SIMULATION BASED STUDY OF EMPENNAGE CONFIGURATIONS FOR SUAVS (GLIDERS AND MOTOR GLIDERS)

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ABSTRACT

Several empennage configurations (conventional, T-tail, H-tail, V-tail) for RC (radio controlled) gliders and fixed-wing SUAVs (small unmanned aerial vehicles) are studied in order to determine their effectiveness in providing the necessary stability to the aircraft in terms of the lift produced by both vertical and horizontal surfaces, and the drag produced in the process. A standard wing (2m span, s7055 airfoil, Aspect ratio 10) is used for this study. The configurations are tested in Solid works CFD and VLM in XFLR5. Fuselage effects are not considered in the latter case due to software constraints. Common sizing methods using tail volume coefficients are used to determine the sizes of tails surfaces. The purpose of the study is to use available findings and data from the study to provide a guideline for selecting best empennage configurations for gliders and motor gliders.

Key words: Empennage configurations, CFD, VLM, RC glider

1. INTRODUCTION

Selecting an appropriate empennage configuration is a very important part of SUAV design. It determines stability and controllability, but also contributes to drag and / or decreases from lift, and can affect other aspects, such as the potential for damage when landing [1]. This paper examines a few popular empennage configurations (Conventional with no taper, conventional, T-tail, H-tail, and V-tail). The conventional tail is the most common configuration and provides stable, safe flight under most circumstances. It is relatively easy to design and construct [1,2].

The T-tail has a few advantages. Notably the horizontal stabilizer is out of the wing wake, wing vortices, and the like. Effectiveness of the VT is increased as well. The disadvantages are the heavier tail structure and the tendency for deep stall [1,2]. The H-tail configuration keeps the VT out of the wing wake at high AOA (Angle of attack), increases HT effectiveness, and makes lateral control better (due to shorter VT). The main disadvantage is the weight of the structure [1,2].

The V-tail has a lower drag than the conventional tail, but in general some control effectiveness may be sacrificed. A Dutch roll tendency has also been noted. V-tails also require more complex controls, but most modern transmitters have V-tail mixers built in [1, 2]. The sizing of a V-tail has provide about the same wetted area as a corresponding conditional tail to be effective, which reduces its perceived drag advantage. However it does offer some reduced inference drag [1,3].

The objective of this paper is to identify the contribution to the lift and drag of the airplane by each of the empennage configurations. A standard airframe is used for all calculations. Further, the effect on controllability is also studied using XFLR5 v6.11.

2. METHODOLOGY

The baseline airframe used is a straight high wing with 5^o dihedral and no taper, with a chord of 0.2 m and a wingspan of 2 m, with an s7055 flat bottomed airfoil [4]. A standard fuselage was used for the solidworks models (60,100mm; 120,0mm; 120,200mm; 80,350mm; 60,500mm; 60,600mm) but was excluded from the XFLR5 simulations due to software limitations, though its weight was included in the inertia calculations. Both models also included a 300g battery positioned at the wing leading edge and a 100g motor below the wing leading edge to account for the most significant weights on the aircraft. All model inertia values entered for the XFLR5 model were based on the assumption that the main construction material was Styrofoam.

All configurations use a 0.5m moment arm for both the horizontal and vertical tails (except for the HT of the T-tail and VT of the H-tail). Tail volume coefficients are $C_H = 0.5$ and $C_V = 0.025$ throughout. These are fairly typical values for gliders [1]. Standard aspect ratios of 5 for HT, and 2 for VT, and taper ratios of 0.8 for HT and 0.6 for VT are used for all tapered configurations. The V-tail configuration used an aspect ratio of 4 and a taper ratio of 0.8. The airfoil used was HT12 [5].

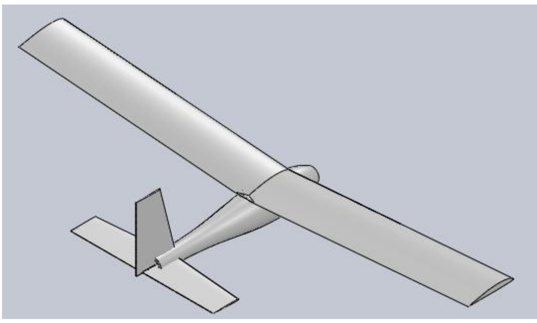

Figure 1: Solidworks model, conventional configuration.

The solidworks models were solved at standard atmospheric conditions (P=101325Pa, T=293.2 K) at an altitude of 0m in air. External analysis, both laminar and turbulent, was used. The selected mesh setting was 5 (approximately 400000 complete fluid cells) which was selected due to resource limitations in calculating 15 models. The computation domain was 2.039m to -2.075m in the x direction, 1.307m to -1.166m in the y direction, 2.206m to -1.377m in the z direction from the centre of the wing leading edge.

The XFLR5 models were calculated in the same standard conditions. The calculation method used was VLM (viscous, where the effects of viscosity are interpolated from previous polars [6]).

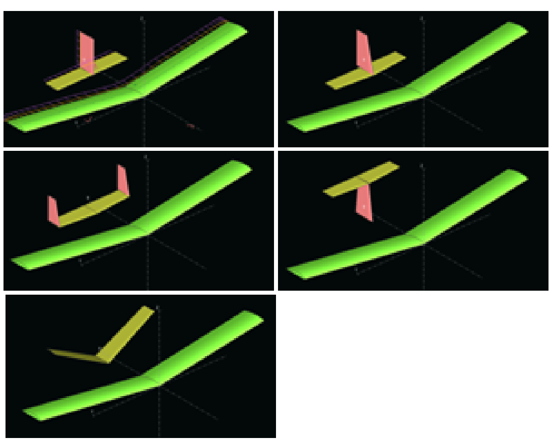

Figure 2: xflr5 models

Further, a stability analysis was carried out to examine the controllability of the designs. The fuselage was not included initially due to XFLR5's guidelines recommending against it, as the wing body connection cannot be modeled accurately without the help of a 3D CAD program [6]. However, due to the disparity of results, a comparable (not identical) fuselage was added to the XFLR5 models.

2.1 Formulas used

The tail areas were determined using the following formulae [1]:

$$S_H = \frac{C_H S_W c_W}{L_H} \qquad (01)$$

$$S_V = \frac{C_V S_W b_W}{L_V} \qquad (02)$$

Where S_H, S_V are the tail areas, C_H, C_V are tail volume coefficients, L_H, L_V are tail moment arms, Sw is the wing area, c_W is the wing chord, b_W is the wing span. These formulas were used for all configurations. All moment arms are with reference to the quarter chord locations of the respective airfoils. The moment arm was adjusted for the H-tail's Vertical tails and the T-tail's horizontal tail so that the quarter chord of the root airfoil of the surface in question coincided with the quarter chord of the tail airfoil of the other surface. Further, the following formulae were used to calculate the tail areas and angles of the V-tail configuration [7]:

$$C_{s\rightarrow v} = \frac{\frac{AR_{VT}}{(AR_{VT}+2)}}{\left(\frac{AR_v}{(AR_v+2)}\right)\times 1.4} \qquad (03)$$

$$S_v = S_H + S_V \qquad (04)$$

$$\theta = tan^{-1}\sqrt{\frac{S_v \times C_{s\rightarrow v}}{S_H}} \qquad (05)$$

Where $C_{s\rightarrow v}$ is a factor for AR compensation, AR_{VT} and AR_{HT} are aspect ratios of HT and VT respectively, S_v is the area of the V-tail (both tails combined), and θ is the angle between the V-tail and the horizontal.

3. RESULTS

The results summary from the Solidworks simulation is given in tables 1 and 2. The results from Soldiworks indicate that the aircraft experiences a drop in lift with almost every configuration.

Table 1: Lift generated, Solidworks models

Configuration	speed	lift	percentage difference
conventional - tapered	10	4.29E+00	0.00E+00
	15	9.71E+00	0.00E+00
	20	4.26E+01	0.00E+00
Conventional - no taper	10	4.69E+00	9.23E+00
	15	1.06E+01	9.37E+00
	20	1.93E+01	-5.47E+01
H-tail	10	4.26E+00	-6.48E-01
	15	9.79E+00	7.64E-01
	20	1.76E+01	-5.86E+01
T-tail	10	3.95E+00	-7.97E+00
	15	8.99E+00	-7.46E+00
	20	1.61E+01	-6.23E+01
V-tail	10	4.11E+00	-4.15E+00
	15	9.34E+00	-3.82E+00
	20	1.66E+01	-6.11E+01

Table 2: Drag generated, solidworks models

Configuration	speed	drag	percentage difference
conventional - tapered	10	1.1166	0
	15	2.4297	0
	20	42.596	0
Conventional - no taper	10	1.029	-7.8452445
	15	2.231	-8.1779644
	20	3.9006	-90.842802
H-tail	10	1.3265	18.7981372
	15	2.9916	23.1263119
	20	5.2018	-87.788055
T-tail	10	1.2025	7.6929966
	15	2.6489	9.02168992
	20	4.6111	-89.174805
V-tail	10	0.98247	-12.012359
	15	2.1455	-11.696917
	20	3.7344	-91.23298

Results concerning drag are less certain, with only the V-tail configuration displaying any consistent reduction is drag. The XFLR5 results are summarized in table 3, for CL/CD ratio, which indicates the overall efficiency of the airplane:

Table 3: C_L/C_D, XFLR5 results: percentage difference relative to tapered conventional

v	α	Conv no taper	H-tail	T-tail	V-tail
10	0	5.63E+0	-7.08E-1	1.82E+0	-1.65E+0
	2	-2.47E-2	-3.11E-1	8.09E-1	-5.28E-1
	5	-1.01E-2	-2.72E-1	4.09E-1	-6.36E-1
15	0	0.00E+0	-3.20E-1	1.73E+0	-1.25E+0
	2	-3.34E-2	-8.36E-2	7.32E-1	-4.18E-1
	5	-4.56E-3	-1.78E-1	3.97E-1	-7.17E-1
20	0	4.42E-2	-1.85E-1	1.65E+0	-1.02E+0
	2	-7.71E-3	7.71E-3	6.43E-1	-3.81E-1
	5	2.18E-2	-1.70E-1	3.39E-1	-7.66E-1

In XFLR5, only the T-tailed model showed a consistent increase in the L/D ratio. Particularly, the V-tailed model consistently showed a decrease.
All models display two well damped Dutch roll modes, and two other non-oscillatory modes, one well damped and the other slightly unstable, in the lateral direction. In the longitudinal direction, all models display a well damped phugoid (two complimentary modes) and two very well damped non-oscillatory modes. The eigenvalues are given in table 4. Overall, this indicates that the tails are roughly equivalent in terms on control effectiveness.

Table 4: Eigenvalues

Configuration	Longitudinal	Lateral
Conventional	-122.7949+0i -40.197+0i -0.0104-0.9777i -0.0104+0.9777i	-48.8127+0i -3.1991-8.4748i -3.1991+8.4748i 0.0244+0i
Conventional no taper	-124.2667+0i -40.8264+0i -0.0102-0.9706i -0.0102+0.9706i	-49.3226+0i -2.954-8.3163i -2.954+8.3163i 0.0264+0i
H-tail	-130.5763+0i -36.3485+0i -0.0102-1.0315i -0.0102+1.0315i	-45.8642+0i -2.6015-7.6136i -2.6015+7.6136i 0.0348+0i
T-tail	-117.9594+0i -40.48+0i -0.0105-0.9363i -0.0105+0.9363i	-50.0119+0i -3.1700-8.5336i -3.1700+8.5336i 0.0147+0i
V-tail	-185.5851+0i -31.2991+0i -0.0131-1.0974i -0.0131+1.0974i	-43.1447+0i -1.5893-5.9494i -1.5893+5.9494i 0.0407+0i

The results from the two sources are not in agreement. The Solidworks simulation indicates that the V-tail has the best performance, as indicated by table 5:

Table 5: lift/drag ratio and percentage difference relative to conventional tapered configuration, Solidworks models

Configuration	speed	lift/drag	percentage difference
conventional - tapered	10	3.84E+00	0.00E+00
	15	4.00E+00	0.00E+00
	20	1.00E+00	0.00E+00
Conventional - no taper	10	4.55E+00	1.85E+01
	15	4.76E+00	1.91E+01
	20	4.95E+00	3.95E+02
H-tail	10	3.21E+00	-1.64E+01
	15	3.27E+00	-1.82E+01
	20	3.39E+00	2.39E+02
T-tail	10	3.28E+00	-1.45E+01
	15	3.39E+00	-1.51E+01
	20	3.48E+00	2.48E+02
	10	4.19E+00	8.93E+00
	15	4.35E+00	8.92E+00
V-tail	20	4.44E+00	3.44E+02

However, the XFLR5 models indicate that the T-tail has the best performance in terms of lift/drag ratio. Existing data indicate that, while the V-tail produces less drag overall, the reduction is not very large due to requiring the same tail area, which translates to the same viscous drag [1,7].

There are several possible reasons for the disparity in results:

1. The inclusion of the fuselage in the Solidworks study while it was not included in XFLR5, due to software limitations. This means the XFLR5 model does not model the interaction between the tail surfaces and the fuselage. Including a similar sizable fuselage in the XFLR5 gives a similar result to the Solidworks simulations, as shown in table 06, with the V-tail configuration performing best. However, the model failed to solve for $\alpha=5^o$.

Table 6: XFLR5 results with fuselage.

v	α	Conv no taper	H-tail	T-tail	V-tail
10	0	-1.28E-1	2.50E-1	-6.09E-1	1.29E+1
	2	-9.83E-2	8.67E-2	5.78E-3	1.32E+1
	5	-9.10E-2	-1.52E-1	4.91E-1	N/A
15	0	-1.41E-1	3.91E-1	-7.14E-1	1.51E+1
	2	-9.93E-2	1.39E-1	-4.96E-2	1.49E+1
	5	-9.95E-2	-1.49E-1	4.92E-1	N/A
20	0	-1.08E-1	3.97E-1	-8.27E-1	1.64E+1
	2	-6.91E-2	1.11E-1	-9.68E-2	1.70E+1
	5	-5.29E-2	-1.80E-1	4.87E-1	N/A

2. Differences and limitations of calculation methods.
   a. VLM was used for the XFLR5 models. Though viscosity was taken into account, the XFLR5guidelines document states that 'The viscous variables (viscous Cd, transitions, etc) are interpolated from the value of Cl on the previously XFoil-generated polars. This obviously raises an issue for high and low C_L, where the Type 1 polar curve may be interpolated either before or after the stall angle.[6]' The results at higher AoA (5^o) are particularly prone to this.
   b. Solidworks uses a CFD based model, but there were limitations on the resolution. Solidworks is also not optimized for low Reynolds number calculation and aircraft design.

4. CONCLUSIONS

The recommended configurations for an SUAV, on low lift to drag ratio alone, would be the V-tail and T-tail configurations.

The results of this study should be verified against experimental results in a wind tunnel. A comparison of the performance of other configurations (such as cruciform, inverted V, and Y) and the effects of varying CG position can also be addressed.

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