Longitudinal Stability Analysis of STTA-12 MXA

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Abstract. This paper present the result of simulation longitudinal stability on STTA-12 MXA aircraft. This aircraft is included in the utility aircraft category with 1 propeller engine and 2 seats. The longitudinal response mode has been determined. The Datcom program is used to estimate the parameters in the longitudinal derivatives. As the next step, the longitudinal motion of aircraft is simulated and the transfer functions of linearized equations of motion have been obtained. The Phugoid and short period modes have been investigated. The damping and frequency of both the phugoid and short period influence the handling or flying qualities of an airplane.

Keywords: stability, longitudinal, STTA-12MXA.

1 Introduction

STTA-12 MXA is a new aircraft designed by STTA. The aircraft is a home-built aircraft with surveillance and recognition missions in a conventional configuration. Stability is the ability of an airplane to return to its initial equilibrium position if the airplane is disturbed from outside or inside. The stability of the aircraft reacts depending on the characteristics of the aircraft itself. Literature has a lot of papers about conceptual and preliminary aircraft design for a classic configuration. In case of a preliminary design of a classic aircraft configuration, some stability derivatives can be neglected as a derivative of a drag coefficient versus elevator deflection (Etkin and Reid, 1996; Cook, 2007; and Nelson, 1998).

The main goal of the research is to investigate a mathematical approach to an effective analysis of an aircraft longitudinal dynamic stability during a conceptual design phase.

2 Aircraft Model

The STTA-12 MXA aircraft is a sport class home-built aircraft. STTA-12 MXA stands for Sekolah Tinggi Teknologi Adisutjipto -12 Multirole eXperimental Aircraft.

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Number 1 represents the number of machines, and number 2 represents the number of seats. Furthermore, the STTA-12 MXA aircraft will only be called STTA-12.

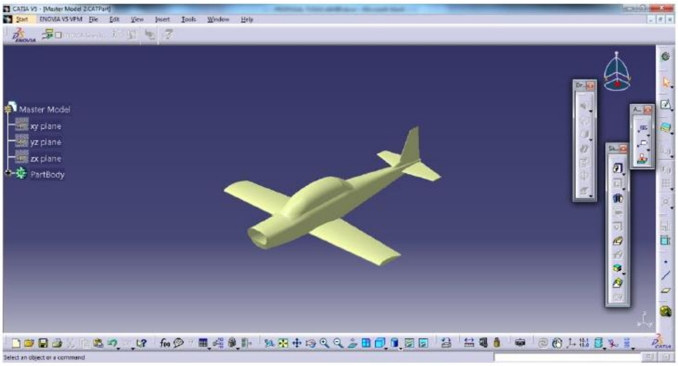

Fig. 1. STTA-12MXA Model

Table 1. STTA-12 Aircraft Weight

Weight	Value	Unit
Maximum Takeoff Weight	1811	lb
Empty Weight	1046	lb
Fuel Weight	275.077	lb
Payload Weight	110	lb

Table 2. STTA-12 Aircraft Geometry Characteristic

Weight	Value	Unit
Fuselage	7.56	m
Wing Span	7.79	m
Wing Area	10.12	m
Aspect Ratio	6	

Table 3. STTA-12 Performance

Weight	Value	Unit
Maximum Speed	103.71	m/s
Stall Speed	27.98	m/s
Range	815	Km
Operating Altitude	4115	m

3 Stability

3.1 Static Longitudinal Stability

Static stability is the initial tendency of the vehicle to return to its equilibrium state after a disturbance. In order to determine the static longitudinal stability, the sensitivities of the lift and moment equations to angle of attack must be calculated. An aircraft is said to have longitudinal static stability if it fulfills the following requirements:

$$C_{m\alpha} < 0 \tag{1}$$

$$C_{m0} > 0 \tag{2}$$

3.2 Dynamic Longitudinal Stability

The study of dynamic stability is about the response of the motion of the vehicle after it is disturbed from its equilibrium point. The reduction of the disturbance with time indicates that there is positive damping. This will make the energy of the motion is being dissipated. Force and moments will oppose the motion of the airplane and cause the disturbance to damp out with time.

The longitudinal motion of the airplane (control fixed) disturbed from its equilibrium flight condition is characterized by two oscillatory modes of motion. The first mode is lightly damped and has a long period. This motion is called the long period or phugoid mode. The second mode is heavily damped and has a very short period. This mode is called the short period mode.

The equation of motion for the aircraft is using the linearized longitudinal equations (linear differential equations with constant coefficient). The coefficient in the differential equation are made up of the aerodynamic stability derivatives, mass, and inertia characteristics of the airplane. These equation is called the state-space or state variable equation and represented as

$$x = Ax + B\eta \tag{3}$$

Where x is the state vector and η is the control vector are given by

$$x = \begin{bmatrix} \Delta u \\ \Delta w \\ \Delta q \\ \Delta \theta \end{bmatrix}, \ \eta = \begin{bmatrix} \Delta \delta_e \\ \Delta \delta_T \end{bmatrix} \tag{4}$$

And the matrices A and B are given by

$$A = \begin{bmatrix} X_u & X_w & 0 & -g \\ Z_u & Z_w & u_0 & 0 \\ M_u + M_{\dot{w}} Z_u & M_w + M_{\dot{w}} Z_w & M_q + M_{\dot{w}} u_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{5}$$

$$B=\begin{bmatrix} X_{\delta e} & X_{\delta T} \\ Z_{\delta e} & Z_{\delta T} \\ M_{\delta e}+M_{\dot{w}}Z_{\delta e} & M_{\delta T}+M_{\dot{w}}Z_{\delta T} \\ 0 & 0 \end{bmatrix} \tag{6}$$

where

$$X_u=\frac{-(C_{Du}+2C_{D0})QS}{mu_0},\ Z_u=\frac{-(C_{Lu}+2C_{L0})QS}{mu_0} \tag{7}$$

$$X_w=\frac{-(C_{D\alpha}-C_{L0})QS}{mu_0},\ Z_w=\frac{-(C_{L\alpha}+C_{D0})QS}{mu_0} \tag{8}$$

$$M_u=C_{mu}\frac{(QS\bar{c})}{u_0I_y},\ M_w=C_{m\alpha}\frac{(QS\bar{c})}{u_0I_y} \tag{9}$$

$$M_{\dot{w}}=C_{m\dot{\alpha}}\frac{\bar{c}}{2u_0}\frac{QS\bar{c}}{u_0I_y},M_q=C_{mq}\frac{\bar{c}}{2u_0}\frac{QS\bar{c}}{I_y} \tag{10}$$

The homogeneous solution to equation (3) can be obtained by assuming a solution of the form

$$x=x_re^{\lambda_rt} \tag{11}$$

Substituting equation (11) into equation (3) yields

$$[\lambda_rI - A]x_r=0 \tag{12}$$

Where I is the identity matrix. For a nontrivial solution to exist, the determinant must be zero.

$$[\lambda_rI - A]=0 \tag{13}$$

The roots (λ_r) of equation (13) are called the characteristic roots or eigenvalues. The aircraft is said to have dynamic longitudinal stability if the position of the characteristic roots is to the left of the imaginary axis or the real values of the roots are negative.

4 Result

Input on the Digital Datcom for the STTA-12 MXA aircraft configuration includes Wing-Body-Horizontal Tail-Vertical Tail, variations in altitude, and aircraft speed. Figure 2 is an example of input entered into the Digital Datcom software, based on the configuration of the STTA-12 MXA aircraft with several variations of angle of attack (between -2° to 20°) and flight altitude (0 meters to 4115 meters) to analyze the stability of the longitudinal dimension statics.

```
DIM M
DERIV RAD
DAMP
PART

****************************
*         Flight Condition *
****************************
 $FLTCON LOOP=1.0,
         NMACH=1.0,MACH(1)=0.2,
         NALT=1.0,ALT(1)=4115.0,
         NALPHA=8.0,ALSCHD(1)= -2.0,0.0,2.0,6.0,10.0,14.0,16.0,20.0$
```

Fig. 2. Flight Condition Data

The Datcom output generated after the program is run is in the form of aerodynamic parameters such as C_L, C_D, and C_M and their derivatives.

Table 4. Parameter C_L, C_D, dan C_M

α (°)	C_L	C_D	C_M
-2	0.0869	0.0188	0.0694
0	0.2674	0.022	0.0510
2	0.4549	0.029	0.0472
6	0.848	0.0557	0.0777
10	1.262	0.101	0.1086
14	1.589	0.1497	0.0656
16	1.701	0.1687	-0.0191
20	1.808	0.1924	-0.2546

Table 5. Longitudinal Derivative

Parameter	Nilai	Satuan
Q	1775.9	kg/m^3
X_u	-0.0086	1/s
X_w	-0.0057	1/s
$X_{\delta e}$	0	$m/rad.s^2$
Z_u	-0.0071	1/s
Z_w	-0.0970	1/s
Z_α	-6.4250	1/s
$Z_{\delta e}$	-3.4325	$m/rad.s^2$
M_u	0	1/m.s
M_w	-0.0038	1/m.s
M_α	-0.2500	$1/s^2$
M_q	-1.4790	1/s
$M_{\dot{w}}$	0.0018	1/m
$M_{\dot{\alpha}}$	0.1192	1/s
$M_{\delta e}$	-5.8448	$1/s^2$

Based on the results obtained in Table 4, the relationship between the angle of attack (α) and the moment pitch coefficient is that the greater the angle of attack value, the smaller the moment pitch coefficient value, so it has a negative line gradient value. In these data the value of the moment pitch coefficient when the angle of attack is equal to zero is positive. The discussion states that the aircraft has longitudinal static stability because the line gradient value ($C_{m\alpha}$) is negative ($C_{m\alpha} < 0$) and the moment pitch coefficient when the angle of attack is zero (C_{m0}) is negative ($C_{m0} > 0$).

The data in Table 5 is used to create matrix A.

$$A = \begin{bmatrix} -0.0086 & -0.0057 & 0 & -9.8 \\ -0.0071 & -0.0970 & 66.25 & 0 \\ 0 & -0.0039 & -1.3598 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

From matrix A, the characteristic roots of the aircraft, damping ratio, natural frequency, and damped frequency are obtained which can be seen in Table 6.

Table 6. Characteristic Roots in the Longitudinal Motion

Modus Gerak	Parameter	Nilai	Satuan
Phugoid (long period)	Eigenvalue	-0.0043 ± 0.0322i	
	Period	193.3287	sec
	Undamped Natural Frequency (ω_n)	0.03257	rad/sec
	Damped Natural Frequency (ω_d)	0.0325	rad/sec
	$T_{1/2}$	160.4651	sec
	$N_{1/2}$	0.8313	cycles
	Damping Ratio	0.132	
Short Period	Eigenvalue	-0.7284 ± 1.0449i	
	Period	4.9473	sec
	Undamped Natural Frequency (ω_n)	1.2734	rad/sec
	Damped Natural Frequency (ω_d)	1.27	rad/sec
	$T_{1/2}$	0.9472	sec
	$N_{1/2}$	0.1917	cycles
	Damping Ratio	0.572	

In table 6 it is known that the characteristic roots are complex numbers and have negative real values. This indicates that the position of the characteristic roots is to the left of the imaginary axis so that it can be said that the STTA-12MXA aircraft has dynamic stability.

The response from each state can be seen in Figure 3.

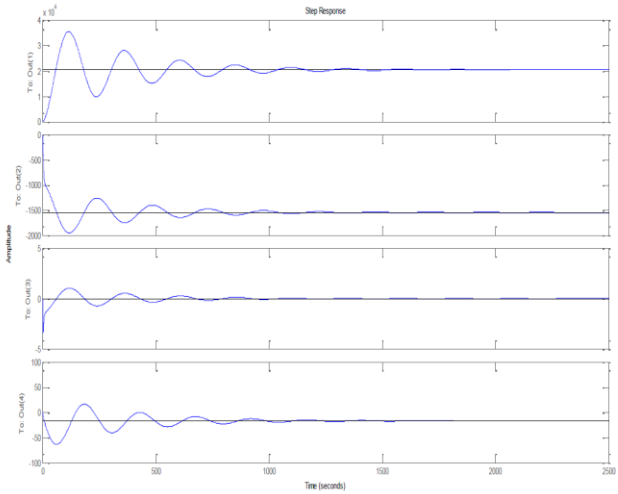

Fig. 3. Response of The Longitudinal Motion

5 Conclusion

The result of simulation with Datcom on STTA-12MXA aircraft have been presented specifically conducted for the purpose of dynamic stability assessment. The longitudinal aircraft stability and the damping characteristic of aircraft response modes have been estimated. The STTA-12MXA aircraft have an longitudinal dynamic stability.

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