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Design and Optimization of SUAV Empennage

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Abstract:Now a days the use of unmanned aerial vehicle (UAV) is getting common, as its size varies from small to large, which has good parameters like, light weight and good stability and can be used for surveillance, agriculture, and in defense as it can be controlled from ground or from other aircraft.

In an UAV wing is blended with fuselage which gives lift to the UAV and the tail is also used for take-off and landing which is also gives higher stability to aircraft. It is important to design an empennage structure at lower drag and for good stability characteristics.

In this present project airfoil coordinates has been generated by using JAVAFOIL, in this project NACA0010 airfoil is created, which is imported to CATIA V5 to design different empennage configurations of same wetted area and UAV empennage has been finally designed in a modeling tool CATIA V5 R19.The model is imported to Ansys through IGES file to simulate CFD analysis, where for analyzing fine meshing is taken for the whole structure of UAV and further CFD flow analysis is done through Ansys CFX software. The results for C_L, C_D and L/D are obtained by varying AOA with different velocity as shown in graphs (fig 13 to 18). A comparison is made for these empennages to check the aerodynamic efficiency and stability created by the different SUAV tails.

Keywords- symmetric airfoil, total pressure, anhedral, ansys CFX

Nomenclature

CFD- Computational fluid dynamics
SUAV - surveillance Unmanned aerial vehicle
CG- centre of gravity
MAC- moment aerodynamic centre
S_W-wing area,
S_{VT}- vertical tail area,
S_{HT}- horizontal tail area,
b_W - wing span,
C_W- mean chord length.
L_{VT} - distance from CG TO MAC of vertical tail
L_{HT} - distance from CG TO MAC of horizontal tail
AOA-angle of attac
C_L-Coefficient of lift
C_D- Coefficient of drag

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have proven that they are successful in military combats; they are also successfully used in surveillance, agriculture. The use of UAVs is getting common because they can be operated sitting on ground or from other aircraft. UAVs can be categorized into four different groups: large, medium, small, and micro [i] as shown in Figure 1.

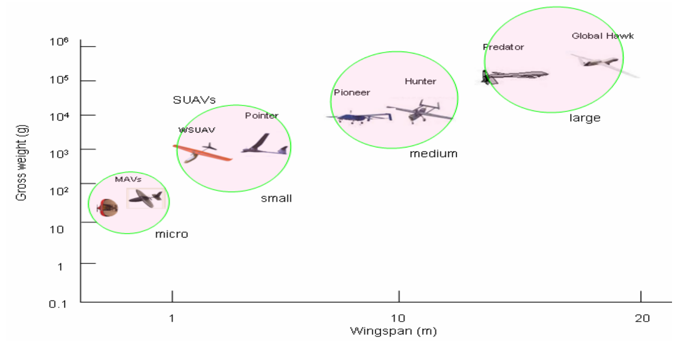

Fig. 1. UAVs can be divided into four groups with respect to its sizes and weights [i].

The empennage in an UAV is used for the longitudinal and directional stability; it consists of horizontal and vertical stabilizer. Empennage should be designed in such way that it has to produce less drag at elevated angle of attack and good stability characteristics at steady flight condition and in different maneuver conditions.

II. NOMENCLATURE OF TAIL

Tail part is located at the aft of the UAV, it mainly consists of two surfaces horizontal and vertical stabilizer, these provide stability to the UAV. Both horizontal and vertical stabilizer is made with symmetric airfoil. Controlling surfaces are connected to these, for pitching moment, elevator is connected and for directional moment, rudder is connected which is connected in vertical stabilizer.

III. DESIGNING OF EMPENNAGE

A. Design requirements

- Endurance =30 min
- Data transmission range = 5 to 10 km
- cruise speed =22 m/s,
- climb rate = 2 m/s
- Take-off =hand-launching
- Landing =Short field landings (parachute recovery)
- Wing span = 2 m
- Propulsion =electric motor
- Mission altitude = 150 m

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*B. **Tail volume coefficients***[2]

$$C_{VT} = \frac{L_{VT} S_{VT}}{b_W S_W} \quad (1)$$

$$C_{HT} = \frac{L_{HT} S_{HT}}{C_W S_W} \quad (2)$$

TABLE I. Angle Between Horizontal And Vertical Tail.

Tail design type	**Angle between S_{HT} and S_{VT} in Degree**
Conventional	90
Anhedral	100
V-Shape	120

Steps to generate the airfoil coordinate in javafoil-

1. Open JAVAFOIL SOFTWARE.
2. Enter the name of the airfoil (NACA 0010).
3. Enter number of points to be generated as 301.
4. Using the airfoil nomenclature enter the values for thickness, camber and the camber location
5. Click on the create airfoil to generate the aerofoil coordinates.[6]

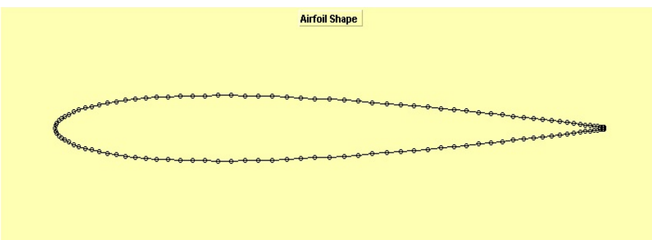

Fig. 2. Generating NACA 0010 airfoil coordinates.

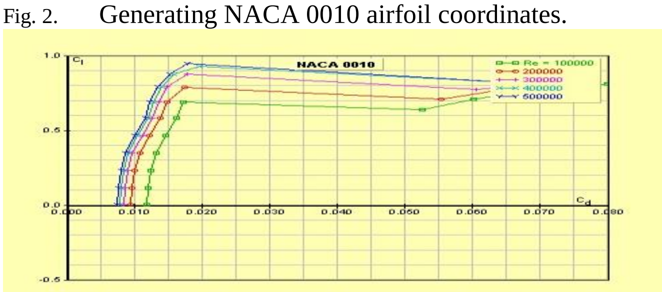

Fig. 3. C_L Vs C_D graph for NACA0010 at different Reynolds number

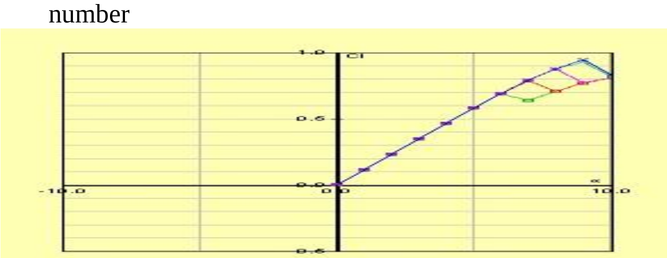

Fig. 4. C_LVS C_D graph for NACA 0010

C. Design of Empennage

Import the airfoil coordinates to CATIA which is saved in *.igs file and design the conventional, anhedral and V shape tails which is having the angle difference between horizontal and vertical tail as 90, 100 and 120 degree respectively.

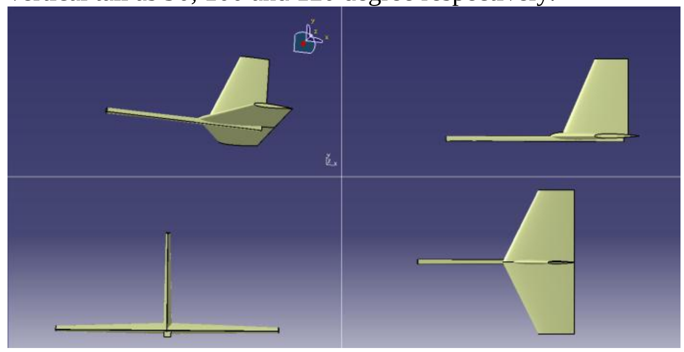

Fig. 5. Conventional tail

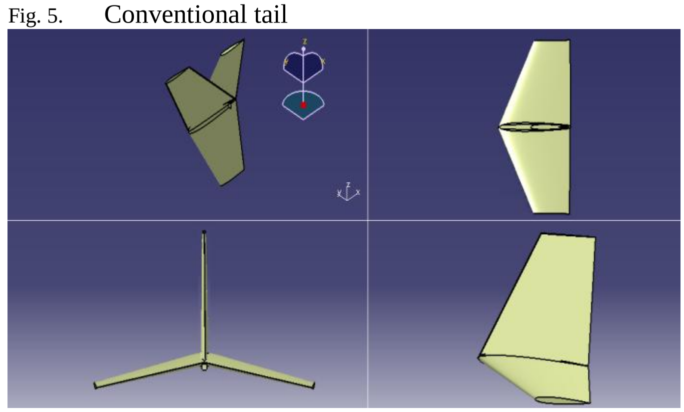

Fig. 6. Anhedral tail

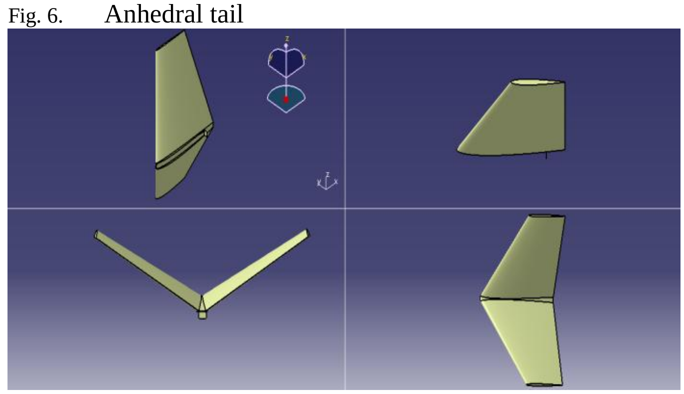

Fig. 7. V-Shape tail

D. Inputs and Boundary Conditions

TABLE II. INPUTS AND BOUNDARY CONDITIONS.

TAKEOFF Condition						
Cases	***M***	***V(m/s)***	***AOA***	***U***	***V***	***W***
1	0.044	15	0	15.0	0.0	0
2	0.044	15	5	14.9	1.3	0
3	0.044	15	10	14.8	2.6	0
4	0.044	15	15	14.5	3.9	0
Cruise Condition						
5	0.059	20	0	20.0	0.0	0
6	0.074	25	0	25.0	0.0	0
7	0.088	30	0	30.0	0.0	0

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$$u = V * \cos\alpha \qquad (3)$$

$$v = V * \sin\alpha \qquad (4)$$

u,v,w are velocity components in x,y,z directions respectively.

TABLE III. GENERAL PROCEDURE FOR CFD ANALYSIS[5]

No.	Steps	Process
1	Problem statement	Information about the flow
2	Mathematical model	Generate 3D model
3	Mesh generation	Nodes/cells, time instants
4	Space discretization	Coupled ODE/DAE systems
5	Time Discretization	Algebraic system Ax=b
6	Iterative solver	Discrete function values
7	CFD software	Implementation, debugging
8	Simulation run	Parameters, stopping, criteria
9	Post processing	Visualization, analysis of data
10	Verification	Model validation / adjustment
11	Saving case and data	Save all the obtain data
12	Comparing	Comparing the outcome values

IV. MESH GENERATION

In order to analyze the fluid flow, the element is spilt into number of elements. If the number of elements is more it gives more accurate values. Here we are using TRIA surface mesh. Near the curved surfaces it has to cover all the surface for that reason we are giving auto mesh, this auto mesh feature makes the mesh to capture properly near the curved surfaces.

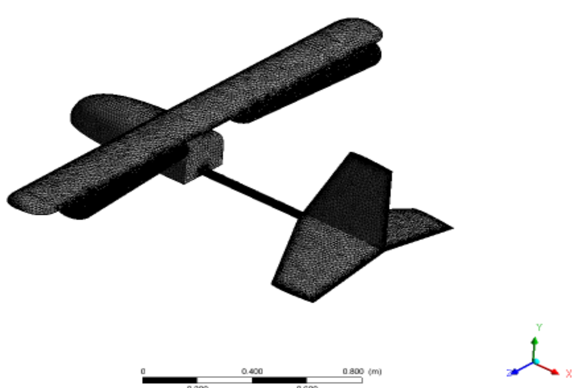

Fig. 8. Surface mesh of anhedral tail.

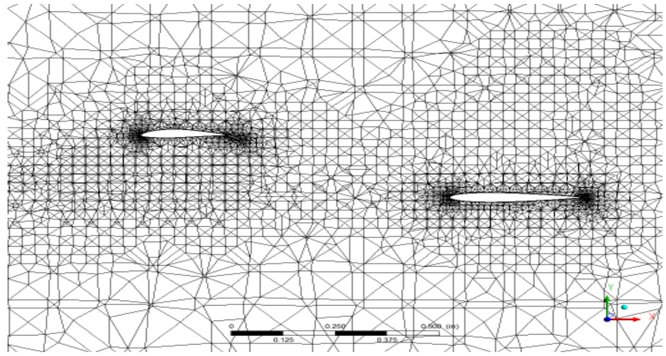

Fig. 9. Meshed region

A. *Contoursplot of total pressure over SUAV for different empennage configurations*

Total pressure is the pressure measured by bringing the flow to rest isentropically (without loss). Total pressure is a Sum of Static pressure and Dynamic pressure. The static pressure is simply the weight per unit area of air above the level under consideration.

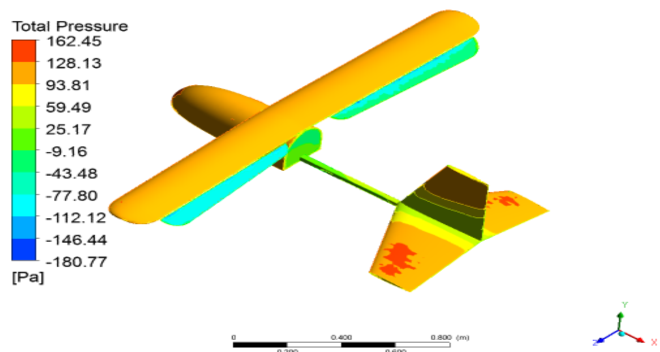

Fig. 10. SUAV Anhedral Tail at velocity 15m/s and AOA 0°

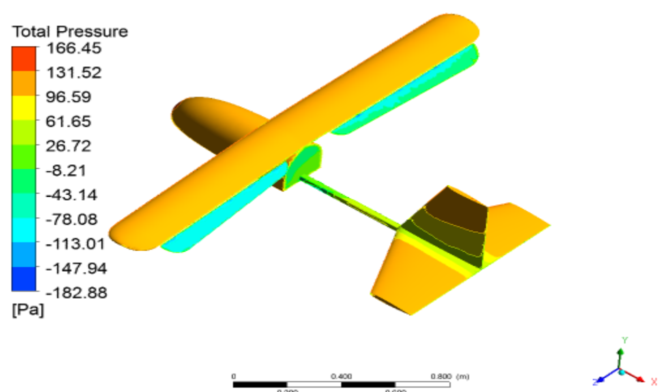

Fig. 11. SUAV Conventional Tail at velocity 15m/s and AOA 0°

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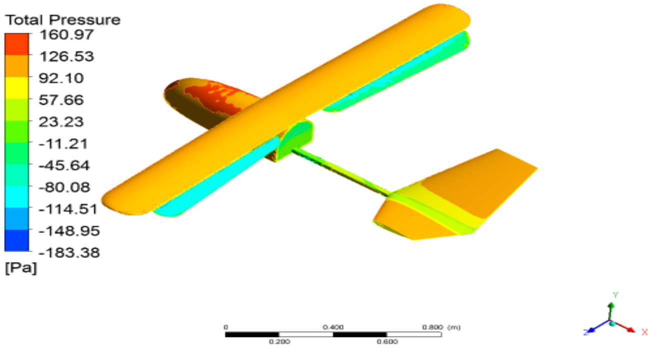

Fig. 12. SUAV V-Shape Tail at velocity 15m/s and AOA 0°

B. Resulting

The result values of C_L, C_D and L/D ratio has been plotted as shown in table IV, V and VI for conventional, anhedral and V-shaped tail by varying AOA with different velocities.

Coefficient of drag is the resultant force of axial force, coefficient of lift is the resultant force of normal force. The solution of component force is brought for different empennage configurations which are obtained in ansys solver for different boundary conditions.

The results are in the form of force components, where the total force is the sum of viscous force and pressure force. By adding total forces of different components of UAV such as fuselage, wing, tail boom, and tail (i.e. horizontal and vertical) as these force components are in x, y and z directions. These force components are converted to C_L and C_D.

TABLE IV. RESULTS FOR CONVENTIONAL TAIL
TABLE V.

V (m/s)	AOA (deg)	SUAV with Conventional Tail		
		C_D	C_L	*L/D*
15	0	0.1130	0.6550	5.80
15	5	0.1523	1.1076	7.27
15	10	0.2209	1.5379	6.96
15	15	0.3160	1.9263	6.10
20	0	0.1122	0.6555	5.84
25	0	0.1104	0.6580	5.96
30	0	0.1102	0.6615	6.00

TABLE VI. RESULTS FOR ANHEDRAL TAIL
TABLE VII.

V (m/s)	AOA (deg)	SUAV with Anhedral Tail		
		C_D	C_L	*L/D*
15	0	0.1129	0.6496	5.75
15	5	0.1519	1.1048	7.27
15	10	0.2217	1.5426	6.96
15	15	0.3158	1.9265	6.10
20	0	0.1121	0.6518	5.82
25	0	0.1115	0.6538	5.86
30	0	0.1112	0.6552	5.89

TABLE VIII. RESULTS FOR V SHAPED TAIL

V (m/s)	AOA (deg)	SUAV with V Shape Tail		
		C_D	C_L	*L/D*
15	0	0.1089	0.6642	6.10
15	5	0.1469	1.0963	7.46
15	10	0.2135	1.5099	7.07
15	15	0.3029	1.8651	6.16
20	0	0.1094	0.6669	6.10
25	0	0.1078	0.6692	6.21
30	0	0.1077	0.6720	6.24

Graphical method is used for easier analysis because it provides clear picture and better understanding for different conditions. Graphs are plotted for C_D and C_L for different angle of attack at velocity 15 m/s and for different velocity at AOA 0^0, as shown in table IV, V, VI.

The graph of C_D Vs AOA at Velocity 15 m/s shows that as the angle of attack increases for different tail configurations drag increases gradually but conventional and anhedral has almost same drag at different AOA, where as in V shape tail drag is less at higher AOA compared to other two configurations, as shown in fig13.

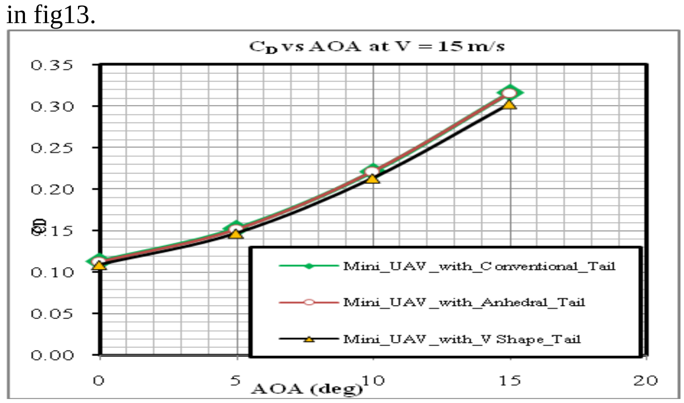

Fig. 13. Graphical representation of C_D Vs AOA for different tail configurations at V=15 m/s

In the graph of C_L Vs AOA at Velocity 15 m/s it shows Coefficient of Lift increases linearly but all three configurations have almost same C_L with minor deviations but at velocity 15 m/s, it has slightly more C_L than other configurations, as shown in fig 14.

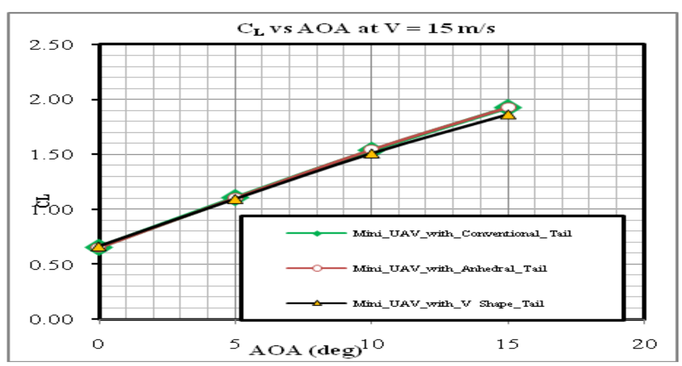

Fig. 14. Graphical representation of C_L Vs AOA for different tail configurations at V=15 m/s

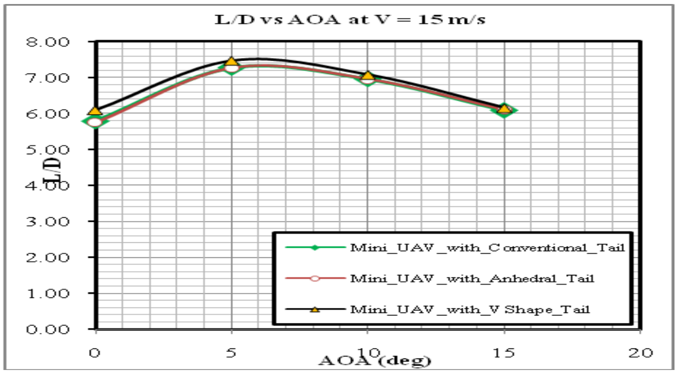

Fig. 15. Graphical representation of L/D Vs AOA for different tail configurations at V=15 m/s

In the graph of L/D Vs AOA at Velocity 15 m/s, it can be seen that for V shapes tail, lift to drag ratio is slightly more at AOA 0, 5, 10^0 and it is minute at AOA 15^0, as shown in fig15.

In C_D Vs Velocity graph it clearly shows that C_D value is reducing but for V shape tail, it is having less C_D than other two configurations at zero AOA, as shown in fig16.

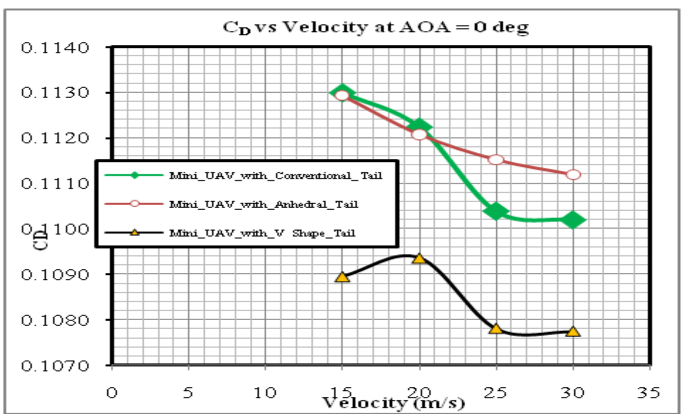

Fig. 16. Graphical representation of C_D Vs velocity for different tail configurations at AOA=0

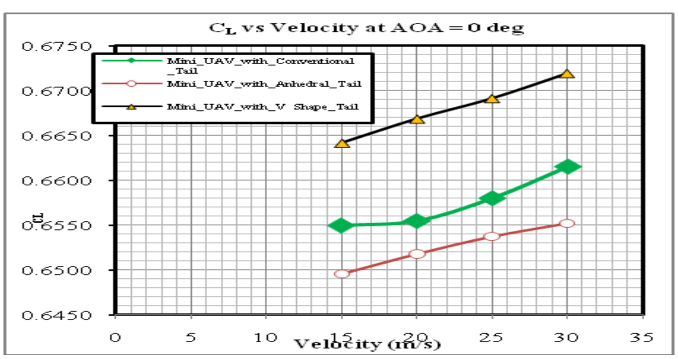

Fig. 17. Graphical representation of C_L Vs velocity for different tail configurations at AOA=0

For any aircraft or UAV C_L value should be more and C_D must be low for better performance in C_L Vs Velocity at AOA 0^0 it shows V shape configuration have more C_L than other, and anhedral is giving lowest lift compared to other configurations, as shown in fig17.

In the graph of L/D Vs Velocity at AOA 0^0, it can be seen that for V shapes tail lift to drag ratio is more at velocity 15, 20, 25, 30 m/s but less for anheral, as shown in fig18.

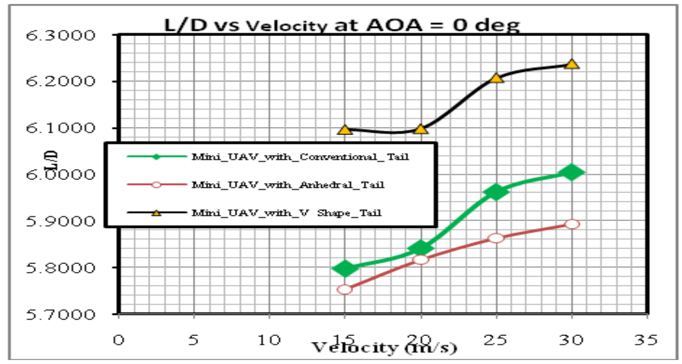

Fig. 18. Graphical representation of L/D Vs velocity for different tail configurations at AOA=0

V. CONCLUSION

Any UAV or aircraft made should have lesser drag and more lift for better performance. By taking suitable airfoil we can achieve this but the same airfoil at different tail configurations will behave different ways. In this project a conventional, Anhedral and V shape tail configurations are taken and analyzed. From the above graphical results it is concluded that V shaped tail configuration gives better performance than other two configurations which has shown and concluded from fig13 to fig18. From the above Graphs, it is concluded that v shaped tail is having fewer Coefficients drag at various velocities and at different AOA. It also observed that there is an increase in C_L at same boundary conditions. From the above results, v shaped tail is considered to be the best suitable configuration for surveillance UAV.

VI. SCOPE

The analysis can be carried out by assuming control surfaces (elevator and rudder), from the above result it is concluded that v-shape is the best configuration, for that configuration structural analysis can be made to check the structural stability.

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