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Determination of the Stability and Control Derivatives of the F/A-18 HARV from Flight Data Using the Maximum Likelihood Method

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ABSTRACT

This document reports on the progresses of the research conducted for the NASA-Ames Cooperative Agreement No. NCC 2-759 with West Virginia University. The principal investigator Marcello R. Napolitano and graduate student Joelle M. Spagnuolo are collaborating on the research. The NASA technical officer for this grant is Albion H. Bowers, associated with NASA Dryden Flight Research Facility. The research being conducted pertains to the determination of the stability and control derivatives of the F/A-18 High Alpha Research Vehicle (HARV) from flight data using the Maximum Likelihood Method. The document outlines the approach used in the parameter estimation (PID) process and briefly describes the mathematical modeling of the F/A-18 HARV and the maneuvers designed to generate a sufficient data base for the PID research.

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INTRODUCTION

The scope of this project is to determine the aerodynamic stability and control derivatives of the NASA F/A-18 HARV from flight data. Although a thorough basis of the vehicle aerodynamics is generated by analytic computations and wind tunnel tests performed by the manufacture during the design process, the true aerodynamic characteristics of the aircraft can be derived from an analysis of flight test data. Therefore, it is beneficial to compare the results from both the initial design and the flight data in order to validate the prediction methods of the aircraft aerodynamics. An additional reason for estimating these parameters is to update the aerodynamic data bank in the flight simulators.

Using flight data to estimate the stability and control derivatives of aircraft has been implemented for many years. In the past, most of the flight testing was limited to conditions in which linearized aerodynamics and linear equations of motion would appropriately describe the aircraft dynamic model. For these cases, the parameter estimation program MMLE3 developed at Ames-Dryden in the mid 1970's was used. However, recent research conducted on the F/A-18 HARV related to high angle of attack flight conditions has generated interest in the parameter identification for non-linear aerodynamic and dynamic conditions. For this purpose, the recently developed pEst estimation software, which is capable of supporting nonlinearities in the dynamic equations of motion, is being used for this project.

The following sections briefly describe the PID process and the modifications of the equations of motion within the pEst software that allow appropriate modeling of the HARV. Furthermore, the type of maneuvers required to obtain data for PID are discussed along with some preliminary results of the estimates of the stability and control derivatives.

PID and Modeling of the HARV

Figure 1 shows a block diagram of the parameter identification process.

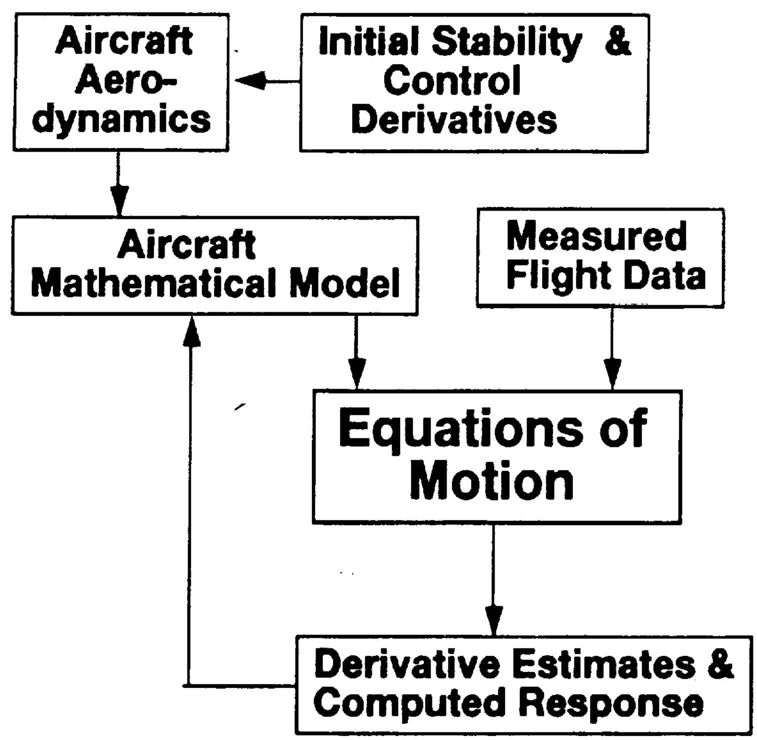

Figure 1: Parameter Identification Process

It can be seen that the estimation process begins with initial values of the stability and control derivatives. These values are generally obtained from previous wind tunnel tests conducted by the aircraft manufacturer. This set of values in addition to the aircraft aerodynamic, geometric, and inertial data constitute the initial mathematical model of the vehicle. The mathematical model is then used along with the measured flight data, which indicates the system inputs and responses, in the equations of motion. These equations are then used to produce a computed response of the aircraft using the initial values of the stability and control derivatives. Then the difference between the measured and computed response is assessed and minimized by assigning new values to the derivatives and iterating the process described above until the results of the estimated derivatives converge.

The pEst software has a standard set of equations that can be modified to suit any aircraft configuration. Since the HARV is a F/A-18 with additional control surfaces and a thrust vectoring system, several modifications needed to be introduced. For instance, the extra control surface deflections and the relative stability and control derivatives had to be accounted for in the total force and moment coefficient equations. Also, the addition of the thrust vectoring control system (TVCS) required modifications in the equations of motion due to the fact that thrust is no longer limited to act along the x-axis. The TVCS essentially consists of three vanes mounted on the back of each engine of the HARV. During vectoring maneuvers, a combination of the vanes are commanded to deflect, and the amount of each vane deflection is recorded. These deflections are combined in the following manner to indicate a single value which represents the overall deflection in either the pitch or yaw direction.

$$\delta_{yv} = \frac{1}{2}\left(\frac{\delta v_2 - \delta v_3}{2} + \frac{\delta v_6 - \delta v_5}{2}\right)$$

$$\delta_{pv} = \frac{1}{2}\left[\delta v_1 - \left(\frac{\delta v_2 + \delta v_3}{2}\right) + \delta v_1 - \left(\frac{\delta v_5 + \delta v_6}{2}\right)\right]$$

where δ_{yv} = yaw vane deflection
δ_{pv} = pitch vane deflection
$\delta v_{1,2..6}$ = deflection of individual vane 1,2,3,4,5 or 6

Note the vane numbering system is illustrated in Figure 2.

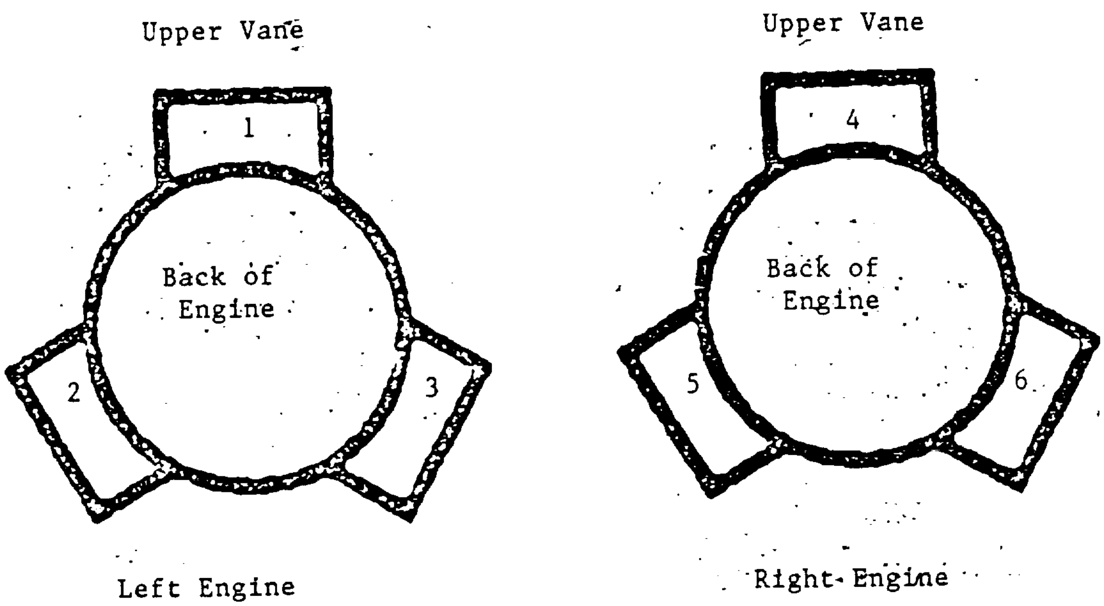

Figure 2. Numbering of Thrust Vector Vanes

The additional thrust forces caused by the TVCS are accounted for by the following terms:

$$\mathit{thrust}(x) - -\mathit{cadpvdyv} * \cos(\delta_{pv})\cos(\delta_{yv}) * \mathit{measured\ thrust\ force}$$

$$\mathit{thrust}(y) - -\mathit{cydyv} * \sin(\delta_{yv})\cos(\delta_{pv}) * \mathit{measured\ thrust\ force}$$

$$\mathit{thrust}(z) - -\mathit{cnormdpv} * \sin(\delta_{pv})\cos(\delta_{yv}) * \mathit{measured\ thrust\ force}$$

where cadpvdyv = axial force due to combined δ_{pv} and δ_{yv}
cydyv = side force due to yaw vane deflection
cnormdpv = normal force due to pitch vane deflection

The state equations incorporate the above modifications as follows:

$$V = \frac{1}{m}[-D\cos\beta + Y\sin\beta + thrust(x)\cos\alpha\cos\beta + thrust(y)\sin\beta + thrust(z)\sin\alpha\cos\beta$$

$$-mg(\cos\alpha\cos\beta\sin\theta - \sin\beta\sin\phi\cos\theta - \sin\alpha\cos\beta\cos\phi\cos\theta)]$$

$$\alpha = \frac{1}{Vm\cos\beta}[-L + thrust(z)\cos\alpha - thrust(x)\sin\alpha + mg(\cos\alpha\cos\phi\cos\theta$$

$$+\sin\alpha\sin\theta)] + q - \tan\beta(p\cos\alpha + r\sin\alpha)$$

$$\beta = \frac{1}{mV}[D\sin\beta + Y\cos\beta - thrust(x)\cos\alpha\sin\beta + thrust(y)\cos\beta - thrust(z)\sin\alpha\sin\beta$$

$$+mg(\cos\alpha\sin\beta\sin\theta + \cos\beta\sin\phi\cos\theta - \sin\alpha\sin\beta\cos\phi\cos\theta)] + p\sin\alpha - r\cos\alpha$$

where D = total Drag, (lb)
L = total Lift, (lb)
Y = total Sideforce, (lb)
m = mass, (slugs)
V = Velocity, (ft/sec)
p = roll rate, (rad/sec)
q = pitch rate, (rad/sec)
r = yaw rate, (rad/sec)
α = angle of attack, (rad)
β = angle of sideslip, (rad)
θ = pitch angle, (rad)
ϕ = bank angle, (rad)

These are the changes introduced in the standard set of equations in pEst. This revised version is to be utilized for the analysis of requested PID flight test maneuvers which are discussed in the next section.

PID Maneuvers and Tests Completed

The design of the maneuvers needed for parameter estimation is based on the need to excite the dynamic modes of the aircraft. It has been determined in previous work that the system modes are best excited by maneuvers with frequencies near the system natural frequencies. This principle implies that optimal inputs would be those that resemble sine waves at the system natural frequencies. Hence, the typical maneuver for PID testing is the doublet performed in the pitch, roll, and yaw planes.

Also, in order to obtain the most accurate results of the PID analysis, the inputs on every control surface must be independent. This is extremely important because if two surfaces move simultaneously during a maneuver, it is practically impossible in non-linear conditions to distinguish the effects of the two individual surfaces. Thus, a new set of control laws was developed at Dryden in order to alleviate correlation among the control surface deflections. The associated flight control system has been named OBES which stands for On Board Excitation System. Several different combinations of surface movements can be programmed into the computer system to obtain the desired results. However, the most effective surface deflection combinations and amplitudes are determined by a trial and error approach in the flight simulator. The tests for the HARV were conducted in the flight simulator, and the following inputs were found to be sufficient for good PID research.

Lateral-Directional

Small Amplitude Doublets:

Differential Tail	+/- 3 degrees
Rudder	+/- 10 degrees
Differential Aileron	-/+ 7 degrees

Large Amplitude Doublets:

Differential Tail	+/- 6 degrees
Rudder	+/- 15 degrees
Differential Aileron	-/+ 10 degrees

Longitudinal-Directional

Small Amplitude Doublets:

Inboard Trailing Edge Flaps	+/- 15 degrees
Outboard Trailing Edge Flaps	+/- 13 degrees
Stabilator	+/- 3 degrees

Large Amplitude Doublets:

Inboard Trailing Edge Flaps	+/- 25 degrees
Outboard Trailing Edge Flaps	+/- 23 degrees
Stabilator	+/- 6 degrees

Each doublet is four seconds long (two seconds each way), and they are performed as the pilot maintains a steady angle of attack.

PID maneuvers were recently tested with the HARV. The points tested were at 10, 25, 30, 40, 50, and 60 degree angles of attack. The preliminary pEst results were very promising at low alphas, and the curve fits of the computed and measured responses were quite accurate. Further analysis of this data has been delayed because of problems associated with the installation of the pEst software at West Virginia University. It is expected that these computer problems will be resolved by mid-November, and the data analysis can be continued there after.

References

1. Maine, R.E., and Iliff, K.W., "Application of Parameter Estimation to Aircraft Stability and Control -The Output Error Approach", NASA RP-1168, June 1986.

2. Duke, E.L., Antoniewicz, R.F., Krambeer, K.D., "Derivation of a Linear Aircraft Model", NASA RP-1207, August 1988.

3. NASA Symposium Report TN-D-7647, "Parameter Estimation Techniques and Application in Aircraft Flight Testing", Volume I,II, April 1974.

4. Bowers, A.H., Noffz, G.K., Grafton, S.B., Mason, M.L., and Peron, L.R., "Multiaxis Thrust Vectoring Using Axisymmetric Nozzles and Postexit Vanes on an F/A-18 Configuration Vehicle", April 1991.