Static Stability Analysis on Twin Tail Boom UAV Using Numerical Method

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Abstract. The development of Unmanned Aerial Vehicle (UAV) technology in both developing and developing countries is accelerating. In particular, UAV technology innovation for maritime affairs. The Aviation Technology Center has developed several UAVs used for the Maritime Surveillance System (MSS), which are marine surveillance and operations systems based on the use of UAV technology. Until now, several UAV variants have been developed, one of which is being developed is the LSU 05-NG. The main target of the design of the LSU 05-NG is to get a UAV as a lightweight utility platform and can operate in the marine environment and near the sea. Therefore it is necessary to do a static and dynamic analysis to determine the performance of the LSU 05-NG flight. In this paper using the numerical method VLM, CFD and DATCOM to analyze the aerodynamic characteristics of LSU 05-NG. Based on the results of the analysis of the values of C_L, C_D, C_M, C_n,and C_l, it can be concluded that LSU 05-NG has static stability. Because the values $C_{M_\alpha} < 0, C_{l_\beta} < 0$ and $C_{n_\beta} > 0$.

INTRODUCTION

The development of drones in Indonesia has attracted many parties to continue innovate. Not only in Indonesia, but also the developed countries developing UAVs. However, the comparison of the development of UAV technology in developed countries with Indonesia is quite significant. In Indonesia, the development of existing UAVs still has significant limitations in terms of flight range, endurance and payload carried for missions. Meanwhile, the development of UAVs has been widely applied to date. Currently UAV (Unmanned Aerial Vehicle) or Drone aircraft have been used in various applications such as the military industry, commercial cargo transportation, and mapping [1]. In addition, UAVs are often used in various rescue and disaster mitigation missions such as volcanic eruptions, floods, landslides, and earthquakes. UAV are also an important data source for inspection, surveillance, land mapping and 3D modeling issues [2].

Pusat Teknologi Penerbangan-LAPAN has developed several UAV variants for application to the Maritime Surveillance System program. One of the UAVs being developed is LAPAN Surveillance UAV 05-New Generation (LSU 05-NG). The LSU 05-NG is a twin tail boom type drone. Two booms connecting the tail to the wings. The main goal of the design of the LSU 05-NG is to get the UAV as a lightweight utility platform that can operate in marine and near sea environments. LSU 05-NG has the main mission, which is to support aerial photography activities by carrying loads in the form of optical devices. In the future this aircraft will also be used as a scientific platform to test satellite-based communication systems developed by LAPAN and can also be used for border surveillance. With this

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mission, the LSU-05 NG must have stability in order to carry out the mission well. Therefore, it is necessary to do research on stability analysis both dynamic and static.

The value of C_m, C_L, C_l, C_n, and C_Y as static stability parameters will show whether the UAV design satisfies a good static stability or needs an improvement. For an object having more difficult geometry, the use of analytical method for solving the fundamental equations of fluid dynamics is not only ineffective but also impractical[3]. Experimentally it also requires a large amount of money. In this case the numerical method is chosen instead. There are many software that could perform stability analysis such as XFLR, DATCOM, and ANSYS CFX. Research related to static stability in UAVs has been carried out[3]. The research conducted shows that the tandem wing UAV has static stability using CFD.

In this study, a study was conducted on the aerodynamic characteristics of the Twin Tail Boom UAV with variations in angle of attack (α) and side angle (β) with several numerical methods. In addition to knowing the stability character, the analysis uses several numerical methods to make sure the results obtained are correct. So that the LSU 05-NG can carry out the mission well.

BASIC THEORY

In this study, an analysis of the aerodynamic characteristics of the LSU 05-NG aircraft was analyzed. Research on the analysis of aerodynamic characteristics has been carried out before [4] from American Institute of Aeronautics and Astronautics (AIAA) do research about the method of estimating the aerodynamic coefficient of UAS-S4 Ethical aircraft uses DATCOM and VLM. Aerodynamic analysis of the wing with various forms of wing configuration has also been carried out [5]. Based on existing research, this research will analyze the aerodynamic characteristics using the Vortex Lattice Method using XFLR5, Computational Fluid Dynamics (CFD) and DATCOM to determine the static stability of the LSU 05-NG. XFLR5 will do the simulation using lifting line theory and can only simulate a simpler geometry [6]. While Datcom refers to experimental data and interpolate them as the result[7].

The Force and Aerodynamic Moment

The phenomenon of flying objects is inseparable from the presence of air flow on the object to produce a force. This force is called the aerodynamic force. There are two types of force and moment components which are determined based on the direction of the force, namely the force with the object and the direction of the wind as shown in FIGURE 1

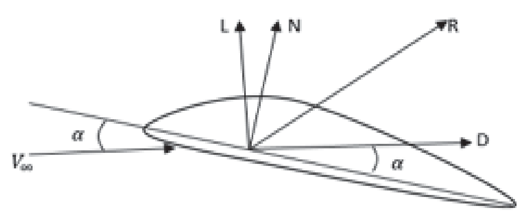

FIGURE 1. The resultant of force and its components

Based on FIGURE 1 can be defined that the lift (L) is the force that is perpendicular to the direction of the wind, while drag (D) is a force that is directed with the coming of the wind. The Normal force (N) is the force that is perpendicular to the chord line (c). While the axial force (A) is the same style as the chord line (c). So it can be defined that the angle of attack is the angle formed between the wind direction and the chord line or between the lift (L) with the normal force (N). Based on FIGURE 1, the mathematic model for L and D as follows:

$$L = N\cos(\alpha) - A\sin(\alpha) \tag{1}$$

$$D = N\sin(\alpha) + A\cos(\alpha) \tag{2}$$

In the discipline of aerodynamics there is dynamic pressure which is defined as follows:

$$q_\infty = \frac{1}{2}\rho_\infty V_\infty^2 \tag{3}$$

This dynamic pressure has the same units as $\frac{kg}{ms^2}$. Defined wing area (S), half the length of the wing (b) and the object's reference length is (l) then the coefficient of force and aerodynamic moment are defined as follows

$$\begin{array}{lll} C_L = \frac{L}{q_\infty S} & C_D = \frac{D}{q_\infty S} & C_M = \frac{M}{q_\infty S l} \\ C_n = \frac{N_A}{q_\infty S b} & C_l = \frac{L_A}{q_\infty S b} & C_Y = \frac{Y}{q_\infty S} \end{array} \tag{4}$$

Vortex Lattice Method

Vortex Lattice Method or VLM is a numerical method used to analyze fluid dynamics. The principle of using VLM is by modeling the surface of the plane to be infinite in number of votices to calculate lift curve slope, induced drag and force distribution on the surface. In terms of its use, the flowing fluid is assumed to be incompressible, inviscid and irrotational and the effect of thickness and viscosity of the flow is negligible.

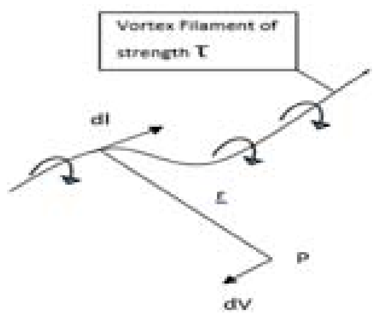

FIGURE 2. Vortex Filament Curve [8]

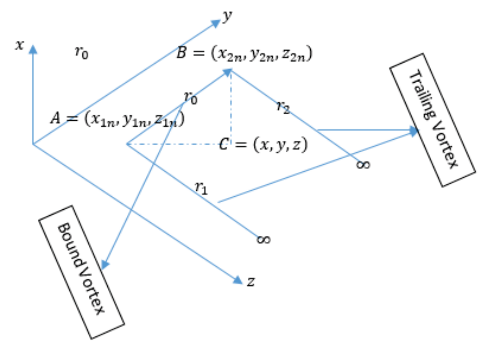

FIGURE 3. Implementation horseshoe vortex in XYZ

Incompressible and irrotational flows can be synthesized by adding a vortex filament [9]. The result of synthesis with the addition of a vortex filament, the incompressible and irrotational flow becomes the vortex ring. The flow field surrounding the line is induced by a vortex filament perpendicular to the radius (r). Based on FIGURE 2 and the definition above, Biot-Savart Law make a mathematical model as follows[10]:

$$V = \frac{\tau_n}{4\pi} \int \frac{dl \times r}{|r|^3} \tag{5}$$

where dl is infinite small partitions of filaments, r is the distance from point P to the point in the filament, τ is the power of the vortex and V is induced speed. Integral in Equation (5) describes the velocity induced in each vortex of a given length. The integral equation above has been solved[11]. The solution of Equation (5) as follows:

$$V = \frac{\tau_n}{4\pi} \frac{\vec{r_1} \times \vec{r_2}}{|\vec{r_1} \times \vec{r_2}|^2} \left[r_0 \cdot \left(\frac{\vec{r_1}}{|r_1|} - \frac{\vec{r_2}}{|r_2|} \right) \right] \tag{6}$$

According to Prandt'l lifting-line theory, vortex ring described as horseshoe vortex. This is done because the ring vortices can be transformed into four filamentous vortices which must be closed as illustrated in FIGURE 3[5]. Based on the formula for the distance between two points in the XYZ plane, it can be defined that the induced velocity is limited by the vortex filament as follows

$$V = V_{AB} + V_{A\infty} + V_{B\infty} \tag{7}$$

According to the Kutta-Joukovsky theorem a certain moving vortex with a velocity force bound in velocity flow V_∞ will produce lift[5], in other words

$$L = \rho_\infty V_\infty \tau \tag{8}$$

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a numerical simulation tool for analyzing and designing systems of fluid flow, heat transfer, and other fluid phenomena. In this study, CFD simulations are used to analyze the airflow that occurs in the aircraft area with the same actual flying conditions. Based on the results of the analysis, it is used to determine the static stability character of the aircraft. There are three important processes that are followed when using CFD as a numerical simulation, namely, preprocessing, solving and postprocessing[12]. To simulate the ANSYS software with CFX solver is used. The Governing Equation that is often used to represent fluid flow behavior is the Navier-Stokes equation [13]. For the incompressible flow assumption, the Navier-Stokes equation is expressed as:

$$\rho\left(\frac{\partial v}{\partial t} + (v\nabla)v\right) = \nabla p + \mu\nabla^2 v + \rho F \tag{9}$$

In this research to find a solution to Equation (9) using the Shear Stress Transport model provided by ANSYS-CFX. The Shear Stress Transport model works by solving a turbulence / frequency based model ($k-\omega$) in the wall and $k-\epsilon$ in the flow[14].

DATCOM

DATCOM is a form of approach for fast and economical estimation in calculating stability and control characteristics. Digital DATCOM can calculate static stability, highest lift, control device and dynamic derivative characteristics using a method[7]. Input parameters on DATCOM consist of FLTCON, OPTINS, SYNTHS, BODY, WGPLNF, HTPLNF, and VTPLNF. FLTCON defines flight conditions such as Mach number, altitude and angle of attack. OPTINS defines the corresponding reference parameters, SYNTHS (synthesis) is very important because it sets the location center of gravity all horizontal calculations are taken from the nose of the plane. All vertical calculations are taken from the reference line positioned at the center of the plane. BODY explained the plane body geometry data. WGPLNF defines related wing planforms, such as span, root chord and chord tip. Swept angle, twist angle, chord stat, and dihedral and airplane wing types. HTPLNF represents the horizontal tail which is described with the same variables on the wing planform, as well as VTPLNF which represents the vertical tail. The problem limitation is when the aircraft is in ideal conditions. The parameters used in this calculation are FLTCON, BODY, WGSCHR, WGSPLNF, SYNTHS, HTPLNF, and VTPLNF

Static Stability Criteria

The static stability of an airplane is generally the first type of stability a designer evaluates. Static stability criteria for the three modes of aircraft rotation (pitch, roll, and yaw) must be considered[15]. Airplane stability is the ability of an airplane in flight to return to its original position in certain flight conditions after receiving external interference without the role of the pilot in restoring the original aircraft position. So an airplane that when it gets a disturbance will tend to return to its original position, then the aircraft is categorized as stable. An aircraft can be declared statically stable if it meets several requirements, namely in the lateral has value $C_{l_\beta} < 0$, longitudinal has value $C_{m_\alpha} < 0$ and in the value directional $C_{n_\beta} > 0$.

Static stability in the longitudinal will be achieved if there is a change in the pitch moment due to the angle of attack being below zero. This means that for a positive disturbance, the aircraft should naturally produce a negative M opposing the is the main requirements for longitudinal static stability [15].

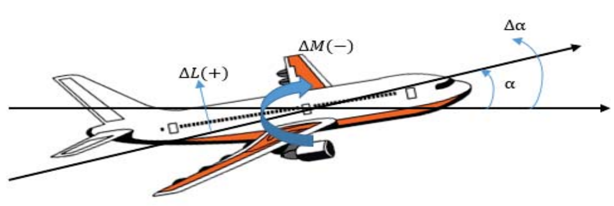

FIGURE 4. Longitudinal static stability illustration

In the same way, the condition of the plane to achieve the lateral-directional static stability condition is the coefficient $C_{l_\beta} < 0$ and $C_{n_\beta} > 0$, meaning that for a positive β disturbance, the aircraft should naturally produce a negative roll moment L (rolling to the left from the pilot's standpoint) and a positive yaw moment N (yawing to the right from the pilot's standpoint) opposing the β.

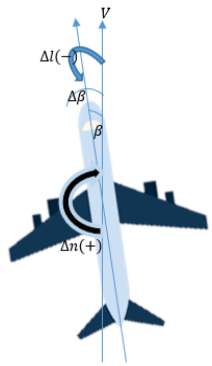

FIGURE 5. Lateral-directional static stability illustration

METHODOLOGY

Aerodynamic analysis is simulated in cruise conditions with several numerical methods, namely VLM, CFD and DATCOM. This analysis was carried out as an initial prediction of the characteristic values C_L, C_D, C_M, C_n, and C_l. The parameters that need to be considered in the simulation process are shown in TABLE 1

TABLE 1. Parameter for Simulation

Parameter	Symbol	Value
Velocity	V	30 m/s
Height	h	300 m
Density	ρ	1,185 kg/m^3
Pressure	P	1 atm

LSU-05 NG has wings that are connected to the fuselage in a high wing configuration. The wing has a 'tapered' platform and is attached to the fuselage. The LSU-05 NG wing uses one airfoil type, namely the FX 76-MP-160 airfoil from the root chord to the tip chord. The geometry of the LSU-05 NG wing is given in TABLE 2:

TABLE 2. Wing Geometry parameters

Parameter	Symbol	Value
Wing Area	S	3.45 m^2
Aspect Ratio	AR	8,769
Wing SemiSpan	b	$2,75m$
Taper Ratio	λ	1,659
Swept Angle	$\wedge$	0°
Aspect Hedral Angle	Γ	0°
Incidence Angle	i	0°
Twist Angle	τ	0°
Root Chord	C_r	0,73 m
Tip Chord	C_t	0,44 m
Mean Aerodynamic Chord	c	$0,597m$
Airfoil	−	FX 76-MP-160
HLD	−	Single Slotted Flap

LSU 05-NG uses a twin boom type tail, which is a twin tail shaft attached to the wing. This concept is very suitable for use in pusher-type propulsion systems because it can position heavy engines closer to the center of gravity (CG) point, thus providing a good CG adjustment. The tail geometry of the LSU 05-NG is given in TABLE 3

TABLE 3. HTP and VTP geometry parameters

Parameter	Symbol	HTP	VTP
HTP and VTP Area	S	0,6603 m^2	0,1610 m^2
Aspect Ratio	AR	3,4	1,6
HTP and VTP Span	b	1,5 m	0,5 m
Taper Ratio	λ	1	0,46
Swept Angle 0.25c	$\wedge$0.25c	0°	40°
Swept angle LE	$\wedge$LE	0°	37°
Root Chord	C_r	0,44 m	0,44 m
Tip Chord	C_t	0,44 m	0,204 m
Airfoil	–	Naca 0012	Naca 0012

The initial design of the fuselage has a total length of 221 *cm* with details of 60 *cm* being the front of the nose which is tapered, 80 *cm* is the middle part with a fixed width and 81 *cm* at the back as a place for installing the wings and has a height of 31.5 *cm*. Based on geometric data TABLE 2 and TABLE 3 obtained images of the LSU 05-NG model as follows:

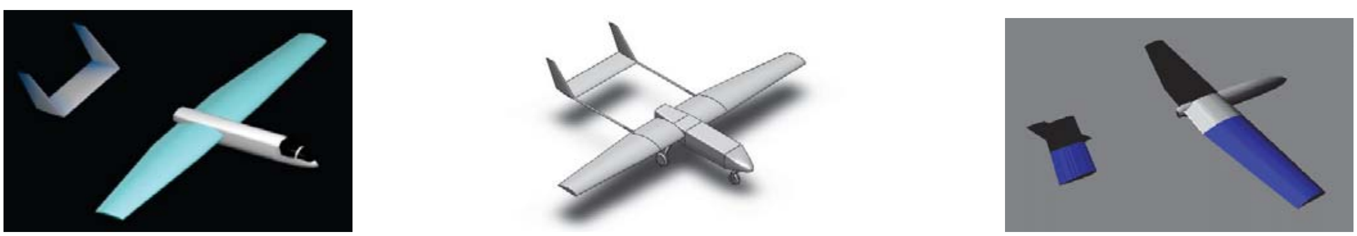

FIGURE 6. LSU 05-NG model with XFLR5, CFD and DATCOM

There are differences in modeling the twin tail boom aircraft using XFLR5, CFD and DATCOM. This is because the software used has advantages and disadvantages of each. As shown by DATCOM. DATCOM cannot draw a plane with two vertical tails. However, during the analysis, the forces on the vertical tail are multiplied by two. So this is the same as the force on the two vertical tails. Full configuration simulation is simulated in cruising flight conditions with input parameters as shown in TABLE 1. After obtaining the results of the LSU 05-NG model, an aerodynamic analysis was carried out which included C_L, C_D, C_M, C_n and C_l. Analysis using the VLM method in XFLR5 software was carried out on the number of panels 2854. These panels form a vortex sheet on the wing, HTP, VTP and fuselage LSU 05-NG as shown in FIGURE 7. Meanwhile, the meshing results obtained by CFD are as shown in FIGURE 8.

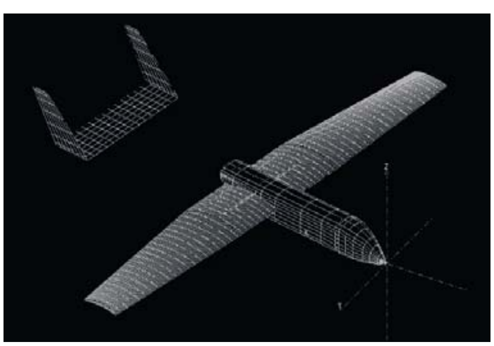

FIGURE 7. Meshing results with XFLR5

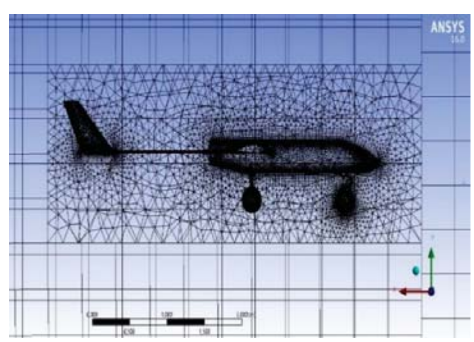

FIGURE 8. Meshing results with CFX ANSYS

Whereas DATCOM does not display the meshing form, only the plane shape as shown in FIGURE 6. In general, the simulation flow of CFD and XFLR5 is used, starting from the aircraft data input to the results shown in FIGURE 9.

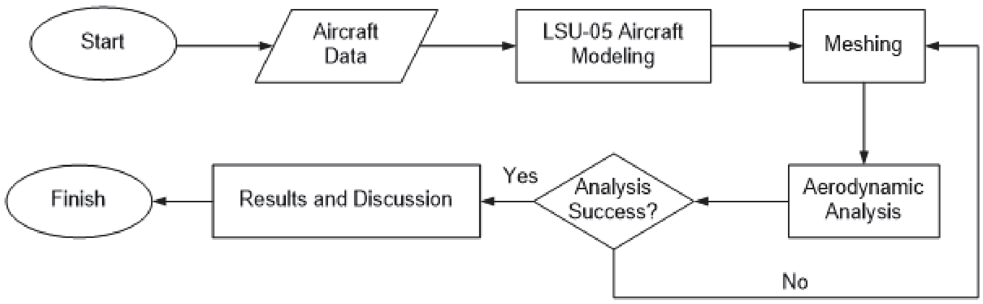

FIGURE 9. Simulation Flowchart using Numerical Method

RESULT AND DISCUSSION

The process of aerodynamic analysis with three numerical methods follows the flow diagram on FIGURE 9 where the CG on the X axis is 1,515 m from the nose and 0.047 m towards the Z axis. Analysis using the Vortex Lattice Method on XFLR5 by entering the angle of attack value $-15°$ to $24°$ with $1°$ intervals. For simulations using CFD with the ANSYS CFX solver carried out at an angle of attack of $-15°$ to $24°$ with intervals of $2°$. The number of mesh used in the analysis process using CFD was 2804124. Meanwhile, the aerodynamic analysis using DATCOM was carried out at an angle of attack of $-14°$ to $14°$ with an interval of $2°$. The results of the numerical analysis of the three numerical methods are shown in FIGURE 10, FIGURE 11, FIGURE 12 and FIGURE 13

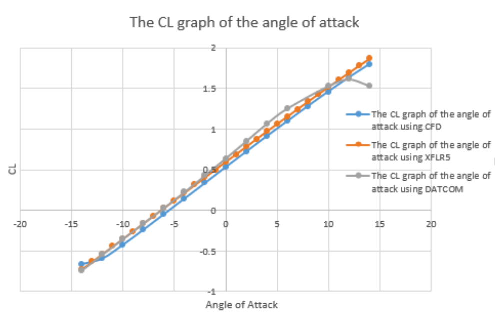

FIGURE 10. The C_L graph of the angle of attack

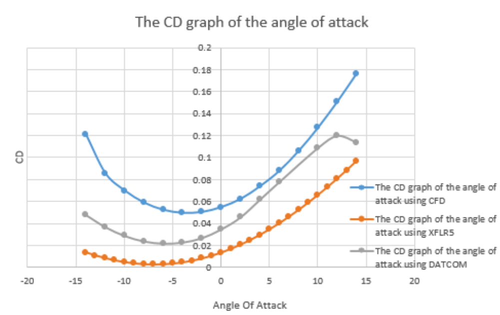

FIGURE 11. The C_D graph of angle of attack

Based on FIGURE 10 which shows a graph of the lift coefficient to the angle of attack shows the difference between the three numerical methods. The results of the analysis using VLM on XFLR5 show a linear graph. This linear result is due to the VLM analysis on XFLR5 using the assumption that the flow is inviscid. Besides that, it is based on Equation (7), matrix V is a matrix whose components are linear equations. Therefore, VLM on XFLR5 cannot analyze values C_L at the angle of stall, different from CFD and DATCOM which can analyze the stall angle at the time C_L maximum.

Meanwhile, based on the results of the analysis with DATCOM, a stall will occur at 14 degrees. Stall is a flow separation phenomenon on the wing surface because it exceeds the angle of the wing and results in a decrease of force[12]. The value of C_L at 0 degrees or flying during cruise conditions using VLM, CFD and DATCOM each have a value of 0.57, 0.53, and 0.63. Based on Equation (4) to get the value of the lift, the lifts are 1084, 1007 and 1198.

The difference is quite significant between the results with VLM and CFD. When the angle of attack is -15 degrees, value of C_D with VLM 0.02 whereas with CFD, the value C_D when the angle of attack is -15 degrees is 0.13. This difference was caused because the simulation with CFD does not ignore the flow viscosity while with VLM the

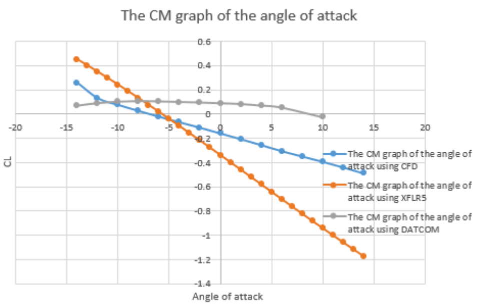

FIGURE 12. The C_M graph of the angle of attack

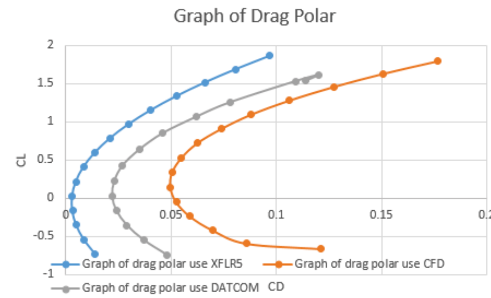

FIGURE 13. The Graph of Drag Polar

flow viscosity is neglected. In FIGURE 12 which is a graph between the moment coefficient value and the angle of attack. Based on the graph shown, the three methods show that the graph C_M to angle of attack has a negative gradient value. Hence the gradient value C_M to angle of attack has a negative value, The LSU 05-NG plane is statically stable in the longitudinal. In addition, analysis was also carried out with angular variations side slip (β) when the angle of attack is 0 degrees. This analysis is carried out to obtain a graph C_n and C_l to side slip (β) angle by using VLM, CFD and DATCOM. However, analysis using DATCOM cannot display graphs C_n and C_l to side slip (β) angle, only that can be displayed is the value of the stability derivative C_n and C_l. Whereas with VLM on the XFLR5 can display graphics C_n and C_l to side slip (β) angle. The results of the analysis with XFLR5 and CFD are shown in FIGURE 14 and FIGURE 15

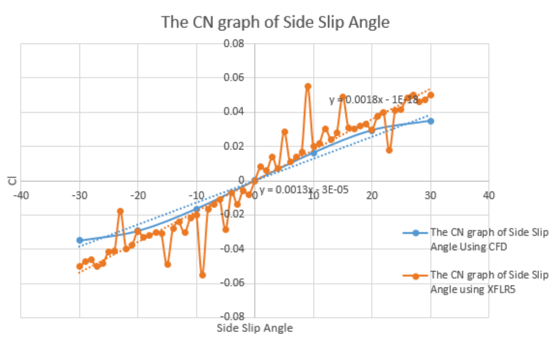

FIGURE 14. The C_n graph of the side slip angle

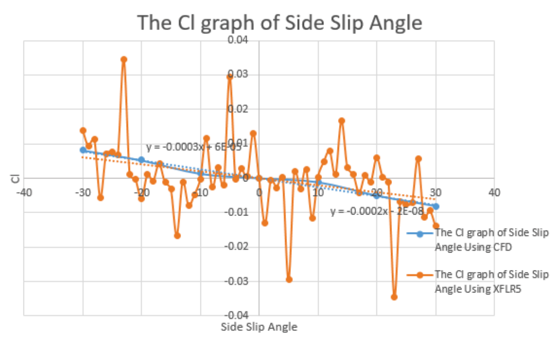

FIGURE 15. The C_l graph of the side slip angle

The analysis with CFD is carried out at side slip (β) angle -30 degrees to 30 degrees with intervals of 10 degrees. Whereas with VLM on the XFLR5 it is done at a side slip angle (β) -30 degrees to 30 degrees with interval 1 degrees. However based on FIGURE 14 and FIGURE 15 there are differences in the shape of the graph. With VLM both graph of C_n and C_l, graphic not smooth. This is due to the analysis with variations in the side slip angle (β) assuming the flow is not viscous or can be called inviscid flow. However, both CFD and VLM have a negative gradient. In general, the value of the graph gradient C_M, C_n and C_l given on TABLE 4.

TABLE 4. Static Stability Derivative Coefficient Value

Method	C_{M_α}	C_{n_β}	C_{l_β}
CFD	-0.0242	0.0013	-0.0003
VLM XFLR5	-0.0543	0.0018	-0.0002
DATCOM	-0.00296	0.000383	-0.00055

Based on FIGURE 12 and FIGURE 10, it can be seen that with the increase in the angle of attack the pitching moment coefficient decreases and the lift coefficient value increases. By using linear regression the values obtained $C_{M_\alpha} < 0$ and $C_{L_\alpha} > 0$. As discussed before, indicate that the UAV have a good longitudinal static stability. Based on

FIGURE 14 and FIGURE 15 the side slip angle increases, the values of C_l decrease while the values of C_n increase. By using linear regression the values obtained $C_{l_\beta} < 0$ and $C_{n_\beta} > 0$. This means that as disturbance increases, the aircraft will naturally produce an increase in negative rolling moment and an increase in positive yawing moment to compensate for this increase. As discussed before, indicate that the UAV have a good lateral-directional static stability.

CONCLUSION

By using three numerical methods (XFLR5, CFD and DATCOM), the $C_{M_\alpha} < 0$ and $C_{L_\alpha} > 0$ values were obtained. This shows that the LSU 05-NG has good longitudinal static satbility. And on the other hand, with variations in the value of the side slip angle β, it shows the $C_{l_\beta} < 0$ and $C_{n_\beta} > 0$ values. This shows that LSU 05 -NG has good lateral-directional static stability. As a result, the LSU 05-NG complies the static stability criteria at its cruise condition.

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