Conceptual Design of Boom Mounted Inverted V-Tail in the Searcher MK II UAV

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Abstract: Long endurance surveillance drones are preferred in both military and meteorological applications. Designers aim to enhance vehicle aerodynamics in view of increasing endurance by introducing methods of drag reduction. This research aims to enhance the performance of an existing UAV widely used in Sri Lanka for surveillance, reconnaissance and other military operations. The UAV is propelled by a pusher type propeller, behind which lies a twin boom mounted H-tail for the stability. The propeller wake from the propeller creates a continuous turbulent flow on the tail surface resulting in higher profile drag. A design is proposed to replace the tail section with inverted V-tail configuration with sufficient clearance from the immediate propeller wake. The new design resulted in a reduction of approximately 21% in total wetted area. CFD simulations were carried out to analyse aerodynamic parameters of the reconfigured aircraft, where 18.69% reduction in drag was observed. The static longitudinal static stability is assessed and found to be within acceptable limits. The final design shows a significant improvement in the performance of the aircraft in terms of range and endurance.

Keywords: Drag reduction, Endurance, Inverted V-tail, Longitudinal Stability, UAV

Introduction

The use of UAVs have become more prominent in recent years for diverse applications due to their capability of rendering efficient and effective results in strategic reconnaissance, surveillance, metrological research, forest fire detection, disaster monitoring, telecommunication links and commercial delivery purposes (Watts, et al., 2012). Therefore, a long-endurance UAV will be the need of future aerial systems that can work as a low orbiting satellites, which will be cheaper to operate and maintain (Cambone, et al., 2005). Searcher Mark II is the UAV that is widely used in Sri Lanka for surveillance purpose, thereby making long endurance a vital requirement for its performance. It is a propeller driven pusher type UAV with Twin Boom H-tail configuration. It has separate sets of rudders and elevators for the yaw and pitch control (IAI, 2019). The performance parameters of aircraft, range and endurance can be maximized by modifying surface designs with optimized lift to drag ratio (Wang, et al., 2013). So, modification of tail design for this UAV is a feasible solution to minimize design related underlying drag.

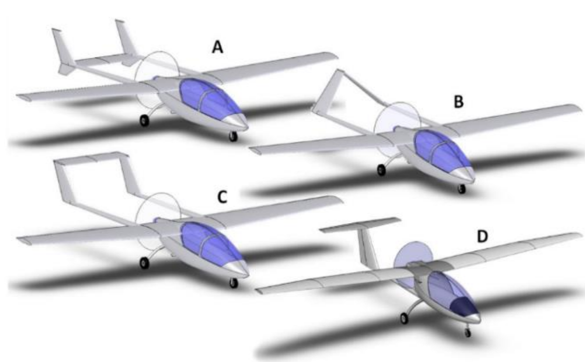

Figure 19 Different configurations of tail for Searcher Mark II UAV(Gudmundsson, 2013)

The tail configuration for an aircraft is decided by studying the aerodynamic and stability requirement of the aircraft. An H-tail is best suited when the vertical tails need the undisturbed airflow during high angles of attack. Also, effectiveness of the elevator increases as the vertical tails give an endplate effect to reduce the induced drag (Sadrey, 2013). However, the weight penalty for the twin boom can make it less attractive for the smaller scale remotely piloted vehicles which is also an added disadvantage for surveillance UAVs. The position of tail in existing Searcher Mark II (UAV) lies immediately behind the propeller which causes significant impact on the stabilizers due to propeller wake. The necessity of larger control surface also results in more drag and adds a heavier weight though the propeller wash on the horizontal stabilizers increases low speed elevator authority (Gudmundsson, 2014). This is uneconomical and undesirable for a long endurance flight vehicle. Thus the complimentary solution can be to either displace the structural support to tail section as in figure 1(D) from the wings to the base of fuselage or change the tail design as in figure 1(B) and (C) by keeping the structural support (tail boom) intact. Displacing the structural support will require stiffer, stronger and heavy structure to react the torsional and bending loads and also resist flutter, but allows a conventional tail configuration (Anon., 2018). Meanwhile, changing the tail design allows more efficient and lighter configuration with lesser drag. Designing an optimum inverted V-tail configuration will allow enhanced performance.

Methodology

The design process was completed following the steps as shown by flowchart in figure 2. All the required dimensions of the prevailing wing and twin boom tail section for H-tail configuration was obtained from the Sri Lanka Air Force.

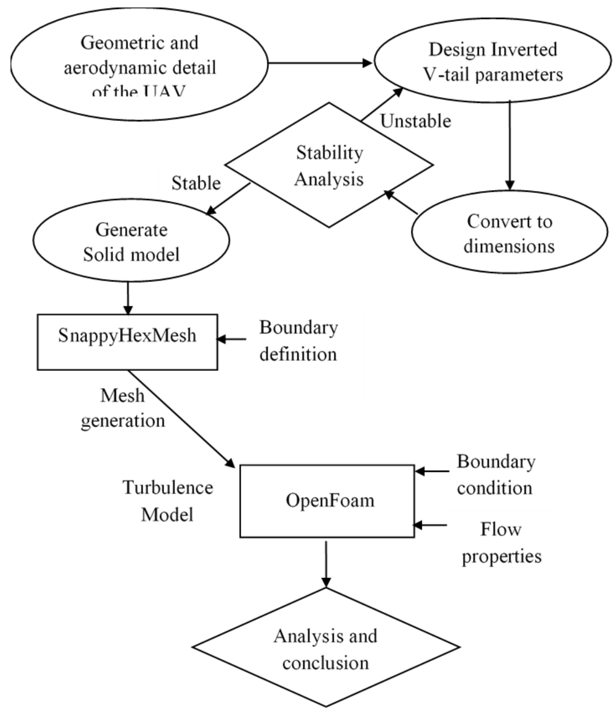

Figure 20 Flow Chart of Methodology

The stability analysis of the UAV was done analytically. Proposed design was checked for the longitudinal stability criteria at cruising conditions. The wing calculation was done by using the empirical formulas as below:

A. Wing Calculation

From the airfoil data sheet for S7055-il,

$$\boldsymbol{a_0 = \frac{dC_l}{d\alpha} = 0.13 \ \text{per degree}}$$

3D lift slope is obtained using equation 1 as,

$$a = \frac{a_0}{1+\frac{57.3\times a_0}{\pi\times e\times AR}} \qquad \text{Equation 1}$$

$$= 0.075 \text{ per degree}$$

where ‘e’ is the span efficiency factor and is equal to 0.95 for rectangular wing form with Aspect ratio larger than 10 (Gudmundsson, 2014). The Mean Aerodynamic Chord is obtained by using the equation,

$$\text{Taper ratio, } \lambda = \frac{C_{tip}}{C_{root}} = 0.60$$

$$MAC = \frac{2}{3} C_r \left(\frac{1+\lambda+\lambda^2}{1+\lambda}\right) \quad \text{Equation 2}$$

$$= 0.54$$

B. Tail Calculation

1) Airfoil Selection:

NACA 0006 airfoil was taken for the inverted tail design. 2D lift coefficient was converted to 3D lift coefficient using same Equation 1. From the airfoil data,

$$\boldsymbol{C_l = 0.78}$$

$$\boldsymbol{a_0} = \boldsymbol{0.116} \text{ per degree}$$

$$\boldsymbol{a} = \frac{\boldsymbol{a_0}}{\boldsymbol{1} + \frac{\boldsymbol{57.3 \times 0.13}}{\boldsymbol{\pi \times 0.95 \times 14.91}}}$$

$$= \boldsymbol{0.11} \text{ per degree}$$

2) Sizing calculation:

The inverted V tail is constrained between the existing dimension of the tail span. Also, the chord length is kept same so that the horizontal projection of the surface area is same as the area of horizontal tail as in H-tail configuration. The dihedral angle of V tail can be obtained from the equation 3 which is also used to estimate the anhedral angle for the tail (Sadrey, 2013).

$$\boldsymbol{\theta = \tan^{-1}\left[\left(\frac{S_{VT}}{S_{HT}}\right)^{\frac{1}{2}}\right]} \quad \text{Equation 3}$$

The remaining dimensions for the tail were derived trigonometrically and is given in figure 9.

3) Longitudinal Stability Analysis:

Tail volume coefficient,

$$\boldsymbol{V_H} = \frac{S_{HT} l_{HT}}{S_W \bar{c}_w} \quad \text{Equation 4}$$

$$= \boldsymbol{0.986}$$

Neutral point is calculated by using equation 5 as (Anderson, n.d.),

$$\boldsymbol{h_n = h_{ac_{wb}} + V_H \frac{a_\alpha}{a}\left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right)} \quad \text{Equation 5}$$

$$= \frac{\boldsymbol{0.135}}{\boldsymbol{0.54}} + \boldsymbol{0.986} \times \frac{\boldsymbol{0.079}}{\boldsymbol{0.11}}(\boldsymbol{1 - 0.01})$$

$$= \boldsymbol{0.95}$$

So, neutral point, $\boldsymbol{l_{np} = 0.95 \times 0.54 = 0.51 m}$

Static margin = $\boldsymbol{l_{hp} - l_{cy}}$

$$= \boldsymbol{0.225\ m}$$

Longitudinal static Stability=

-a x (Static margin)

$$= \boldsymbol{-0.016}$$

Since the moment coefficient curve has negative slope, it can be concluded that the design is stable.

C. CFD Analysis

CFD simulation for cruising condition was completed in three stages:

1) Pre-Processing:

The solid model for the existing tail configuration and the proposed design was created using SOLIDWORKS 2018. Blockmesh and snappyHexMesh utilities were used in OpenFoam to generate the mesh for facilitating the flow transport equations. Freestream boundary conditions for the cruising speed at cruising altitude was set with necessary initial conditions. Further refinement of mesh was done by adding special refinement regions and boundary layers throughout the surface.

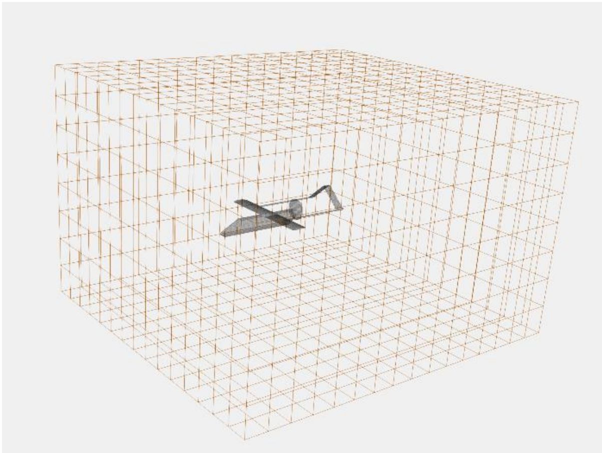

Figure 21 Mesh for inverted V-tail simulation

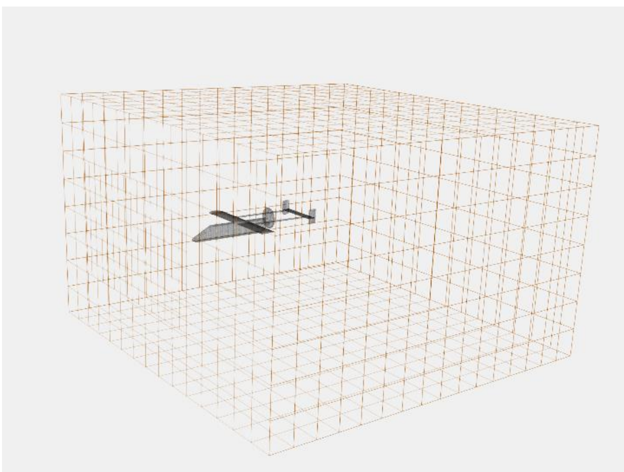

Figure 22 Mesh for H-tail configuration

2) Simulation

The simulation was done in OpenFOAM open source software. SimpleFoam solver was used to simulate a steady state flow till convergence of the force coefficient was obtained. K-Omega turbulence model was used for its consistent accuracy for varying geometries in boundary layer flows.

3) Post-Processing

Flow field visualization was done in paraview software to visualize the overall effect of the tail configuration on the UAV. Also, the separate simulations for tail configuration alone was done to observe the change in drag coefficient due to interference effect. The comparison of the force coefficient was done by plotting the graphs as shown in figure 5

Results and Discussion

For an aircraft to have static longitudinal stability, the slopw of the moment coefficient curve needs to be negative and the coefficient of moment at zero lift needs to be positive as shown in figure 5. As per the analytical calculation of the longitudinal static stability showed a stable design with the stability of -0.016.

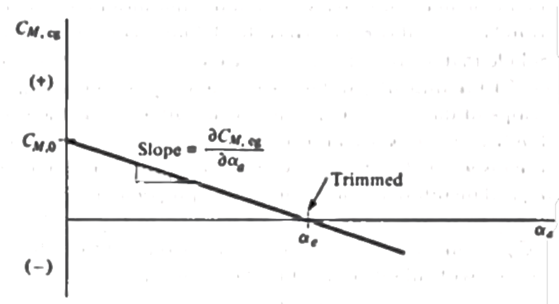

Figure 23 Moment coefficient curve with negative slope (Anderson, n.d.)

Further observation through solid modelling showed the total reduction of 0.558 m^2 area while switching from H-tail to V-tail configuration with dimension as shown in figure 8. The CFD simulation for these two configurations showed the decrease in drag by 18.69% for the new design as shown in figure 7. This drag reduction was mainly due to reduction in the total weted area and number of joints that causes interference drag. Flow visualization of both configurations are illustrated in figure 6.

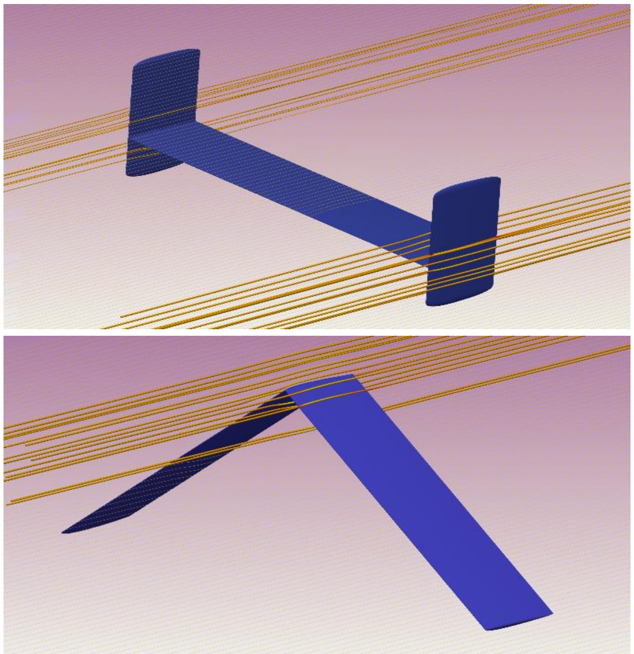

Figure 24 Flow visualization around isolated H-tail and inverted V-tail configurations

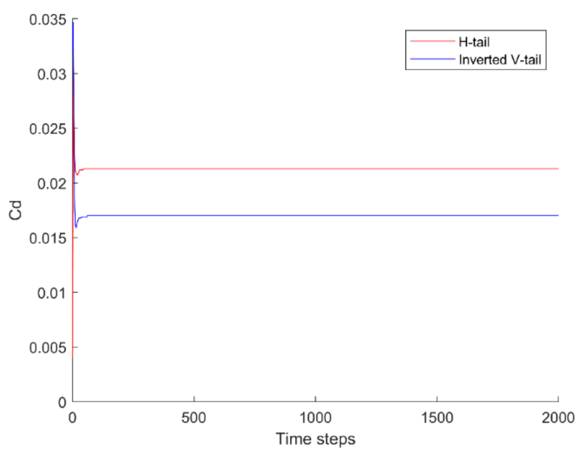

Figure 25 Comparison of C_D for H-tail and inverted V-tail configuration

One critical factor that affects the range and endurance of an aircraft is the specific fuel consumption (Anderson, 1998). Endurance can be increased by flying the aircraft at minimum power required. The cost of power required is directly related to the force required to overcome drag force. So, the flow around overall drag of the UAV was visualized by simulating the simplified full body model in cruise condition. Volume flow field of the simulation is given in figure 8.

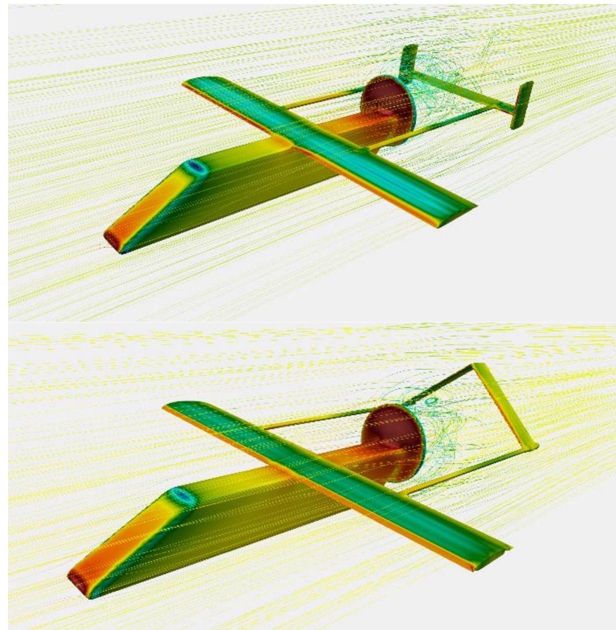

Figure 26 Volume flow visualization for full body H-tail and Inverted V-tail configuration

Profile drag due to the skin friction is a major form of drag in the region with high turbulence intensity. The region of the H-tail configuration behind the propeller wake has higher drag due to the propeller wash. This was seen to be reduced when the inverted-V tail's dimensions was out of the wake. The flow visualization of the propeller wake in the tail section can be seen in figure. Hence the endurance of the UAV can be increased by redesigning the tail section with an optimized inverted V-tail configuration. Thereby, increased fuel economy was estimated (Wang & Hailian, 2013).

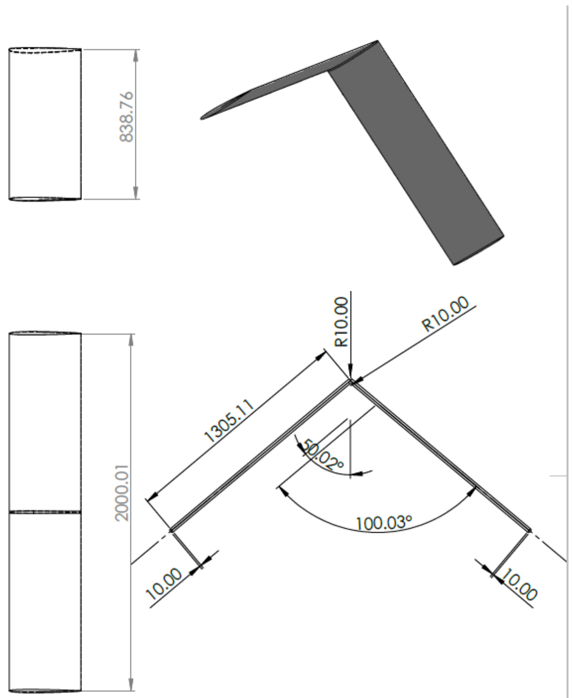

Figure 27 Dimensions of the Inverted V-tail

Conclusion

The necessity of changing the tail design configuration in the Search MARK II UAV was assessed by considering several factors of underlying higher profile drag. An inverted V-Tail configuration was proposed and the negative moment coefficient slope was confirmed. The solid model of the design was generated which was further analysed for drag reduction using CFD solver. The reduction in the drag by using inverted V-tail configuration and the addition of associated advantages proved the necessity of using this tail configuration to lessen the fuel consumption and increase the endurance of the UAV

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