FLIGHT ATTITUDE CHARACTERISTIC ANALYSIS OF LSU-01 WITHOUT CONTROL SYSTEM

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Abstract

The paper present the modeling of dynamic characteristic of UAV. The dynamic model was developed using first principle method. The flight dynamic parameter is calculated using Datcom and the dynamic characteristic is analyzed usingMatlab software. The simulation shows that the real part of eigenvalue LSU-01 is on the left of imaginary axis, which means that the system has static and dynamic stability. The place pole of LSU-01 in the s-plane shows similarity with common aircraft mode.

Key Words : *modeling, flight dynamic, datcom, LSU-01*

1. Introduction

1.1. Background

Unmanned Aerial Vehicles (UAVs) are available alternative to manned aircraft and satellites for variety of applications,such as environmental monitoring, agriculture, and surveying. They promise greater precision and much lower operating costs. Critical to the success of UAV systems is the auto-pilot system which keeps thevehicle in the air, and in control in the absence of a human pilot. The development of autopilotsystems for UAVs is an area whichundergoingintensive research. The ability to test autopilot systems in a virtual (software) environment, using a software flight dynamics model, forUAVs is significant for development. In many cases, testing newly developed autopilot systems in a virtual environment is the only way to guarantee absolute safety. Additionally the model would allow better repeatability in testing, with controlled flying environments[1)].

A major hazard to flight test of UAV is being in uncontrollabe condition when the mode ischanged from manual to autonomous. There are two of causal factors for the UAV unstable condition, that the influence of environment and problem in theUAV itself[2)].

Numerical modeling of flight dynamics has a long history in the aerospace industry, and isused in the development of all modern aircraft and satellites. A flight dynamics model is amathematical representation of the steady state performance and dynamic response that isexpected of the proposed vehicle, in this case a UAV. Example applications include control algorithms testing,stability and flight characteristics evaluation of preliminary designs, onboard embedded autopilot systems, and onboard Inertial Navigation Systems (INS).

In the development of UAVs and auto-pilot systems, a flight dynamics model for flightsimulations allows rapid and safe testing on a computer. However, a software model developed from first principles has unknown accuracy. For such a model to be of real use,its development process is necessary to include implementation, verification and validation.

Therefore state space of LSU-01 as object of research and development is important. Fromthese equations, the vehicle attitude flight chararcteristicscan be analyzed. Thecalculation toget the value of the parameters is done using datcom[3)]and for the analysis of dynamic characteristic is done using Matlab[4)].

1.2. Objective

- Calculating of dynamicparameters value of LSU-01
- Developed state space model in longitudinal and lateral directional
- Data collecting for build state space of LSU-01
- Simulationto know theflight dynamic characteristic of the vehiclewithout control system

2. Theory

2.1. Longitudinal Motion

Longitudinal motion influenced by Fx and Fz force, and pitch moment caused by elevator deflection and small changed of thrust, but not appear of roll and yaw moment and Fy[5,6)].For wing level flight cruise, we get equations as follow:

$$\sum \Delta Fx = m(\dot{U} + WQ)$$
$$\sum \Delta Fz = m(\dot{W} - UQ) \quad (1)$$
$$\sum \Delta M = \dot{Q}Iy$$

Linear and angular speed total is :

$$\begin{aligned} U &= Uo + u & P &= Po + p \\ V &= Vo + v & Q &= Qo + q \\ W &= Wo + w & R &= Ro + r \end{aligned} \quad (2)$$

With*U0, V0, W0, P0, Qo, R0*is equilibrium value and *u, v, w, p, q, r*is change caused disturbance. Representation of stabilize axis show in figure bellow.

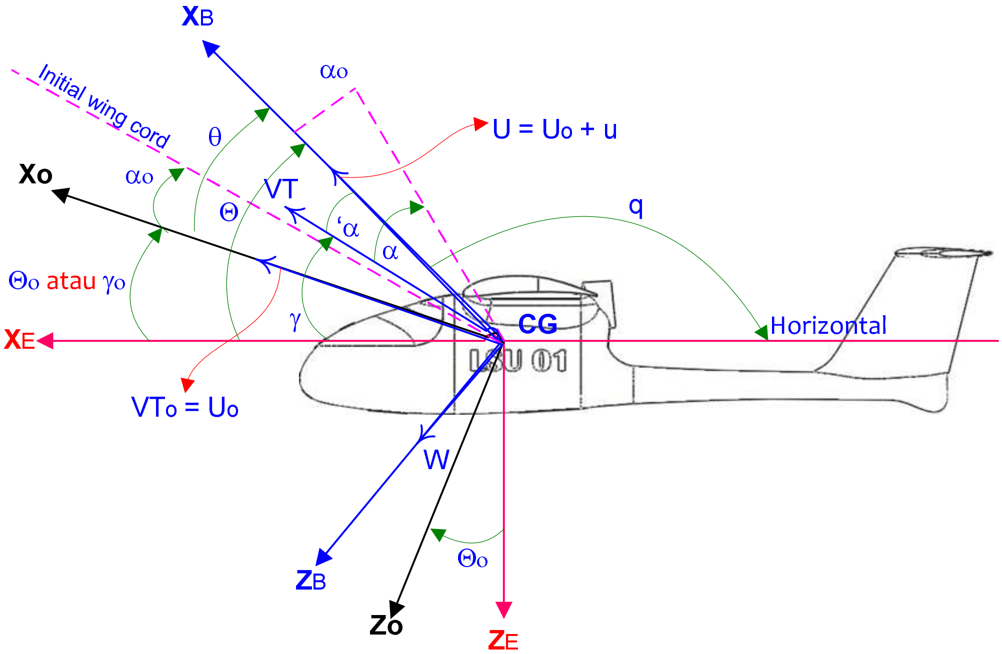

Fig. 1.Stabilize axis for euqilibrium condition and disturbance on LSU-01

From Eq. (2)obtained the relationship :

$$\begin{aligned} &{}'\alpha = \frac{W}{U} \\ &\alpha = \alpha_0 + {}'\alpha \\ &\Theta = \Theta_0 + \theta \\ &\gamma = \Theta - {}'\alpha \\ &\gamma = \theta - {}'\alpha \rightarrow \Theta_0 = 0 \\ &W_0 = 0 \end{aligned} \quad (3)$$

The equation above used for dynamic analysis with taking stabilize axis $\Theta_0 = \gamma_0$. Change Θ same with θ, result from rotation at Y axis and $q = \dot{\theta}$.In these condition U = U_0 + u and W = w, where Uo is constant then $\dot{U} = \dot{u}$and $\dot{W} = \dot{w}$, move aircraft without acceleration Q0 = 0 and q_b= q. Therefore the force equation can be writtenas :

$$\sum \Delta Fx = m\,(\dot{u} + wq)$$
$$\sum \Delta Fz = m\,(\dot{w} - U_0\, q - uq) \quad (4)$$

Assumption that small disturbance to equilibrium condition, consequently that the product from multiple is neglected. Assumption that the angle is small to equilibrium angle, and then resulted equations :

$$\sum \Delta Fx = m\dot{u} \qquad (5)$$
$$\sum \Delta Fz = m(\dot{w} - U_0\, q) = m(\dot{w} - U_0\dot{\theta})$$
$$\sum \Delta m = \dot{q} I_y = \ddot{\theta} I_y$$
$$q = \dot{\theta}$$

By substitute, manipulation and assumption, then obtained four equation which the all evaluated at equilibrium condition, that is :

$$\frac{mU}{Sq}\dot{u}' - Cx_u u' - Cx'_\alpha \alpha - \frac{c}{2U} Cx_{\dot{\alpha}}\,'\dot{\alpha} - (C_w \cos\Theta)\theta - \frac{c}{2U} Cx_q \dot{\theta} = Cx_{\delta e}\,\delta e + \frac{Cx_T}{Sq} Tc \qquad (6)$$

$$-Cz_u u' + \left(\frac{mU}{Sq} - \frac{c}{2U} Cz_{\dot{\alpha}}\right)'\dot{\alpha} - Cz'_\alpha \alpha + \left(-\frac{mU}{Sq} - \frac{c}{2U} Cz_q\right) q - (C_w \sin\Theta)\theta = Cz_{\delta e}\,\delta e + \frac{Cz_T}{Sq} Tc \qquad (7)$$

$$-Cm_u u' - Cm_\alpha\,'\alpha - \frac{c}{2U} Cm_{\dot{\alpha}}\,'\dot{\alpha} + \frac{I_y}{Sqc}\dot{q} - \frac{c}{2U} Cm_q\, q = Cm_{\delta e}\,\delta e + \frac{z}{c}\frac{Cm_T}{Sq} Tc \qquad (8)$$

$$q = \dot{\theta} \qquad (9)$$

Where :

$$Cx_u = \frac{U}{Sq}\frac{\partial Fx}{\partial u} \quad Cx_\alpha = \frac{1}{Sq}\frac{\partial Fx}{\partial \alpha} \quad Cx_{\dot{\alpha}} = \frac{1}{Sq}\left(\frac{2U}{c}\right)\frac{\partial Fx}{\partial \dot{\alpha}} \quad C_w = \frac{-mg}{Sq} \quad Cx_q = \frac{1}{Sq}\left(\frac{2U}{c}\right)\frac{\partial Fx}{\partial q}$$

$$Cz_u = \frac{U}{Sq}\frac{\partial Fz}{(\partial u)} \quad Cz_\alpha = \frac{1}{Sq}\frac{\partial Fz}{\partial \alpha} \quad Cz_{\dot{\alpha}} = \frac{1}{Sq}\left(\frac{2U}{c}\right)\frac{\partial Fz}{\partial \dot{\alpha}} \quad Cz_{\delta e} = \frac{1}{Sq}\frac{\partial Fz}{\partial \delta e} \quad Cz_q = \frac{1}{Sq}\left(\frac{2U}{c}\right)\frac{\partial Fz}{\partial q}$$

$$Cm_u = \frac{U}{Sqc}\frac{\partial m}{\partial u} \quad Cm_\alpha = \frac{1}{Sqc}\frac{\partial m}{\partial \alpha} \quad Cm_{\dot{\alpha}} = \frac{1}{Sqc}\left(\frac{2U}{c}\right)\frac{\partial m}{\partial \dot{\alpha}} \quad Cm_{\delta e} = \frac{1}{Sq}\frac{\partial m}{\partial \delta e} \quad Cm_q = \frac{1}{Sqc}\left(\frac{2U}{c}\right)\frac{\partial m}{\partial q}$$

$$Cx_T = \frac{\partial Fx}{\partial T} \quad Cz_T = \frac{\partial Fz}{\partial T} \quad Cx_T = \frac{1}{z}\frac{\partial m}{\partial T} \quad Cx_{\delta e} = \frac{1}{Sq}\frac{\partial Fx}{\partial \delta e}$$

2.2. Lateral-Directional Motion

Equations of lateral-directional motionconsist of Fyforce, roll moment (Δl) and yaw moment (Δn), that is[5,6] :

$$\sum \Delta F_y = m(\dot{V} + UR - WP) \qquad (10)$$
$$\sum \Delta l = (\dot{P} I_x - \dot{R} J_{xz} + QR(I_z - I_y) - PQJ_{xz})$$
$$\sum \Delta n = (\dot{R} I_z - \dot{P} J_{xz} + PQ(I_y - I_x) + QRJ_{xz})$$

Equation is decoupled Q = 0 (aero), x-axis equilibrium is a long line flight, without slide and no accelerated. Therefore equation can be written as :

$$\sum \Delta F_y = m(\dot{v} + ur + U_0 r) \qquad (11)$$
$$\sum \Delta l = (\dot{p} I_x - \dot{r} J_{xz})$$
$$\sum \Delta n = (\dot{r} I_z - \dot{p} J_{xz})$$

Force to y-axis caused by linear and angular disturbance, and then partial differential is linear as long as disturbance, initial value is zero and all differential on steady state condition. Finally obtained four equation for lateral-directional motion, that is:

$$\frac{mU}{Sq}\dot{\beta} - \frac{b}{2U} Cy_p\, p + \left(\frac{mU}{Sq} - \frac{b}{2U} Cy_r\right) r - Cy_\beta \beta - Cy_\varphi\, \varphi = Cy_{\delta a}\,\delta a + Cy_{\delta r}\,\delta r \qquad (12)$$

$$\dot{p} = \frac{\sum \Delta\, l}{I_x} = \frac{1}{I_x}\left(\frac{\partial l}{\partial \beta}\beta + \frac{\partial l}{\partial p} p + \frac{\partial l}{\partial r} r + \frac{\partial l}{\partial \delta_a}\delta_a + \frac{\partial l}{\partial \delta_r}\delta_r\right) \qquad (13)$$

$$\dot{r} = \frac{\sum \Delta n}{I_z} = \frac{1}{I_z}\left(\frac{\partial n}{\partial \beta}\beta + \frac{\partial n}{\partial p}p + \frac{\partial n}{\partial r}r + \frac{\partial n}{\partial \delta_a}\delta_a + \frac{\partial n}{\partial \delta_r}\delta_r\right) \quad (14)$$

$$\dot{\varphi} = p + r\tan\Theta_s \quad (15)$$

Where :

$$Cy_\beta = \frac{1}{Sq}\frac{\partial Fy}{\partial \beta} \qquad Cy_\varphi = \frac{1}{Sq}\frac{\partial Fy}{\partial \varphi} = \frac{mg}{Sq}\cos\Theta \qquad Cy_p = \frac{1}{Sq}\frac{\partial Fy}{\partial\left(p\frac{b}{2U}\right)} \qquad C_{lp} = \frac{1}{Sqb}\frac{\partial l}{\partial\left(p\frac{b}{2U}\right)}$$

$$Cy_r = \frac{1}{Sq}\frac{\partial Fy}{\partial\left(r\frac{b}{2U}\right)} \qquad Cy_{\delta a} = \frac{1}{Sq}\frac{\partial Fy}{\partial \delta a} \qquad Cy_{\delta r} = \frac{1}{Sq}\frac{\partial Fy}{\partial \delta r} \qquad C_{lr} = \frac{1}{Sqb}\frac{\partial l}{\partial\left(r\frac{b}{2U}\right)}$$

$$C_{l\beta} = \frac{1}{Sqb}\frac{\partial l}{\partial \beta} \qquad C_{l\delta_a} = \frac{1}{Sqb}\frac{\partial l}{\partial \delta_a} \qquad C_{l\delta_r} = \frac{1}{Sqb}\frac{\partial l}{\partial \delta_r} \qquad C_{np} = \frac{1}{Sqb}\frac{\partial n}{\partial\left(p\frac{b}{2U}\right)}$$

$$C_{nr} = \frac{1}{Sqb}\frac{\partial n}{\partial\left(r\frac{b}{2U}\right)} \qquad C_{n\beta} = \frac{1}{Sqb}\frac{\partial n}{\partial \beta} \qquad C_{ln} = \frac{1}{Sqb}\frac{\partial n}{\partial \delta_a} \qquad C_{n\delta_r} = \frac{1}{Sqb}\frac{\partial n}{\partial \delta_r}$$

3. Modeling State Space of LSU-01

3.1. Spesification of LSU-01

Table 1.Spesification of LSU-01

No	Componen name	Size	Dimention
1	Wingspan	1900	Mm
2	Fuselage Length	1200	Mm
3	Maximum load	0,5	Kg
4	Average speed	45	km/h
5	Maximum speed	60	km/h
6	Airspeed Stall	30	km/h
7	Endurance	50	Minutes
8	Engine : brushless motor	980	kV
9	Power source : batery	5000	mAh
10	Take off : throwed		
11	Control System :	- Take Off/Landing by Remote Control - Cruise : Autonomous	

Aircraft model of LSU-01 showed in Fig. 2 follow.

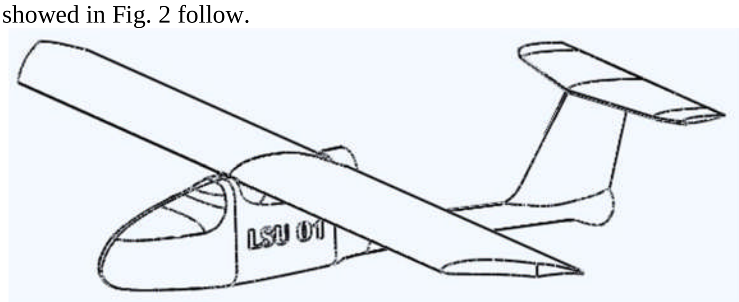

Fig.3. LSU-o1Aircraft model of LSU-01

3.2. State Space Equation of LSU-01

It is assumed, that the air craft is rigid-body and the distance between any point on the aircraft do not change in flight. When the rigid-body moving in space, its motion can be considered to have six degree of freedom. By applying Newton's second law to that rigid-body the equation of motion can be established in terms of the translational and angular accelerations which occur as a consequence of some forces and moments being applied to the aircraft.

3.2.1. LongitudinalMotion

By using Eq. (6) until (9) and constans value of LSU-01 for longitudinal montion, obtained the state space as Eq. (16).

Table 2.Parameter value for longitudinal motion

Parameter	Value	Parameter	Value
Cxu	-0.1530	Cxq	0
Czu	-0.1440	Czq	-0.9147
Cmu	0	Cmq	-15.9600
Cxα	0.3007	Cxδe	0
Czα	-5.9540	Czδe	-0.2865
Cmα	-1.3150	Cmδe	-0.9740
Cxα'	0	Cx_T	1.0000
Czα'	-0.4107	Cz_T	0
Cmα'	-7.2160	Cm_T	1.0000

State space of longitudinal motion as :

$$\begin{bmatrix} \dot{u}' \\ '\dot{\alpha} \\ \dot{\theta} \\ \dot{q} \end{bmatrix} = \begin{bmatrix} -0.2083 & 0.4090 & -0.7545 & 0 \\ -1.5493 & -8.0594 & 0.0131 & 0.9843 \\ 0 & 0 & 0 & 1.0000 \\ 2.2335 & -18.4711 & -0.0189 & -4.6074 \end{bmatrix} \begin{bmatrix} u' \\ '\alpha \\ \theta \\ q \end{bmatrix} + \begin{bmatrix} 0 & 1.3609 \\ -0.3880 & 0 \\ 0 & 0 \\ -21.7281 & -6.5117 \end{bmatrix} \begin{bmatrix} \delta e \\ \delta_T \end{bmatrix} \tag{16}$$

Table 3.Eigen value, damping ratio and frequency of LSU-01

Eigenvalue	**Damping**	**Freq. (rad/s)**	**Explanatory**
λ1 = -6.79e-002 + 7.89e-001i	8.58e-002	7.92e-001	Short period
λ2 = -6.79e-002 - 7.89e-001i	8.58e-002	7.92e-001	
λ3 = -6.37e+000 + 3.96e+000i	8.49e-001	7.50e+000	phugoid
λ4 = -6.37e+000 - 3.96e+000i	8.49e-001	7.50e+000	

The real part eigen value of system is negative, the meaning is that the system (LSU-01) have characteristic static stable at longitudinal motion.

3.2.2. Lateral-Directional Motion

By using Eq. (12) until (15) and constans value of LSU-01 for lateral-directional motion, obtained the state space as Eq. (17).

Table 4.Parameter value for lateral-directional motion

Parameter	Value	Parameter	Value
Cyb =	-0.1873	Clr	0.1430
Cyphi =	0.5539	Clda	0.0790
Cyp	0	Cldr	0.0040
Cyr	0	Cnb	0.0299
Cyda	0	Cnp	-0.0897
Cydr	0.0573	Cnr	-0.0405
Clb	-0.0766	Cnda	-0.0072
Clp	-0.300	Cndr	-1.6300

State space in Lateral-Directional motion is :

$$\begin{bmatrix} \dot{\beta} \\ \dot{p} \\ \dot{r} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} -0.2549 & 0 & -1.0000 & 0.7538 \\ -33.4161 & -9.5637 & 4.5587 & 0 \\ 3.9794 & -0.8724 & -0.3939 & 0 \\ 0 & 1.0000 & -0.0174 & 0 \end{bmatrix} \begin{bmatrix} \beta \\ p \\ r \\ \varphi \end{bmatrix} + \begin{bmatrix} 0 & 0.0780 \\ 34.4630 & 1.7450 \\ -0.9583 & -216.9375 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta a \\ \delta_r \end{bmatrix} \tag{17}$$

Eigen value and damping ratio show in table follow,

Table 5.Eigen value, damping ratio and frequency of LSU-01 for Lateral-Directional

Eigen value	**Damping**	**Freq. (rad/s)**	**Explanatory**
λ1 = -9.7476	1.00e+000	9.75e+000	Roll mode
λ2 = -0.2482+ 3.1100i	7.96e002	3.12e+000	Dutch roll
λ3 = -0.2482- 3.1100i	7.96e002	3.12e+000	Dutch roll
λ4 = 0.0302	-1.00e+000	3.02e-002	Spiral mode

4. Analisis of Simulation Result

4.1. Analysis of Longitudinal Motion

Pole zero placed in s-plane show in figure follow.

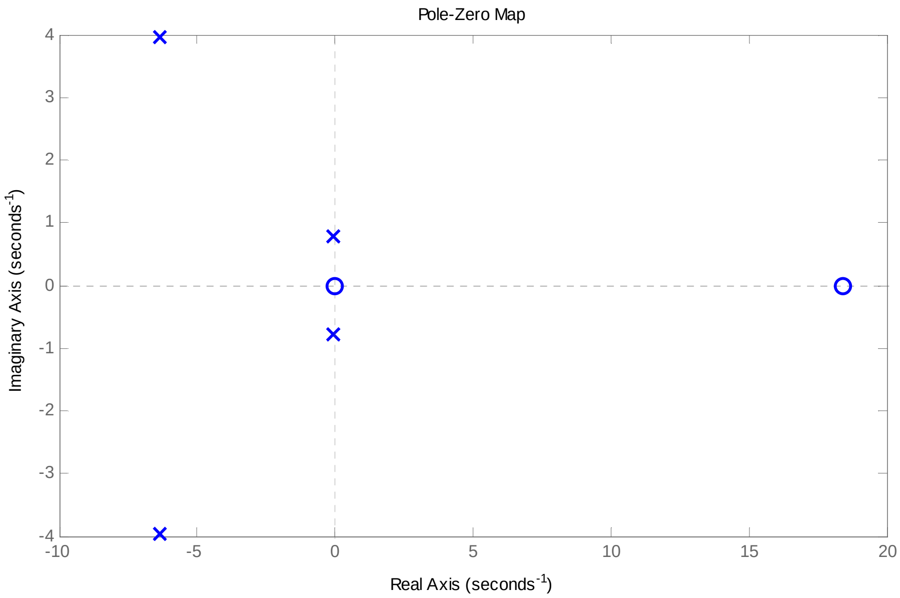

Fig. 4.Pole zero in s-plane

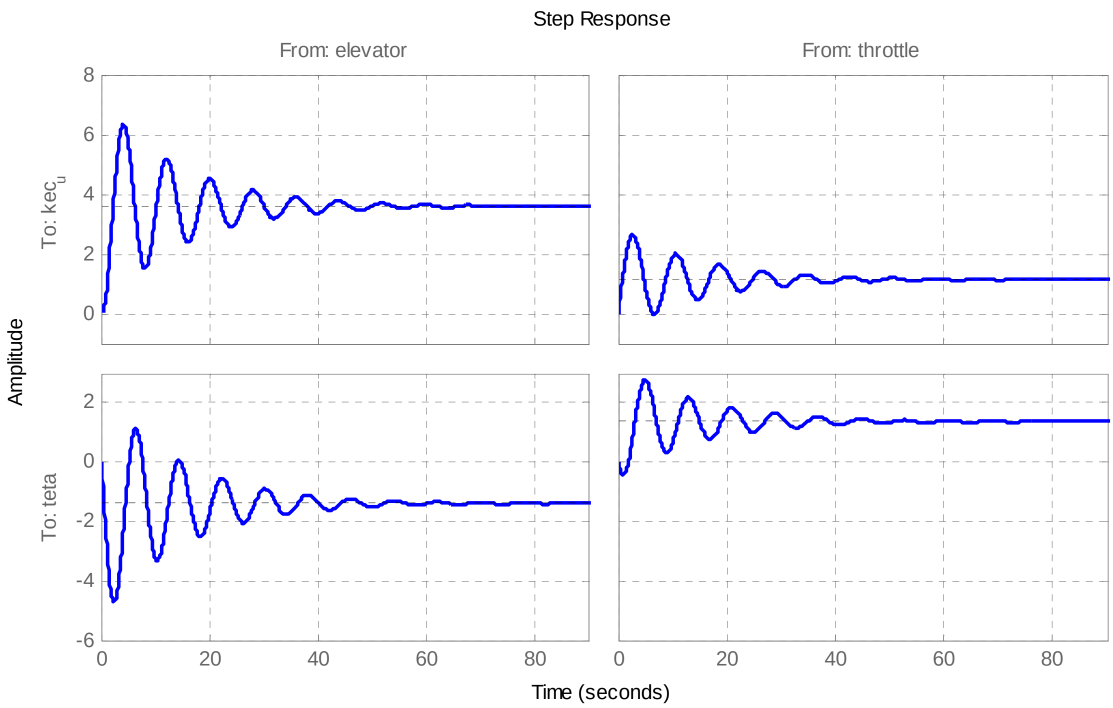

Fig. 5.Output system graph

Bode diagram show in figure follow.

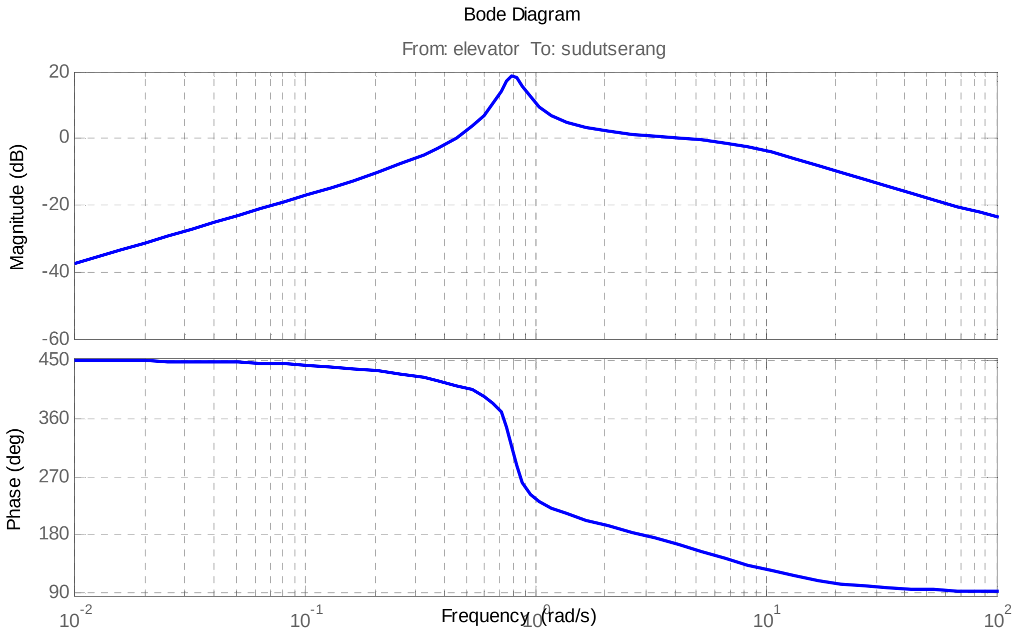

Fig. 6.Bode diagram

Root of system show in figure follow.

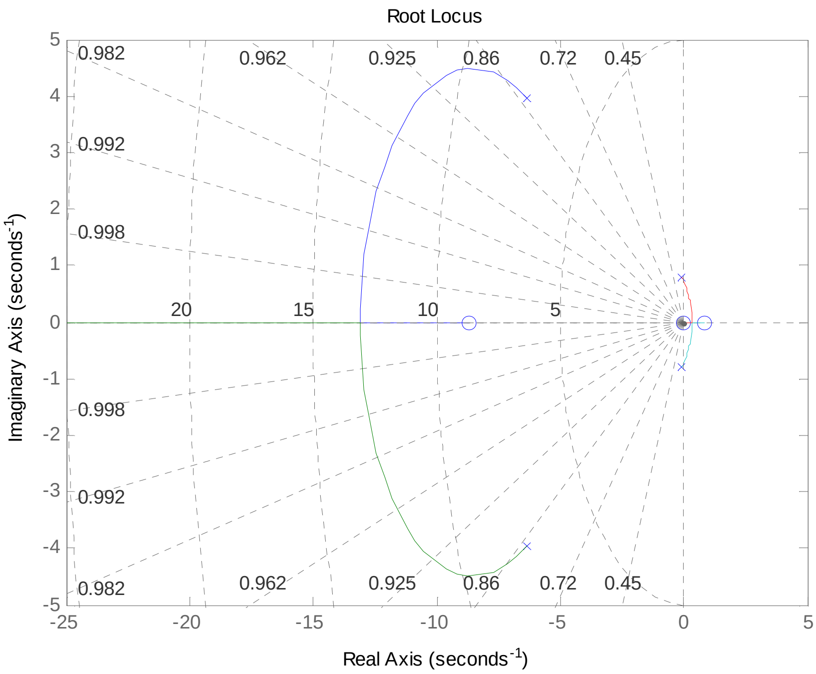

Fig. 7.Root locus of LSU-01 with grid

4.2. Analysis of Lateral-Directional Motion

Pole-zero placed in s-plane is follow,

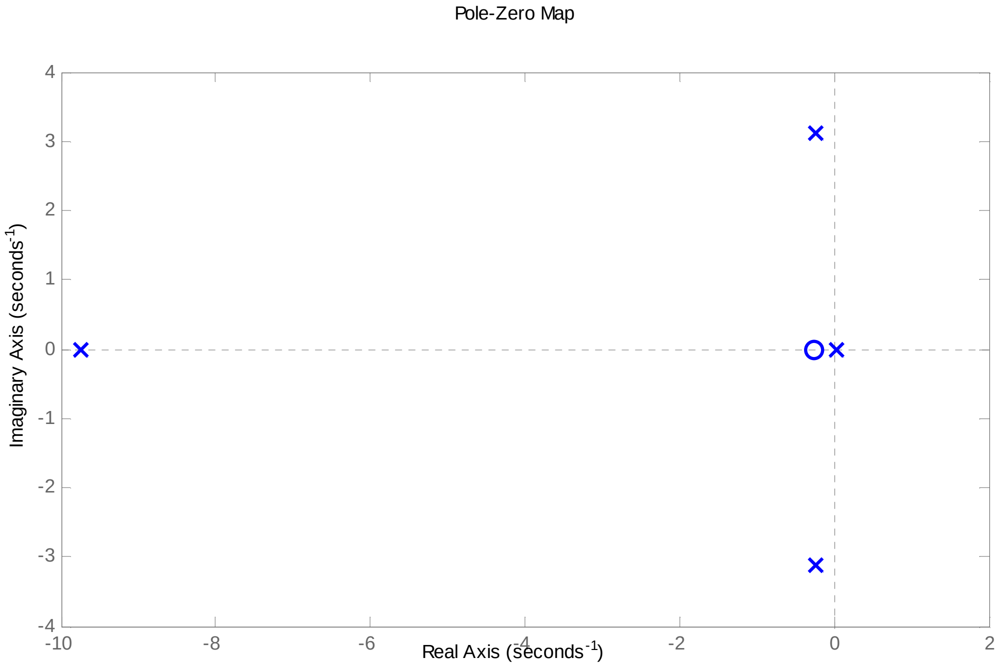

Fig. 8.Pole aero place in s-plane

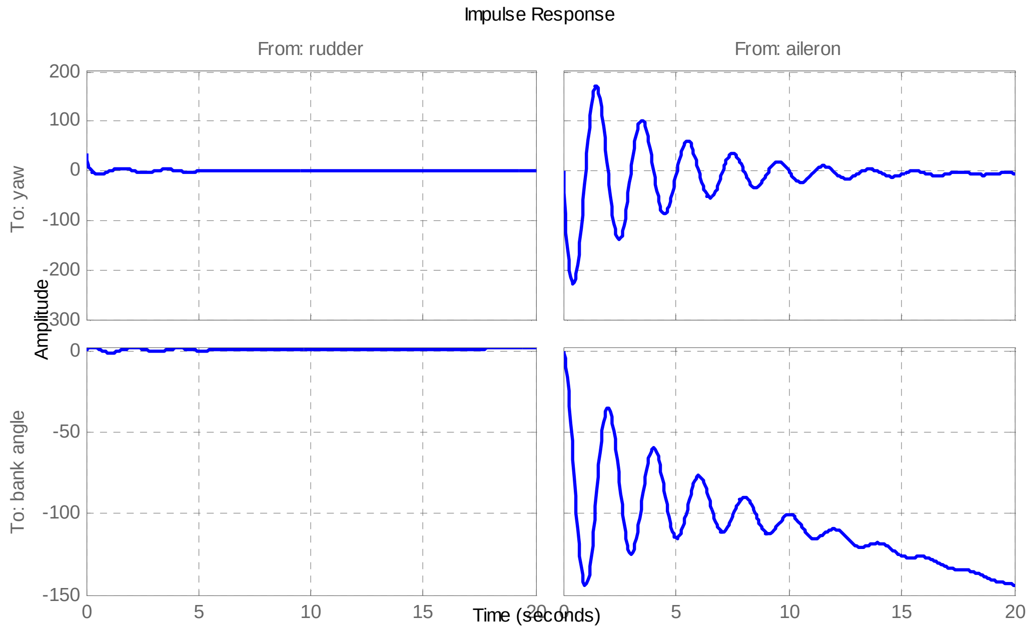

Fig. 9.Output respon to doubled input signal of LSU-01

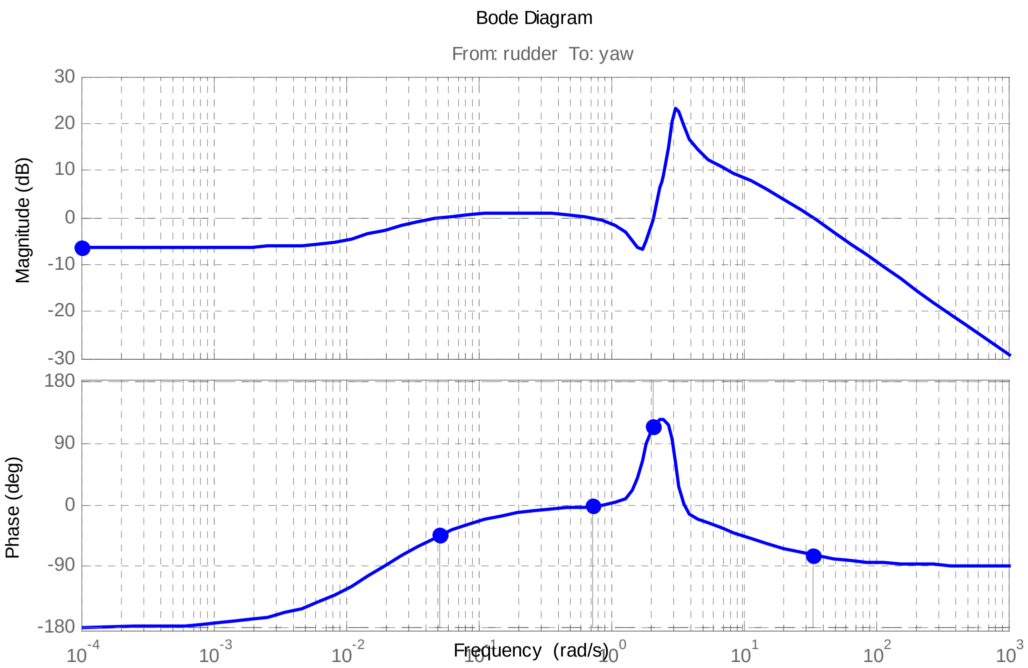

Fig. 10.Bode diagram

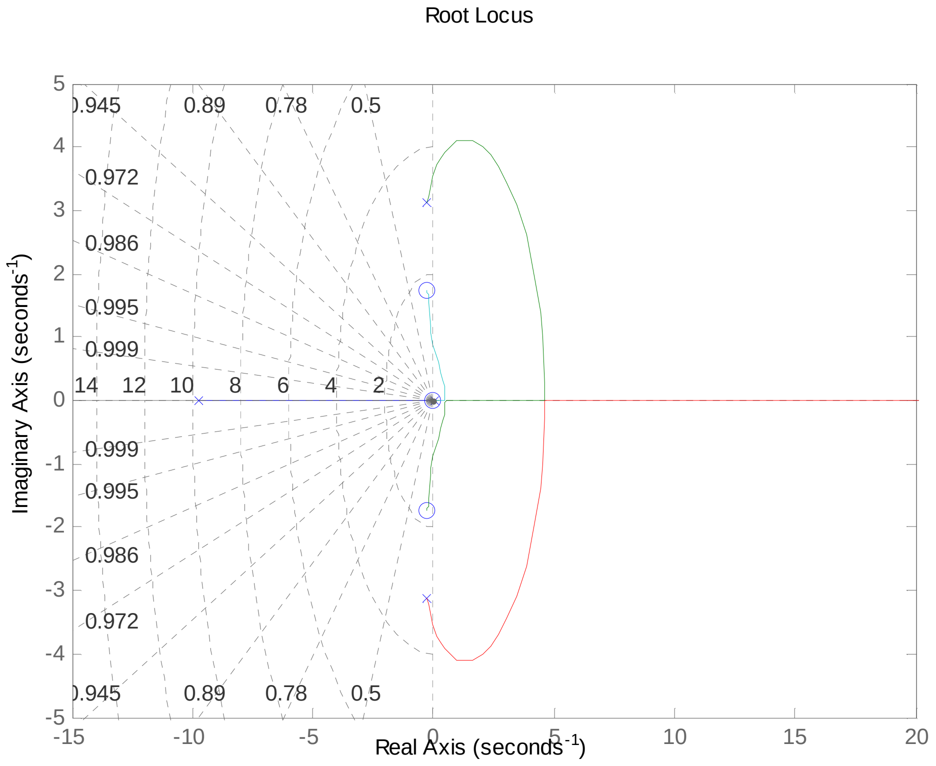

Fig. 11.Root locus position with grid

The simulation results above show that LSU-01 has static and dynamic stability characteristics. It is proved by the pole placement exist at left imaginary axis both atlongitudinal and lateral s-plane (Fig. 4 and Fig. 8). The performance of stability perhaps getting better after using closed loop control system in order to reach faster stability respon time than the open loop condition.

Pole zero placement in longitudinal and lateral motion have the samegeneral mode as a manned aircraft. Pole of longitudinal motion consist of 2 complex number, one as short period which far from imaginary axis and the other one as phugoid that place near the imaginary axis. In addition, Pole of Lateral motion consist of one pole as roll mode which far from imaginary axis, 2 pole represented as complex number-dutch roll, and another pole called spiral mode.

By taken 2% of error margin from steady state (time settling,Ts), longitudinal motion will take 50 seconds time settling (Fig. 5). While steady state of lateral motionwill take 5 seconds towards rudder deflection and 15 seconds towards aeleron defflection (Fig. 9).

5. Conclusion

- Thecalculationof the flight dynamic parameters of LSU-01 have been done using Datcom
- The state space of LSU 01 was done succesfully in longitudinal and lateral motion.
- Simulation results show that equation of motion of LSU 01 has static stability and dynamic stability
- Regarding pole zero placement, LSU-01 has the samegeneral mode as manned aircraft.

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Discussion

Question:

1. There are no models non linear? (Bambang Sridadi, PT. Dirgantara Indonesia)
2. There are no models of flight test results? (Bambang Sridadi, PT. Dirgantara Indonesia)
3. If the model is stable, meaning no need SAS (Stability Augmentation System)?
   (Bambang Sridadi, PT. Dirgantara Indonesia)
4. How characteristic for LSU 2, LSU 3 and so on? (Bambang Sridadi, PT. Dirgantara Indonesia)

Answer:

1. The fact is non - linear models, but for the purpose of controlling the design and implementation of non- linear control systems is very difficult. Therefore linier for linearized models at the plant do not change behavior (LSU - 01). From the simulation results of the linearized pretty good and do not deviate from the actual condition, it means that the simulation results obtained from the behavior of the system is equal to the actual conditions.
2. For LSU - 01 is still in the open- loop analysis, a model flight test results have not been there. In 2014 will be conducted flight test data will be used to validate the theoretically derived equations used in computer simulations.
3. The model is stable means stable static and dynamic in a state not fly. It means that a plant must have the characteristics of stability, controllability and observability. If an uncontrolled plant (uncontrollable) then it may proceed to the design of the control system. So that meant the plant is stable in open loop simulation scale, the use of the control system to improve performance (performance) from plants itself. For example, to improve response time, reduce overshoot, etc.
4. Characteristics LSU-02, stable and lowered earlier in 2011, this is because the LSU-02 is used as a plant in PKPP2011 research. Further measures 02 LSU-PID control system has been implemented and has managed to record MURI can fly as far as 200 km and back to autonomous mode. While LSU-3 is currently set-up for a test flight directly into autonomous mode having experience of LSU-3. While LSU-05 is UAV design results Pustekbang, so continue to experience improvement in several parts before being implemented.