A progress report on a programme of research into the aerodynamics, stability and control characteristics of a combat aircraft having a forward swept wing

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ISBN 0 947767 27 4
£7.50

"The views expressed herein are those of the authors alone and do not necessarily represent those of the Institute."
Acknowledgement

The study which is the subject of this report was initiated by MOD(PE), Aerodynamics department, Royal Aircraft Establishment, Farnborough in response to a proposal by the College of Aeronautics under the terms of Agreement No. AT/2028/0156. This report is an interim statement on the progress made in the period November 1984 to October 1985.

The support and encouragement of the technical monitor, Dr. A.J. Ross is gratefully acknowledged.
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1 INTRODUCTION

It was initially intended that this report should have been a full technical statement of progress achieved in the last year of the research programme. However, the rather large amount of material amassed made the preparation of such a report impractical in the timescale. Also, some aspects of the work were not quite complete and it was thus decided that a better statement could be produced at a later date. Consequently, the available material is currently being reviewed in preparation for final reporting whilst the present statement is intended as a brief non-technical statement of progress.

The background to the current years' study is reported in references 1 to 4. In particular, reference 4 covers the work which was foundation laying in preparation for the experimental investigations which have been the main occupation in the present year. At the commencement of the present year the detail aerodynamic design of the FSW aircraft was complete and a model of that aircraft for use on the dynamic wind tunnel test rig was very nearly ready for preliminary trials. Indeed, some static trials were already underway at that time. It was intended to utilise a computational parameter identification technique to estimate the aerodynamic stability derivatives of the aircraft model from dynamic response data and a start had already been made on the development of the essential computer programs. The parameter identification programs were running and had been tested using contrived response data obtained from a computer simulation of an aircraft with known characteristics. Thus the entire research programme was poised ready to move on into the main experimental investigation phase.
2 OBJECTIVES

The broad objectives of the present 12 month study were to determine as completely as possible the aerodynamics, stability and control characteristics of the FSW aircraft and to gain some insight into the likely stability augmentation requirements. With this in mind the following tasks for the years work were defined at the outset.

(i) Completion of the FSW aircraft wind tunnel model including fitting the model to the dynamic test rig and the establishment of working electrical and control interfaces. This work was effectively completed at the commencement of the present period of study.

(ii) To undertake a series of wind-off static tests with the model in the test rig for the purposes of measuring moments of inertia, centre of gravity variations, mass distribution limits and control surface calibrations.

(iii) To carry out a series of static wind tunnel tests to determine basic aerodynamic force, moment and trim data for the model.

(iv) Establish signal interfaces between the aircraft model, dynamic test rig and a micro computer for the acquisition, preprocessing and storage of response data.

(v) To carry out a series of dynamic wind tunnel tests to obtain control response data from which the dynamic stability characteristics of the aircraft would be estimated by means of a computational parameter identification technique.

(vi) To develop as necessary the parameter identification software to facilitate the analytical aspects of the research programme.

(vii) To analyse the results of the experimental work in order to determine the aerodynamic stability derivatives of the FSW aircraft and to determine its stability and control characteristics.

(viii) To commence investigations into stability augmentation requirements using a statically stable version of the FSW aircraft model on the dynamic wind tunnel test rig.
3 SUMMARY OF PROGRESS

In the period November 1984 to October 1985 progress has been very considerable and many of the earliest objectives of the entire research exercise, as set out in reference 1, have been achieved in whole or in part. Broadly, progress has been made in four areas of activity; completion of the development of the experimental facility, completion of static and dynamic wind tunnel tests with a stable version of the FSW airframe model, some analysis of results and commencement of experimental studies using feedback control techniques to modify the aircraft behaviour. A brief summary of these achievements is described below.

3.1 Development of Experimental Facility

Most of the hardware comprising the experimental facility shown on fig. 1 was completely assembled at the commencement of the present period of study, it remained to get it all working together and to calibrate the signals of interest. In particular static wind-off tests were carried out to measure moments of inertia, define a useable c.g. range and to calibrate control surface angle and attitude pick-off signals. Some difficulties were experienced with signal instability and noise in the model. However, in the course of calibration the cause was identified and cured. The other main activity concerned the addition of a digital data acquisition capability. This was implemented with a general purpose analogue-to-digital converter unit connected to a Commodore micro-computer with dual disc drive. A program was written to sample the signals of interest at the appropriate rate, to scale and otherwise preprocess the digitised data appropriately prior to storing on disc. Retrieval of the data to the DEC VAX-750 computer was then undertaken off line by means of a similar Commodore machine connected as a terminal to the VAX. Having achieved a basic working mechanical facility the addition of the digital interfaces was accomplished with few difficulties and worked very well.

3.2 Dynamic Wind Tunnel Tests

During the course of the work a large number of dynamic wind tunnel tests have been completed to support the process of learning how to make best use of the facility. Generally, these tests have been carried out to accommodate variations in model configuration, changes to the support system and signal interfacing and to take advantage of the continuing improvements to the computer programs. However, all of the tests were
carried out to produce response data from which the dynamic stability and control characteristics of the model could be estimated.

Because of the limitations of the model and suspension system all tests were concerned with the short period motions only. The tests included the longitudinal short period transient response and the lateral transient response to control surface inputs. The longitudinal motion tests were limited to two c.g. positions over a limited range of wind tunnel speeds. Wind speed was limited to realistic scale values and also because the vertical freedom of the model was found to be insufficient at the higher speeds. Even for very small control inputs the resulting transient motion of the aircraft model in heave at the higher tunnel speeds was found to be considerable. During these tests the control input and various output response signals were digitised, preprocessed and stored for further analysis. Some strip chart records were also made for more immediate observations of performance.

3.3 Static Wind Tunnel Tests

The design of the FSW aircraft and the dynamically scaled wind tunnel model was undertaken with the aid of various computer programs as reported in references 2 to 4. Collectively, the programs attempt to optimise the design layout for static margin and minimum induced drag. However, as the aerodynamic data available for such a layout was minimal and at best relatively crude it was decided to carry out a series of static wind tunnel tests on the scale model using the College of Aeronautics 8ft by 6ft low speed wind tunnel. The object was to obtain estimates for the basic aerodynamic characteristics such as lift curve slope, pitching, rolling and yawing moments. Two series of tests were run, the first to obtain longitudinal data and the second to obtain lateral data, the scope of the tests was limited to a maximum speed of 30 m/sec and a maximum angle of incidence of 20° as it had already been established that the model could safely be flown to these limits from earlier dynamic tests.

The results of the longitudinal tests showed reasonably good agreement with the theoretically derived aerodynamic models given in reference 4. However, the main area of difference concerned the static margin. Calculations backed with simple static tests with the model on the dynamic test rig showed the stick fixed static margin to be -1% with the c.g. at 0.444m from datum; these values apply to the model configuration with inboard wing trailing edge extensions which were added to ensure a safe margin of stability for the initial wind tunnel tests. The static wind
tunnel test measurements showed the model with trailing edge extensions to have a static margin of -6% with the c.g. at 0.435m from datum and, without trailing edge extensions the static margin was found to be -14% for the same c.g. position. Some decrease in stability was expected to allow for the experimental differences but the change observed was certainly greater than expected.

The lateral static wind tunnel tests covered yaw characteristics mainly with some limited experiments to measure roll data. Again, reasonably good agreement with the theory was established. However, it was found that yawing moment variation with rudder angle became constant for yaw angles greater than 10° and incidence angles greater than 20° indicating that the fin and rudder become ineffective when immersed in the wing-body wake. This observation was also made in the dynamic tests.

3.4 Development of the Parameter Identification Program

The initial development of the parameter identification program had been completed to a satisfactory working level at the commencement of the present study as reported in reference 4. As initial development had not used actual dynamic test rig data some further development of the extended Kalman filter code was necessary in order that it could cope with the noise content of the recorded data. As no attitude rate response signals were available from the dynamic model it was necessary to derive those states by differentiation. However, as the basic signals were noisy the derived rate signals were quite unusable. The technique adopted to overcome the difficulty was to fit high order polynomials to the response data and then to differentiate the polynomials to derive approximate rate signals. This data was then used quite successfully in the estimation program.

Analysis of experimental response data resulted in estimates for the aerodynamic stability and control derivatives being obtained from the parameter identification program. Validation of the derivatives was achieved by setting up a computer simulation of the aircraft to include the estimated values for the derivatives. Response data from the simulation compared very well with experimentally obtained response data even when allowances were made for the inevitable errors associated with non-linearities, suspension system friction, wind tunnel blockage effects and wind tunnel resonance effects. It was concluded with some confidence that the estimated stability derivatives were representative of the FSW aircraft configuration.
3.5 Analysis of Results

As a large amount of data had been amassed from the static and dynamic wind tunnel tests, parameter identification program and simulation program a start was made on an attempt to correlate the information and understand the differences where they exist. This work is continuing.

Included in the output from the first order FSW aircraft configuration optimisation program described in reference 4 were theoretically derived estimates for the aerodynamic stability derivatives. Not surprisingly these values do not compare very favourably with those produced by the parameter identification program. This was expected for two reasons: firstly, the theoretical optimisation program predicted a longitudinal stability margin in the range 2% to 6% whereas the measured value was around zero indicating neutral or near neutral stability. Secondly, the theoretical estimates were based on aerodynamic data pertinent to trimmed flight whereas the measured results related to dynamic conditions.

Further, comparison of the measured static aerodynamic data with the originally used theoretical models showed certain disparities particularly in pitching moment characteristics. However, it was found that when the measured static aerodynamic characteristics were used in the theoretical models in the optimisation program the estimated stability derivatives showed much closer agreement with those obtained from the parameter identification program. This obviously improved confidence in the original theoretical aerodynamic models used in the definition of the FSW aircraft configuration.

3.6 Control System Developments

To date most control system design work has attempted to extend the usefulness of the test rig to enable data to be obtained for flight conditions previously excluded for practical reasons. The major practical difficulty was caused by the magnitude of the height excursions of the model when undergoing longitudinal short period tests at higher tunnel speeds. To overcome this difficulty a simple height measuring device was designed and built to sense the vertical position of the model on the suspension system. Experiments were then undertaken to design a simple height hold autopilot. A simple proportional plus integral feedback system was tried but with the gain levels set to accommodate tunnel speed fluctuations due to blockage effects and lateral perturbations the height control response was too sluggish. A more sophisticated two state feedback system was tried in which proportional height and pitch signals were used in combination. The addition of roll and yaw attitude feedback loops using propor-
tional plus integral controllers was found to provide a satisfactory solution to some of the earlier problems.

Although the scope of the simulation was increased by these means the non-linearities arising from the suspension system mechanics gave rise to a height autopilot with a response resembling the natural phugoid motion of an aircraft. It was concluded that given the present experimental facility it would be difficult if not impossible to produce an ideal controller of the kind attempted. However, sufficient improvement was obtained to permit a useful extension to the flight envelope of the model.

In terms of autostabilisation of the FSW aircraft model it was found possible to control the model satisfactorily even when the longitudinal static stability is relaxed. It should be possible therefore to undertake further experimental studies with an unstable model in which the static margin could be as much as 4% negative with confidence.
4 CONCLUSIONS

Although a great deal has been learned about the aerodynamics, stability and control of the FSW aircraft configuration studied, some analysis remains to be done to complete the exercise. Some of the more obvious observations made from the work completed to date are as follows,

(i) The theoretical aerodynamic models developed for the aircraft appear to match the observed aerodynamic performance reasonably well.

(ii) The estimated stability derivatives for the aircraft when incorporated into a computer simulation provide response characteristics which agree particularly well with experimentally derived responses.

(iii) The parameter identification technique devised to cope with the limitations of the experimental facility has been shown to be particularly effective.

(iv) Theoretical predictions of longitudinal static stability margins indicated the aircraft to be more stable than was found to be the case from experiment. The differences have not yet been properly explained.

(v) The application of feedback control to the model has been relatively straightforward except that the mechanical shortcomings of the dynamic test rig have limited the potential scope for more searching investigations.

(vi) It has been established that the experimental system will permit dynamic tests to be made on the aircraft model with a longitudinal static stability margin as small as -4%. A more unstable model than this would be too difficult to control with the limited feedback facilities available.
It is considered that for the purposes of obtaining aerodynamic, stability and control data for the FSW aircraft configuration in question the limitations of the experimental facility preclude any further significant studies. The only outstanding exception to this is the possibility of investigating a statically unstable version of the airframe. Thus, based on the continuing use of the present facilities the following limited further activities would be useful and would bring the work to a natural conclusion.

(i) Carry out experiments with the FSW aircraft model on the dynamic wind tunnel test rig to obtain some stability and control data for varying levels of longitudinal static instability to the practical limit.

(ii) Carry out further analysis of existing results to try and achieve some correlation across the various activities comprising the research programme.

(iii) As far as is reasonably practical write separate concluding reports on the various subject areas covered in the work. Because of the broad nature of the study and the large amount of material amassed this is thought to be the most satisfactory way of presenting the results.
6 REFERENCES


FIGURE 4 The Experimental Facility