JOINT INSTITUTE FOR ADVANCEMENT OF FLIGHT SCIENCES

Program of Research in Flight Dynamics in the
JIAFS at NASA Langley Research Center

NASA Cooperative Agreement NCC1-29

Summary of Research Report

December 1, 1979 - November 30, 1998

School of Engineering and Applied Science
The George Washington University
Washington, D.C. 20052

OVERVIEW

The program objectives were defined in the original proposal entitled "Program of Research in Flight Dynamics in the JIAFS at NASA Langley Research Center" which was originated March 20, 1975, and in yearly renewals of the research program dated December 1, 1979 to December 1, 1998.

The program included three major topics:

1) Improvement of existing methods and development of new methods for flight and wind tunnel data analysis based on system identification methodology.
2) Application of these methods to flight and wind tunnel data obtained from advanced aircraft.
3) Modeling and control of aircraft, space structures and spacecraft.

The principal investigator of the program was Dr. Vladislav Klein, Professor at The George Washington University, Washington, D.C.. Thirty-seven Graduate Research Scholar Assistants, two of them doctoral students, also participated in the program. The results of the research conducted during nineteen years of the total co-operative period were published in 23 NASA technical reports, 2 D.Sc. Dissertations, 14 M.S. Theses and 33 papers. The list of these publications is included. The results were also reported in more than 30 seminar lectures presented at various research establishments world-wide.

For contributions to the research supported by the co-operative agreement, three NASA Awards were received:

1) NASA LaRC Group Achievement Award, May 30, 1990, to Dr. V. Klein as a member of the X-29 Drop Model Team.

2) NASA Medal for Exceptional Engineering Achievement, March 27, 1992, to Dr. V. Klein for innovative contributions in the development of advanced techniques and computer programs in the field of system identification.

3) NASA LaRC Team Excellence Award, May 7, 1994, to Dr. V. Klein as a member of the X-31 Drop Model Team.

SIGNIFICANT ACCOMPLISHMENTS

Significant accomplishments were achieved in the research on system identification methodology and its application for advanced, high performance aircraft. Based on the urgent need of the Langley Stall-Spin Research Program to have mathematical models of aircraft at high angles of attack, an algorithm was developed for determination of a structure for aerodynamic model equations and estimation of their parameters from flight test data (ref. 1.2, 3.4, 3.5 and 3.7). The algorithm was based on a stepwise regression and several statistical criteria that select the "best" model. The aerodynamic forces and moments were modeled either by polynomials or polynomial splines (ref. 1.3). The method was first applied to various general aviation aircraft (ref. 1.6 and 3.6). Because the algorithm has the advantage of being stable for either stable or unstable dynamical systems, it was later successfully applied to the high angle of attack data of several inherently unstable flight vehicles including Royal Aircraft Establishment (RAE) High Incidence Research Model (ref. 1.13, 3.16 and 3.18), X-29 and X-31 research aircraft (ref. 1.16, 2.9, 3.26 and 3.31). The model structure determination technique and the resulting computer software were adopted by several aerospace laboratories and companies worldwide.

An additional problem surfaced in attempting to analyze data from highly augmented aircraft in both linear and nonlinear regions. The various control surfaces were often highly correlated in their time histories by the onboard control laws. This led to difficulties in establishing the effects on individual control surfaces and sometimes in ill-conditioning of the entire problem. This obstacle was approached through the study of various methods for collinearity diagnostics and biased estimators, and incorporated those into the regression program (ref 1.9, 3.14, 3.22 and 3.25).

To improve the accuracy of measured flight data a data consistency analysis was developed. This technique reconstructs the flight path and, at the same time, estimates bias errors in the measured data (ref. 1.8 and 3.1). Then the corrected data are used in the main part of the system identification methodology, i.e. state and parameter estimation. Attention was also given to obtaining better information about the accuracy of estimated parameters. An algorithm for the parameter confidence interval determination of maximum likelihood estimates was developed (ref. 2.2 and 3.11). Also an algorithm for estimation of the parameter covariance matrix that accounts for colored residuals resulted in consistently accurate measures of the scatter in the parameter estimates (ref. 1.21 and 3.30).

The ever increasing problems in identification caused by insufficient excitation of transient motion, and correlated inputs and outputs led to a study of practical and optimal input form that would maximize the information matrix and be flyable by a human pilot or computer based input command system (ref. 2.6, 2.8 and 3.23).

An additional approach to aerodynamic parameter estimation was formulated in the frequency domain using the maximum likelihood method (ref. 1.1). The application of this method resulted in estimates which compared favorably in the linear region with those obtained in time domain analysis. The computer program or algorithm has been in wide use for helicopter parameter estimation since the time of method development. The frequency domain analysis was also successfully used in estimating parameters of the inherently unstable X-29 aircraft (ref. 2.3) and handling qualities criteria of the supersonic Tu-144 aircraft (ref. 2.16).

An outline of system identification methodology applied to aircraft which was developed under the co-operative agreement and close cooperation with NASA LaRC researchers is given in ref. 3.21, 3.27 and 3.33.

During the last four years of the co-operative agreement the attention was focused on modeling and identification of linear and nonlinear unsteady aerodynamics. The measured data for identification were obtained from wind tunnel experiments during which the test model was subjected to either one-degree oscillatory motion about one of its body axes or motion excited by ramp input. The aerodynamic models were formulated in terms of indicial functions (ref. 1.17, 1.19 and 1.20). The form of these functions were selected either as simple exponential functions (linear case) or as exponential functions with terms dependent on the angle of attack (nonlinear case). The parameters in postulated models were estimated by methods based on the least squares and maximum likelihood principles. The identified models fit the experimental data well and were also good predictors (ref. 1.22 and 1.23).

PUBLICATIONS

Technical Reports

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1.22 Klein, Vladislav; Murphy, Patrick C.; Curry, Timothy J. and Brandon, Jay M.: Analysis of Wind Tunnel Longitudinal Static and Oscillatory Data of the F-16XL Aircraft. NASA TM-97-206276, 1997.

1.23 Klein, Vladislav and Murphy, Patrick C.: Estimation of Aircraft Nonlinear Unsteady Parameters From Wind Tunnel Data. NASA TM-1998-208969, 1998.

<u>Dissertations and Theses submitted to The George Washington University, School of Engineering and Applied Science, Washington, D.C.</u>

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