

## Dynamic Analysis of Aircraft Designs Using Archangel 98

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### Abstract

A user friendly software program called Archangel98 has been developed that provides rapid visual analysis of aircraft dynamics given aircraft stability derivatives and flight conditions. Its purpose is to provide a quick yet accurate look at the effects of design changes on the dynamics and handling qualities of aircraft. Using an intuitive "drag and drop" interface allows the user to look at aircraft data, root locus plots and a new graphical tool called Response Locus Maps. Response Locus Maps use traditional graphical residue computations and Eigenspace analysis to show the controllability of aircraft at a given operating point. Archangel98 also links to MATLAB for use of its resources in further design analysis. Archangel98 uses the latest software design concepts allowing a very open design process, working with virtually all other applications.

### Introduction

Archangel98 is the latest in a series of programs built around the idea of providing a rapid analysis tool for students to use in aircraft stability and control design. There are two versions developed: a Student Edition as well as a Full Edition. The Student Edition does not have any of the more advanced tools such as Root Locus and Response Locus Maps, but is fully capable of exporting any analysis data to other programs for its reuse.

Archangel98 begins with the Standard Aircraft Data (SAD) file. The aircraft data can include non-dimensional or dimensional stability derivatives and flight condition parameters. The file is built around the aircraft input files from Appendix C of [Airplane Flight Dynamics](#)<sup>1</sup>. The input has been expanded to accommodate the Archangel98 equation engine. From here, the user has several tools to use in analysis.

### Equation Engine

The equations of motion which comprise the Archangel98 engine are an expanded version of standard textbook equations, which allow the aircraft to have certain initial flight condition values such as pitch rate and flight path angle. The object is to allow for the least restrictive steady state flight condition. The user can also select the equations of motion used by eliminating unnecessary force expansions. In addition, Archangel98 uses two modes of longitudinal system equations, which are assembled from two sets of perturbed axis and steady state axis rotations. The first rotation follows traditional assumptions and has a steady state Euler pitch angle equal to the body axis pitch angle. The second rotation has a steady state Euler angle equal to the flight

path angle. The user selects which of the three modes to analyze: *longitudinal theta*, *longitudinal gamma* or *lateral*.

### Matrices and Literal Factors

The matrices can be viewed in two ways: standard state space system matrices and classical system matrices. The literal factors available include classical phugoid, short period and dutch roll approximations. Because of the flexibility in setting the equations of motion, the user can in essence create custom literal factors by eliminating certain force expansions and/or stability derivatives.

### Root Locus

Once the aircraft data has been entered, the users can view the root locus plot of any mode. Below is a screen shot of the Root Locus form.

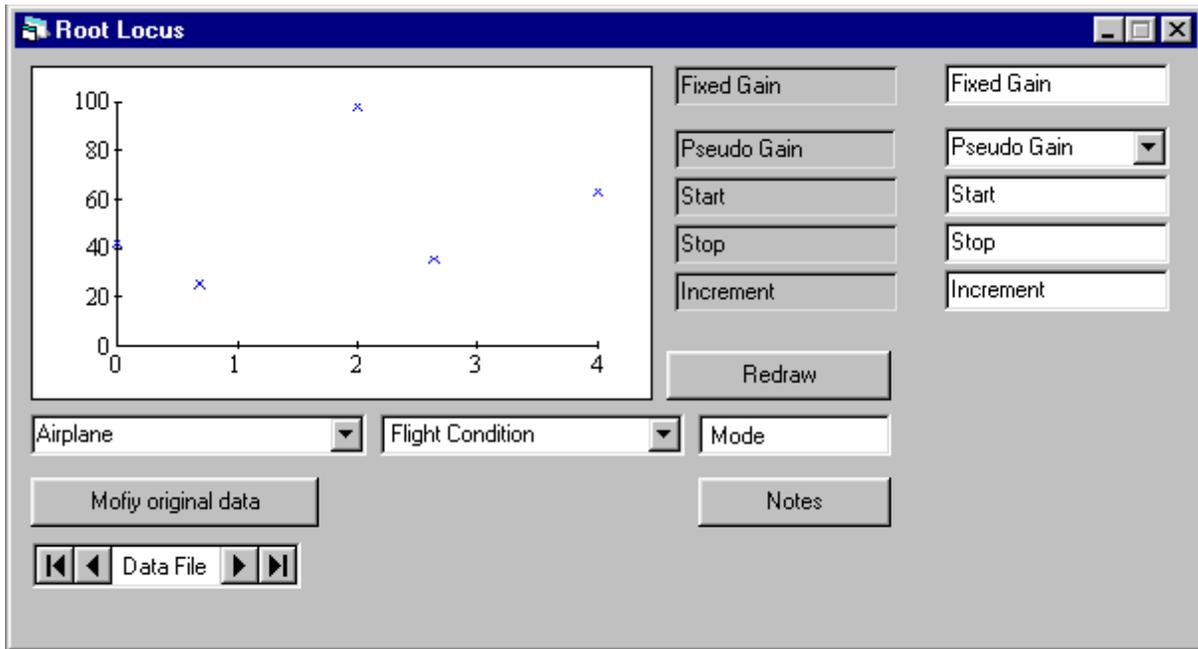


Figure 1 – Root Locus

Aside from the traditional root locus plots, Archangel98 allows the user to choose any element in the system to be the “gain”, or pseudo gain. The user chooses a fixed closed loop gain, and then chooses any element in the system to be the pseudo gain, as well as selecting its range of values. At this point, the closed loop poles are migrated as the pseudo gain is varied. What this provides is more of an educational tool than a design tool, in that the user can see the effect a parameter has on the system.

## Response Locus Map

This is perhaps the most unique and most powerful tool of Archangel98. Below is a screen shot of the Response Locus Map form.

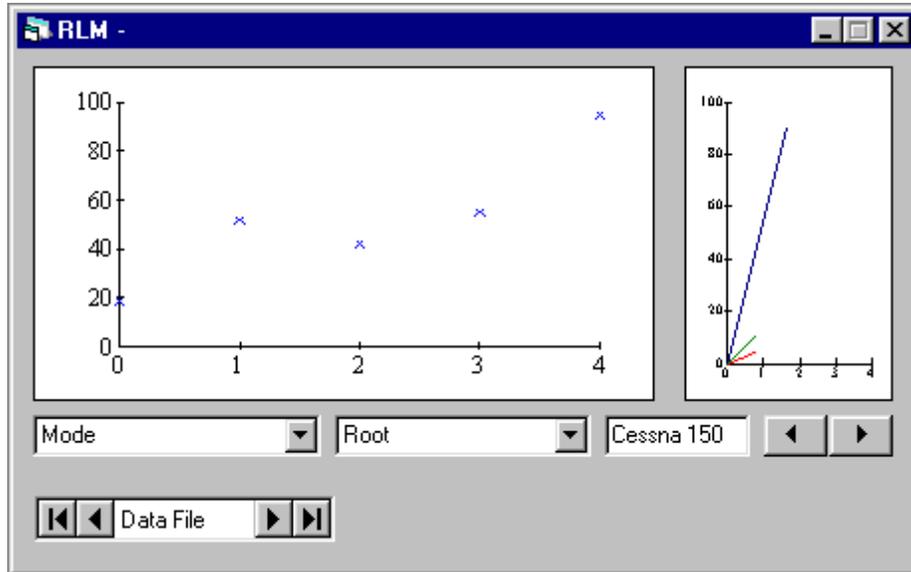


Figure 2 – Response Locus Map

This tool is based on a correlation between two derivations of system residues. The first derivation comes from a partial fraction expansion, and yields the following formula<sup>2</sup>:

$$\frac{x_m(s)}{u(s)} = R_1 \frac{1}{s - \lambda_1} + \dots + R_n \frac{1}{s - \lambda_n} = \sum_{i=1}^n R_i \frac{1}{s - \lambda_i}$$

The second derivation comes from an eigenspace analysis of the system and yields the following formula:

$$\frac{\bar{x}(s)}{u(s)} = \sum_{i=1}^n \begin{vmatrix} e_{1i} \\ \bar{m}_i^T |B| \\ e_{ni} \end{vmatrix} \frac{1}{s - \lambda_i} = \sum_{i=1}^n \bar{e}_i \frac{\bar{m}_i^T |B|}{s - \lambda_i}$$

It can be seen that the scaled eigenvectors are the residues for the system. The dot product of the inverse eigenvector matrix and the control matrix provides the scaling factor, which determines the system's response. The Response Locus Map is used in two modes: *graphical* and *eigensystem*. The *graphical* mode computes the system poles and zeros, from which the system residues are calculated for each pole using the classical graphical method, shown below<sup>3</sup>:

$$R = \left. \frac{b_m (s + p_k) \prod_{i=1}^m (s + z_i)}{\prod_{i=1}^m (s + p_i)} \right|_{s=-p_k}$$

where  $b_m$  is the system gain,  $p$  and  $z$  are the individual system poles and zeros, respectively. The residues for each pole can be seen when the user selects both the root and the control to use.

The *eigensystem* mode uses traditional EISPACK and LINPACK routines to compute the system eigenvalues and eigenvectors, and then scales the eigenvectors according to the aforementioned formula. These are the system residues. At this point, the user has many options: a residue plot, a scaling vector plot and bar chart comparison. The residue plot provides the same functionality as its counterpart in the *graphical* mode. The scaling vector plot shows the distribution of the control input across the different roots. What this demonstrates is the ability of the control to excite the states at each root. The bar chart comparison not only shows the relative residues for each state, but also the steady state and scaled components that comprise each residue. This is more of an intuitive comparison, since the different residues carry separate units, so care must be taken in unit selection.

### Links to Other Analysis Programs

Archangel98 was designed with the intention of it being used as one of a suite of tools for aircraft design. Therefore, it has many options for saving and exporting data as well as automatically linking to two well known analysis programs, Program CC from STI and MATLAB from Mathworks. There are built in routines for saving files in formats necessary for both linked analysis programs as well as the ability from within Archangel98 to launch those programs and automatically load aircraft files.

### Conclusion

Archangel98 provides a useful suite of tools for stability and control analysis of conventional aircraft. By using graphical tools to represent the various eigensystem parameters, it gives an intuitive look into the behavior of aircraft systems. The design goal was to provide both a good preliminary design program as well as include educational tools for students to gain a feel for the importance of eigensystems in stability and control analysis.

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**Mr. Dushan Bilbija** will be receiving his Masters Degree in June 1998 from the Aeronautical Engineering Department at Cal Poly State University, San Luis Obispo. He is currently a consultant specializing in network administration and program development for several technology companies.

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