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A REPORT ON NUMERICAL INVESTIGATION OF WINGS: WITH AND WITHOUT WINGLET

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Abstract

The main goal of the proposed paper is the numerical investigation of Wings with and without winglet designs. This investigation shows the various performance and parameters for the wings when designed with a winglet and without a winglet and thus comparing the parameters for both the designs. The discussions were focused on the aerodynamics characteristics which include drag coefficient CD, lift coefficient CL, and lift-to-drag ratio L/D. In this investigation two Different wings are used: An Elliptical wing and a Short wing. The airfoil used in this investigation is NACA 2412 with which both the wings are designed. The Geometry of the models is carried out in the CATIA V5 R19 Software and is designed in Part and Wireframe and Surface Design. The airfoils of Different Chord length are designed with different Stations using the geometry given in the DESIGNFOIL Software. The winglet is then designed for both the wings. The investigation aims to produce better aerodynamic performance with the implementation of the winglet for both wing designs. One of the objectives of this work is reduce the induced drag formed on wing during the fight operation, thus improving the efficiency of the aircraft. The analysis part is done by using the ANSYS Software, flow parameters (like the lift and drag) are measured for different design configurations and are compared with the plane wing and the wing designed with winglet.

***Keywords**: CATIA; Elliptical Wing; ANSYS*

1. Introduction

A winglet is a device used to improve the efficiency of aircraft by lowering the lift induced drag caused by wingtip vortices. It is a vertical or angled extension at the tips of each wing. Winglets improve efficiency by diffusing the shed wingtip vortex, which in turn reduces the drag due to lift and improves the wing's lift over drag ratio Winglets increase the effective aspect ratio of a wing without adding greatly to the structural stress and hence necessary weight of its structure.

Research into winglet technology for commercial aviation was pioneered by Richard Whitcomb in the mid 1970's.

Small and nearly vertical fins were installed on a KC-135A and flights were tested in 1979 and 1980. Whitcomb revealed that in full size aircraft, winglets can provide improvements in efficiency of more than 7%. For airlines, this translates into millions of dollars in fuel costs. Winglets are being incorporated into most new transport aircraft, including business jets, the Boeing 747-400, airliners, and military transport.

Many other researchers have investigated their behavior, designing winglets for commercial and general aviation aircraft as well as for sailplanes. Furthermore, the added friction and interference drag has to be cancelled out by the forward thrust generated by the winglet lift. The upward angle (or *cant*) of the winglet, its inward or outward angle (or *toe*), as well as its size and shape are critical for correct performance and are unique in each application.

2. Theory and Basic Definitions

2.1 WINGLET THEORY:

Due to circulation about the horseshoe vortex, there exists an induced downwash-which in turn produces induced drag

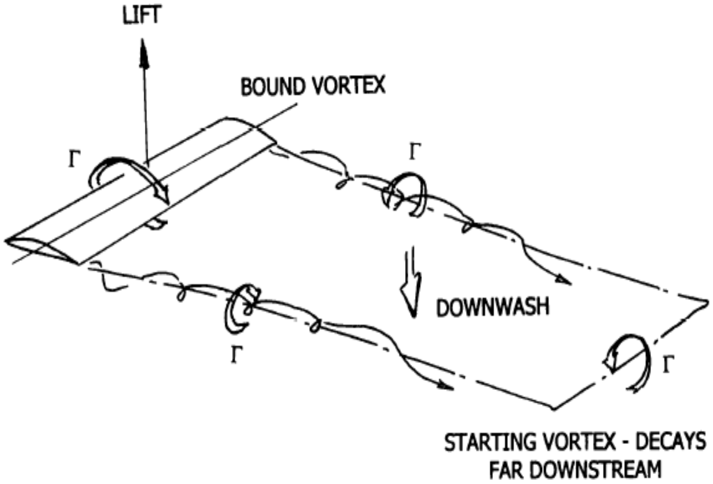

Fig 2.1 Vortex Formations

Adding winglets alters the flow at the tip which in turn decreases the downwash, ultimately reducing induced drag.

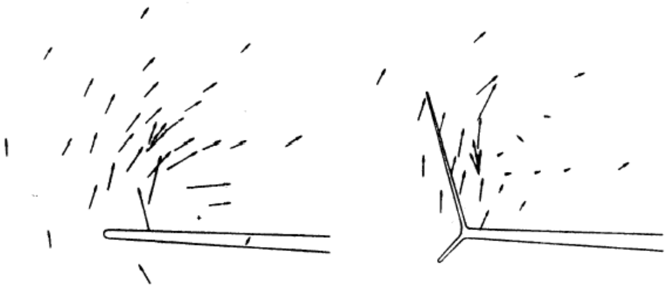

Fig 2.2 Reduction of Induced Drag by adding Winglets

2.2 INDUCED DRAG:

Induced drag is a force that occurs whenever a moving object redirects the airflow coming at it.

It is also called as "*Drag due to lift*" as it a source of wing drag.

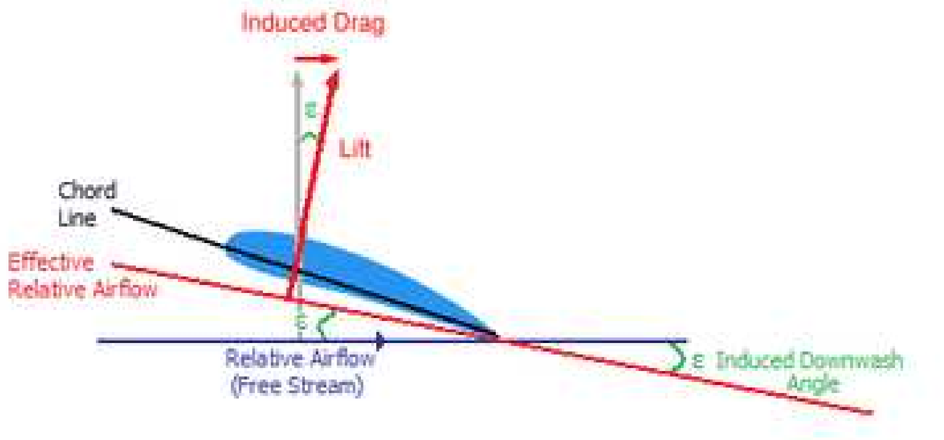

Fig 2.3 Induced Drag

2.3 WINGLET BENEFITS

Winglets belong to the class of wingtip devices aimed to reduce induced drag. Selection of the wingtip device depends on the specific situation and the airplane model. In the case of winglets, the reduction of the induced drag is accomplished by acting like a small sail whose lift component generates a traction force, draining energy from the tip vortices. The wingtip might be considered a *dead zone* regarding to the aerodynamic efficiency, because it generates lots of drag and no significant lift. The winglet contributes to accelerate the airflow at the tip in such a way that it generates lift and improves the wing loading distribution, which is related to the induced drag. In addition, the aircraft will fly at a slightly lower angle of attack for the same lift coefficient. Thus, it should always be possible to obtain significant drag reductions by using wingtip devices even for high-aspect wings.

Away to avoid this design issue is to employ raked wingtips like Boeing did for its 767-400 aircraft. Thanks to winglets the aircraft will climb to initial altitude faster and save fuel due to a more efficient climb profile. Otherwise, the aircraft can take off at lower thrust settings, which reduce the aircraft noise footprint and extend engine life.

2.4 TYPES OF WINGLETS

In general any wingtips that not end the wing simply horizontally are considered as some kind of a winglet.
Basically three types of winglets exists,

- BLENDED WINGLETS
- RAKED WINGTIPS
- WINGTIP FENCES

2.4.1 BLENDED WINGLETS (the real Winglets):

A blended winglet is attached to the wing with smooth curve instead of a sharp angle and is intended to reduce interference drag at the wing/winglet junction. A sharp interior angle in this region can interact with the boundary layer flow causing a drag inducing vortex, negating some of the benefit of the winglet. The blended winglet is used on business jets and sailplanes, where individual buyer preference is an important marketing aspect.

Fig 2.7Blended Winglets

2.4.2 WINGTIP FENCES:

These are a special variant of winglets that extend both upward and downward from the tip of the wing. Preferred by European plane-maker Airbus, it is featured on their full product range (except the A330/340 family and the future A350).

Fig 2.8 Wingtip Fences

2.4.3 RAKED WINGTIPS:

These are the most recent winglet variants (they are probably better classified as special wings, though), where the tip of the wing has a higher degree of sweep than the rest of the wing. They are widely referred to as winglets, but they are better described as integrated wingtip extensions as they are (horizontal) additions to the existing wing, than the previously described(near)vertical solutions.

Fig 2.9 Raked Wingtips

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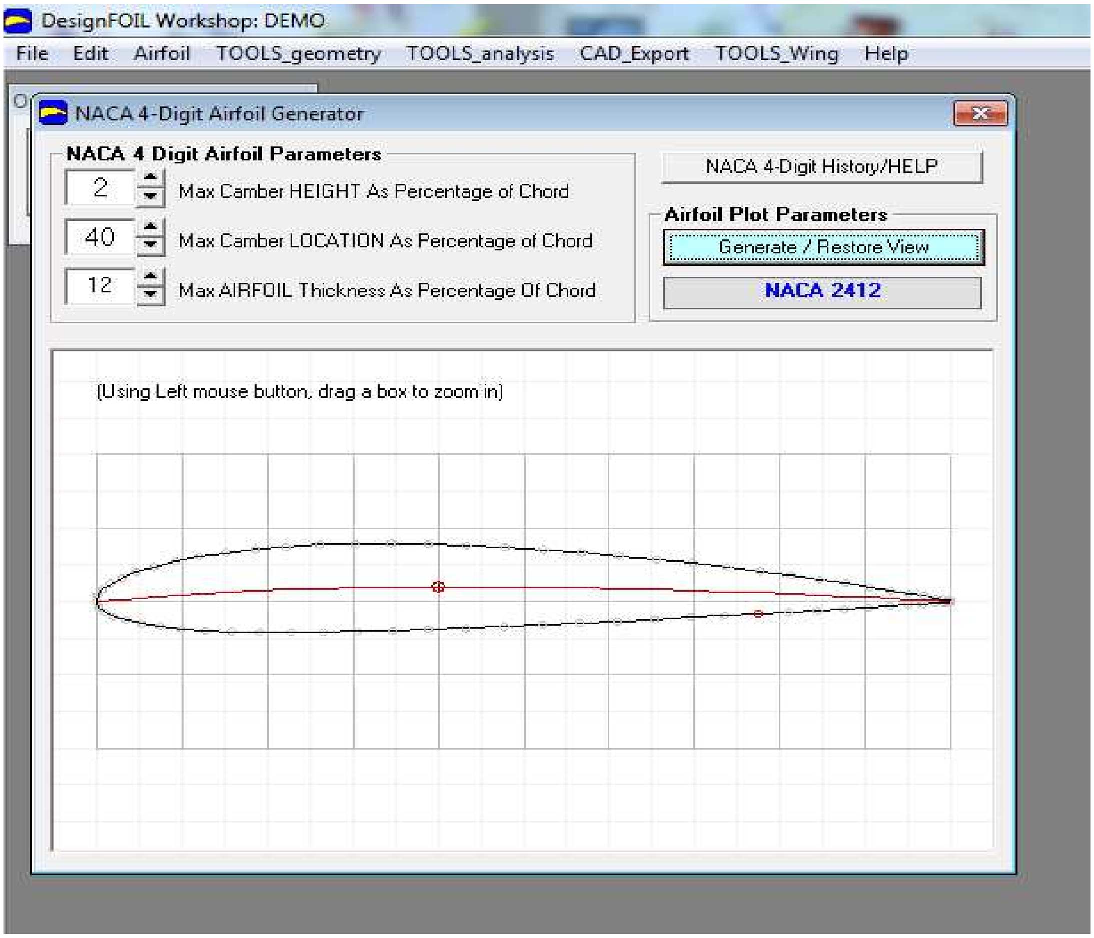
3. The Aerofoil

3.1 Aerofoil

The Elliptical Wing and the Short wing are designed taking the NACA 2412 airfoil station points from the DESIGN FOIL software in the CATIA V5 R19 software.



2 Max Camber HEIGHT As Percentage of Chord

40 Max Camber LOCATION As Percentage of Chord

12 Max AIRFOIL Thickness As Percentage Of Chord

NACA 2412

(Using Left mouse button, drag a box to zoom in)

Screenshot 3.1 NACA 2412 airfoil Stations

3.2 ELLIPTICAL WING

An elliptical wing is a wing platform shape that minimizes induced drag. Elliptical taper shortens the chord near the wingtips in such a way that all parts of the wing experience equivalent downwash, and lift at the wing tips is essentially zero.

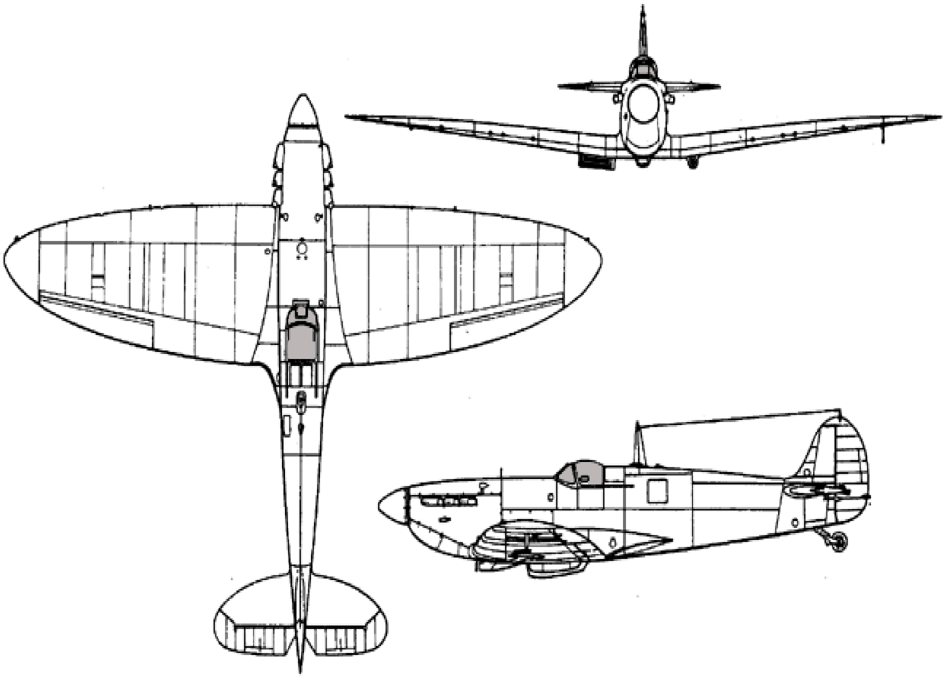
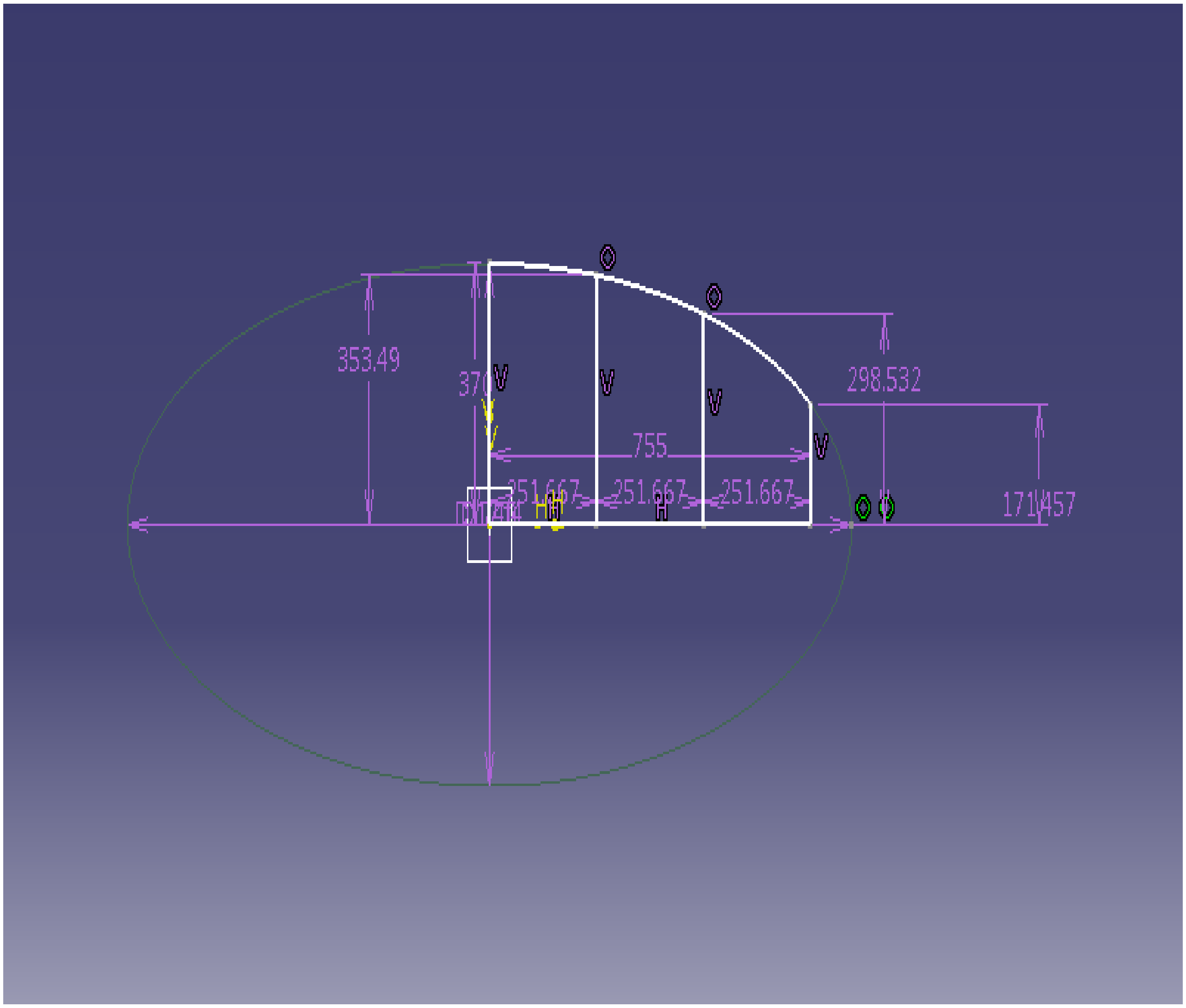


Fig 3.1 Elliptical Wing

For the Elliptical Wing, the root chord of the wing is taken as 370mm, the tip chord is 171.457mm and the wingspan is 1510mm, but here we are taking half of the length i.e., 755mm. The Elliptical wing is designed with total of four airfoils with decreasing chord lengths.

Table 3.1 Geometrical characteristics of wings

	b (mm)	**S (mm2)**	**Cr (mm)**	**Ct (mm)**	**AR**
Elliptical (Total wing)	1510	452	370	171.457	10100
Short wing	1230	400	370	233	7600



Screenshot 3.2 Designing of an elliptical wing

Similarly, the Short wing with two airfoils is designed. The root chord is 370mm, the tip chord is 233mm and the wingspan is 615mm (half).

The single classical Winglet is also designed using the airfoil geometry and are made to attach with the elliptical wing for the required investigation.

The winglets were designed, using the indications obtained from the panel method analysis, with different sweep, twist and toe angles, see Figure 3.2 for definitions. In this case the aspect ratio was not the same of the elliptical wing (AR=1008mm), like in the previous case, but was slightly higher of the short wing (820mm compared to 760mm relative to the short wing).

3.3: DESIGN OF WINGLET

Geometry of Winglet

3.3.1: Winglet Airfoil

Goal:

Generate enough lift while maintaining the lowest possible drag, Should not stall before wing during low speed flight, and the Geometry driven by aerodynamic characteristics of the airfoil.

3.3.2: Chord Distribution

If the Chord Distribution is too small then the airfoil will require a large lift coefficient and when it is too big then the high winglet loading causes outboard section of wing to stall prematurely.

The Elliptical plan form will help with load distribution over a large range of flight regimes.

3.3.3: Winglet Height

The Height of the Winglet is determined by the optimal induced drag and profile drag relationship.

3.3.4: Twist/Sweep

The Twist /Sweep angles have similar effects on the winglet and They Tailor the load distribution.

3.3.5: Toe Angle

It controls overall loading on winglet, Effects the load distribution on main wing and it is only optimum for one flight condition.

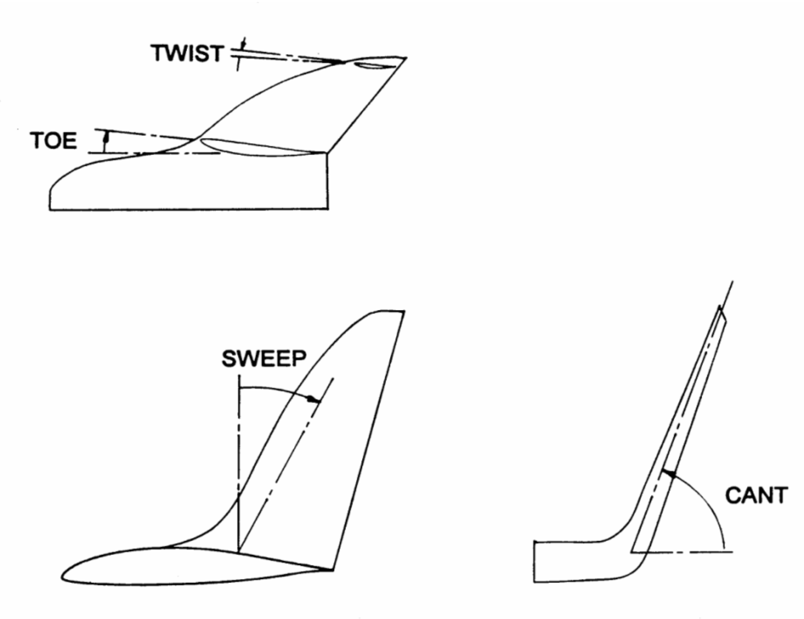


Fig 3.2Geometric quantities used to define a winglet

The Geometrical characteristics of the elliptical wing are listed in the following tables (table 3.2, table 3.3, table 3.4 and table 3.5).

Table 3.2–Station Points for the aerofoil of chord length 370mm

X=x/100*370		Y=y/100*370		X=x/100*370		(-Y)=y/100*370	
0.124%	0.4588	0.8%	2.96	0.279%	1.0323	-0.76%	-2.812
1.588%	5.8756	2.414%	8.9318	2.015%	7.4555	-2.062%	-7.6294
4.642%	17.1754	3.991%	14.7667	5.266%	19.4842	-3.062%	-11.3294
9.199%	34.0363	5.432%	20.0984	9.898%	36.6226	-3.75%	-13.875
15.115%	55.9255	6.625%	24.5125	15.776%	58.3712	-4.133%	-15.2921
22.197%	82.1289	7.467%	27.6279	22.71%	84.027	-4.237%	-15.6769
30.201%	111.7437	7.883%	29.1671	30.491%	112.8167	-4.116%	-15.2292
38.854%	143.7598	7.841%	29.0117	38.887%	143.8819	-3.844%	-14.2228
47.8%	176.86	7.396%	27.3652	47.706%	176.5122	-3.463%	-12.8131
56.796%	210.1452	6.668%	24.6716	56.617%	209.4829	-2.978%	-11.0186
65.561%	242.5757	5.73%	21.201	65.33%	241.721	-2.45%	-9.065
73.811%	273.1007	4.6625%	17.2494	73.564%	272.1868	-1.923%	-7.1151
81.282%	300.7434	3.547%	13.1239	81.054%	299.8998	-1.431%	-5.2947
87.738%	324.6306	2.472%	9.1464	87.554%	323.9498	-0.995%	-3.6815
92.978%	344.0186	1.52%	5.624	92.851%	343.5487	-0.632%	-2.3384
96.839%	358.3043	0.77%	2.849	96.768%	358.0416	-0.357%	-1.3209
99.204%	367.0548	0.291%	1.0767	99.173%	366.9401	-0.184%	-0.6808
100%	370	0.126%	0.4662	99.983%	369.9371	-0.126%	-0.4662

The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

Where C= chord length.

Table 3.3 –Station Points for aerofoil for chord length 353.49mm

X=x/100*353.49		Y=y/100*353.49		X=x/100*353.49		(-Y) =y/100*353.49	
0.124%	0.438328	0.8%	2.828	0.279%	0.9862371	-0.76%	-2.686524
1.588%	5.613	2.414%	8.533	2.015%	7.123	-2.062%	-7.288938
4.642%	1.409	3.991%	14.108	5.266%	18.615	-3.062%	-10.8238638
9.199%	32.518	5.432%	19.202	9.898%	34.988	-3.75%	-13.255875
15.115%	53.43	6.625%	23.419	15.776%	55.767	-4.133%	-14.6097417
22.197%	78.44	7.467%	26.395	22.71%	80.278	-4.237%	-14.9773713
30.201%	10.76	7.883%	27.866	30.491%	107.78	-4.116%	-14.5496932
38.854%	137.35	7.841%	27.717	38.887%	137.46	-3.844%	-13.5881556
47.8%	168.97	7.396%	26.144	47.706%	168.64	-3.463%	-12.2413587
56.796%	200.77	6.668%	23.571	56.617%	200.14	-2.978%	-10.5269322
65.561%	231.75	5.73%	20.255	65.33%	230.94	-2.45%	-8.660505
73.811%	260.91	4.668%	1.48	73.564%	260.04	-1.923%	-6.7976127
81.282%	287.32	3.547%	12.538	81.054%	286.52	-1.431%	-5.0584419

87.738%	310.15	2.472%	8.738	87.554%	309.49	-0.995%	-3.5172255
92.978%	328.67	1.52%	5.373	92.851%	328.22	-0.632%	-2.2340568
92.839%	342.32	0.77%	2.722	96.768%	342.07	-0.357%	-1.2619593
99.204%	350.68	0.291%	1.029	99.173%	350.57	-0.184%	-0.6504216
100%	353.49	0.126%	0.4453974	99.983%	353.43	-0.126%	-0.4453974

The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

Where C= chord length.

Table 3.4 –Station points for the aerofoil of chord length 298.532mm

X=x/100*298.532		Y=y/100*298.532		X=x/100*298.532		(-Y)=y/100*298.532	
0.124%	0.37018	0.8%	2.388256	0.279%	0.832904	-0.76%	-2.26884
1.588%	4.740688	2.414%	7.206562	2.015%	6.01542	-2.062%	-6.15573
4.642%	13.85786	3.991%	11.91441	5.266%	15.7207	-3.062%	-9.14105
9.199%	27.46196	5.432%	16.21626	9.898%	29.5487	-3.75%	-11.195
15.115%	45.12311	6.625%	19.77775	15.776%	47.09641	-4.133%	-12.3383
22.197%	66.26515	7.467%	22.29138	22.71%	67.79662	-4.237%	-12.6488
30.201%	90.15965	7.883%	23.53328	30.491%	91.02539	-4.116%	-12.2876
38.854%	115.9916	7.841%	23.40789	38.887%	116.0901	-3.844%	-11.4756
47.8%	142.6983	7.396%	22.07943	47.706%	142.4177	-3.463%	-10.3382
56.796%	169.5542	6.668%	19.90611	56.617%	169.0199	-2.978%	-8.89028
65.561%	195.7206	5.73%	17.10588	65.33%	195.031	-2.45%	-7.31403
73.811%	220.3495	4.662%	13.91756	73.564%	219.6121	-1.923%	-5.74077
81.282%	242.6528	3.547%	10.58893	81.054%	241.9721	-1.431%	-4.27199
87.738%	261.926	2.472%	7.379711	87.554%	261.3767	-0.995%	-2.97039
92.978%	277.5691	1.52%	4.537686	92.851%	277.1899	-0.632%	-1.88672
96.839%	289.0954	0.77%	2.298696	96.768%	288.8834	-0.357%	-1.06576
99.204%	296.1557	0.291%	0.868728	99.173%	296.0631	-0.184%	-0.5493
100%	298.532	0.126%	0.37615	99.983%	298.4812	-0.126%	-0.37615

The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

Where C= chord length.

Table 3.5 –Station points for aerofoil of chord length 171.457

X=x/100*171.457		Y=y/100*171.457		X=x/100*171.457		(-Y) =y/100*171.457	
0.124%	0.212607	0.8%	1.371656	0.279%	0.478365	-0.76%	-1.30307
1.588%	2.722737	2.414%	4.138972	2.015%	3.454859	-2.062%	-3.53544
4.642%	7.959034	3.991%	6.842849	5.266%	9.028926	-3.062%	-5.25001
9.199%	15.77233	5.432%	9.313544	9.898%	16.97081	-3.75%	-6.42964
15.115%	25.91573	6.625%	11.35903	15.776%	27.04906	-4.133%	-7.08632
22.197%	38.05831	7.467%	12.80269	22.71%	38.93788	-4.237%	-7.26463
30.201%	51.78173	7.883%	13.51596	30.491%	52.27895	-4.116%	-7.05717
38.854%	66.6179	7.841%	13.44394	38.887%	66.67448	-3.844%	-6.59081
47.8%	81.95645	7.396%	12.68096	47.706%	81.79528	-3.463%	-5.93756
56.796%	97.38072	6.668%	11.43275	56.617%	97.07381	-2.978%	-5.10599
65.561%	112.4089	5.73%	9.824486	65.33%	112.0129	-2.45%	-4.2007
73.811%	126.5541	4.662%	7.993325	73.564%	126.1306	-1.923%	-3.29712
81.282%	139.3637	3.547%	6.08158	81.054%	138.9728	-1.431%	-2.45355
87.738%	150.4329	2.472%	4.238417	87.554%	150.1175	-0.995%	-1.706
92.978%	159.4173	1.52%	2.606146	92.851%	159.1995	-0.632%	-1.08361
96.839%	166.0372	0.77%	1.320219	96.768%	165.9155	-0.357%	-0.6121
99.204%	170.0922	0.291%	0.49894	99.173%	170.0391	-0.184%	-0.31548
100%	171.457	0.126%	0.216036	99.983%	171.4279	-0.126%	-0.21604

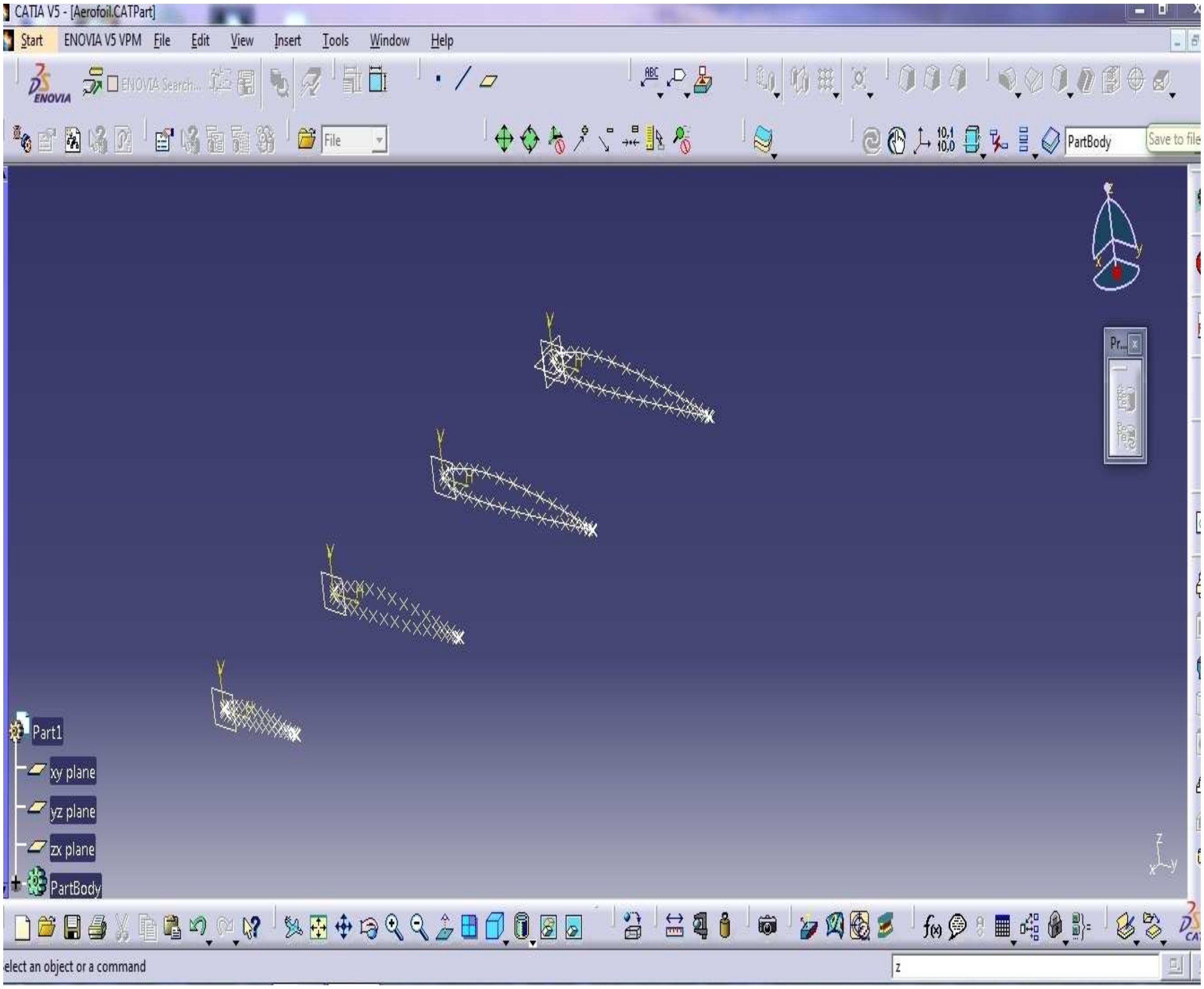
The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

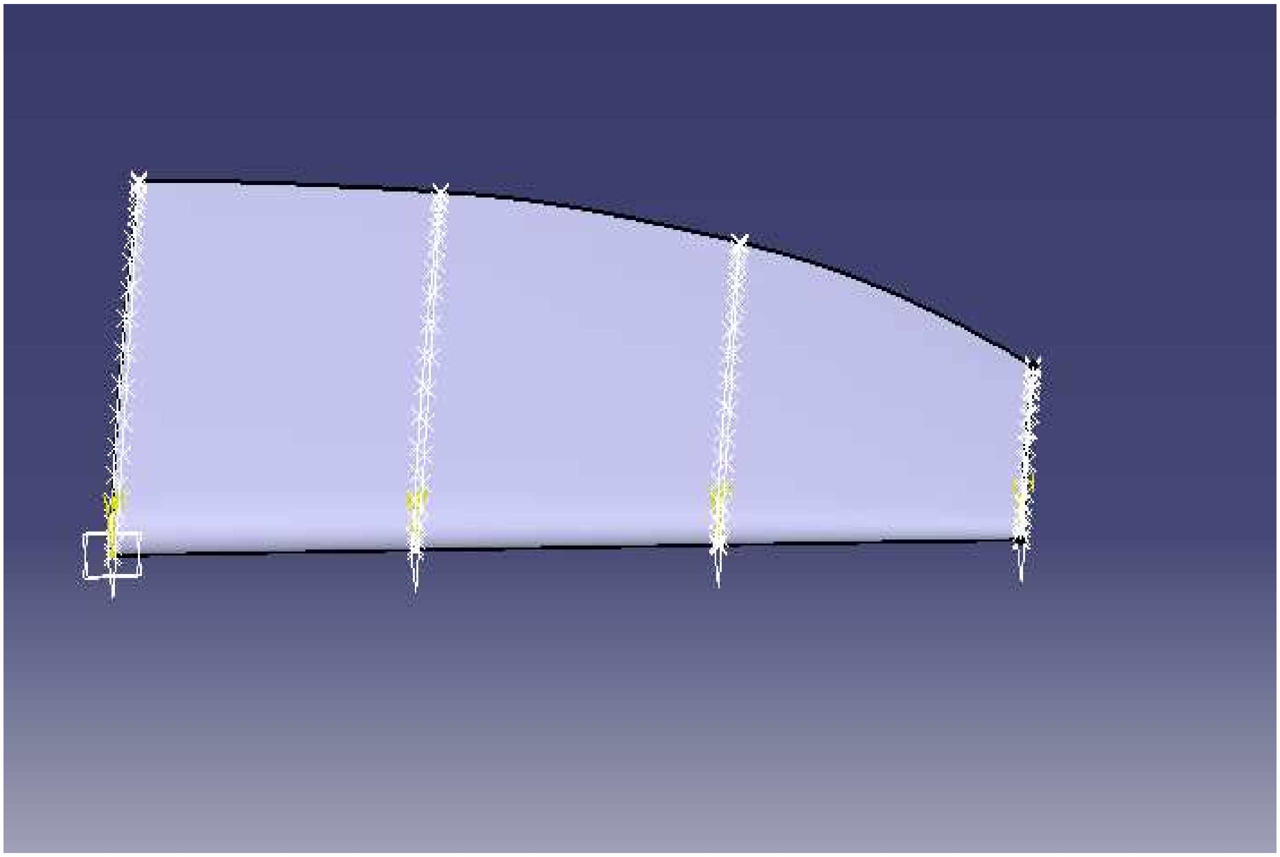
Where C= chord length.

Therefore all the Four Airfoils are designed with their station points and are joined together to form a wing.



Screenshot 3.3 Four Airfoils of the Elliptical wing

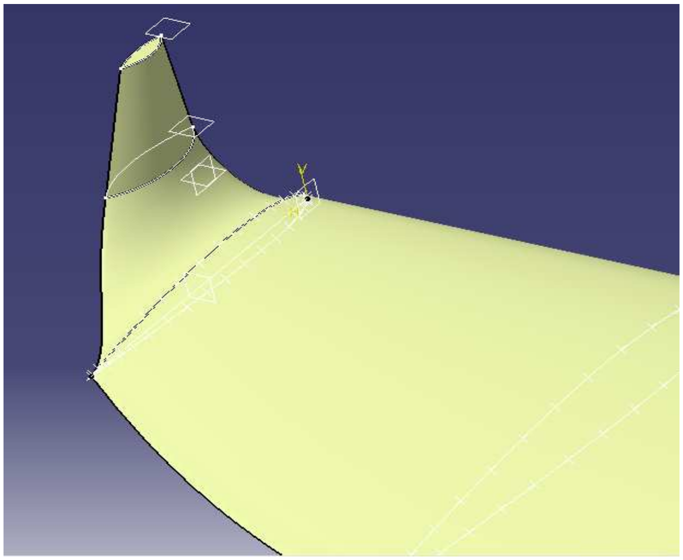
After plotting the points for all the four different chord length airfoils in the CATIA V5 software the airfoils are joined by the tool “Multi-section solid”. The below screenshot (2.4) shows the total structure of the elliptical wing.



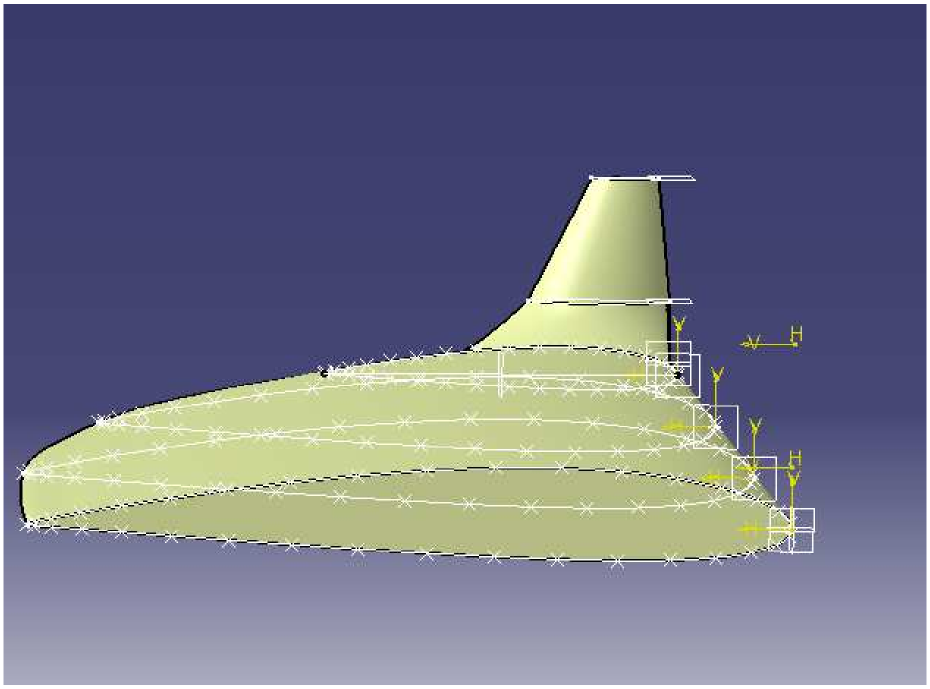
Screenshot 3.4 The designed Elliptical wing

3.4 WINGLET FOR ELLIPTICAL WING

Now the winglet is designed with the given geometry on the wingtip of the elliptical wing in the “Wireframe and Surface design” tool of the CATIA Software.



Screenshot 3.5: WINGLET



Screenshot 3.6: Winglet on elliptical wing

3.5 SHORT WING

The Geometrical characteristics of the short wing are listed in the following tables (Table 3.6 and table 3.7).

Table 3.6 –Station Points for aerofoil for short wing of chord length 370mm

X=x/100*370		Y=y/100*370		X=x/100*370		(- Y)=y/100*370	
0.124	0.4588	0.8	2.96	0.279	1.0323	-0.76	-2.812
1.588	5.8756	2.414	8.9318	2.015	7.4555	-2.062	-7.6294
4.642	17.1754	3.991	14.7667	5.266	19.4842	-3.062	-11.3294
9.199	34.0363	5.432	20.0984	9.898	36.6226	-3.75	-13.875
15.115	55.9255	6.625	24.5125	15.776	58.3712	-4.133	-15.2921
22.197	82.1289	7.467	27.6279	22.71	84.027	-4.237	-15.6769
30.201	111.7437	7.883	29.1671	30.491	112.8167	-4.116	-15.2292
38.854	143.7598	7.841	29.0117	38.887	143.8819	-3.844	-14.2228
47.8	176.86	7.396	27.3652	47.706	176.5122	-3.463	-12.8131
56.796	210.1452	6.668	24.6716	56.617	209.4829	-2.978	-11.0186
65.561	242.5757	5.73	21.201	65.33	241.721	-2.45	-9.065
73.811	273.1007	4.662	17.2494	73.564	272.1868	-1.923	-7.1151
81.282	300.7434	3.547	13.1239	81.054	299.8998	-1.431	-5.2947
87.738	324.6306	2.472	9.1464	87.554	323.9498	-0.995	-3.6815
92.978	344.0186	1.52	5.624	92.851	343.5487	-0.632	-2.3384
96.839	358.3043	0.77	2.849	96.768	358.0416	-0.357	-1.3209
99.204	367.0548	0.291	1.0767	99.173	366.9401	-0.184	-0.6808
100	370	0.126	0.4662	99.983	369.9371	-0.126	-0.4662

The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

Where C= chord length.

Table3.7 –Points for the aerofoil for short wing of chord length 233mm

X=x/100*233		Y=y/100*233		X=x/100*233		(-Y)=y/100*233	
0.124	0.28892	0.8	1.864	0.279	0.65007	-0.76	-1.7708
1.588	3.70004	2.414	5.62462	2.015	4.69495	-2.062	-4.80446
4.642	10.81586	3.991	9.29903	5.266	12.26978	-3.062	-7.13446
9.199	21.43367	5.432	12.65656	9.898	23.06234	-3.75	-8.7375
15.115	35.21795	6.625	15.43625	15.776	36.75808	-4.133	-9.62989
22.197	51.71901	7.467	17.39811	22.71	52.9143	-4.237	-9.87221
30.201	70.36833	7.883	18.36739	30.491	71.04403	-4.116	-9.59028
38.854	90.52982	7.841	18.26953	38.887	90.60671	-3.844	-8.95652
47.8	111.374	7.396	17.23268	47.706	111.155	-3.463	-8.06879
56.796	132.3347	6.668	15.53644	56.617	131.9176	-2.978	-6.93874
65.561	152.7571	5.73	13.3509	65.33	152.2189	-2.45	-5.7085
73.811	171.9796	4.662	10.86246	73.564	171.4041	-1.923	-4.48059
81.282	189.3871	3.547	8.26451	81.054	188.8558	-1.431	-3.33423
87.738	204.4295	2.472	5.75976	87.554	204.0008	-0.995	-2.31835
92.978	216.6387	1.52	3.5416	92.851	216.3428	-0.632	-1.47256
96.839	225.6349	0.77	1.7941	96.768	225.4694	-0.357	-0.83181
99.204	231.1453	0.291	0.67803	99.173	231.0731	-0.184	-0.42872
100	233	0.126	0.29358	99.983	232.9604	-0.126	-0.29358

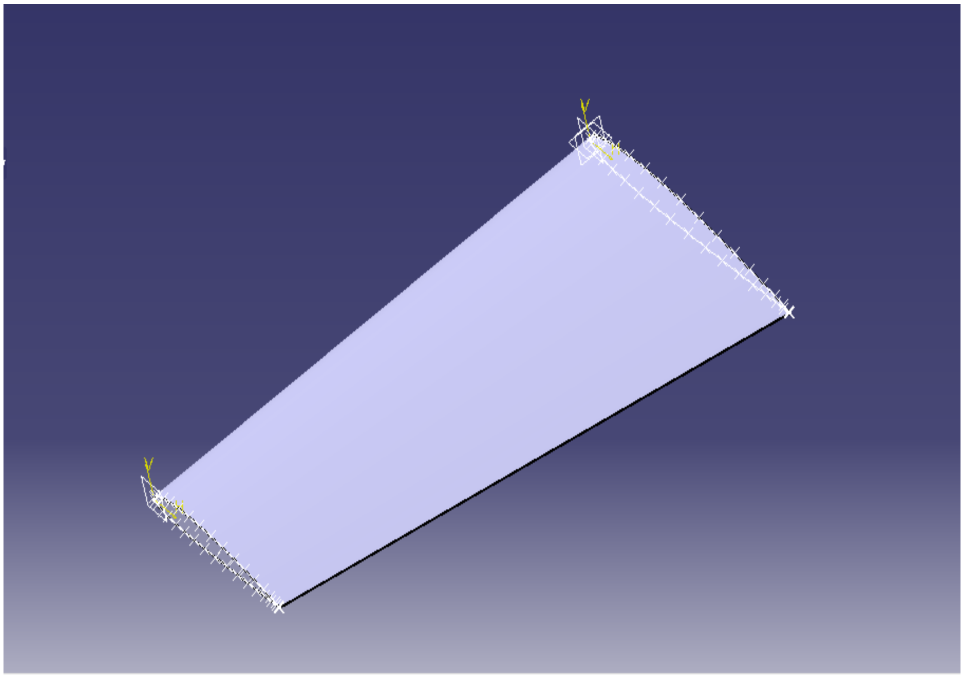
The Station points are calculated as,

For x-coordinate $x = \frac{x\%}{100} * C$

For y-coordinate $y = \frac{y\%}{100} * C$

Where C= chord length.

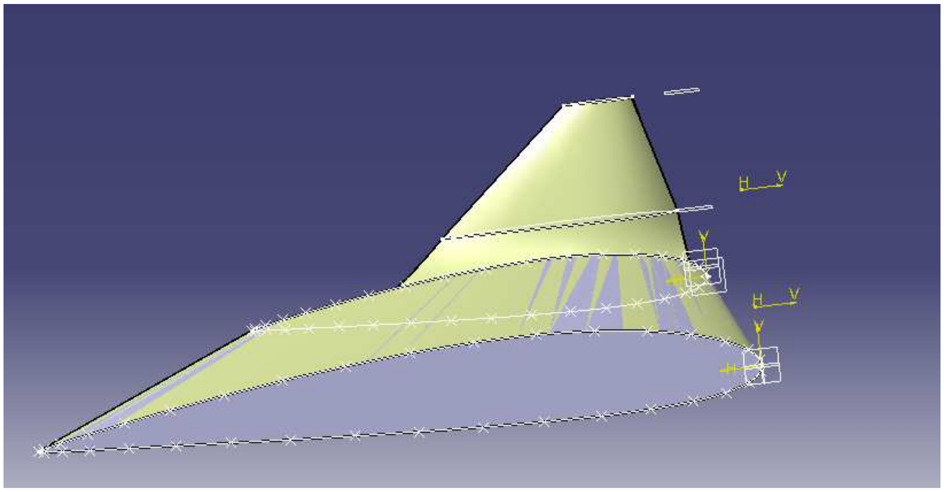
Thus, the root chord and the tip chord with their station points are designed and are joined together to form the Short wing.



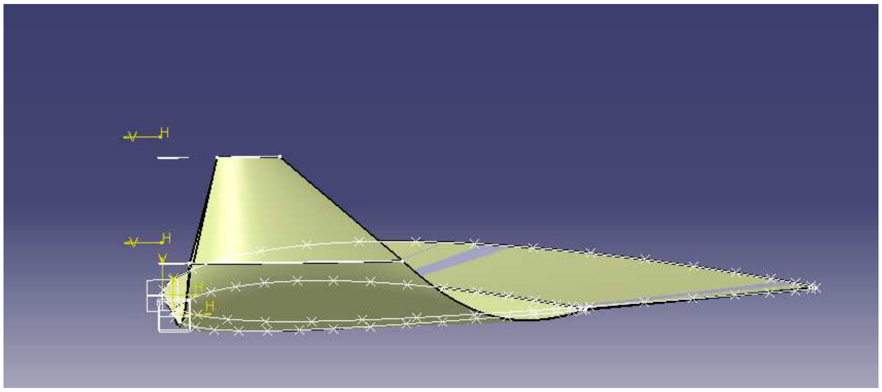
Screenshot 3.7: The Designed Short wing

3.6 WINGLET FOR SHORT WING

After designing the Short wing, the winglet is designed as for it similar to that of the previous one designed for the elliptical wing.



Screenshot 3.8: Winglet- Short wing



Screenshot 3.9: Winglet on Short wing

4. Analysis of the Experiment

The Analysis is carried out in the FOTRAN and STRUCTURAL analysis method of the ANSYS software and the flow and Structure analysis will be done on the elliptical wing and short wing with and without winglet. The analysis is done by measuring and comparing various aerodynamics characteristics which include drag coefficient CD, lift coefficient CL, and lift-to-drag ratio L/D. The Analysis Part of this dissertation is carried on in the Final Main Project.

5. Conclusion

This project proposes alternatives in the design of winglet from the conventional designs. An improved winglet design will significantly yield a better performance of an aircraft and reduce the fuel consumption. Despite the benefits of winglets, there are some drawbacks that need to be addressed. For example, the bending moment at the wing root is higher, and may require additional structural reinforcement of the wing. Winglets although can produce a low drag wing, they add to the cost and complexity of construction. They also modify the handling and stability characteristics. The viscous drag of the winglet can be too big, nullifying the reduction of the induced drag. Winglets have to be carefully designed so that these and other problems can be overcome.

Hence analysis is done and different aerodynamics characteristics are measured and compared for implementing a winglet on the wing, thus giving a better aspect of reducing the induced drag and increasing the performance of the aircraft with better efficiency.

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