RESEARCH ON THE LONGITUDINAL STABILITY OF FIGHTER AIRCRAFT USING COMPUTATIONAL FLUID DYNAMICS BASED METHOD

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ABSTRACT
Stability is the most important factor of a certain aircraft model, especially fighter ones due to its strong effect on the ability to control and maneuver. Therefore, stability research is crucial in developing and validating flight simulator. In the scope of this work, the longitudinal stability of Flanker-C-Like model was numerically assessed based on MIL-F-8785C standard to confirm that its longitudinal behaviors are similar between the numerical model and real aircraft. Specifically, Computational Fluid Dynamics (CFD) method was utilized to generate the aero-lookup table in the aerodynamic model. This is the reason why, the flight dynamics model was developed to describe the six Degrees of Freedom (DOF) motion based on the forces and moments generating on the aircraft. The aero-lookup table contains static and dynamic coefficients calculated by Ansys Fluent and Athena Vortex Lattice respectively. The flight dynamics model continuously calculated the states of aircraft by solving a system of differential equations which represents the effect of gravity, engine and aerodynamic forces. The longitudinal stability was analyzed by introducing a disturbance of control signal into “trim” flight condition and then, observing the response of aircraft in the angle of attack, velocity, and altitude. The result showed that the present model was successfully described as the high maneuverability airplane which is in good agreement with Flanker-C-Like’s classification. The result also proved practical application of the CFD-based method in building the aerodynamic and flight dynamics model to access the longitudinal stability of flight objects.

KEYWORDS: Fighter Aircraft, Longitudinal Stability, Dynamic Stability Derivatives & Computational Fluid Dynamics

1. INTRODUCTION
The stability is the ability to recover stable flight condition from disturbance experience. Normally, the stability research on the aircraft can be divided into longitudinal and lateral types. Longitudinal static stability is the stability of an aircraft in the longitudinal or pitching motion under steady flight condition. Longitudinal dynamic stability addresses the rate of change in time of motion when experiences a disturbance; it normally refers to the short period and phugoid. Meanwhile, the lateral-directional mode involves rolling motion and yawing motion, which includes static and dynamic stability relating to spiral, dutch roll, and rolling modes. The scope of this work only focuses on analyzing the longitudinal dynamic stability.

In general, longitudinal stability research of an aircraft can be approached by analytical, experimental and numerical method. The first one is the simplest and fastest method normally applied in the preliminary design because of its lack of accuracy. The second one is considered as an accurate method to test the longitudinal stability; however, it requires a costly and time-consuming process. The numerical method is more advanced and practical to fill the gap between the analytical and experimental method, thanks to the development of high-performance computer and cloud-based computing. The numerical approach mentioned above is used to generate the aero-lookup table and calculate real-time states of fighter aircraft. In this work, the Computational Fluid
Dynamics (CFD) method was applied to handle the main challenge, which is the estimation of both static and dynamic aerodynamic coefficients in the region of interest. Moreover, the flight dynamic model is also developed to solve a system of governing equations describing six Degrees of Freedom (DOF) motion of fighter aircraft.

In order to investigate the longitudinal stability, at first, the “trim” flight condition has to be determined. Theoretically, in “trim” flight condition, the summation of forces and moments is zero. Therefore, the aircraft moves with constant states (speed, angle of attack and sideslip angle) except for position. Then, during “trim” flight condition, a disturbance of control signal (throttle or pitch control panel) is introduced. Taking into account the responses of the system via the damping ratio, and natural frequency, then comparing them to MIL-F-8785C standard of longitudinal stability can determine the level of aircraft stability. Following MIL-F-8785C standard [1], airplane types are classified broadly into 4 classes according to size and weight: (I) Small light airplanes; (II) Medium weight, low to medium maneuverability airplanes; (III) Large, heavy, low to medium maneuverability airplanes; (IV) High maneuverability airplanes. Moreover, the flight phase categories are defined as 3 categories: (A) Non-terminal flight phases that require rapid maneuvering, precision tracking, precision flight path control; (B) Non-terminal flight phases that require gradual maneuvering, less precision tracking and accurate flight path control; (C) Terminal flight phases that require gradual maneuvering and precision flight path control. In fact, Flanker-C is a multirole combat aircraft [2] with high maneuverability, thus, it is a class IV airplane. Besides, in the scope of this research, Flanker-C-Like model has investigated the longitudinal stability in the cruise phase (Category A). Thus, the response of Flanker-C-Like model should satisfy the standard of damping ratio and natural frequency related to Class IV airplane and Category A flight phase.

In the aerodynamic model, there are two types of aerodynamic coefficients: static and dynamic coefficients; out of which, the numerical method to calculate static coefficient, which is widely researched in the CFD community for the decade. Now-a-days, RANS turbulence model, average quality of grid and moderate computer resource could generate a good result comparing to experiment [3]. Regardless the limitation of computation, using advanced turbulence model and increasing mesh refinement capability, CFD method can yield very good agreement with flight-test data [4–6]. The determination of dynamic coefficient is more complicated than static one due to the transient calculation, deforming mesh, and result analysis. Andrea Da Ronch[7] studied about the conventional method to numerically estimate the dynamic coefficient or stability derivatives of the Standard Dynamics Model geometry based on RANS (Reynolds Average Navier-Stokes) solution. The time-dependent aerodynamic coefficients are analyzed using Taylor series expansion to approximately calculate forces derivatives and pitching moment derivatives with respect to angle of attack rate and pitch rate. Bai-gang Mi[8] presented a new systematic CFD method to calculate static and single dynamic stability derivatives of aircraft. In the research, angle of attack step response is used to obtain static derivative directly; then translation acceleration dynamic derivative and rotary dynamic derivative can be calculated by employing the step response motion of rate of the angle of attack and unsteady motion of pitching angular velocity step response, respectively. The result shows a good agreement with reference value and experiments data. However, the drawbacks of this method are the need of the hardware resources and the significant computing cost. Research[9] shows that the comparison of stability derivatives obtained from CFD and Athena Vortex Lattice (AVL) on twin boom UAV. The result proves the fair similarity between 02 methods in the certain range of angle of attack. Based on the purpose of current research, the longitudinal stability in the cruise phase of flight is studied. Therefore, this work proposes a new method to generate aerodynamic databases. Out of which, the static coefficients are calculated by high-fidelity CFD to achieve a good approximation and the dynamic one are obtained by low-fidelity CFD for a optimization of computing cost and level of accuracy.
For the flight dynamics model, David Allerton [10] and Hou [11] presented the governing components including forces, moments and six degree of freedom (6 DOF) to determine the states of aircraft. To be more specific, the signals from the pilot were converted to control signals in the flight control module. Then, the dynamic module collects all the data from forces, moments and previous states to determine the current states of aircraft. The flight dynamics model is used in so many previous researches and show its accuracy such as (1) Luat T. Nguyen [12] researched on stall/post-stall characteristics of fighter airplane with relaxed longitudinal static stability by using simulator; (2) Antony Snell [13] developed a nonlinear inversion flight control, a super maneuverable aircraft; (3) Albostan[14] focused on the high angle of attack maneuvering control of F-16 aircraft based on nonlinear dynamic inversion and eigen structure assignment design applied on nonlinear F-16 aircraft dynamic. This work aims to develop a flight dynamics model which is customized in the general form to study longitudinal stability. M. Kamal [15] used 6 DOF nonlinear model and aero database calculated by using Digital DATCOM to simulate a small commercial aircraft (Tiger – Trainer airplane).

The current work is not only focusing on generating the aerodynamic model using CFD and developing flight dynamic model but also combining aerodynamic model and flight dynamic model in order to build a numerical solution of longitudinal stability assessment. For an improvement, the developed solution was applied to investigate the longitudinal stability on Flanker-C-Like model in the subsonic region. In general, this paper includes 5 parts: (1) Brief introduction of current research and literature review; (2) CFD work was performed to calculate static and dynamic aerodynamic coefficients of Flanker-C-Like model; (3) Flight dynamics model was described in detail to calculate the real-time states of aircraft from pilot action; (4) Longitudinal stability was studied via the response of the Flanker-C-Like model with and without disturbance; (5) Final part summarized the result, discussion, and future work.

2. COMPUTATIONAL FLUID DYNAMIC

The CFD-based method is the numerical method to predict the aerodynamic coefficient, both static and dynamic, such as lift, drag, pitching moment coefficients. In this study, two types of CFD code were combined to generate the full aero look-up table over a range of angle of attack (AOA) from -5 to 10 degree. Concretely, Ansys Fluent is high-fidelity CFD code to estimate static aerodynamic coefficient [16], while AVL is used to calculate the dynamic aerodynamic coefficient in the low angle of attack region [17,18]. These aerodynamic coefficients were used as parameters of the aerodynamic model in the flight dynamic model to calculate the states of aircraft.

2.1. Methodology

A numerical method is required to solve a complicated set of ODEs including mass and momentum conservative equations. In the present work, the turbulence equation is also calculated to capture the complex behavior of airflow over the sharp edges of the airfoil. These governing equations can be written as:

Mass conservation equation

$$\frac{\partial}{\partial t}(\rho) + \nabla(\rho \mathbf{v}) = 0$$

(1)

Momentum conservation equation

$$\frac{\partial}{\partial t}(\rho \mathbf{v}) + \nabla(\rho \mathbf{v} \mathbf{v}) = -\nabla P + \nabla \mathbf{f} + \rho \mathbf{g}$$

(2)

Turbulence equation (k-ε model)
\[ \frac{\partial}{\partial t}(\rho k) + \nabla \cdot (\rho k \vec{v}) = \nabla \cdot \left( \frac{\mu}{\sigma_k} \nabla k \right) + C_k - \rho \varepsilon \]  

(3)

\[ \frac{\partial}{\partial t}(\rho \varepsilon) + \nabla \cdot (\rho \varepsilon \vec{v}) = \nabla \cdot \left( \frac{\mu}{\sigma_\varepsilon} \nabla \varepsilon \right) + C_{1\varepsilon} \rho_k - C_{2\varepsilon} \rho \varepsilon \]  

(4)

Here, \( \rho \) is the density, \( \vec{v} \) is the velocity, \( P \) is the combined pressure for the two phases, \( g \) is the gravitation acceleration, \( \tau \) is the tensor term of stress-strain, and \( \sigma_k, \sigma_\varepsilon, C_{1\varepsilon}, C_{2\varepsilon} \) are constant. Overall, the procedure includes 3 steps as follows: (1) The geometry domain is subdivided into finite volumes; (2) The PDEs are integrated over the finite volume and overtime to yield to a set of non-linear algebraic equations. The boundary conditions are also put into an algebraic form; (3) The system of equations can be solved numerically by replacing the partial derivatives by finite differences on a discrete numerical grid and then advancing the solution in time via some numerical schemes algorithm. The process is repeated until steady-state established or out of time. The next section presents a detailed description of the CFD model, which is divided into 2 main parts: pre-processing and post-processing.

2.2 Pre-Processing

2.2.1 Geometry Domain and Meshing Generation

The geometry, shape and parameters of Flanker C model used for calculation of dynamic coefficient are shown in figure 1 and table 1.

In order to produce the aero-lookup table for aerodynamic coefficient, building a wind tunnel around the fighter aircraft with high-quality meshing is a must for Ansys Fluent, as shown in figure 2a. Similarly, the AVL also requires a fair approximation of geometry, as shown in figure 2b. Assuming the aircraft is symmetrical along the longitudinal plane,
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figure 2a illustrates geometry domain for half of the aircraft in order to save computational cost while maintaining the accuracy of the model. The surface mesh of the aircraft and symmetry plane was made up by the triangles as shown in figure 3. Moreover, the boundary layers in quadrilateral shape near the aircraft wall were added in the symmetry plane. It is very important to resolve the near-wall regions in order to capture the behavior of flow over the wing and tail, where the edges are very sharp and small compared to the whole model.

Figure 2: Numerical Geometry Domain and Meshing Generation: (a) Fluid Domain Surrounding the Aircraft (Ansys Fluent); (b) Approximation of the Aircraft Surface (AVL).

Figure 3: The Surface Mesh of half of the Aircraft and the Symmetry Plane.

After generating a good-quality surface mesh with closed areas, volume meshing can be proceeded. Total 8 (eight) layers of hexahedral cells were generated with a smooth transition. The rest of the model was meshed with tetrahedral elements. Some detailed areas surrounding wings, tails and small gaps between the engine and fuselage were meshed with finer cells. The detail of the volume mesh is described in Figure 4. A total of approximately 9.2 million elements were generated with a maximum skewness less than 0.9 and a maximum aspect ratio of around 1200. According to mesh quality criterion [19], this mesh met the requirement and was chosen for further study.
2.2.2 Boundary Conditions and Solver Settings

The airflow was considered to be compressible at Mach number of 0.6, steady-state and viscous turbulent flow. The boundary condition was set to be pressure far-field for the inlet and pressure outlet for the outlet. Wall boundary conditions were set to be smooth (no-slip condition), which means velocity at the wall has zero tangential components. As mentioned in the meshing, the symmetry boundary condition was also applied. Mathematically, normal gradients to the symmetry plane of flow field variables were set to zero throughout the symmetry plane. Gravitational acceleration ($g = 9.81 \text{ m/s}^2$) was applied in the reversed y-direction. In order to calculate the force and moment coefficients at a different altitude, the angle of attack (AOA) was set to be 0 (Zero), 5 (five) and 10 (ten) degrees.

The pressure-based solver was utilized to solve the governing equations in a coupled manner, which means the continuity and momentum were solved simultaneously. This solution’s convergence rate is greatly enhanced compared to the sequential pressure algorithm. To ensure the convergence of the model, first-order upwind was used first until the solution got stable, then solver was switched to second-order upwind for better accuracy.

2.3 Post-processing

The contours of pressure and velocity distribution for the case AOA = 0 degree are shown in this section. Figure 5 presents the pressure distribution on the body of the aircraft. The pressure is highest at the nose and leading edges of the wings and tails, which confronts the wind. Moving over the nose, wing, and tail, the pressure dropped significantly before increasing slightly at the trailing edges. This observation is in agreement with other works such as Chen and Yong-Chao [20] and Xie et al [21].

![Figure 5: Pressure Distribution on the Body of Aircraft.](image)
The effect of airfoil on the pressure and velocity distribution was also studied in figure 6 and figure 7. The lift was generated due to the difference in pressure between lower and upper regions. As shown in figure 6, the upper surface experienced lower pressure compared to the lower surface. According to Bernoulli’s principle, the airflow accelerated along the upper surface and its velocity decreased along the lower surface. This phenomenon is observed in figure 7. At the trailing edge, the flow separation was also presented. This is due to the high-resolution mesh with boundary layers in these sharp edges.

![Figure 6: Effect of the Airfoil of the Wings on the Pressure Distribution.](image1)

Figure 8 described the velocity distribution of the incoming flow stream over the fuselage of the aircraft. This allows investigating local velocity and how it changes for a specific surface in parametric study. For example, figure 9 compared the velocity streamlines in cases of AOA = 0 and AOA = 5 degree. It is clear that airflow in case AOA = 5 degrees experienced higher acceleration and turbulence at the tail, while airflow in case AOA = 0 degree remained laminar.

![Figure 7: Effect of the Airfoil of the Wings on the Velocity Distribution.](image2)
Figure 8: Velocity Streamline over the Fuselage of the Aircraft.

Figure 9: Effect of Angle of Attack (AOA) on the Velocity Streamlines over the Wings.

3. FLIGHT DYNAMIC MODEL

The flight dynamics model was developed based on a set of modules including engine, environment, gravity and aerodynamic module \cite{6,13}. These modules calculated forces and moments which affect aircraft using the parameters from airframe parameters unit. Environment module was designed to determine the properties of surrounding air such as density and Mach number which strongly affect aerodynamic, engine forces and moments \cite{23}. Moreover, the role of the controller module was to convert the control action of pilot to control signals which are directly used in the aircraft dynamic model. Six DOF module or integration module, collecting the forces and moments as an input, integrated the differential equation system describing the states of fighter aircraft \cite{10}. Mathematically, these dynamic equations are illustrated in figure 10 with the reference from previous research \cite{10,22-24}. Here, the response of aircraft (position, velocities, and Euler angles) is obtained as an output of the pilot action.
The aircraft dynamic equations are presented below, including 12 equations to calculate the aircraft’s position \((p, q, r)\) in a set of equation 3; aircraft’s velocities \(\dot{v}, \dot{w}\) in a set of equation 4; Euler angles \(\varphi, \theta, \psi\) in a set of equation 5 and Euler rates \(\dot{\varphi}, \dot{\theta}, \dot{\psi}\) in a set of equation 6:

\[
\begin{align*}
\dot{v} &= \left( \frac{c_{\theta}}{c_{\theta}} - c_{\theta} \right) + \left( \frac{s_{\theta} \psi}{s_{\theta} \psi} - c_{\theta} \right) \frac{s_{\theta} \psi}{s_{\theta} \psi} \psi \\
\dot{w} &= \left( \frac{s_{\theta}}{s_{\theta}} + c_{\theta} \right) + \left( \frac{s_{\theta} \psi}{s_{\theta} \psi} + c_{\theta} \right) \frac{s_{\theta} \psi}{s_{\theta} \psi} \psi \\
\dot{\varphi} &= \frac{1}{\psi} \left( \frac{c_{\theta} \varphi}{c_{\theta} \varphi} + c_{\theta} \right) \frac{c_{\theta} \varphi}{c_{\theta} \varphi} \psi \\
\dot{\theta} &= \frac{1}{\psi} \left( \frac{c_{\theta} \varphi}{c_{\theta} \varphi} + c_{\theta} \right) \frac{c_{\theta} \varphi}{c_{\theta} \varphi} \psi \\
\dot{\psi} &= \frac{1}{\psi} \left( \frac{c_{\theta} \varphi}{c_{\theta} \varphi} + c_{\theta} \right) \frac{c_{\theta} \varphi}{c_{\theta} \varphi} \psi
\end{align*}
\]

(3) 

(4) 

(5) 

(6) 

Where \(F_r, l, m, n\) are respective forces and moments acting on aircraft shown in figure 10; symbols: \(c_{\theta} = \cos \theta, s_{\theta} = \sin \theta\), \(\Gamma_i\) coefficients relate to the inertial momentums of aircraft, are calculated in several flight dynamic books [10,22].

As shown in Figure 10, the pilot actions are converted to control signals by controller module in which throttle, pedal, and joystick signals are normally variant in the range of \([0, 1]\) or \([-1, 1]\). Then, a predefined map is provided to determine the values of the control surface or control signals. These values are important to look-up the aerodynamic coefficients or the propulsive force of the engine. The engine module determines the propulsion of the engine in
longitudinal and vertical axes. In addition, the engine generates a pitch moment because the center of gravity is not aligned with the propulsion force vector. Gravity module simply calculates the gravitational force acting on the aircraft that depends on the aircraft states. In order to study the longitudinal stability, the longitudinal aerodynamic coefficient (lift, drag and pitching moment) is definitely important. Mathematically, the total aerodynamic coefficient of longitudinal channel is derived as a summation of static and dynamic coefficient as following [25]:

\[ C_A = C_{A,\text{static}} + qC_{Aq} + \alpha C_{A\alpha} + \dot{q}C_{Aq} + ... \]  

(7)

Where subscript A represents for both force and moment. Moreover, in equation 7, \( C_{A,\text{static}} \) is a table of coefficient describing the change of force or moment purely due to the change of angle of attack. The rest represents for the change of force or moment due to the speed of change of AOA, so-called, stability derivatives. These coefficients are completely pre-defined using CFD as shown in the previous part.

4. LONGITUDINAL STABILITY

An aircraft is in a state of equilibrium or “trim” flight condition only if the sum of the forces and moments acting on the aircraft is equal to zero. It means that the aircraft experiences no accelerations, the aircraft stays at a steady condition of flight with maintaining the velocity and altitude. Thus, the static stability is regularly interpreted to describe the tendency of aircraft’s movement after undergoing a disturbance from the equilibrium state. Theoretically, static stability is classified into the three types of static stability: positive, neutral and negative [24,26,27]. Concretely, an aircraft that has positive static stability tends to return to its original altitude when it is disturbed. Meanwhile, neutral static stability aircraft tends to stay in its new altitude. And, an aircraft that has negative static stability tends to continue moving away from its original altitude when it is disturbed. To achieve the function of requirement and fly easily, Flanker-C fighter design must be positive static stability or at least natural static stability [2].

Dynamic stability deals with the resulting motion with time after acting the perturbation. If an object is disturbed from equilibrium, the time history of the resulting motion defines the dynamic stability of the object. In general, an object demonstrates positive dynamic stability, if the amplitude of oscillation decreases with time. Inversely, if the amplitude of oscillation increases with time, the object is dynamic instability. It is similar to static stability; any aircraft must meet a certain requirement of dynamic stability. If an aircraft were designed with static instability and a rapid rate of dynamic instability, the aircraft would be very difficult, even impossible to fly. If an aircraft has a tendency to go to a constant AOA, then it is longitudinal stability. Indeed, positive dynamic stability is an important condition of aircraft design to prevent divergent-oscillations.

As mentioned above, longitudinal stability refers to motion in pitching motion such as short period mode and phugoid mode [27]. In this part, the longitudinal stability characteristic of Flanker-C-Like model was studied. The achieved results (damping ratio, the natural frequency of short-period mode and phugoid mode) were compared with MIL-F-8785C standard to determine the type of aircraft. This result should be suitable for the role and ability of Flanker-C fighter aircraft.

In fact, aircraft’s stability affects maneuverability and controllability characteristic of aircraft. If the aircraft is high stability, it has low maneuverability. Because, the fighter aircraft normally require high maneuverability, thus in exchange, its stability level is often low.
4.1. Methodology

After finishing with the modules in the flight dynamics model, especially for the aerodynamic model, the “trim” flight condition must be calculated by the trimming process. The objective of trimming is to predict a special state of aircraft when the total forces and moments acting on the aircraft are equilibrium. That is the flight condition when the axial, normal, side forces, and the roll, pitch, yaw moments are approximately zero \[^{22,28}\]. In the scope of this work, trimming in longitudinal direction is considered, assuming that aircraft is symmetrical. The result of the trimming process is a “trim” flight condition with constant altitude, speed, AOA, pitching rate and Euler angles. After that introducing a disturbance of elevator surface, then, aircraft’s stability can be analyzed and compared with stability standard of MIL-F-8785C \[^{1,29}\]. The algorithm of trimming process on the longitudinal channel in detail is shown in figure 11 below.

![Diagram of Longitudinal Trimming Process](image)

**Figure 11:** Algorithm of Longitudinal Trimming to Find the Equilibrium Point.

5. RESULT AND DISCUSSIONS

This research focused on analyzing the longitudinal stability at Mach 0.6 of fighter aircraft. At first, the result of trim mode of Flanker-C-Like model is presented in Figure 12. The aircraft stayed at constant altitude level and velocity state during the flying time with the tolerance of less than 0.001\%. Therefore, the trim mode is totally correct with the flight theory as mentioned above. The equilibrium states and control inputs are presented in table 2 and table 3 respectively.

**Table 2: Aircraft’s State at Equilibrium Point**

| Position (m) | \(|V, \alpha, \beta| \) (m/s rad rad) | Euler Angle (rad) | Euler Rate (rad/s) |
|--------------|-------------------------------------|-------------------|-------------------|
| 0            | 0 5000 192 0.0563 -7.4x10^{-10} | 0.00025 0.0563 0 | -3.2x10^{-9} 2.4x10^{-8} 3.1x10^{-10} |

**Table 3: Aircraft’s Control Surfaces at Equilibrium Point**

<table>
<thead>
<tr>
<th>Elevator</th>
<th>Aileron</th>
<th>Rudder</th>
<th>Throttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5.25°</td>
<td>0.0°</td>
<td>0.0°</td>
<td>0.193</td>
</tr>
</tbody>
</table>
Firstly, the elevator’s disturbance with the magnitude of 1 degree per second was applied to research on phugoid dynamic around the equilibrium point. In Figure 13, the phugoid mode has oscillations with a damping ratio of 0.0426, frequency of 0.0786 rad/s. The result follows with the MIL-F-8785C standard for supper maneuver aircraft which has damping more than 0.04 such as in Table 4. During this mode, the aircraft maintains essentially a constant angle of attack. Aircraft has dynamic stability which is near natural stable to permit high maneuver of fighter aircraft. Because, the period of this oscillation is 79.93 seconds and the amplitude changes lightly (±50m of altitude and ±2m/s of velocity), the pilot can control aircraft easily.

<table>
<thead>
<tr>
<th>No.</th>
<th>Mode</th>
<th>Factor</th>
<th>MIL-F-8785C Result</th>
<th>Actual Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Short – period</td>
<td>Damping ratio $\zeta_{SP}$</td>
<td>$\zeta_{SP} \leq 1.50$</td>
<td>0.279</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency $f$ (Hz)</td>
<td>$0.28 &lt; f &lt; 3.6$</td>
<td>0.748</td>
</tr>
<tr>
<td>2</td>
<td>Phugoid</td>
<td>Damping ratio $\zeta_{SP}$</td>
<td>$\zeta_{SP} &gt; 0.04$</td>
<td>0.0426</td>
</tr>
</tbody>
</table>
Secondly, the elevator’s disturbance with the magnitude of 1 degree per 4 seconds around the equilibrium point was applied to research the short period dynamic stability in fighter aircraft. The oscillation of short-period mode has a damping ratio of 0.279, frequency of 0.748 Hz. This aircraft follows the MIL-F-8785C standard in short period mode for high maneuver aircraft which have frequency from 0.28 to 3.6 Hz such as in table 4. In addition, location of poles are calculated as ssp = $-0.00335 \pm 0.0786i$ which can be drawn in s plane like figure 14. This figure shows the location of poles which are very close to imaginary axis and on the left side of this axis, so it is low stable [30]. Figure 15 shows the variation of the angle of attack over time. This angle has quickly overshot with initial disturbance. After the disturbance disappears, this angle is stable near the equilibrium state. Aircraft with low short period damping rations tends to be easily excited by control inputs and have long oscillation. The short period mode occurred immediately when the disturbance appeared and existed in a short time, so it affects lightly to control ability.

Finally, these above results are following the MIL-F-8785C standard. Flanker-C-Like fighter has low stability, but it can be ably controlled and also rely on electronic system to aid it’s in its flight. These results guarantee the compulsory requirement of fighter aircraft that is highly manoeuvre. The consequently, the aerodynamic data created by combining CFD and AVL method can be used to model and analyze the fighter aircraft.

**Figure 13: The Response of Aircraft in Phugoid with Elevator’s Disturbance.**
Figure 14: Location of Poles in Short Period Mode.

Figure 15: The Response of Aircraft in a Short Period with Elevator Disturbance.

6. CONCLUSIONS

In the present work, the CFD-based approach was carried out to assess the longitudinal stability of fighter aircraft, namely Flanker-C-Like model. The result is in good agreement with the description of this fighter aircraft referring to MIL-F-8785C standard. Concretely, the fighter aircraft is a multi-role combat aircraft with high maneuverability, rapid maneuvering, precision tracking, and precision flight path control. Firstly, the aerodynamic model is developed to describe the response of aircraft under the effects of surrounding airflow. The aero-lookup table is generated based on the CFD
method (finite volume and vortex lattice method) both static and dynamic coefficient. Secondly, the flight dynamic model is also built to predict the six DOF motions of fighter aircraft under the acting of engine, environment, gravity and aerodynamic model. In order to study the longitudinal stability of Flanker-C-Like fighter, “trim” flight condition is determined as the initial condition. Then, a disturbance is introduced into the control signal of fighter aircraft. Thus, the response shows the longitudinal stability of Flanker-C-Like model in comparison with the stability standard. The result of research proves the CFD-based approach as a practical tool to estimate the longitudinal stability for aircraft design and flight simulation. For the future work, the lateral stability will be studied, in order to completely assess the stability characteristics of Flanker-C-Like model or any type of aircraft.

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