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EXPERIMENTAL FIGHTER AIRCRAFT GROUND MANEUVER SIMULATION

Ida Farida[1*], Kukuh Prasetyo[2], Eka Irianto Bhiftime[3], Nick Holson Manggiring Silalahi[4], Ahmad Hasan Fauzi[5], Kurniawan[6], Tia Dikatama Tsania[7]

[1,3,4,5]Departemen Teknik Mesin, Fakultas Sains dan Teknologi Pertahanan UNHAN RI,
[2]Departemen Teknik Dirgantara, Fakultas Teknik Mesin dan Dirgantara ITB,
[6,7]National Air and Space Power Of Indonesia;

**corresponding author: ida.farida@idu.ac.id*

Abstrak — *This study aims to explore and analyze various factors that affect ground maneuvers on fighter aircraft, focusing on the steering system and landing gear design. Fighter aircraft, as a major component in military operations, must not only have optimal air maneuverability, but also be able to maneuver on the ground effectively and efficiently. The ability to move quickly and precisely on the ground is essential. Precise ground maneuvers not only ensure the safety of the aircraft, but also affect operational efficiency and response time in dealing with emergency situations. In this study, simulations were conducted using a mathematical model developed in MATLAB/Simulink software to model and analyze aircraft movements during the ground operation phase. This model considers various important parameters such as aircraft speed, nose landing gear deflection, and weight distribution settings to obtain more accurate results. The results of this simulation show that changes in the nose landing gear deflection affect aircraft movements, including the ability to change direction with a smaller radius and shorter time. Thus, the results of this study are expected to provide new insights into fighter aircraft design to improve ground maneuver performance and improve fighter aircraft operational efficiency in various field conditions.*

Keywords: *ground maneuver, fighter aircraft, simulation, stability, MATLAB/Simulink.*

1. *INTRODUCTION*

In addition to being designed to optimize maneuverability in the air, fighter aircraft must also be able to maneuver effectively on the ground. In many situations, such as landing, takeoff, or moving at an air base, the aircraft's ability to execute precise and responsive maneuvers is crucial. Fighter aircraft ground maneuvers involve a series of actions that affect safety, speed, and the ability to accurately change direction. The ground operation phase requires the aircraft to have a highly responsive rudder system, optimal weight distribution, and efficient landing gear design. Several previous studies have shown that larger landing gear designs and more efficient rudder systems can reduce the time required to execute narrow-radius maneuvers, especially at low speeds (Johnson et al., 2018). In this context, simulations are an important tool for understanding how aircraft react to various operational parameters and terrain condi tions. The results of these simulations can be used to improve fighter aircraft design and ensure that the aircraft can operate efficiently in a variety of situations. This study aims to explore the factors that influence ground maneuver in experimental fighter aircraft and provide design recommen ations to improve operational performance on the ground.

2. METHODOLOGY

2.1 Assumptions and Limitations

This research involves complex calcula tions of the air equations based on the

derivation of Newton's first law. The follo wing are the assumptions and limitations in creating the simulation model in this study:

- *The aircraft mass is constant over the time interval in which the aircraft's motion is examined*
- *The aircraft is considered a rigid body*
- *The aircraft's mass distribution is sym metrical relative to the x-z plane*
- *The Earth's surface is considered a plane*
- *The simulation is not performed at all points in the flight envelope, but rather at specific points with constant configurations of aircraft weight, center of gravity, thrust, and flap deflection.*

2.2 Calculation of Stability Derivatives

Stability derivatives are coefficients that measure how forces and moments on an aircraft respond to changes in flight conditions, such as speed, orientation, or control surface inputs. These stability derivatives are crucial in analyzing the sta bility and characteristics of an aircraft's control system and help model how the aircraft will behave when faced with distur bances or changes in flight conditions. The type of aircraft used in this modeling is an experimental fighter aircraft from previous research (Prasetyo, 2016). The stability derivatives of the experimental fighter air craft used in this dynamic modeling were obtained using AAA (Advanced Aircraft Analysis) software. Figure 1 below shows the reesults of the stability derivative calculations from previous research.

Parameters		h = 3000 m		
		V = 340 m/s	V = 360 m/s	V = 400 m/s
C_X	C_{X_0}	-0,0149	-0,0149	-0,0149
	C_{X_α} (/rad)	0,1658	0,173	0,1454
	$C_{X_{\alpha^2}}$ (/rad)	0,0055	0,0055	0,0055
	$C_{X_{q\alpha}}$	0,0027	0,003	0,0035
	$C_{X_{\delta_E}}$ (/rad)	0	0	0
	$C_{X_{\delta_{EM}}}$ (/rad)	0,0033	-0,0038	0
C_Y	C_{Y_β} (/rad)	-0,6685	-0,6685	-0,6685
	$C_{Y_{r\alpha}}$	0	0	0
	$C_{Y_{p\alpha}}$ (/rad)	0,5952	0,5894	0,5786
	$C_{Y_{\delta_A}}$ (/rad)	0,1281	0,0829	0,0049
	$C_{Y_{\delta_R}}$ (/rad)	0	0	0
C_Z	C_{Z_0} (/rad)	3,0401	3,3298	3,7369
	C_{Z_α}	0,1078	0,1059	-0,0548
	$C_{Z_{\alpha^2}}$ (/rad)	5,7818	5,5973	5,8977
	$C_{Z_{q\alpha^2}}$ (/rad)	-0,0027	-0,0027	-0,0027
	$C_{Z_{\delta_E}}$ (/rad)	0	0	0
	$C_{Z_{\delta_{EM}}}$ (/rad)	-0,2306	-0,1128	-0,0619
C_l	C_{l_0}	0	0	0
	C_{l_β} (/rad)	-0,0891	-0,0894	-0,0895
	C_{l_p} (/rad)	-0,2388	-0,222	-0,2231
	$C_{l_{\delta_A}}$ (/rad)	0,015	0,0097	0,0006
	$C_{l_{\delta_R}}$ (/rad)	0,1112	0,1158	0,422
C_m	C_{m_0}	-0,049	-0,0497	-0,0619
	C_{m_α} (/rad)	-0,9263	-1,1154	-1,144
	$C_{m_{\alpha^2}}$	0,0039	0,0044	0,0037
	C_{m_q} (/rad)	-4,6024	-4,9754	-4,3082
	$C_{m_{\delta_E}}$ (/rad)	0	0	0
	$C_{m_{\delta_{EM}}}$ (/rad)	0,3347	0,1501	0,0086
C_n	C_{n_0}	0	0	0
	$C_{n_{\beta^2}}$ (/rad)	0,2371	0,2329	0,2269
	C_{n_r} (/rad)	-0,3722	-0,3592	-0,3471
	$C_{n_{\delta_A}}$ (/rad)	-0,0843	-0,0546	-0,0032
	$C_{n_{\delta_R}}$ (/rad)	-0,0032	-0,003	0,0006

Gambar 1. Turunan Kestabilan Sumber: (Prasetyo, 2016).

The stability derivatives which include forces and moments at three speed variations as shown in Figure 1 are used in making the ground model of the experi mental fighter aircraft to be studied.

2.3 Ground Model

The ground model in this study is a mathematical model created in MATLAB/ Simulink to simulate the ground maneuvers of the experimental fighter aircraft being studied. This ground model is a modification of previous research (Prasetyo et al., 2016) based on the general equations of aircraft motion (Lewis et al., 2003):

Translation equation:

$$\dot{u} = rv - qw - g\sin\theta + a_x$$
$$\dot{v} = pw - ru + g\sin\varphi\cos\theta + a_y$$
$$\dot{w} = qu - pv + g\cos\varphi\cos\theta + a_z$$

Rotation equation:

$$\dot{p} = (C_1 r + C_2 p)q + C_3(L_A + L_T) + C_4(N_A + N_T)$$
$$\dot{q} = C_5 pr - C_6(p^2 - r^2) + C_7(M_A + M_T)$$
$$\dot{r} = (C_8 p - C_2 r)q + C_4(L_A + L_T) + C_9(N_A + N_T)$$

Kinematic equations:

$$\dot{\varphi} = p + \tan\theta\ (q\sin\varphi + r\cos\phi)$$
$$\dot{\theta} = q\cos\varphi - r\sin\phi$$
$$\dot{\psi} = \frac{q\sin\varphi + r\cos\phi}{\cos\theta}$$

Position equation:

$$\dot{X} = u\cos\theta\cos\psi + v(\sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi) + w(\sin\varphi\sin\psi + \cos\varphi\sin\theta\cos\psi)$$

$$\dot{Y} = u\cos\theta\sin\psi + v\,(\sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi) + w\,(-\sin\varphi\cos\psi + \cos\varphi\sin\theta\sin\psi)$$

$$\dot{h} = u\sin\theta - v\sin\varphi\cos\theta - w\cos\varphi\cos\theta$$

Description of variable C:

$$C_1 = \frac{(I_{yy} - I_{zz})I_{zz} - J_{xz}^2}{I_{xx}\,I_{zz} - J_{xz}^2}$$

$$C_2 = \frac{(I_{xx} - I_{yy}I_{zz} + I_{zz})J_{xz}^2}{I_{xx}\,I_{zz} - J_{xz}^2}$$

$$C_3 = \frac{I_{zz}}{I_{xx}I_{zz} - J_{xz}^2}$$

$$C_4 = \frac{J_{xz}I_{zz}}{I_{xx}\,I_{zz} - J_{xz}^2}$$

$$C_5 = \frac{I_{zz} - I_{xx}}{I_{yy}}$$

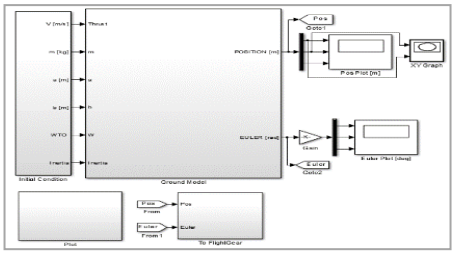
$$C_6 = \frac{J_{xz}}{I_{yy}}$$

$$C_7 = \frac{1}{I_{yy}}$$

$$C_8 = \frac{(I_{xx} - I_{yy})I_{xx} - J_{xz}^2}{I_{xx}\,I_{zz} - J_{xz}^2}$$

$$C_9 = \frac{I_{xx}}{I_{xx}\,I_{zz} - J_{xz}^2}$$

Where:
(u,v,w): linear velocity along the x,y,z axes
(p,q,r): angular velocity along the x,y,z axes
(φ,θ,ψ): Euler angles or aircraft attitude angles (roll, pitch, yaw)
(L,M,N): aerodynamic moments about the x,y,z axes (subscripts A and T represent the Aerodynamic and Thrust factors, respectively)
(Ixx,Iyy,Izz): aircraft moments of inertia about the x,y,z axes
g: acceleration due to gravity
h: flight altitude
These equations are then converted into a block model in Simulink, as shown in Figure 2 below.

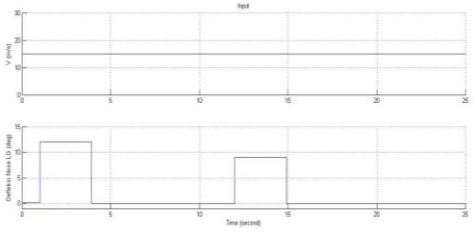


Gambar 2. Ground Model dalam Simulink

3. RESEARCH RESULTS AND DISCUSSION

3.1. Input Graph

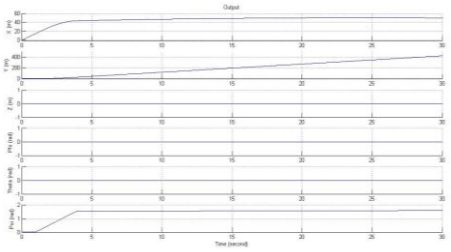
The input used in this ground maneuver is a constant speed of 15 m/s and nose landing gear deflection (δN) in the form of a pulse signal with a maximum value of 12 degrees for 3 seconds (Figure 3).



Gambar 3. Input Kecepatan dan δ_N

3.2. Output Graph and Results Visualization

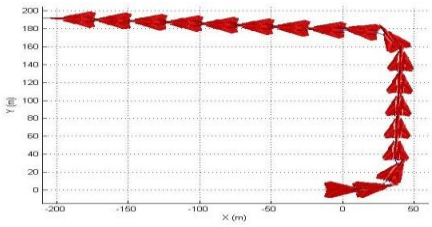
The simulation was run for 30 seconds, with the output displayed being the position (X,Y,Z) of the aircraft's center of gravity (c.g) relative to the initial position and the aircraft's attitude angles (φ,θ,ψ), as shown in Figure 4 below:



Gambar 4. Output Posisi c.g dan Sudut Sikap Pesawat (atas ke bawah: X,Y,Z,φ,θ,ψ)

The results of this ground maneuver simulation are also visualized in Trajectory and Attitude Plot Version 3, which is an add-on program in MATLAB (Valerio, 2016). This visualization provides a clearer picture of the aircraft's response to changes in nose landing gear deflection. Figure 5 below is a visualization of the results of the ground maneuver simulation. As seen in Figure 5 below, the aircraft's response is in accordance with the input given, namely two pulse signals to the nose landing gear

deflection variable, where the aircraft turns twice.



Gambar 5. Visualisasi Hasil Simulasi Ground Maneuver

4. CONCLUSION AND RECOMMENDATIONS

4.1. Conclusion

Based on the simulation results, it can be concluded that the steering system and landing gear design play a crucial role in determining a fighter aircraft's ability to perform ground maneuvers. The research shows that with proper nose gear deflection settings, the aircraft can change direction more quickly and efficiently, especially at the low speeds typically encountered during ground operations. Efficient and responsive ground maneu vers are crucial in various situations, such as when changing positions at an air base or during emergency situations on the battlefield. Furthermore, aircraft stability, influenced by weight distribution and landing gear design, significantly impacts the aircraft's ability to maneuver stably over various ground conditions or uneven terrain.

4.2. Recommendation

- *For further development, there are several things that need to be considered in this research. First, it is recommended that this research include more external variables, such as varying ground conditions and weather, which can affect the aircraft's ground maneuvering performance. The influ ence of uneven terrain, such as rough runways or rocky ground conditions, needs to be analyzed more thoroughly to see how the aircraft design can be adapted to better handle these conditions.*

- *Furthermore, further study is needed on the effect of additional loads on the aircraft, such as cargo or military equip ent, Furthermore, further studies are needed to examine the effects of additional loads on the aircraft, such as cargo or military equipment, which can affect the aircraft's balance and stability during ground maneuvers. Designing a more flexible rudder and landing gear system that can adapt to the aircraft's load could also be a focus of further research. In this regard, improvements in the aircraft's weight distribution are crucial for improving ground maneuver performance. Implementation of the results of this research is expected to contribute to the development of more efficient and safer fighter aircraft under various operational conditions, as well as to improve the effectiveness of fighter aircraft missions in the field.*

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