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Matlab-Based Application Design for Flight Recording Data Analysis in Short Period Oscillation

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***Abstract* - This study aims to design an application to process flight test data in the short period oscillation phase of an aircraft. The short period mode is a phenomenon related to the flight stability of an aircraft. This mode has strong damping characteristics and a short oscillation period. Therefore, the analysis of this oscillation mode is very important to ensure the performance and safety of the aircraft in meeting the targets. The application designed in this study has the function to process flight test data, process signals, display the results in graphical form, and calculate the damping ratio of the aircraft. By using numerical data processing methods, this application can produce graphs that describe the characteristics of aircraft oscillations, such as amplitude and frequency, which then produce aircraft damping values to assess stability when airborne. Data processing and graphic visualization are carried out using the MATLAB application, with the Savitzky-Golay Filter approach and identification of vibration characteristics using the time step response method. The results of this study are expected to be an effective tool for aviation engineers in identifying potential problems in the short period mode and providing recommendations for design decisions that meet the criteria.**

Keywords: Application Design, Short Period Mode, Savitzky-Golay Filter, Time Step Response, MATLAB.

I. INTRODUCTION

In the aerospace industry worldwide, to ensure the safety of every item produced or intended for use, each item must undergo a testing and certification process. This certification process encompasses various aspects, such as structure, efficiency, and stability. The stability of an aircraft is assessed by its ability to return to a state of equilibrium flight after being subjected to a disturbance (Yechout & Morris, 2003). In achieving its normal flight state, an aircraft will oscillate in accordance with the axis of the disturbance.

Oscillations in aircraft are normal and inevitable as a result of the exchange between kinetic forces in the form of speed and potential forces in the form of height (Cook, 2007). There are two types of oscillation modes in an aircraft: short-period and long-period. The most fundamental differences between these two modes of vibration are the damping value and the length of the period.

Long-period oscillations are characterized by low damping, a prolonged period of time, and a very low amplitude that can stop spontaneously without the pilot even realizing the oscillation. This contrasts with short-period oscillations, which have high damping and a short duration. In practice, short-period oscillations are regulated by the Federal Aviation Administration (FAA) through FAR 25.181, which regulates damping, oscillation period, and oscillation speed.

Processing flight test data requires several mathematical approaches to obtain good results. One such approach is smoothing the data. These methods include the Savitzky-Golay Filter and Kernel Smoothing.

This research aims to provide a new option for an airline company to use a simple application that is used to process and display flight test data when there is a short-period oscillatory motion. The application can then be used by airline engineers to identify potential problems in the short-period mode and provide recommendations for design decisions that meet the criteria.

II. RESEARCH OBJECT

2.1 Damping coefficient

Damping is the loss of energy in an oscillating system due to dissipation (Escudier & Atkins, 2019). Some common examples of damping include surface friction, internal resistance of the oscillator, and viscous damping due to fluids. In aviation, viscous damping, in the form of drag, contributes significantly to the overall drag; both viscous drag and skin drag.

The damping coefficient describes the characteristics of the waves. A damping coefficient (ζ) below 1 indicates underdamped characteristics, a damping coefficient above 1 indicates overdamped characteristics, a critically damped

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value of 1, and a damping coefficient of 0 indicates undamped characteristics.

2.2 Short Period Mode

Short-period mode is an aircraft oscillation mode that occurs on the longitudinal axis of motion. This mode of oscillation has a relatively short period, lasting only a few seconds to less than 1 second. Because this oscillation mode occurs so quickly, it can only be observed during the initial phase of the disturbance (Nelson, 1998).

This oscillation mode is caused by a disturbance to the aircraft that causes a change in its angle of attack. Because the oscillation is short-lived, aircraft entering this oscillation mode generally maintain their momentum, so changes in speed and altitude is ignored. Figure 1 illustrates the motion of an aircraft in this vibration mode.

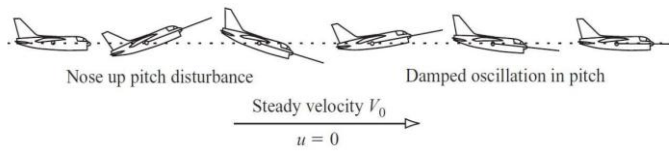

Figure 1: Aircraft motion in Short Period mode (Cook, 2007)

2.3 Savitzky-Golay Method

For a signal measured at a measurement point and using a filter of width w, the Savitzky-Golay method computes a fitting polynomial of order n in each filter window, as the filter is moved across the signal. One example of this process is shown in the three filter windows on the left of Figure 2, with w = 7. In this case, the signal is a spectrum measured at discrete points (shown by the blue dotted line). The estimated filtered output at the center of each window is given by the approximated polynomial at the point. An example fitting for window [22, 28] is shown in the subplot at the top right of Figure 2. The filtered signal at the center point, point 25, is indicated by an "X" in the subplot.

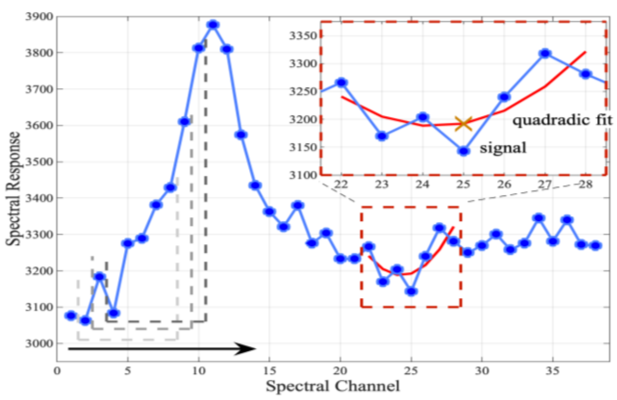

Figure 2: The example of Savitzky-Golay Filter plotting (Gallagher, 2020)

2.4 Time Step Response

Time-Step Response Identification (TSI) is a system identification technique that utilizes the system's response to step-input changes to obtain a dynamic model of the system. In this approach, the system is given an input signal in the form of a sudden surge from one constant value to another, and the resulting output response is observed and analyzed to estimate the system's characteristic parameters. This method is widely used for systems with LTI (Linear Time-Invariant) characteristics (Stocco, 2023).

$$\zeta = \frac{-\ln\left(\frac{\%OS}{100}\right)}{\sqrt{\pi^2 + ln^2\left(\frac{\%OS}{100}\right)}} \quad (1)$$

$$\omega_{nr} = \frac{\pi}{T_r \beta} - \tan^{-1}\left(\frac{\beta}{\zeta}\right) \quad (2)$$

$$\%OS = \frac{Y_{max} - Y_{steady}}{Y_{steady}} \times 100 \quad (3)$$

$$\beta = \sqrt{1 - \zeta^2} \quad (4)$$

Equation 1 above is used to find the damping ratio (ζ). Equation 2 is used to find the natural frequency of oscillation. The oscillation percentage is the ratio of the difference between the peak and steady-state values to the steady-state value, as can be seen in Equation 3. The Beta (β) value can be seen in Equation 4. The Tr value is the time required for the system to rise from 10% to 90% of its highest peak.

III. METHODS

MATLAB Graphical User Interface (GUI) is a feature provided by MATLAB to facilitate the development of graphical user interfaces. Through the GUI, users can interact with the developed program without having to type commands directly in the Command Window, but rather simply by utilizing visual elements such as buttons, sliders, text boxes, dropdown menus, and graphics. The use of GUI in MATLAB aims to increase comfort and ease in program operation, minimize data input errors, and speed up the process of interaction and analysis of data or simulation results.

The original data provided by the sensors is stored in Excel format, containing thousands of discrete data points from eight different variables. All of this data is measured over time and used to analyze the aircraft's flight dynamics during testing. The eight variables are: altitude, velocity (horizontal speed or ground speed), angle of attack, elevator deflection (DE), elevator control force (FE), and three

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components of the aircraft's rotation rate: pitch rate (Q), roll rate (R), and yaw rate (P).

The data presentation format in the Excel file has an unconventional structure, where all values for each variable are arranged lengthwise in a single column, rather than in a table with separate columns as is typical. This pattern is repeated for each variable sequentially and continuously, creating a long, vertical block of data. An illustration of this format can be seen in Figure 3.

Each variable has a time-varying representation, meaning each data point reflects the value of that variable at a specific point in time. The naming codes used in this data include: HP1 for altitude, VI for ground speed, AOA for angle of attack or the angle between the aircraft's longitudinal axis and the direction of incoming airflow, DE and FE respectively represent the elevator deflection and elevator control force felt by the pilot. Meanwhile, P, Q, and R respectively describe the yaw rate (rotation rate about the vertical axis), pitch rate (rotation rate about the lateral axis), and roll rate (rotation rate about the longitudinal axis).

	A	B	C	D
1	PARAM. NO : 1954; SYMBOL : HP1; UNIT : FEET; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
2	PARAM. NO : 3348; SYMBOL : VI; UNIT : KNOT; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
3	PARAM. NO : 1975; SYMBOL : AOA; UNIT : DEG; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
4	PARAM. NO : 8821; SYMBOL : DE; UNIT : DEG; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
5	PARAM. NO : 1463; SYMBOL : FE; UNIT : LBS; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
6	PARAM. NO : 5234; SYMBOL : Q; UNIT : DEG/S; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
7	PARAM. NO : 5235; SYMBOL : P; UNIT : DEG/S; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
8	PARAM. NO : 5236; SYMBOL : R; UNIT : DEG/S; START TIME: 08 51 00.050; END TIME : 08 54 00.950			
9				
10	KEBAWAH : 1 1 | TIME -vs- HP1			

Figure 3: Flight Test Data Excel Structure

IV. RESULTS AND DISCUSSION

Below are the results of the analysis in the form of an application design flow diagram given in Figure 4 and an application flow diagram in Figure 5.

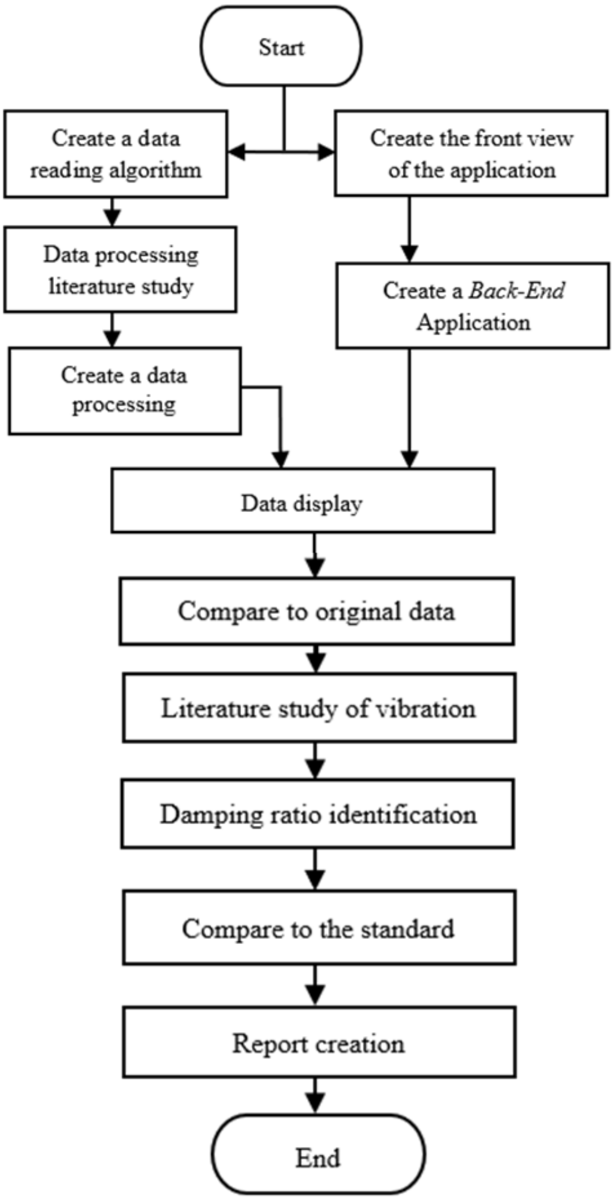

Figure 4: Flow diagram of application design

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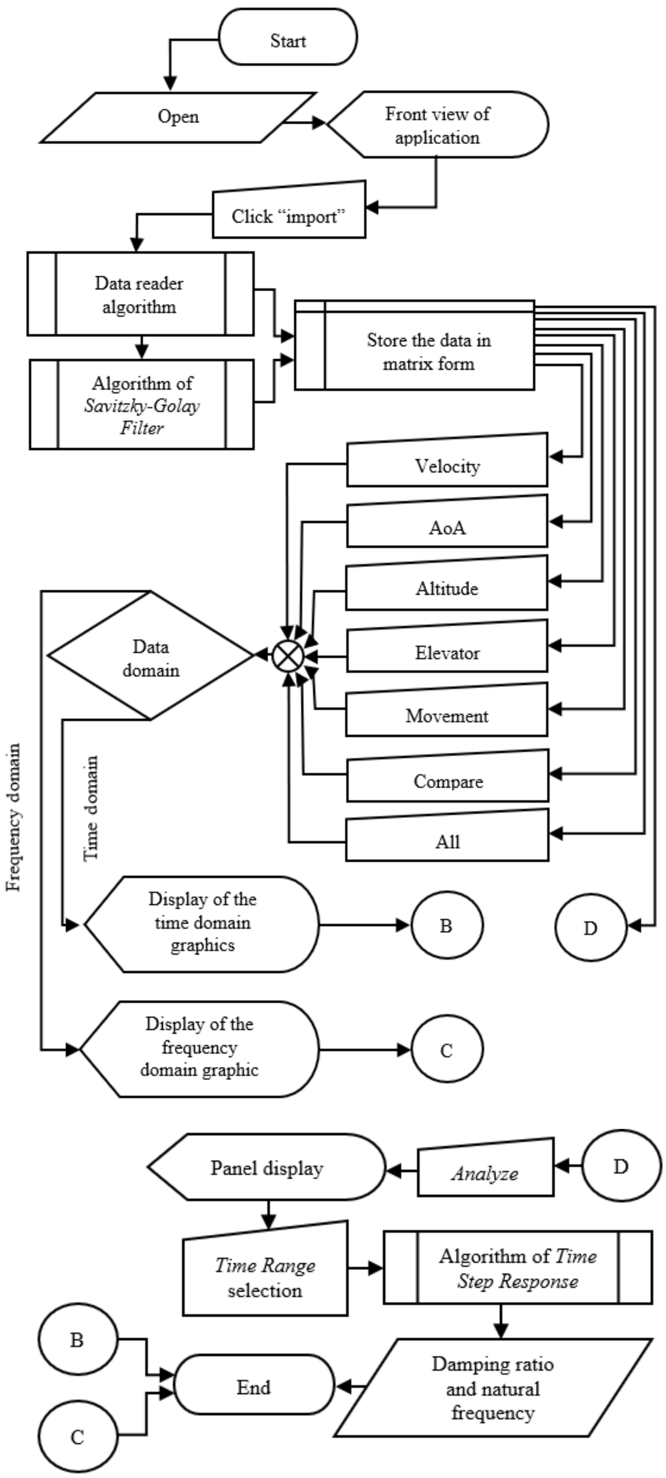

Figure 5: Flow diagram of application

Savitzky-Golay Filter Data Processing

To ensure the signal's primary characteristics were maintained, the authors compared the original data and the processed results using the Fast Fourier Transform (FFT) method. The results in Figure 6 show that low-frequency components remain dominant, while high-frequency components are successfully reduced. This indicates that the Savitzky-Golay filter, with a frame length of 11 and a polynomial order of 3, is effective in reducing high-frequency noise without altering the shape of the primary signal.

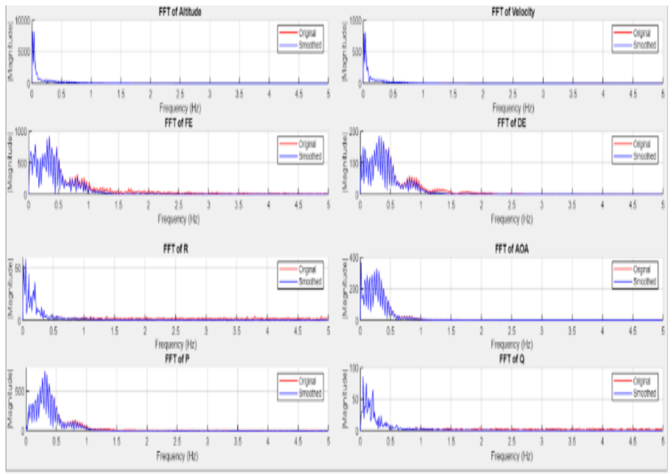

Figure 6: FFT Domain of Each Flight Test Data Variable

In the context of aircraft oscillation analysis, low frequencies are more important because they are related to the overall aircraft response. Therefore, the filter configuration used proved appropriate and optimal for the oscillation identification process.

Damping Ratio Analysis Results

In this test, the primary focus was on identifying the short-period mode, a type of aircraft longitudinal dynamic mode characterized by a rapid response and significant changes in angle of attack (AoA) over a short period of time. According to Cook (2007), this mode is characterized by high-frequency oscillations with small changes in angular velocity and relatively constant aircraft momentum. Therefore, the angle of attack (AoA) parameter was chosen as the primary variable in the identification process because it most accurately represents short-period dynamics. The analysis focused on AoA data because this component provides the dominant response to disturbances that trigger short-period mode.

Using the previously developed identification method, the author entered the time interval value into the application and selected the angle of attack (AoA) variable data. Using the default threshold value provided by Matlab, 2%, the damping ratio (ζ) was obtained for the first test, which was 0.3656, and for the second test, it was 0.2003. These test values can be seen in Figures 7 and 8.

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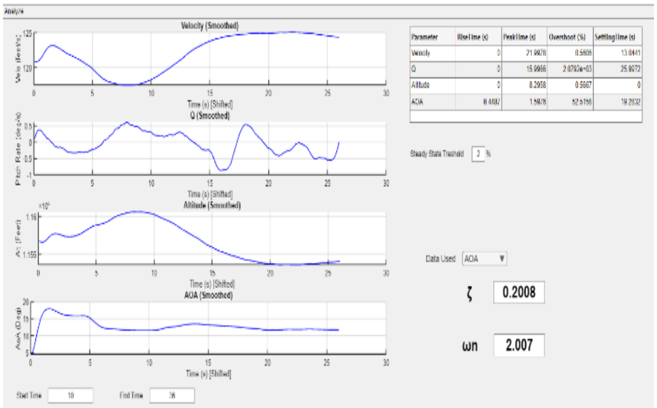

Figure 7: Display of the Application Used to Find the Damping Ratio Value 1

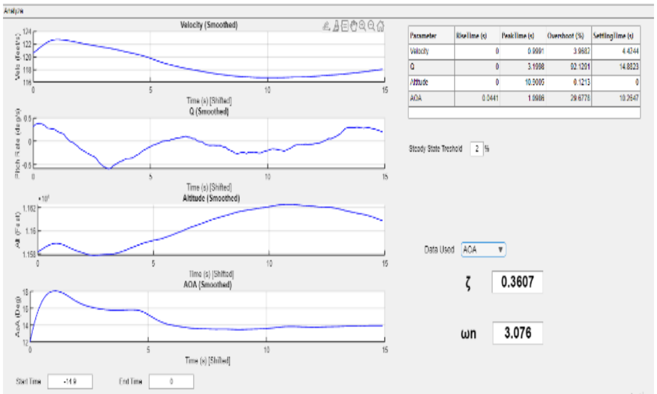

Figure 8: Display of the Application Used to Find the Damping Ratio Value 2

Application Display

Figure 9 shows the angle of attack data versus time. It can be seen that in the given data, there are two short-period oscillation mode tests.

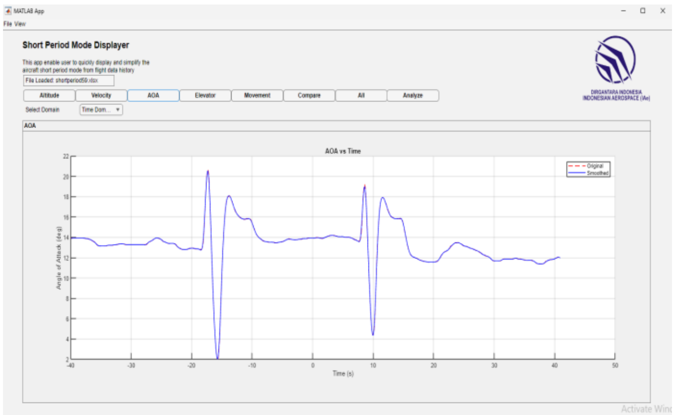

Figure 9: Feature Display Showing Angle of Attack Data in the Time Domain

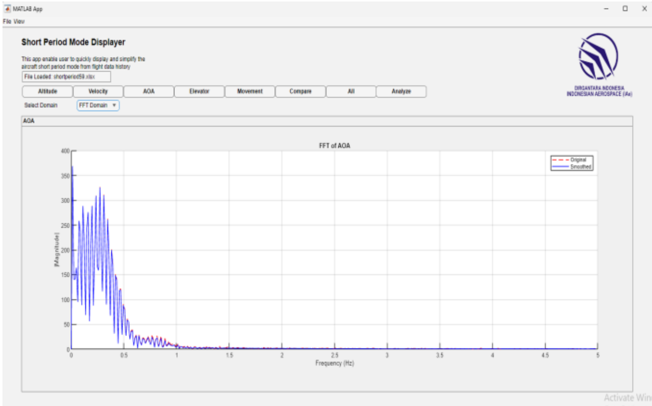

Figure 10: Feature Display showing Angle of Attack Data in the Frequency Domain

Figure 10 shows a feature in the application that displays angle-of-attack data in the frequency domain. Through this representation, users can easily identify the dominant frequency components of the oscillations occurring at the angle of attack, particularly for detecting short-period oscillations. The frequency domain is used to assess the data processor's ability to retain the main characteristics of the oscillations.

Figure 11 displays the application feature used to compare data. This feature allows users to observe how two parameters behave simultaneously over time, making it easier to identify correlations between parameters A and B. This view is useful for analyzing aircraft dynamics during short-period oscillations, making it more intuitive.

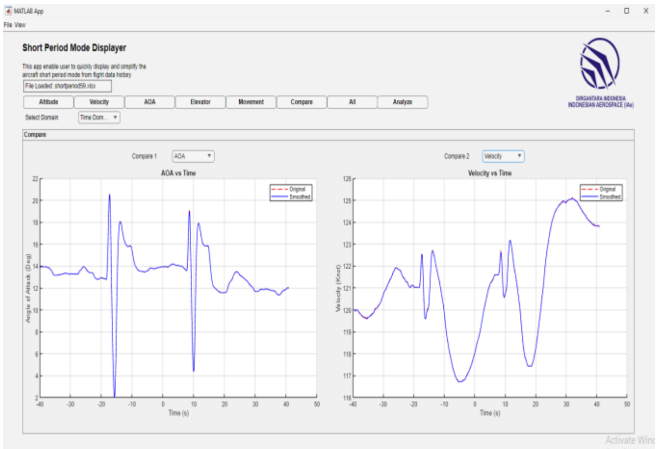

Figure 11: Display of Application Features Comparing the Time Domain of Aircraft Angle of Attack and Speed

Figure 12 displays the application's features for simultaneously comparing all flight test data parameters in the time domain. This feature allows users to observe the behavior of multiple flight variables simultaneously. This comprehensive data presentation aims to simplify the analysis of the aircraft's longitudinal dynamics, particularly during

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short-period oscillations. By directly viewing the interrelationships between parameters, users can gain a comprehensive picture of the aircraft's dynamic response during short-period oscillations and identify patterns or anomalies that might not be apparent if the data were analyzed separately.

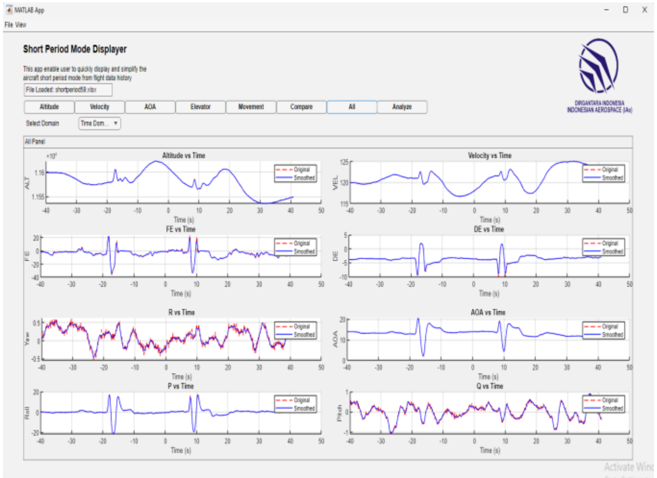

Figure 12: Display of Application Features that Compare the Time Domain of all existing Data

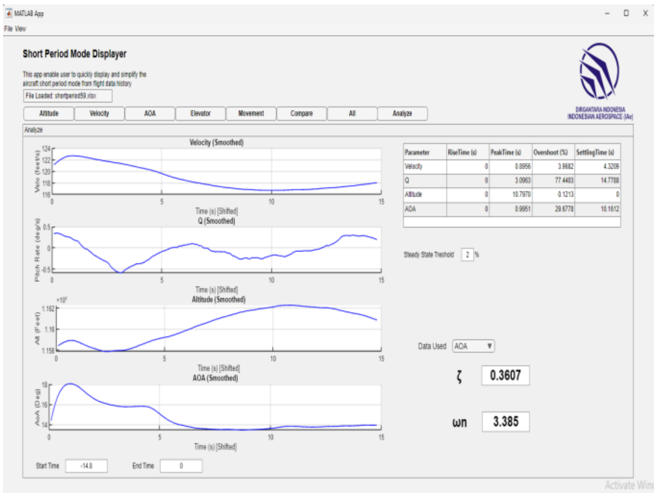

Figure 13: Display of Application Features that Calculate Damping Ratio and Natural Frequency Values

Figure 13 displays the application's features for calculating the damping ratio and natural frequency from flight test data. These two parameters are critical components in aircraft dynamic stability analysis, particularly in identifying oscillation modes such as short-period oscillations. By utilizing angle-of-attack data or other parameters in the time domain, the application automatically estimates the system's dynamic characteristics using a time-step response approach. This feature facilitates users in obtaining relevant quantitative information for dynamic performance evaluation and control system design adjustments.

V. CONCLUSION

Several conclusions were drawn from this test, including:

1. An application was produced that PT Dirgantara Indonesia can use to identify the damping ratio and natural frequency of short-period mode oscillations.
2. The data processing method using a Savitzky-Golay filter with a frame length parameter of 11 and a polynomial order of 3 proved effective in producing data with characteristics similar to the original data.
3. The time-step response identification method was able to produce values for the aircraft's damping ratio and natural frequency.
4. The results of the first short-period test yielded a damping ratio of 0.3656, and the second test yielded a damping ratio of 0.2007, with an average of 0.2786. Therefore, the aircraft used for testing passed flight phase categories A and B at level 2.

VI. SUGGESTION

The author's suggestions regarding this internship are as follows:

1. More flight data using the same aircraft is needed to ensure the accuracy of the values.
2. Data on the aircraft's actual conditions, such as lift coefficient, drag coefficient, aircraft inertia, and so on, are needed to obtain analytical calculations.
3. More testing of identification methods is needed to determine the best method for all conditions.

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