial software FLUENT ANSYS-14, a steady-state RANS evaluation has been carried out. The initial tornado cone that generates the suction force on the wing surface was observed by ANSYS 14 POST-CFD processing software using a variety of proposed detections. The results of lift and drag force coefficients at different angles of attack have been compared in two experimental and computational methods. The experimental and numerical results are in good agreement with each other. [10]

The performance of the transport-sensitive model in predicting the flow structure on the delta wing:

The transition of laminar regime and turbulence may have a noticeable effect on the performance of aerodynamic devices at high and medium speeds. Two recently developed transfer-sensitive models, TR-SST and kT–kL-ω, are employed to exploit their capabilities for the complex flow physics over a delta wing. This processing is done on a 2.6 x 106 wing design where there is a combination of laminar, transfer and delta flow fields with a 50 degree retraction angle at the turbulence Reynolds number. The accuracy of these models has been evaluated in the calculation of the boundary layer with the surface of a delta wing with an angle of backswing of 70 degrees and 1×10^6 and 1.2×10^6 Reynolds numbers. Large Eddy simulation and Smagorinsky model and high were also used to predict the transfer on the delta wing. All numerical simulations are compared with available experimental data. [11]

A comprehensive solution for supersonic flow passing over a delta wing:

This article looks into the mathematical aspects of supersonic flow passing over a delta wing. The delta wing is defined as a triangular plate or a triangular wing with a specific thickness, and the flow is described by the flow potential equation. The issue can be reduced to a degenerate nonlinear boundary value problem with an elliptic equation and a free boundary in a similar coordinate system. The existence of a solution to this issue has been established by developing a non-linear iteration scheme and using Schuder's fixed point theory. with the finding that the oncoming flow's collision angle is less than the critical value determined by the data. [12]

DDES study on aerodynamic forces and flow physics of a delta wing in static ground effect: The performance of an aircraft with a delta wing configuration is significantly impacted by "ground effect" during the takeoff and landing phases. This article uses DDES simulation and the Spall-Rett-Almaras turbulence model to examine the geostatic effect for a VFE 2 delta wing with a sweep angle of 65 degrees, a sharp leading edge, and an angle of attack of 20 degrees. The delta wing's lift, drag, and nose-down twisting moment should increase nonlinearly with a decrease in movement height, with the geostatic effect of the delta wing side wind accounting for the majority of the increase in aerodynamic forces. By lowering the height, the flow under the wing is temporarily stopped, which causes a rise in static pressure and a rise in the flow along the span close to the attack's and the side tornado's tornado's edge. The strengthened leading edge vortex spreads out in the direction of the span and deepens the low pressure. Before the tornado breaks up, the jet-like flow in the primary tornado cone accelerates as the movement height decreases, while the revival-like flow decelerates. [13]. It is necessary to mention other researches, including: Taghipour et al.[14] studied Risk analysis in the management of urban construction projects from the perspective of the employer and the contractor. Mahboobi et al.[15] discussed Assessing ergonomic risk factors using combined data envelopment analysis and conventional methods for an auto parts manufacturer, occupational injuries are currently a major contributor to job loss around the world. Taghipour et al.[16] studied The impact of ICT on knowledge sharing obstacles in knowledge management process (including case-study). Mohammadi et al.[17] studied “Investigating the role and impact of using ICT tools on evaluating the performance of service organizations. Taghipour.[18] studied A review of the sustainability indicators’ application in vehicle routing problem. ” Moosavi and Taghipour.[19] studied Turbine vibration condition monitoring in region 3. Taghipour and Vaezi.[20] studied Safe power outlet. Taghipour et al.[21] studied Project Planning and Control System in Multi-project Organizations under Fuzzy Data Approach Considering Resource Constraints(Case Study:Wind Tunnel Construction Project). Molavi and Taghipour.[22] studied A survey on electrical cars advantages. Taghipour and Yazdi[23] studied Seismic analysis (non-linear static analysis (pushover) and nonlinear dynamic) on Cable-Stayed Bridge. Taghipour et al. [24] studied “Identification and modeling of radio wave propagation channel in industrial environments. Taghipour et al. [25] studied Implementation of software-efficient DES Algorithm. Sedaghatmanesh & Taghipour.[26] studied Reduction of losses and capacity release of distribution system by distributed production systems of combined heat and power by graph methods. Taghipouret et al.[27] studied A survey of BPL technology and feasibility of its application in Iran (Gilan Province). The innovation of this research is mainly the creation of a computing platform in which the aerodynamic model and the functional model of a light UAV with delta wing are compiled and it can be used to find the relationships between parameters and to understand the nature of aerodynamics. Such a study has not been done before for this specific UAV sample. It is also possible to design a lightweight drone that has relatively high controllability and flight time.

2. Specifications of the present model

2.1. Flight height

For better photography, the UAV should be as close to the target area or subject as possible. On the other hand, it must maintain its proper distance from the subject. First, if it is too close to the area, it will pass quickly and the mission time will be too short. Secondly, there may be natural and artificial obstacles near the ground, such as trees, mountains, electricity pylons, etc. Therefore, for the flight altitude of this UAV, an average value is considered, i.e. about 8000 meters above the ground.

2.2. Flight time

Depending on the mission of the UAV, a time of 30 minutes to go to the target, complete the requested mission and return to the origin is sufficient. Of course, the useful time to complete the mission is 15 minutes.

2.3. Payload

Since this UAV is designed for photography, its payload is a camera, which for the initial estimate, it makes sense to consider about 1.2 kg. The total take off weight is estimated to be 18 kg.

2.4. Engine

The type of engine was specified in the concept design. The selected engine for the present project is P180-NX, which is made in Germany and produces 180 N of thrust force. It is a brushless, fully encapsulated fuel pump integrated on the turbine side as well as a brushless starter/generator system. The rotor of the fuel pump runs in the fuel, which eliminates the need for shaft seals. The starter/generator works completely contact-free to the turbine shaft. This makes the "clutch" from starter to turbine shaft resistant to all conceivable contamination (no slipping of the starter clutch due to contamination or O-ring wear, for example).

3. Statistical study

It is necessary to obtain an estimate of the original quantities based on the properties of similar UAVs. Therefore, similar specimens of the present UAV have been searched and collected from various references. After extensive searching of references, 13 similar specimens (Delta-wing UAV) were found. After collecting the information, the desired UAV’s parameters can be extracted by drawing design diagrams. Design diagrams help us to derive a good and initial estimate for the design parameters of the desired UAV. In all graphs, data that is inconsistent with the rest of the others is removed to get the best estimate. For this purpose, the curve fitting method has been used.

3.1. Wing span in terms of take-off (launch) weight

In figure 1, the x-axis represents the take-off weight of the UAV and the y-axis represents its wing width. However, due to the relatively high speed of the present UAV, it is possible to reduce the dimensions and sufficient lift force is created for this purpose without any problem. Therefore, the dimensions of the UAV were made 13% smaller and the length of the Span is considered to be 1.3 meters as well.

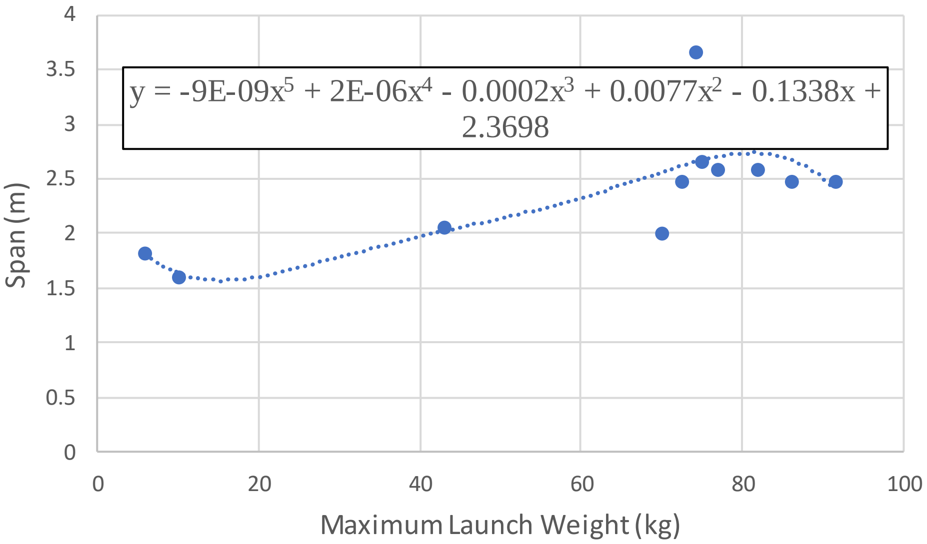


Figure 1: Wing span versus maximum take-off (launch) weight

3.2. Wing span in terms of UAV length

In figure 2, the x-axis represents the length of the UAV and the y-axis represents its wing span. According to this diagram, if the desired value of spin, i.e. 1.5 meters is put in this curve, it gives the value of UAV's length about 1.64 meters. But as it was mentioned in the previous section, one can reduce the dimensions of the UAV up to 13%, therefore the length of the UAV is considered to be 1.5 meters as well.

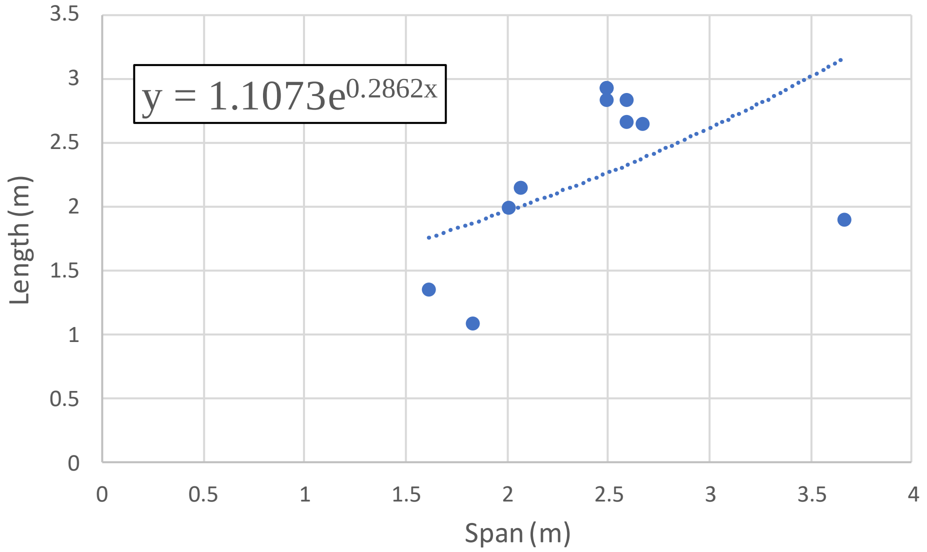


Figure 2: UAV length versus wing span

3.3. Wing area in terms of weight and angle

In figure 3, the x-axis represents the take-off weight of the UAV and the y-axis represents its wing area.

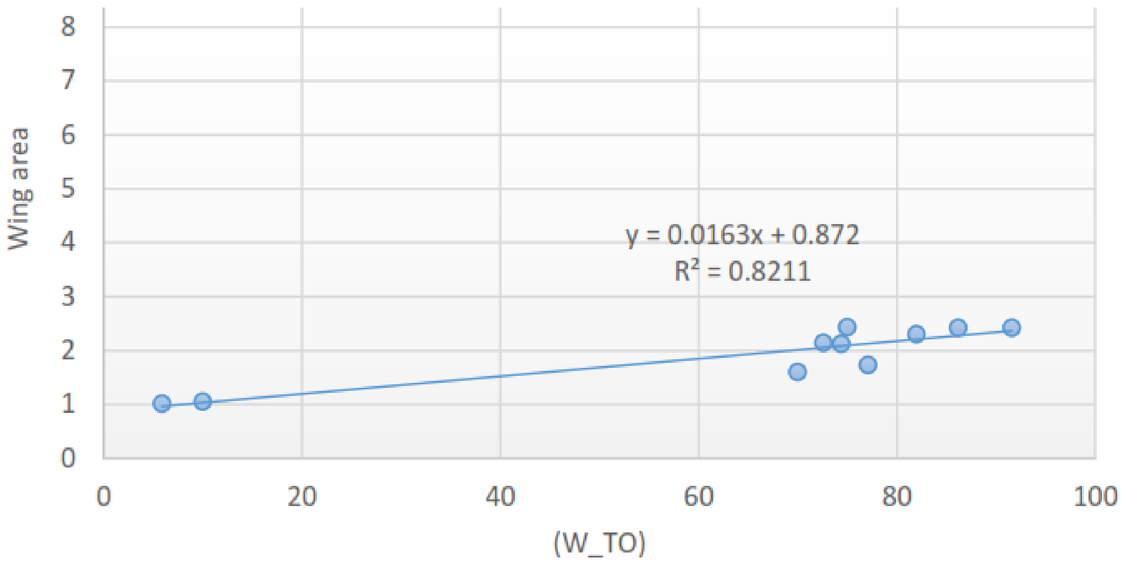


Figure 3: Wing area versus take-off weight

The following result is obtained from the third diagram:

$W_{TO} = 18\ Kg \rightarrow Wing\ Area \approx 1.3\ m^2$

Now, in order to obtain the above area, it is necessary to obtain the wing angle (ʌ). Therefore, with the help of the following geometric relation, a 45 degree angle was obtained for installing the wing.

$\Lambda = \arctan((c_r - c_t)/(b/2))$ (1)

Where c_r and c_t are root chord and tip chord of the wing, and are equal to 0.727 and 0.184 m, respectively for NACA 0012-64 airfoil.

3.4. Configuration and dimensions

Now, after obtaining the desired UAV's specifications, it is time to configure and determine the appearance of the UAV. This is shown in Figure 4. Dimensions are in mm.

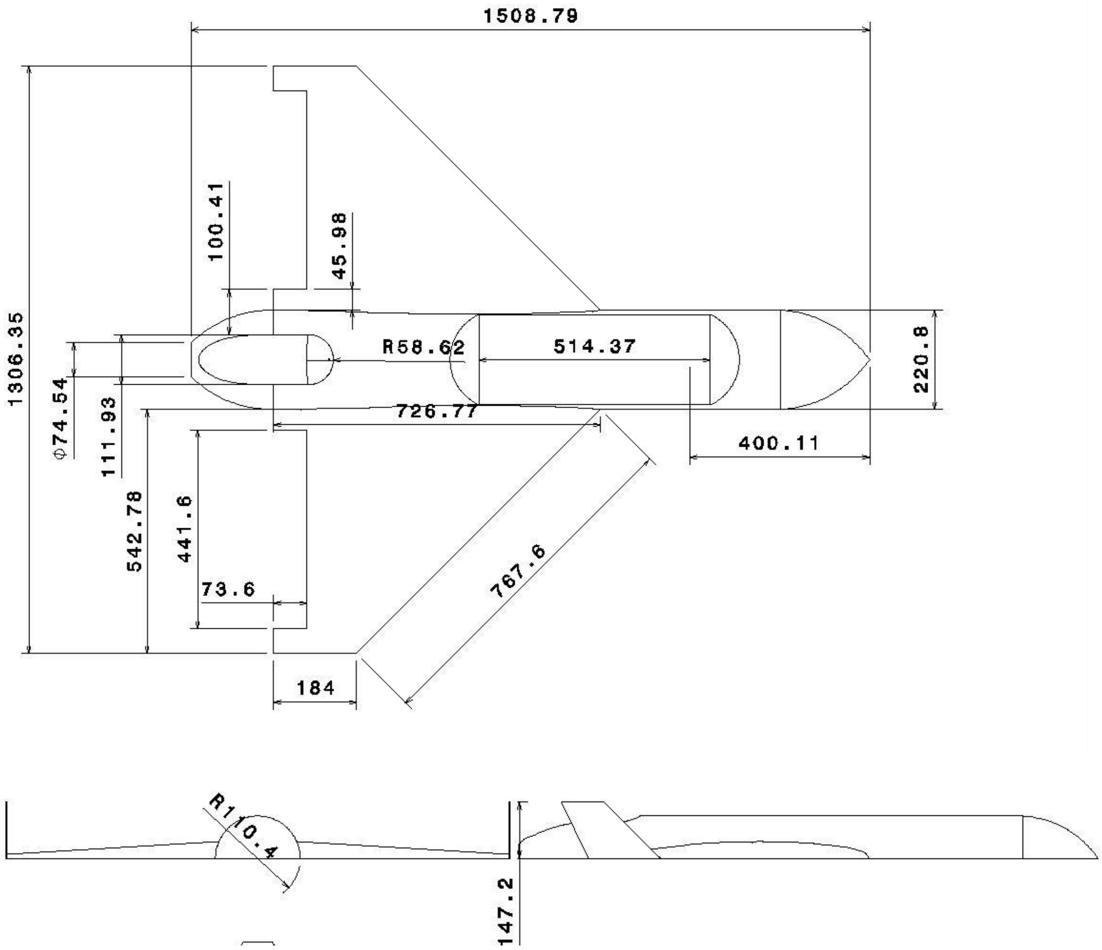


Figure 4: Configuration and 3D views of the present Delta-wing UAV (dimensions are in mm).

Figure 5 shows the simulated UAV in Catia software for CFD calculations in the following sections. The camera can be mounted on the top of the UAV using a canopy to cover it. A space also has been considered for the engine in the tail part of the present UAV.

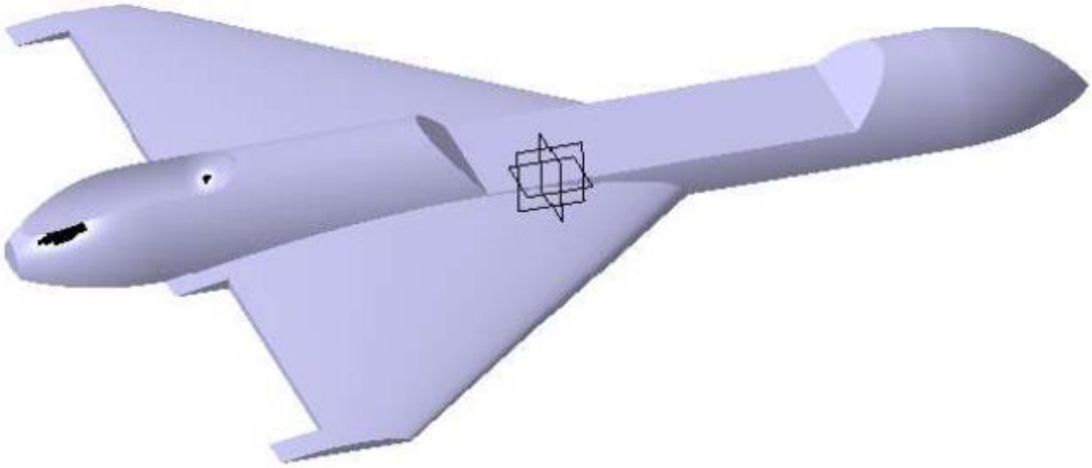


Figure 5: Model drawn by Catia software (half of the model is shown.)

4. Results and discussion

4.1. Calculations of UAV flight performance at different altitudes

First the amount of fuel consumption in which the UAV is launched to reach its maximum altitude is calculated here. The present UAV is going to be launched at angle of 45 degrees respect to the horizon. The goal for the UAV is to reach an altitude of 8,000 meters above the see level in 4 minutes (240 seconds) with the speed of 55 m/s. For this purpose, the initial launch speed and acceleration is found as follows:

$$\Delta x = \frac{V_1+V_2}{2} * t \quad (2)$$

By placing the values and knowing that $\Delta x = 8000\sqrt{2}m$, the initial launch speed value is equal to 40 m/s. Also, the acceleration of motion is calculated from the equation 3.

$$a = \frac{V_2-V_1}{t} \quad (3)$$

By replacing the values of V_1 and V_2, the acceleration value of 0.0625 m/s^2 is obtained. Of course, since the effect of air friction is not considered in the above equations, so to ensure that the UAV reaches the desired speed at the desired altitude, the initial velocity value is considered to be equal 50 m/s. The second point about this UAV is that the altitude of the launching place is about 2000 meters above sea level, which helps in fuel consumption as well as the time required to reach the desired speed and altitude. However, due to the simplicity of the work, calculations have been considered for sea level.

Since the value of fuel consumption in the engine used in the UAV for the maximum-load equals to 0.5 kg/min, and in addition, this UAV travels every 1000 meters of altitude within 30 seconds. So fuel consumption is about 0.25 kg for every 1000 meters. Therefore, by the time it reaches its maximum altitude, the UAV has lost 2 kg of weight. This point is taken into account in all calculations related to the thrust and lift forces and other flight parameters of the UAV. It should also be noted that the value of air density and gravity acceleration varies with altitude, so these parameters are given in terms of altitude in table 1.

Table 1: Air characteristics and UAV's weight at different altitudes [14]

Altitude from sea level (m)	(kg/m^3) Density	Dynamics Viscosity (kg/m.s)	UAV weight (kg)	Gravity (m/s^2)
1000	1.112	1.758	17.75	9.804

Altitude from sea level (m)	(kg/m³) Density	Dynamics Viscosity (kg/m.s)	UAV weight (kg)	Gravity (m/s²)
2000	1.007	1.726	17.50	9.801
3000	0.9093	1.694	17.25	9.797
4000	0.8194	1.661	17	9.794
5000	0.7364	1.628	16.75	9.791
6000	0.6601	1.595	16.50	9.788
7000	0.5900	1.561	16.25	9.785
8000	0.5258	1.527	16	9.782

Reynolds is a dimensionless parameter that expresses the flight conditions of the aircraft. In fact, by considering the Reynolds parameter in the design process, without having the aircraft in real dimensions, the aircraft behavior during flight can be studied by having a model of the aircraft in smaller dimensions, which has the same Reynolds parameter of the real aircraft, regardless of air viscosity. In aircraft, the Reynolds number is defined as equation 4.

$$Re = \frac{\rho V C}{\mu} \qquad (4)$$

Where ρ is density of air in desired altitude (kg/m^3), V is relative air velocity (m/s), C is average chord length of aircraft and μ is dynamic viscosity of air (kg/(m.s)).

Now, while stating some of the specifications of the target UAV, it is necessary to calculate its Reynolds number at different speeds. The target UAV has the ability to fly up to an altitude of 8000 meters and its maximum speed is 80 m/s. The aspect ratio of the aircraft is considered to be A.R. = 1.3.

The density of air at an altitude of 8000 m above sea level according to table 4-3 equals to $\rho_{8000} = 0.5258$ kg/m^3 and the dynamic viscosity at this altitude equals to $\mu_{8000} = 1.527 \times 10^{-5}$ kg/m.s.

In the aircraft design process, the design should be done in the best case, i.e. in the case where the aircraft is at the highest design altitude (the density of the air in this case had the lowest value) and also the lowest speed, i.e. the speed close to stall velocity (Vs). It should be noted that the C (average chord length) of the Delta-wing UAV is derived with respect to the wing in figure 4 from the equation 5.

$$C = \frac{C_r + C_t}{2} \qquad (5)$$

As mentioned in previous section, C_r is the root cord and equals to 0.727 m and C_t is the tip chord of the wing and equals to 0.184 m. By replacing in the above equation, the average chord value will be 0.4554 m. Therefore, the Reynolds numbers at different speeds and at an altitude of 8000 meters above sea level equals to:

$$Re_{V_s} = \frac{\rho V_s C}{\mu} = 275{,}128$$

$$Re_{V_C} = \frac{\rho V_C C}{\mu} = 871{,}095$$

$$Re_{V_{max}} = \frac{\rho V_{max} C}{\mu} = 1{,}219{,}533$$

Among the above calculations, Re = 275,128 should be considered as the design Reynolds parameter, because in the C_D diagram according to C_L airfoil, the amount of C_{D0} in lower Reynolds number is the maximum value.

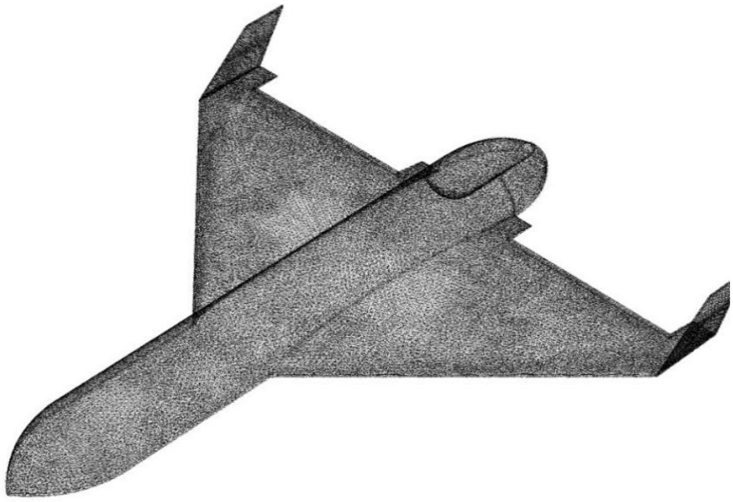
4.3. Numerical simulation

Computational fluid dynamics is commonly known as CFD, a branch of fluid mechanics that uses numerical methods to solve and analyze problems involving flow. Computers are used to perform the calculations needed to simulate fluid interactions on surfaces defined by boundary conditions. Advances in software research have helped improve the efficiency, accuracy, and speed of complex simulations, as well as the use of supercomputers. The basis of almost all CFD problems is the solution of the Navier-Stokes equations.

4.4. Computational domain

Ansys Fluent software was used in the present project to do the calculations. First, the model is read in Star CCM software and define the calculation domain for it and create its mesh. Then the model is analyzed in Ansys Fluent software. To better understand this, Figure 6 shows the domain in the Ansys Fluent 19 software. It is worth mentioning that the mesh used for this model is unstructured.

The model has 461,643 cells as mesh numbers. Also, the minimum mesh size is 4.029×10^{-9} m^3. It is worth noting that due to the symmetry of the UAV, half of it is modeled and the Symmetry condition is used. This reduces the cost and time of calculations.



(a)

(b)

Figure 6: a) Present model in Ansys Fluent software b) computational domain

The CFD domain is in the Cartesian fixed coordinate system, which includes UAV and computational domain. The dimensions of the computational domain is considered 3 times the size of the UAV. In fact, if you consider the length of the UAV as L, the distance from the middle of the UAV to the inlet and the outlet of the computational domain equals to 1.964 m (1.5 L) and also the width and height of the wind tunnel are equal to 3L and 1.5L, respectively (See figure 6b).

4.5. Numerical results

In the modeling, the motion of the UAV is considered at altitude of 8000 meters while the air flow passes over it with a speed of 77 m/s and temperature of 263 K. At this stage, the angle of attack of the UAV is considered zero relative to the horizon and Mach number equals to 0.282 (subsonic flow).

The turbulence model of Spalart-Allmaras is used for the numerical simulation. This turbulence model is a relatively simple model that shows good results for boundary layers exposed to reverse pressure gradients, especially at points where there is no separation or slight separation.

Figure 7 illustrates the pressure around the UAV. One can see

that the maximum pressure is in the sections of jointied wings to the body. As a results, these sections must be strength during the manufacturing process.

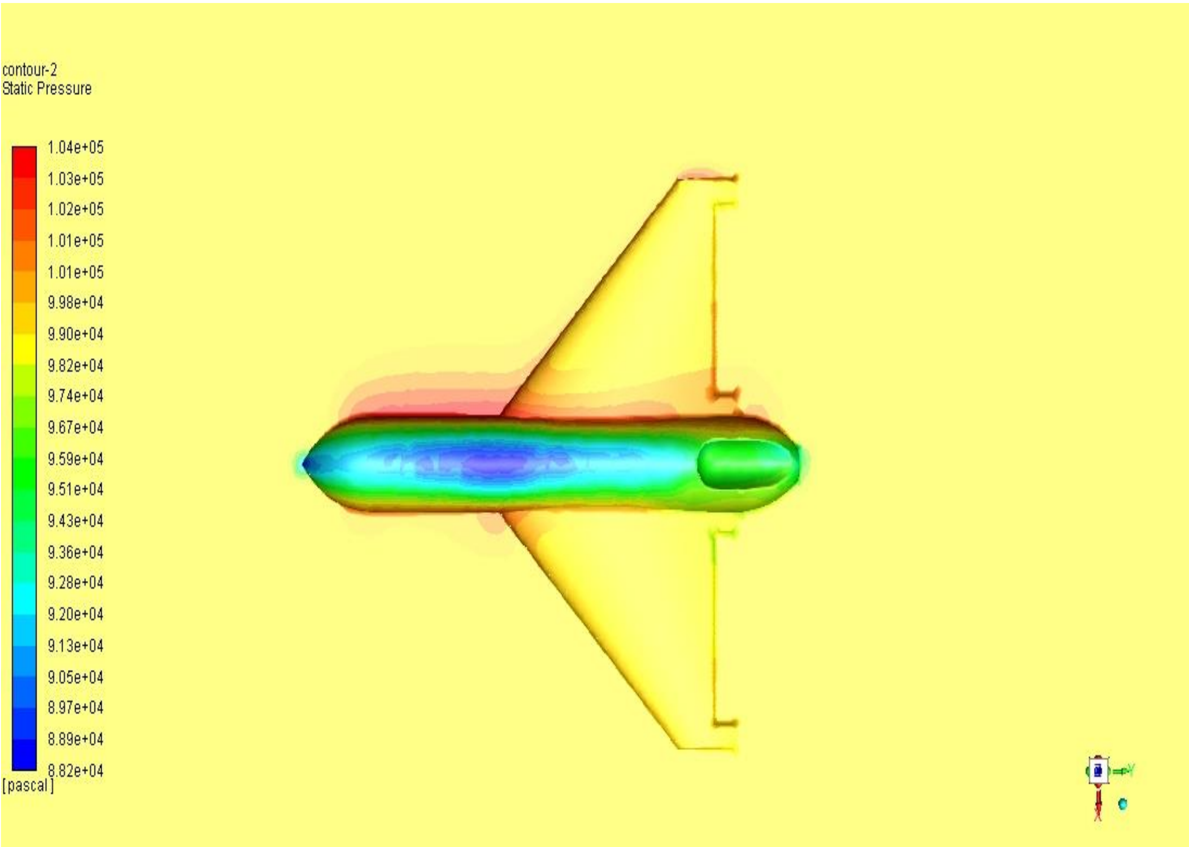


Figure 7: Pressure contour around the UAV

Distribution of Mach number at the altitude of 8000 m around the present UAV can be found in figure 8. As can be seen, the Mach number is below 1 at all points and the shock wave phenomenon does not occur at all.

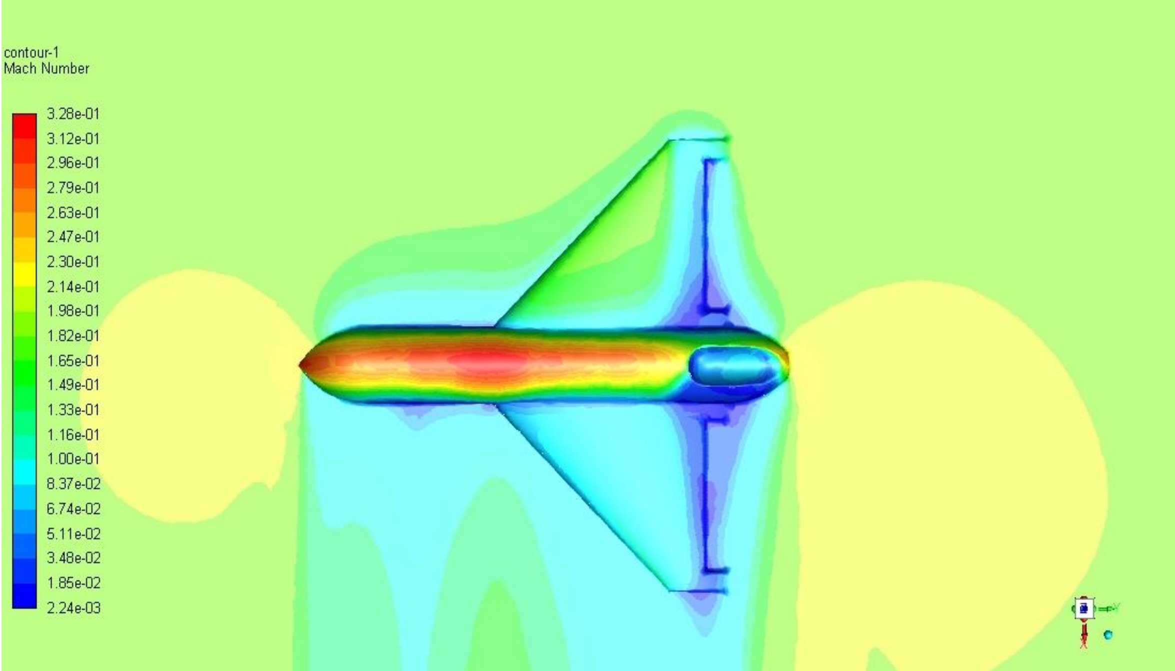


Figure 8: Mach number contour on the UAV

5. Conclusion

In this research, conceptual design and initial design of a Delta wing UAV was studied and after that modeling and parameter study was done. The main steps were:

1- Compilation of the mission plan

2- Collecting data and creating a database

3- Statistical study and extraction of statistical curves

4- Separation of significant relationships

5- Choosing a target system and conceptual design

6- Derivation of the geometric design and placement and initial weight estimation

7- System studies and overall system performance such as speed, flight height and angle of attack on the performance

8- Three-dimensional CFD model study and checking parameters such as Mach number

9- Finding the mathematical relationship between the size of the vortices around the trapezoidal wing with parameters such as Mach number, angle of attack and speed

While studying the available sources regarding delta-wing UAVs and providing a set of statistical data in this field, the conceptual design and then the initial design of a delta-wing UAV based on the mission requirements were discussed. In the design process, a base UAV was used and tried to improve its geometric characteristics based on aerodynamic modeling and considering the effect of geometric variables on performance. Simultaneously a CFD model was simulated for investigate the flow properties around the UAV. Delta wing aerodynamic modeling was one of the innovations of this research due to its different physics in the production of lift force in such a way that the resulting model was simple and at the same time efficient. This modeling provided a suitable platform for parametric study. Delta wing aerodynamic modeling was done by using a set of simple algebraic equations that obtained lift and drag forces in general. The present obtained results showed that the maximum thrust increased with increasing flight speed but decreased with increasing altitude. Regarding to the angle of attack, this was the opposite and increased with the angle of attack. In addition, CFD results showed that the Mach number around the present UAV during the flight is below 1 at all points and the shock waves do not occur.

Competing interests: The authors declare there are no competing interests.

Data availability: All data can be sent on demand.

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