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Design and Analysis of Flying Wing UAV using XFLR5

Sai Vinay Sandapeta, Sai Kiran Parre, Yakkaluru Dedeepya, Habeeb Jaffar al Aidroos, Mariyada Vamshi Krishna Reddy

***Abstract*— This paper presents the design and analysis of flying wing UAV. The design and analysis was performed using XFLR5 code (an interactive program for the design and analysis of subsonic UAVs), where the Mathematical Modeling with efficient numerical method i.e. Vortex Lattice Method (VLM1) through XFLR5 results of Flying Wing UAV of the airfoil MH 60 10.08% (Martin Hepperle MH 60 for flying wings Max thickness 10.1% at 26.9% chord & Max camber 1.7% at 36.6% chord) is discussed.**

Keywords— ***flying wing UAV, Tailless aircraft, Body-less model aircraft, Aerodynamic Design Static Stability, longitudinal stability, lateral stability.***

Sai *Vinay Sandapeta (UG Student)*
Department of Aeronautical Engineering,
Institute of Aeronautical Engineering, Hyderabad, India

Sai *Kiran Parre (UG Student)*
Department of Aeronautical Engineering,
Institute of Aeronautical Engineering, Hyderabad, India

Yakkaluru Dedeepya (UG Student)
Department of Aeronautical Engineering
Institute of Aeronautical Engineering, Hyderabad, India

Habeeb Jaffar al Aidroos (UG Student)
Department of Aeronautical Engineering
Institute of Aeronautical Engineering, Hyderabad, India

I. Introduction

The importance of UAV in operations and the unprecedented variety deployed today is growing. The UAVs can be used both for military , civilian and Commercial purposes such as science & Research (Forest and Natural Resources Management , Studying Biodiversity , Measuring nuclear contamination , climate observation , Meteorological Research) , Security (Anti-Terror Operations , Criminal Investigation , Traffic Surveillance , Searching for missing persons , Emergency communication networks , Anti – privacy operations , Monitoring International summit meetings) , Inspections (Oil, Gas & Methane pipelines, Solar panel , power line / cable , cooling tower ,Bridge , Dams) , cargo delivery application, construction applications and surveying applications. These Indications are that there is a growing market for this type of aircraft.

So next-generation UAVs will require low-cost and efficient configurations. Many of existing UAV use conventional (i.e.: low/mid/high-wing, fuselage tail and tractor engine) and unconventional (i.e.: flying wing, three surfaces, low/mid/high-wing, high aspect ratio wing, fuselage tail/canards/inverted V-tail and pusher engine) configurations. The design of low-cost and efficient configurations of UAV becomes increasingly more important for improving the performances, flight characteristics, handling qualities and UAV operations. Most of small UAV fly at low Reynolds number, this allow to uses fuselage-wing-tail with laminar flow technology, to improve its cruise performance. Therefore, the understanding of and ability to design and analyze those configuration and technology for UAV is a problem that must be solved in order to allow the UAV designer to develop a UAV which satisfy the prescribe design requirements and objectives.

However, the presence of unconventional configuration and laminar flow technology seriously complicates design and analysis procedures because of important and often complex interaction between the individual elements of UAV often present very different and distinct challenges. Here in this paper, we have flying wing configuration where ***the wing is everything***. It does not have a conventional tube type fuselage for payload. All structure, engine and payload are fixed inside the wing. The design and analysis of it done through VLM1 Mathematical Modeling by XFLR5.

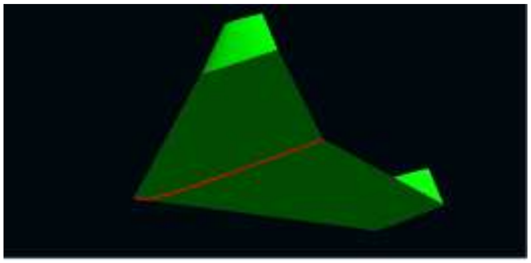

Fig 1: Flying wing designed in XFLR5

II. Airfoil Selection and analysis

Conventional cambered airfoils produce a negative pitching moment (Cm), nose-down effect, on the airfoil. This is counteracted through the empennage by the horizontal stabilizers. In a flying wing type aircraft, careful selection of the airfoils is essential, since Cm strongly contributes to the aerodynamic longitudinal stability of the aircraft

The Cm is measured around the aerodynamic centre (A.C.). With no tail for longitudinal stability, the airfoils selected should have low or zero Cm. Instead of using a symmetric airfoil, which has zero Cm at zero α, a suitable solution is to choose a reflex airfoil. It can be seen that swept wing have Reflex airfoil with small twist which can produce zero pitching moment. We can estimate amount of Reflex required to have negative pitching moment [1].

It can be observed that influence of location camber on Reflex airfoil's moment coefficient, where at X/c=20% -40% we have low moment coefficient at same Angle Of Attack (According to Reference I). On this basis, we can select the best results predicating Reflex airfoil (i.e.; Max thickness 10.1% at 26.9% chord & Max camber 1.7% at 36.6% chord) from below surveyed airfoils.

The following Reflex airfoils were surveyed which had widely used.

MH 60, t/c = 10.08%
MH 61, t/c = 10.28%
MH 62, t/c = 9.30%
MH 64, t/c = 8.61%
MH 44, t/c = 9.66%
MH 45, t/c = 9.85%
MH 46, t/c = 11.39%
MH 49, t/c = 10.50%

In these paper, it had been selected MH 60 t/c=10.08% due to its characteristics where this is compatible for stable flying wing design which can be observed from the following airfoil analysis results at range of Re=1,50,000 to 2,50,000.

Characteristics: **Table 1:** Characteristics of MH 60 t/c=10.08% airfoil

Thickness	10.12%
Low moment coefficient	$C_{m\frac{c}{4}} = +0.0140$
Re	≥1,50,000

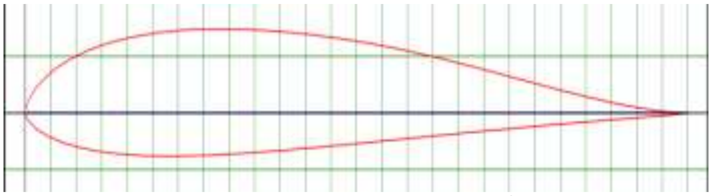

Fig 2 : MH 60 t/c=10.08% Airfoil

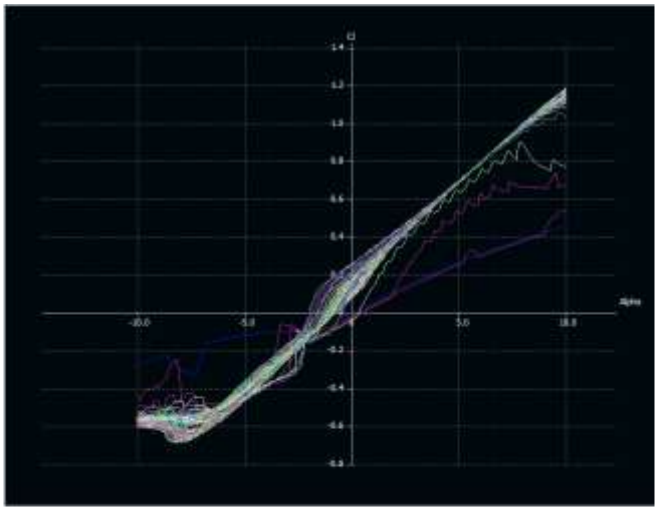

Fig 3 : Cl vs. Alpha Plot

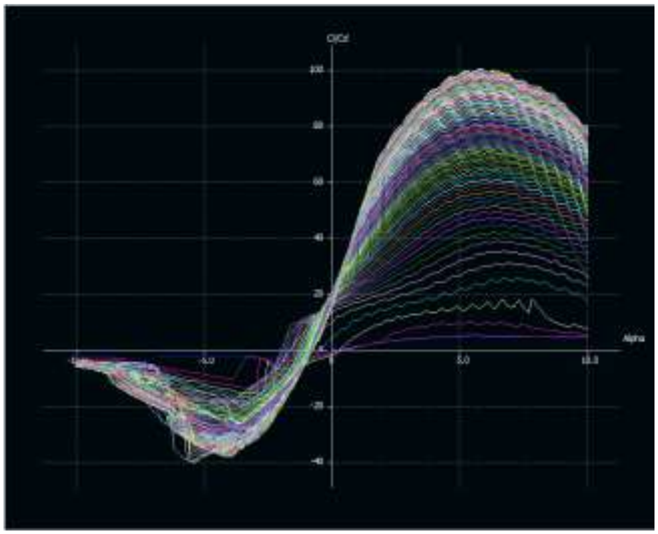

Fig 4 : Cl/Cd vs. Alpha Plot

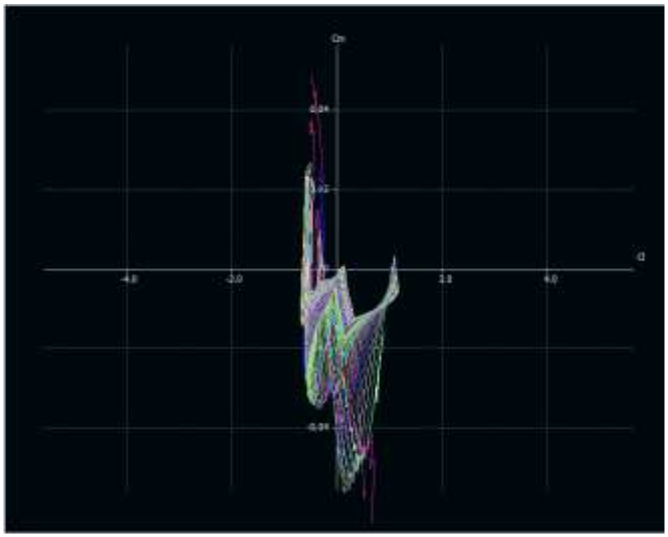

Fig 5 : Cm vs. Cl Plot

Mariyada Vamshi Krishna Reddy (UG Student)
Department of Aeronautical Engineering
Institute of Aeronautical Engineering, Hyderabad, India

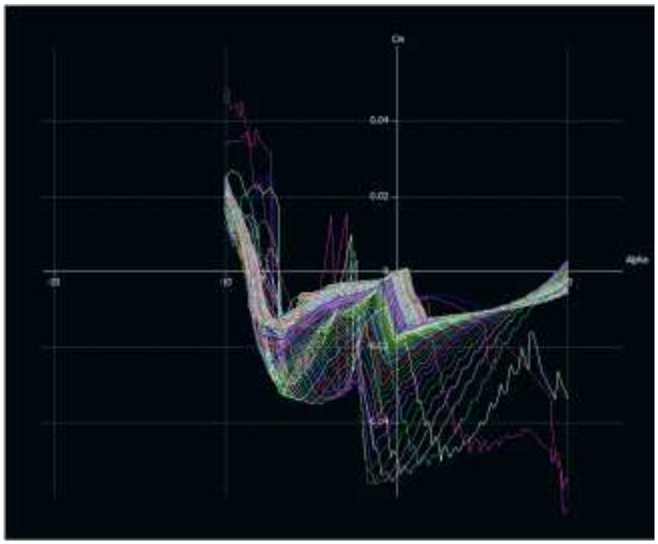

Fig 6 : Cm vs. Alpha Plot

III. Flying Wing Design and Analysis

XFLR5 is software that enables 2D and 3D aerodynamic analysis of bodies and bearing areas, separately or jointly. The software makes analysis for small Reynolds numbers. The latest version has implemented five applications: a direct 2D analysis and design, a 3D analysis and design (airfoil & wing), two ways to design and compare 2D, design a 2D QDES and MDES. According to XFLR5 manual (Guidelines for XFLR5, 2011), the steps should be taken into account when developing polar diagrams appropriate to the input data.

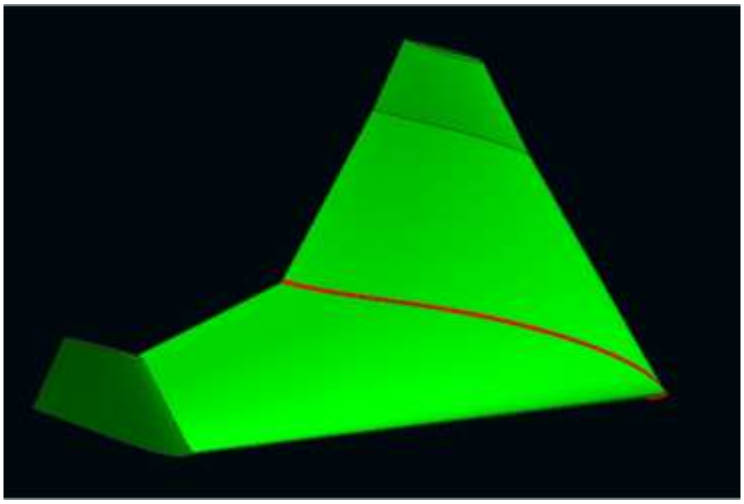

Fig 7 : Orthogonal View

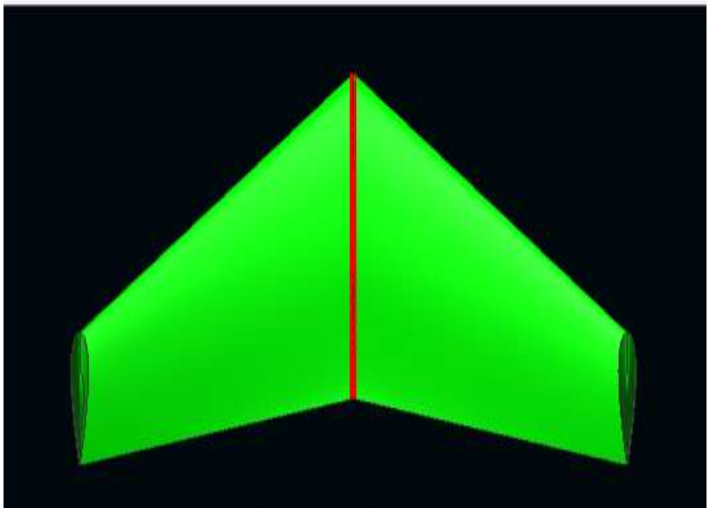

Fig 8 : Top View

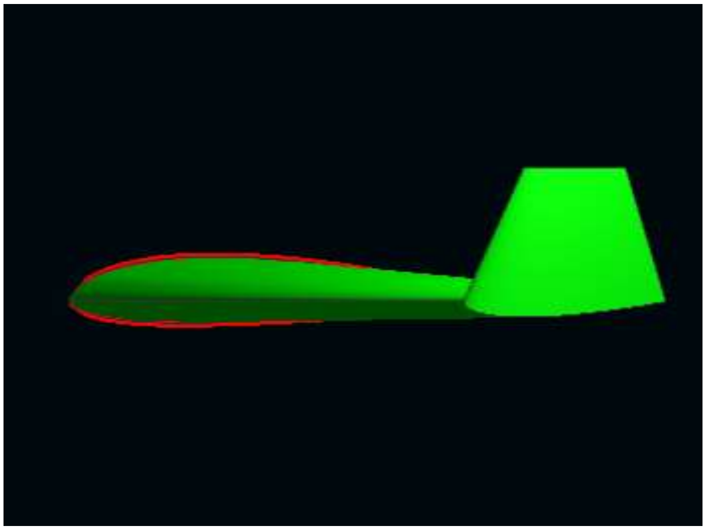

Fig 9 : Side View

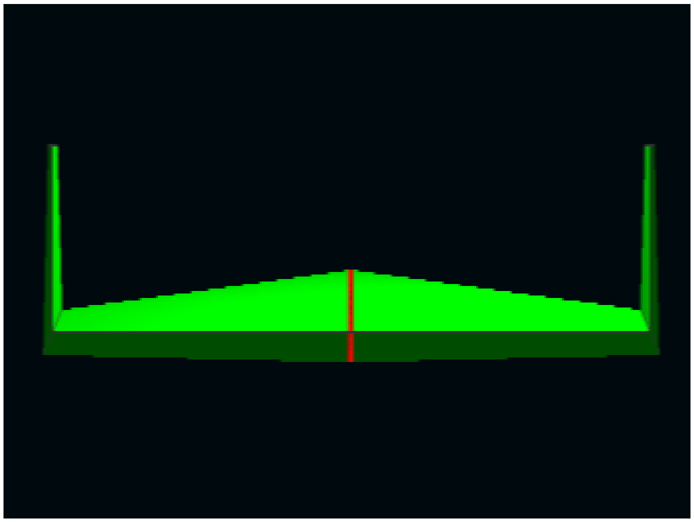

Fig 10 : Front View (-X direction)

Table 2 : Flying Wing UAV Data

Span	1900mm
Root chord	980mm
Mean Geometric chord	607.89mm
Mean aerodynamic chord	687.04mm
Aspect ratio	3.126
Swept angle	36.58 degrees
Mass	1.420kg
Surface Area	1.155
Wing loading	1.372kg/m^2

Table 3 : Atmospheric Data

Density	1.225 kg/m^3
Viscosity	1.5e-05

On simulating using VLM at fixed speed about 15 m/s on the following flying wing, XLFR5 software gave the following results as follows:

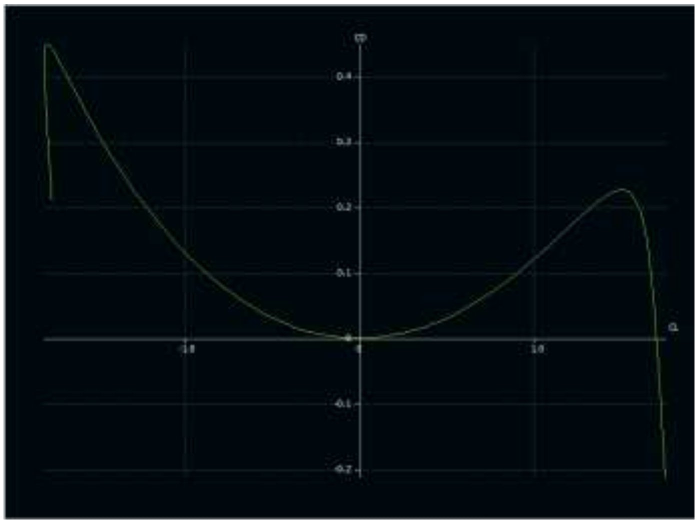

Fig 11 : Cd vs. Cl Plot

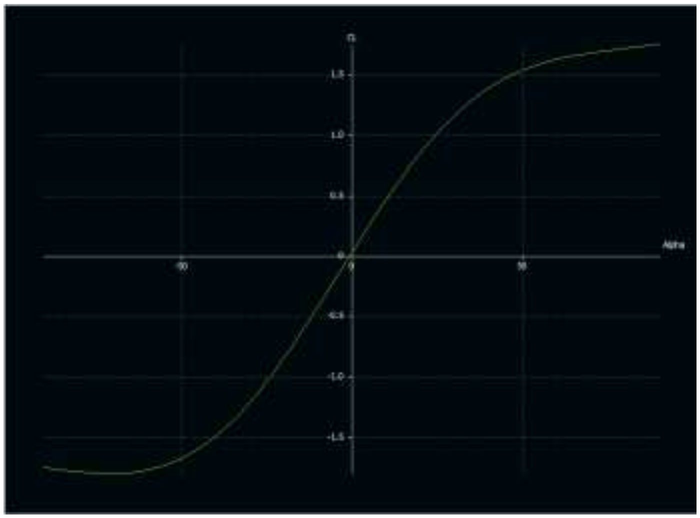

Fig 12 : Cl vs. Alpha Plot

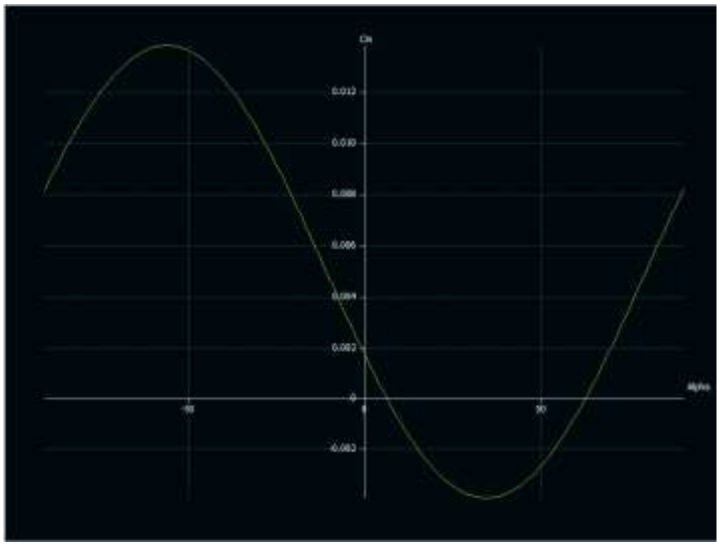

Fig 13 : Cm vs. Alpha Plot

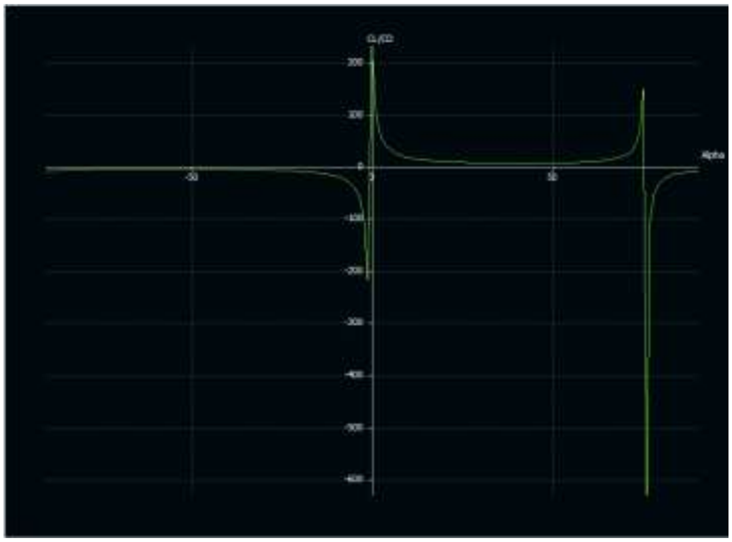

Fig 14 : Cl/Cd vs. Alpha Plot

IV. Static Stability

After analyzing the results (Fig 4.1.a, 4.1.b, 4.1.c, 4.1.d, 4.1.e) we can say that flying wing has static stability (through guideline of XFLR5)

$dC_m/d\alpha < 0$ as per Fig 5.a [Source: Guidelines for XFLR5], we denotes that the following flying wing has static stability.

At $\alpha = 0.00$ degrees, the following XFLR5 analysis report:

X_{NP}=1109.237mm & X_{CG}=744.084mm, which are obtained from Fig 5.b discusses about analysis done with XFLR5.

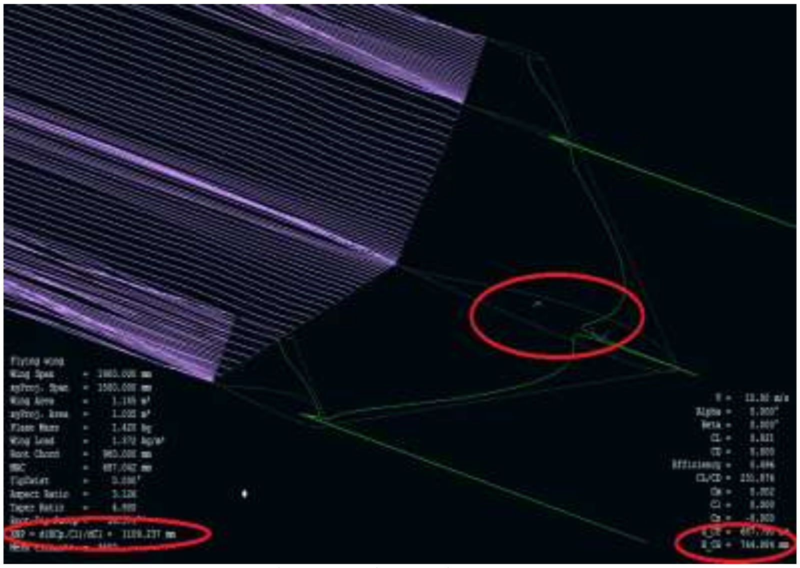

Fig 15 : Static Margin

$X_{NP} > X_{CG}$, which is satisfied as per Fig 5.c [8]. So, the flying wing designed using XFLR5 has stable configuration since neutral point position is behind the centre of gravity position.

V. Boundary Conditions (BC)

In a VLM calculation, the BC are necessarily of the Neumann type, i.e. the velocity's component normal to the surface must be zero. In a 3D-Panel calculation, the BC may be either of the Neumann or Dirichlet type. In the latter case the velocity's potential on the panel's inside surface is zero, so that the total potential inside the body is equal to the free stream velocity's potential. After a trial and error process, the Dirichlet BC have been preferred to the Neumann BC. The latter method is more sensitive to local geometry changes, and leads to less convincing results.

The conventional static margin of a wing or a plane may be determined by an iterative process. It is the CG position (or moment reference position X_{CmRef}) for which

$$dC_{m'}/ dx < 0$$

Here is the flow diagram (Fig6.4 [Source: Guidelines of XFLR5]) for the following analysis done in XFLR5 for flying wing:

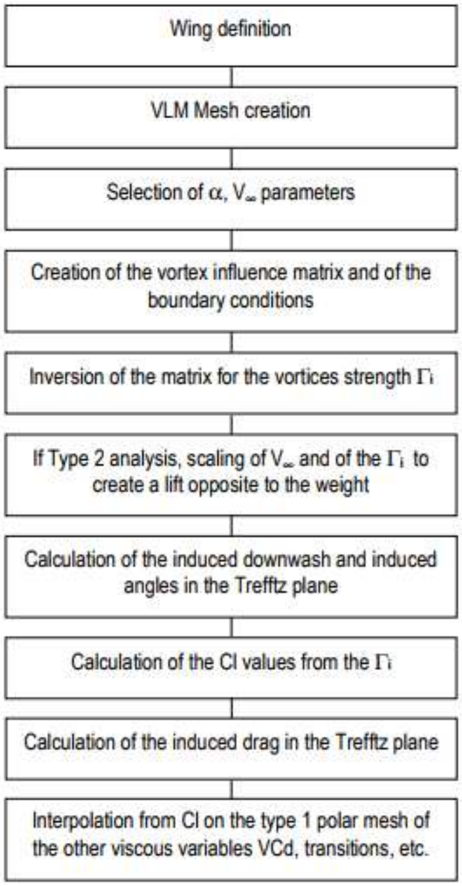

Fig 16 : Flow diagram of VLM

Vortex Lattice Method 1 –VLM1
Launching the 3D Panel Analysis....
Flying wing
Type 1 - Fixed speed polar

Wings as thin surfaces
Using horseshoe vortices- VLM1
Using Neumann boundary conditions for wings

Density = 1.225kg/m3
Viscosity = 1.5e-5m²/s

Reference Area = 1.155m²
Reference length = 1.9m

Counted 3600 panel elements

Mass= 1.420 kg

Center of Gravity Position - Body axis
CG_x= 0.7441 m

CG_y= 0.0000 m
CG_z= 0.0101 m

Inertia - Body Axis - CG Origin
I_{xx}= 0.1478 kg.m²
I_{yy}= 0.1435 kg.m²
I_{zz}= 0.2904 kg.m²
I_{xz}= -0.001679 kg.m²

```
Solving the problem...
Creating the influence matrix...
Creating the unit RHS vectors...
Performing LU Matrix decomposition...
Solving the LU system...
Creating source strengths...
Calculating doublet strength...
Calculating aerodynamic coefficients in the far field plane
Calculating point  -90.00°....
 So on up to
 Calculating point  90.00°....

 Computing On-Body Speeds...
 Computing Plane for alpha= -90.00°
 Calculating aerodynamic coefficients...
 Calculating wing...Main Wing
So on up to
 Computing Plane for alpha= 90.00°
 Calculating aerodynamic coefficients...
 Calculating wing...Main Wing

Panel Analysis completed successfully
```

VI. Dynamic Stability

(a) Longitudinal stability

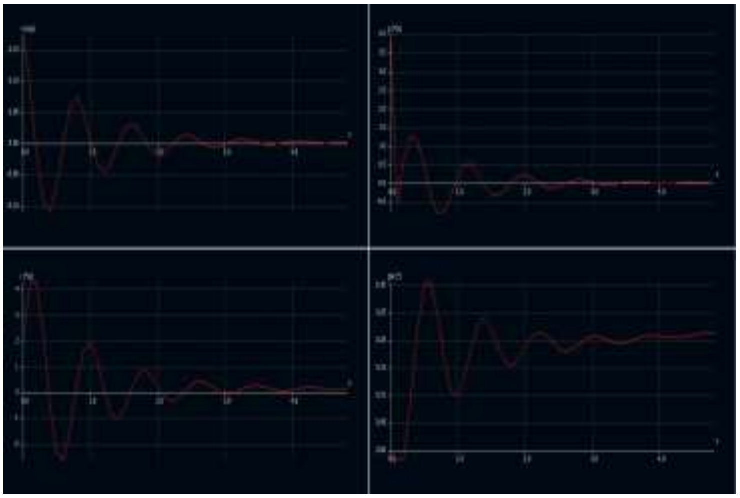

Fig 17 : Damping Longitudinal Stability Plot

(b) Lateral stability

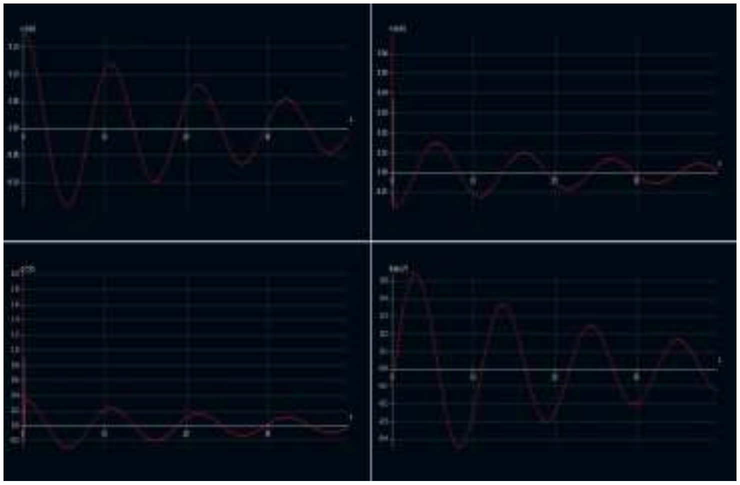

Fig 18 : Damping Lateral Stability

The observation from resultant plots from dynamic stability analysis, the graphs are damping.

VII. Conclusion

The design of an aircraft is not an easy process, it is complicated process. It does not mean whether it is manned or unmanned, regular or micro or Nano; they have their own complexity. Flying wing has been heard from decades, which is recently has rise in fabrication. It was shown that there are many trade-offs when designing the wing plan form. When one aspect of the design is increased or optimized then at least one, most likely multiple, aspects or parameters will be decreased. Many important factors were left out such as materials, structures, and the propulsion unit enough the aerodynamic modeling was briefly described, however a detailed analysis of the aerodynamics and thrust forces and moments need to be conducted in order to create the needed complex flight control system. This paper helps to know the stability of flying wing with following analysis wing platform. As more aircraft of this design are developed, the aerodynamic performance will become greater and a detailed design layout will become just as generalized as a conventional tube and wing aircraft.

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