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Study and Analysis of Control System Responses on Aircraft Stability

Pritam Ghosh[1], Lingamgunta Vijay Kumar[2], Arif Mahammed Shaik[3], Gourav Deep Das[4], Ashok Kumar A[5], Shankar Gouda[6]

U G Student, Department of Aeronautical Engineering, SCE, Chikkaballapura, Karnataka, India[1].

U G Student, Department of Aeronautical Engineering, SCE, Chikkaballapura, Karnataka, India[2].

U G Student, Department of Aeronautical Engineering, SCE, Chikkaballapura, Karnataka, India[3].

U G Student, Department of Aeronautical Engineering, SCE, Chikkaballapura, Karnataka, India[4].

Asst. Professor, Department of Mechanical Engineering, SCE, Chickballapur, Karnataka, India[5].

Asst. Professor, Department of Mechanical Engineering, SCE, Chickballapur, Karnataka, India[6].

ABSTRACT: The project deals with the analysis of the aircraft stability. It determines the stability characteristics on the basis of time and frequency domain using Bode plots and root locus plots. Aircrafts adopts an eclectic approach for parameter identification method. Time- domain method for stability control parameters estimation is used alongside frequency –domain methods which are chiefly used for determining flying qualities parameters. Stability is an important factor for an aircraft and it is important for one should know about various stability factors before commenting on the aircraft stability. Determining the stability of the aircraft using complex mathematical calculations is often time taking and approximate values are considered. In this project, the stability of aircrafts like – Boeing 767 aircraft is analyzed. The stability factors are determined by using both complex mathematical calculations and using software- MATLAB. Using the software for determining the stability makes the work simple and it is less time consuming. It gives more accurate values and the results are more convincing.

KEYWORDS: Aircraft Stability, State Space Equation, Transfer Function, MATLAB.

I. INTRODUCTION

In this project we have considered a ‘fly-by-wire’ aircraft i.e. an aircraft with electronic control system and an autopilot option. System identification methods compose a mathematical model or series of models, from measurements of inputs and outputs of dynamics system. These extracted models allow the characterizations of the response of the aircraft or the overall component behavior and the constant values or the variations are noted. System identification is a procedure for accurately characterizing the dynamic response behavior of completer aircraft and its control system response. This key technology for modern fly-by-wire flight control system development and integration provides a unified flow of information regarding system performance. The obtained values form the mathematical models. These models can be defined by two approaches using time domain analysis i.e. root locus technique and frequency domain analysis using bode plot technique.

II. LITERATURE SURVEY

Christopher D. Regan [1]: This paper deals with the system description, methods, and sample results of the in-flight stability analysis of a desired aircraft. The factors that determine the stability of the given aircraft in flight are crucially important. As the aircraft in-flight condition undergoes many forces hence it is of extreme importance that the stability is analyzed at this condition. The paper mentioned deals with the shifts that eliminate the frequency leakage effect, which deemphasizes the importance of windowing, and does not affect the excitation peak factors. Transformation

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from time domain to frequency domain was initially performed using a Discrete Fourier Transformation (DFT). This transformation provided good results for tightly spaced frequency components.

Branimir Stojiljkovic [2]:The paper is an application of the root locus technique for the design of the feedback control system of an F-104A aircraft. The analysis of the longitudinal aircraft stability was performed for the Single Input Single Output (SISO) open-loop system, using linearized equation of aircraft motion and aerodynamic derivations of an F-104A aircraft. The Dynamic behavior of the open -loop system was unsatisfactory and led to the introduction of the feedback control system. The transfer function parameters of each element of the feedback control system are determined according to previously set design requirements.

III. METHODOLOGY

The control system responses are considered and the desired effect on the stability is recognized. The desired effect results in the deflection of the control surfaces. This deflection is noted and the data is acquired. The data taken in the form of matrices and the further calculation is done and the results so obtained. The data is then used to obtain the root-locus plot and bode plots.

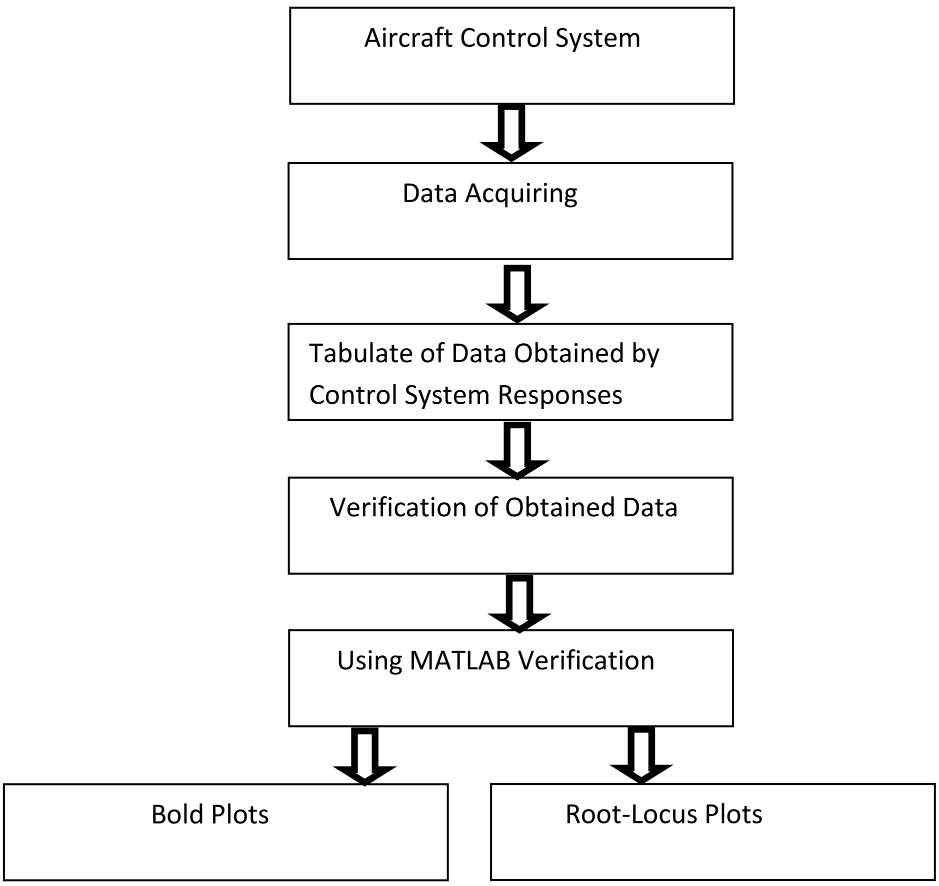

Fig.1: Flow Chart for the Determination of Aircraft Stability

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State-Space Equations

The State Equation shows the relationship between the system's current state and it's input, and the future state of the system. the state space equations of a particular system are not unique, and there are an infinite number of ways to represent the equations by manipulating the A, B, C and D matrices using row operations. There are a number of "standard forms" for these matrices, however, that make certain computations easier. Converting between these forms will require knowledge of linear algebra.

We have 4 constant matrices: A, B, C, and D. We will explain these matrices below:

- **Matrix A:**

Matrix A is the system matrix, and relates how the current state affects the state change x'. If the state change is not dependant on the current state, A will be the zero matrixes. The exponential of the state matrix, is called the state transition matrix, and is an important function that we will describe below.

$$A = \begin{bmatrix} a11 & a12 \ldots\ldots\ldots\ldots\ldots a1n \\ a21 & a22 \ldots\ldots\ldots\ldots\ldots a2n \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. & \\ an1 & an2 \ldots\ldots\ldots\ldots\ldots ann \end{bmatrix}$$

- **Matrix B:**

Matrix B is the control matrix, and determines how the system input affects the state change. If the state change is not dependant on the system input, then B will be the zero matrix.

$$B = \begin{bmatrix} b11 & b12 \ldots\ldots\ldots\ldots. b1n \\ b21 & b22 \ldots\ldots\ldots\ldots.. b2n \\ . \quad . & \ldots\ldots\ldots\ldots\ldots \\ bn1 & bn2 \ldots\ldots\ldots\ldots. bnn \end{bmatrix}$$

- **Matrix C:**

Matrix C is the output matrix, and determines the relationship between the system state and the system output.

$$C = \begin{bmatrix} c11 & c12 \ldots\ldots\ldots\ldots. c1n \\ c21 & c22 \ldots\ldots\ldots\ldots c2n \\ .. & \ldots \quad \ldots\ldots. \\ cn1 & cn2 \ldots\ldots\ldots\ldots\ldots cnn \end{bmatrix}$$

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- **Matrix D**

Matrix D is the feed forward matrix, and allows for the system input affecting the system output directly. Basic feedback systems like those we have previously considered do not have a feed forward element, and therefore for most of the systems we have already considered, the D matrix is the zero matrixes.

$$D = 0$$

IV. MATLAB CODING AND CALCULATIONS

BOEING 767 AIRCRAFT

The longitudinal and lateral state space models are given. The state space vector are as follows:

$$\mathbf{x}_{\text{long}} = \begin{bmatrix} u \text{ (ft/s)} \\ \alpha \text{ (deg)} \\ q \text{ (deg/s)} \\ \theta \text{ (deg)} \end{bmatrix}, \mathbf{x}_{\text{lat}} = \begin{bmatrix} \beta \text{ (deg)} \\ p \text{ (deg/s)} \\ \phi \text{ (deg/s)} \\ r \text{ (deg)} \end{bmatrix}$$

$$\mathbf{u}_{\text{long}} = \begin{bmatrix} \delta_E \text{ (deg)} \\ \delta_T \text{ (\%)} \end{bmatrix}, \mathbf{u}_{\text{lat}} = \begin{bmatrix} \delta_A \text{ (deg)} \\ \delta_R \text{ (deg)} \end{bmatrix}$$

Equilibrium point

Speed	$V_T = 890$ ft/s $= 980$ km/h
Altitude	$h = 35\ 000$ ft
Mass	$m = 184\ 000$ lbs
Mach-number	$M = 0.8$

Longitudinal model

```
A=[-0.0168 0.1121   0.0003  -0.5608
   -0.0164 -0.7771 0.9945  0.0015
   -0.0417 -3.6595 -0.9544 0
   0   0   1.0000  0];
B=[-0.0243  0.0519
   -0.0634 -0.0005
   -3.6942 0.0243
   0   0];
C=[0 1 0 0;
  0 0 0 1];

D=[0 0;
  0 0];
states = {'u' 'alpha' 'q' 'theta'};
inputs = {'elevator' 'thrust'};
outputs = {'pitch' 'w'};
sys = ss(A,B,C,D,'statename',states,...
              'inputname',inputs,...
              'outputname',outputs);
sys;
sys11=sys('pitch' ,'elevator');
```

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```
h=rlocusplot(sys11);
zeta=1.523;
wn=2.09;
sgrid(zeta,wn);
```

V. RESULTS AND PLOTS

The stability analysis is done and through MATLAB coding, the root locus and bode plots are obtained. The plots are studied and then the comment on stability is being made. The root locus plot determines the stability of the aircraft by analyzing on the basis of time-domain mode and bode plot determines the stability of the aircraft on the basis of frequency-domain analysis. In time-domain analysis, the frequency variation is not prominently determined. Hence, bode plots play an important role in determining the stability of the aircraft on the basis of frequency variation of the aircraft.

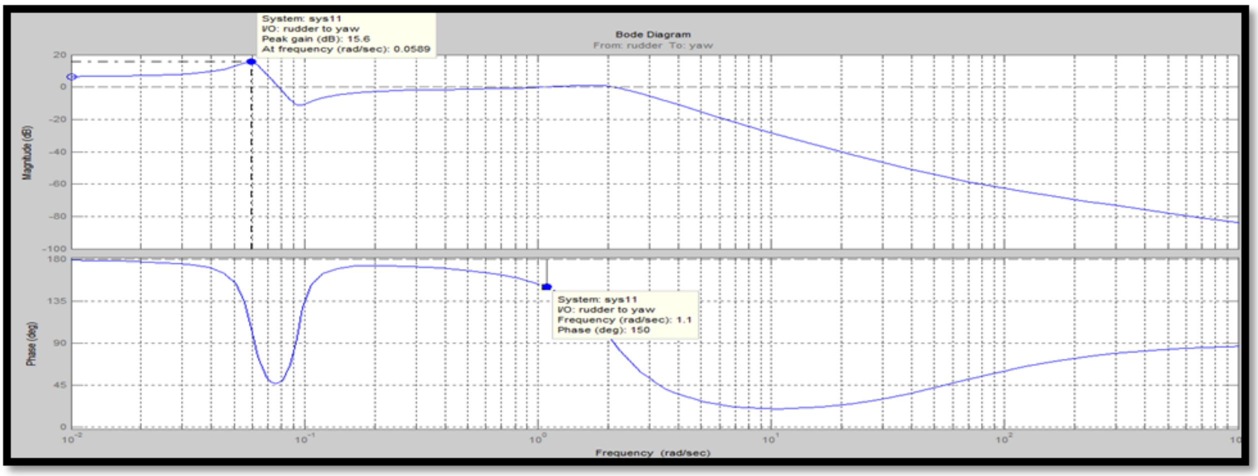

Fig.2: Bode plot of boeing-767 aircraft

The bode plot is used as the frequency response technique. Here we have logarithmic gain in db and phase in degree. Hence it is stable.

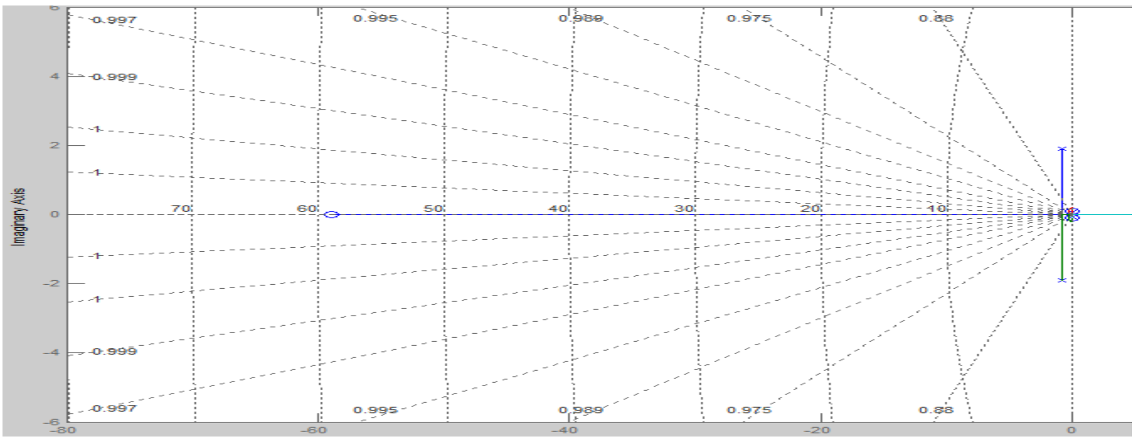

Fig.3: Root locus plot of boeing-767 aircraft

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As we can see we have 4 poles and 3 zeroes hence as the number of poles are greater than number of zeroes we can say the system is stable. We have two poles away from the imaginary margin which predicts the long period mode and 2 poles at near the imaginary margin which predicts the short period mode. Therefore as all the poles and zeroes lies on the left side of the imaginary plane we can say the system is stable when rudder is moved and yaw motion takes place.

VI. CONCLUSION

Finally we have considered aircraft “BOEING-767” which is a transportation aircraft the following aircraft have been used to analyze the stability. The aircraft have been in service hence it’s been effective to analyze the stability of the aircraft. Using the stability derivatives of the aircraft, under the desired conditions, the analytical results have been found and comparative statements have been made to determine their stability.

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BIOGRAPHY

Mr. PRITHAM GHOSH, pursuing Aeronautical Engineering, 8th semester from Sha-Shib of Engineering, Chikkaballapura, Karnataka. Published papers in national & International journals on aeronautical topics

Mr. LINGAMGUNTA VIJAY KUMAR, perusing Aeronautical Engineering, 8th semester from Sha-Shib of Engineering, Chikkaballapura, Karnataka. Published papers in national & International journals on aeronautical topics.

Mr. ARIF MAHAMMAD SHAIK, pursuing Aeronautical Engineering, 8th semester from Sha-Shib of Engineering, Chikkaballapura, Karnataka. Published papers at national level on aeronautical topics.

Mr.GOURAV DEEP DAS, pursuing Aeronautical Engineeering,8th semester from Sha- Shib collage of Engineering, Chickaballapura ,Karnataka. Published papers in national & International journals on aeronautical topics.

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Mr. Ashok Kumar Currently working as Asst. Professor in Sha-Shib College of Engineering, Chikkaballapur. He did his M.tech in Machine Design from Nagarjuna College of Engineering & Technology, Bangalore. He has published several papers in various International Journals.

Mr. Shankar Gouda Currently working as Asst. Professor in Sha-Shib College of Engineering, Chikkaballapur. He did his M.tech in Product Design & Manufacturing from EPCET, Bangalore. He has published several papers in various International Journals.