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Flight Mechanics Report 187

F-111C FLIGHT DATA REDUCTION AND ANALYSIS PROCEDURES

by

M.I. Cooper
J.S. Drobik
C.A. Martin

Approved for public release

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A series of flight trials was performed on the F-111C aircraft at the RAAF’s Aircraft Research and Development Unit in February and October 1987. Data obtained from the tests were analysed at the Aeronautical Research Laboratory to determine the aircraft aerodynamic and control derivatives. This report describes the methods and computer programs which are used to process and analyse the flight test data. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Although the test programme was conducted on a F-111C aircraft, with minor alterations the computer programs and procedures can be used for other aircraft test programmes.
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Notation

a Coefficient of linear equation
a_n, a_z, a_y Normal, longitudinal and lateral acceleration, g
b y-intercept of linear equation for curve fitting
C_l Rolling moment coefficient
C_n Yawing moment coefficient
C_Y Side force coefficient
c Reference chord
c.g. Centre of gravity as a fraction of reference chord
CADS Central Air Data System
g Gravitational acceleration
H Altitude
I_{xx}, I_{yy}, I_{zz} Moments of inertia about roll, pitch and yaw axes
I_{ss} Cross product of inertia
K_a, K_b Flow amplification factors for angle-of-attack and sideslip
M Mach number
m Mass of aircraft
NBTU Nose Boom Transducing Unit
p Roll rate
q Pitch rate
\dot{q} Dynamic pressure
r Yaw rate
R Degrees per radian (57.2958)
S Reference area
T Thrust
TACT Transonic Aircraft Technology
u Control vector
V Velocity
x State vector
x_a, x_b Longitudinal instrument offsets from c.g.
y_a Lateral instrument offsets from c.g.
z Measured observation vector
z_a, z_b Vertical instrument offsets from c.g.
\alpha Angle of attack
\beta Angle of sideslip
\delta Control deflection
\delta_a Aileron deflection \left(\frac{\delta_{a_{\text{A}}}}{2} + \frac{\delta_{a_{\text{R}}}}{2}\right)
\delta_r Rudder deflection
\delta_p Spoiler deflection
\delta_s Stabilator deflection
\epsilon Error between model and flight data
\theta Pitch angle
\Lambda Wing sweep angle
\phi Roll angle
## Subscripts

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM</td>
<td>Crew module instrument</td>
</tr>
<tr>
<td>L</td>
<td>Left (port)</td>
</tr>
<tr>
<td>m</td>
<td>Measured quantity</td>
</tr>
<tr>
<td>NBTU</td>
<td>Nose Boom Transducing Unit</td>
</tr>
<tr>
<td>$\dot{a}, \dot{b}, \dot{p}, \dot{q}, \dot{r}$</td>
<td>Rate derivatives with respect to indicated quantity (per degree/sec)</td>
</tr>
<tr>
<td>R</td>
<td>Right (starboard)</td>
</tr>
<tr>
<td>$\alpha, \beta$</td>
<td>Static derivatives with respect to indicated quantity (per radian)</td>
</tr>
<tr>
<td>$\delta, \delta_u, \delta_r, \delta_p$</td>
<td>Control derivatives with respect to indicated quantity (per degree)</td>
</tr>
<tr>
<td>STANDARD</td>
<td>Standard aircraft baseline configuration</td>
</tr>
<tr>
<td>0</td>
<td>Bias</td>
</tr>
</tbody>
</table>
+ Lift gives $C_l$
+ Rolling Moment
+ Side Force
+ Yawing Moment
- Lift gives $C_l$
- $\delta_s$ for T.E. above sym. position
- $\delta_s$ gives $C_l$
- $\delta_t$ gives $-C_n$
+ Drag
- $\beta$
+ $\alpha$
+ Drag gives $C_m$
- $\delta_e$
+ Pitching Moment

Force and Moment Sign Convention (Stability Axes)
1 Introduction

Models of aircraft flight dynamics are used for a range of applications, for example, the analysis of aircraft behaviour, for aircraft design, and for driving flight simulators. Part of this modelling procedure involves the estimation of the aerodynamic stability and control derivatives from various sources such as empirical, wind tunnel and flight tests. This report describes the methods and computer programs which are used to process and analyse data obtained from a flight test programme conducted on a General Dynamics F-111C aircraft. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Data extraction is carried out on a VAX 750 computer using Fortran programs developed at the Aircraft Research and Development Unit (ARDU). Data processing and analysis is carried out on the ARL ELXSI 6400 computer using Fortran programs either acquired or specifically developed at ARL. Data presentation is carried out on an IBM PS2 personal computer using a computer program written in Pascal.

Flight testing of the aircraft was carried out at ARDU in 1987. Data from the programme has been used to validate a comprehensive flight dynamic model of the F-111C which was developed at ARL and this model will be used to upgrade the F-111C flight training simulator at RAAF Base Amberley.

2 Test Aircraft and Instrumentation

The F-111C test aircraft A8-132, illustrated in Figure 1, was extensively modified under ARDU Test Schedule 1650 with flight test quality instrumentation and data recording equipment. This equipment known as the Airborne Flight-Test Recording and Analysis System (AFTRAS) provides on-board digital magnetic-tape recording and telemetry information for real-time flight test monitoring. The instrumentation was developed for use for store-carriage and release tests and for the flight dynamic measurements and is capable of measuring 200 measurands at a sampling rate of 60 per second. Special equipment was developed for recording, and for manual adjustment of the pitch and roll adaptive gain values. Because of insufficient time, the instrumentation required to monitor other parts of the adaptive control system was not installed. Similarly, the instrumentation for monitoring engine parameters required for detailed performance measurements was not fitted. These parts of the instrumentation were not required for the estimation of the aerodynamic coefficients, but were required for the related investigation of the adaptive control system behaviour and aircraft performance characteristics.

The Nose Boom Transducing Unit which was used for the second phase of the trials, was constructed by the Advanced Engineering Laboratory (AEL) Salisbury and was designed to provide high quality measurements of pitot pressure, angle-of-attack, angle-of-sideslip and linear accelerations parallel and normal to the local
airflow direction. The unit was modelled on the CONRAC Nose Boom Instrumentation Unit (NBTU) Model 25126F, developed by the USAF for flight dynamic performance measurements. The NBTU is shown in Figure 2 and a detailed description of the assembly is given in Reference [1].

A list of the instrumentation channels (measurands), including their ranges and accuracies, which are used for the flight dynamic analysis is given in Table 1. These channels were recorded at a rate of 60 samples per second using the AFTRAS system.

The measurement of the pressure error corrections for the NBTU was carried out by ARDU as part of the Test Schedule 1691. Details of these measurements are presented in Appendix D.

3 Flight Test Programme

An outline of the flight test programme is presented below. Full details of the programme are contained in the flight data analysis reports (References [2] to [7]).

3.1 Test Points

The flight test programme was carried out in two phases. The matrix of test points covered in Phase 1 and Phase 2 is given in Table 2. The first phase covered 75 test conditions representing combinations of wing sweep, altitude and Mach number. At each test point two longitudinal and two lateral manoeuvres were performed. The flow angles in this phase were obtained from transducers in the aircraft’s standard Central Air Data System (CADS). For the second phase of the programme a Nose Boom Transducing Unit (NBTU) was available for the measurement of the angles of attack and sideslip. A number of Phase 1 test point manoeuvres were repeated in Phase 2 to compare the accuracy of the results using the aircraft system (CADS) and the NBTU system for measurements of angle of attack and angle of sideslip. The remaining tests were made at Mach numbers between those tested in Phase 1 to provide a more comprehensive data coverage. The total test program required 24.6 test hours of flying.

3.2 Test Manoeuvres

The following manoeuvres were performed at each test point.

1. accurate trim
2. pitch input where the stick is pulled back (1 to $\approx 2 \text{ g}$') then pushed forward to neutral and the aircraft allowed to damp in pitch.
3. trim
4. pitch input where the stick is pushed forward (1 to $\approx 0 \ 'g'$) then pulled back to neutral and the aircraft allowed to damp in pitch.

5. accurate trim

6. rudder step input to left followed by aileron doublet to achieve $\approx \pm 30^\circ$ bank angle. Rudder and aileron released together.

7. trim

8. manoeuvre 6. repeated but rudder input to right and opposite roll applied

9. trim

These specified manoeuvres are designed to give an aircraft response which is optimum for the determination of stability and control derivatives using the techniques described in Section 4. Advice provided by NASA Dryden test personnel from experience with the F-111A TACT aircraft, indicated that large rapid control inputs were necessary to provide large amplitude excitation of the natural modes of the aircraft with the automatic flight control system engaged.

Manoeuvres were also flown with the aircraft in the landing and take off configurations. These cases are summarised in Table 3.

Supplementary manoeuvres were performed to enhance the prediction capability of the validated ARL flight dynamic model and for use as test manoeuvres for the F-111C flight training simulator. These included:

1. longitudinal roller-coaster manoeuvres
2. lateral oscillatory manoeuvres
3. dutch rolls
4. steady heading sideslips
5. longitudinal trims

The manoeuvres and the flight conditions at which they were performed are summarised in Table 4.

3.3 Flight Control System Status

The tests were conducted with the flight control system in the normal mode and with the system gains determined by the normal adaptive mode gain changer. However, when rapid control inputs were applied at some flight conditions, motion due to the adaptive mode was superimposed on the natural motion of the aircraft. The problem of adaptive mode ringing was overcome by pumping the stick and driving the control system gains down to a level where the aircraft natural response dominated the motion.
4 Flight Data Processing and Analysis

Flight data processing and analysis was carried out in the order shown in Figure 3. The procedures used, and the software developed and acquired for this purpose are summarised in this section. Details of the procedures are given in the Appendices. Figures 4 and 5 list the names of the input and output files used by various procedures and lists the analysis programs.

A significant aspect of the programme involved the management of large amounts of data. Approximately 10.5 million data points were acquired in this programme, being the aggregate of 33 measurands sampled at 60 samples per second for test manoeuvres totaling 46 seconds at each of the 162 test conditions. Approximately 20 hours of CPU time and 15 Megabytes of disk storage on a high speed mainframe computer was required to analyse the cases for a complete Mach number range at one sweep angle and one altitude. A total of 6 sweep angles was tested at 5 different altitudes in the clean configuration. Additional measurements were also made in the take off and landing configurations.

4.1 Data Extraction

The AFTRAS flight data system provides organised procedures for accessing selected channels, for applying calibrations to give engineering units, and for formatting the data for subsequent analysis. Calibrations are stored as polynomial coefficients against the date of calibrations and are appended to the data files obtained from each flight. Details of these procedures are given in Reference [8]. The procedures are carried out using program EXTRACT which can be run on the ARDU or ARL VAX computers. Appendix A describes the EXTRACT procedures in detail and through the use of an example, indicates the information which has to be provided and the form of the data extracted.

The input data required for use by the parameter estimation techniques needs additional processing to provide the required data format and also to apply further measurement error corrections. This processing stage is carried out within program FDP on the ARL ELXSI computer and is described in detail in Appendix C. The corrections are required:

1. to compensate the airspeed, Mach number and altitude for pressure errors and compressibility effects at the pitot-static sensor locations
2. to apply time shifts to the time history records to compensate for instrument signal conditioning and recording lags
3. to calculate pitch and roll control deflections from the measured stabilator deflections
4. to calculate weight, c.g. and moments of inertia information from the fuel tank contents data

4
4.2 Aircraft Mass Characteristics

Accurate information is required of all-up weight, horizontal, vertical and lateral centre of gravity position and inertia properties for the analysis of dynamic manoeuvres. This information is used to convert the aerodynamic derivatives into non-dimensional coefficients, to provide references for instrumentation and sensor position and to allow valid comparisons of the derivatives obtained from different flights where the mass characteristics, especially the C of G position, may be different. Aerodynamic moment data obtained from wind tunnel tests are usually referenced to a given C of G position and an adjustment for the actual flight test positions must be included if a valid comparison is to be made.

Procedures for determining the mass characteristics for the test aircraft A8-132 were as follows:

- Aircraft was weighed to establish baseline data.
- Fuel calibration tests were conducted.
- Software was developed using manufacturers data to calculate mass characteristics and adjustments made to reflect weight and fuel calibration results.
- At each test point the indicated fuel tank contents were recorded.

4.2.1 Aircraft Weighings

The aircraft was weighed in accordance with standard RAAF weighing procedures. Tables 5 to 10 show the results for the various configurations which form the baseline aircraft information. The change in weight and C of G for the aircraft with the NBTU fitted (Phase 2 flights) was derived from the information contained in Table 10.

4.2.2 Fuel Calibration

A fuel calibration was obtained by emptying the fuel tanks of all useable fuel and adding a known amount to the forward and aft tanks then recording the indicated and actual tank contents. During the flight test the aircraft loading and centre-of-gravity varied in accordance with the aircraft auto-fuel schedule, which is described in Appendix B. After take-off the aircraft would use all fuel in the wing and primary weapons bay fuel tanks before any flight test manoeuvres commenced. Prior to each test point the indicated forward and aft fuel tank contents were recorded on the pilots test card and, by applying the fuel calibration, an accurate calculation of C of G and AUW was made. Figure 6 shows a typical test card with relevant information highlighted. During the test manoeuvres, the aircraft weight was typically near 70,000 lb.
4.3 Instrumentation Time Lags

A procedure for identifying the relative time lags between instrumentation channels was developed at ARL and is documented in Reference [9]. This procedure also uses the maximum likelihood technique and was applied to a number of selected time histories to determine the lag parameters. The resulting parameters are given in Table 11 where a positive integer indicates \( n \) time samples \((n/60 \text{ seconds})\) lagged with respect to the control deflection signals. The table shows that the NBTU signal for angle-of-attack leads the control deflection signals by two sample intervals, showing that this instrumentation has smaller signal delays than the Phase I instrumentation.

4.4 Calibration of \( \alpha \) and \( \beta \) Flow Vanes Using Flight Path Reconstruction

In addition to determining the pressure error corrections to airspeed and altitude it is also necessary to determine the position errors (or calibration constants) for the angle-of-attack and angle-of-sideslip transducers. In particular the aircraft CADS transducers are mounted close to the forward fuselage where local flow angles can differ substantially from the free-stream value. A Flight Path Reconstruction (FPR) method for determining these calibration constants is described in Reference [10].

The flight path reconstruction technique uses an extended Kalman filter to determine the calibration parameters relating the computed and measured output variables.

This method uses a combined parameter and state estimation technique and is based on using the kinematic equations of motion of a rigid body. Using longitudinal, lateral and normal accelerations and pitch, roll and yaw rates as inputs, the state variables, ie. the body axes velocities \((u, v \text{ and } w)\) and roll, pitch and yaw attitudes \((\phi, \theta \text{ and } \psi)\) are estimated. From these estimates, the output quantities, velocity, angle-of-attack, angle-of-sideslip, bank and pitch angle and altitude \((V, \alpha, \beta, \phi, \theta \text{ and } h)\) are calculated and compared with measured values of the outputs. The calibration constants are adjusted along with instrument bias parameters to minimise these output errors.

As an example of the procedure consider the force equation in the Y body axis direction for a rigid aircraft (equation 5.8.2(b) Reference [11]).

\[
\begin{align*}
  \frac{\dot{Y}}{m} + g\cos \theta \sin \phi & = m(\dot{u} + ru - pw) & \text{(1)}
\end{align*}
\]

Forces in the X, Y and Z direction cannot be measured directly but use can be made of accelerometers. Dividing equation (1) by \( m \)

\[
\frac{\dot{Y}}{m} + g\cos \theta \sin \phi = (\dot{u} + ru - pw) & \text{(2)}
\]
gives:
\[ a_V + g \cos \theta \sin \phi = (v + ru - pw) \]...

The above equation is a kinematic equation relating acceleration, velocity and displacement. Assuming small angles (< 10°), a relationship between the measured kinematic variables and angle of attack \( \alpha \) and angle of sideslip \( \beta \) can be developed:

\[ \alpha \approx \frac{w}{V}, \beta \approx \frac{v}{V} \text{ and } \frac{\alpha}{V} \approx 1 ...

Then dividing both sides of equation (3) by \( V \) gives:

\[ \frac{a_V}{V} + \frac{g}{V} \cos \theta \sin \phi = \frac{\dot{v}}{V} + \frac{ru}{V} - \frac{pw}{V} \]...

Substituting for \( \alpha \) and \( \beta \) gives:

\[ \frac{a_V}{V} + \frac{g}{V} \cos \theta \sin \phi = \dot{\beta} + r - p \alpha \]...

Rearranging equation (6) gives \( \dot{\beta} \) in terms of other kinematic variables:

\[ \dot{\beta} = \frac{a_V}{V} + \frac{g}{V} \cos \theta \sin \phi - r + p \alpha \]...

Now assuming that all of the variables on the right hand side can be measured with no scale factors or bias errors \( \beta \), can be calculated by integration of equation (7):

\[ \beta = \int \left( \frac{a_V}{V} + \frac{g}{V} \cos \theta \sin \phi - r + p \alpha \right) + \text{constant} \]...

A comparison can be made between the measured value of sideslip \( \beta_m \) and the value calculated from equation 8 assuming a linear relationship between the local flow angle and the free stream value of the form:

\[ \beta_m = K \beta_{\text{actual}} + b \beta \]

From this comparison the scale factor \( K \beta \) and bias \( b \) can be determined.

For a jet aircraft with no asymmetric flow, the constant of integration or the bias can be expected to be zero. A similar procedure is carried out with the \( Z \) force equation to determine an expression for angle of attack \( \alpha \).

The estimation software used for this purpose was developed for ARL under a research agreement with the University of Newcastle. (References [12] and [13]). Application of the method to the measured time histories gave estimates for the calibration constants for the CADS and NBTU angle-of-attack and angle-of-sideslip measurement systems. For the angle-of-sideslip sensor the calibration constant varied with Mach number. Values of between 1.49 and 1.60 (CADS) were used for Phase 1 and 1.06 and 1.20 (NBTU) for Phase 2.
The CADS angle-of-sideslip sensor which is located beneath the forward fuselage over estimated the true value by 50-60% indicating strong cross-flow in this region. The NBTU gave, as expected, more accurate estimates of angle-of-sideslip, over-reading by only approximately 10-20%. While some small variations occur in the angle of attack scale factor, \( K_\alpha \) with Mach number and sweep angle, these variations are not well defined within the accuracy of the data and so constant values of 0.94 and 1.06 have been used for Phase 1 and Phase 2 respectively. An investigation into the effect of \( K_\alpha \) variation showed that errors in \( K_\alpha \) of 10 % resulted in an adjustment of typically 5 % in the major derivatives.

4.5 A priori Data from Model

A six degree of freedom flight dynamic model of the F-111C aircraft, as described in Reference [14], has been developed at ARL and includes representation of the flight control system. A comprehensive aerodynamic data base is used to obtain a priori or initial estimates of the aerodynamic stability and control derivatives. Configuration data and initial conditions are defined for each test point as described in Appendix G.

4.6 Parameter Estimation

A number of techniques have been developed in recent years for the estimation of aerodynamic derivatives from flight test measurements. These techniques generally use a statistical approach to the process of fitting a flight dynamic model to aircraft response time histories. The aerodynamic stability and control derivatives are then calculated from the coefficients of the flight dynamic model. For the F-111C data analysis, a Maximum Likelihood technique was used. A priori information for the Maximum Likelihood technique was obtained using the ARL six degree of freedom flight dynamic model and is described in Appendix G. The technique and associated computer program are described in References [15] and [16] and an example MMLE3 analysis is given Appendix H.

Within the range of flight conditions tested in the F-111C programme, it is assumed that the aircraft motion can be adequately represented by separate classical linear flight dynamic models for longitudinal and lateral motion. The longitudinal and lateral flight dynamic models, used for this purpose are derived assuming small disturbance motion and linear aerodynamic characteristics. The equations are presented in Appendix I and J.

The maximum likelihood technique uses a Newton-Raphson search algorithm to iterate to a converged solution. The program defines a cost function which is the weighted sum of the difference between the model prediction and measured time histories (see Figure 7). Convergence is declared when the cost function is less than a specified level.
The stabilator angle deflection was used as the input for the longitudinal manoeuvres and the rudder, differential stabilators and spoilers for the lateral manoeuvres. Note, spoilers only operate for cases with wing sweep less than 47°. The angle of attack, pitch rate and normal acceleration comprise the outputs for the longitudinal model. The angle of sideslip, roll rate, yaw rate and lateral acceleration comprise the outputs of the lateral model.

The derivatives used in the linear identification model and their importance are summarised in Figure 8. The derivatives can be divided into three categories. The static derivatives are fundamentally 'stiffness' parameters and the dynamic derivatives are 'damping' parameters. The analogy is drawn with a second order mass spring damper system. The control derivatives describe the forces and moments due to control surface deflections. Figure 9 compares the pitch response to an elevator input measured in flight with the response calculated from the estimated derivatives.

To assist the identification procedure, particularly for derivatives which make only a small contribution to the motion, a priori information can be used in the identification procedure. A facility exists to constrain selected parameters to either a priori values or to other model parameters. Constraints were used in the longitudinal model but not in the lateral model.

For the unconstrained parameters the estimation procedure calculates a measure of the estimation accuracy known as the Cramer-Rao bound. The interpretation of this quantity is given in Reference [15].

The results plotted for each aerodynamic derivative show an average value for this prediction error calculated from the data points on each plot, which can be used in conjunction with the observed repeatability to indicate the estimation accuracy. To account for the fact that the signal noise is bandwidth limited, the Cramer-Rao bound is factored by a multiple of 10 in accordance with the procedures described in Reference [16]. Two additional procedures were used prior to the application of the maximum likelihood technique to improve the quality and consistency of the measured time histories. These are discussed in Appendix H.

4.7 Curve Fitting of Derivative Results

It is planned that the data from these flight tests will be used to update the aerodynamic data base used in the RAAF's F-111C simulator. To correct the existing data-base, the new derivative information must be presented as variations with Mach number for each sweep and altitude. The approach which has been used is to relocate the model data curve to best fit the flight derivatives, therefore combining the general information from the flight tests and the detailed trends given by the model. The procedure used is shown in Figure 10. Details of this process are presented in Reference [17]. Details of the notation used to name analysis files is given in Appendix K.
5 Concluding Remarks

This report describes the steps involved in processing and analysing data from a flight test program on an F-111C aircraft to determine aerodynamic stability and control parameters. All stages in the process are described and details of the individual procedures are given in separate Appendices. Computer programs developed for the analysis are described and running instructions are provided. The programs and procedures can be used for other aircraft test programmes with minor alterations.

Acknowledgements

The authors of this report would like to thank the staff of ARDU for the instrumentation, flight test planning and for the conduct of the test programme. The support received from Peter Gibbens, Shane Hill, Leon MacLaren, Rodd Perrin, Wim Dekkers and Justin Baker at ARL is also acknowledged.
References


[19] ARDU, Determination of the Pressure Error Correction For the F111C Aircraft, Technical Note Aero 80 (with Annex), 1987
[20] ESDU Airspeed Data for Performance Calculations. ESDU Data Item 69026, October 1969 (with Amendment A)


Appendix A - Extracting Data From Flight Test Tapes

The AFTRAS program EXTRACT is used to extract flight test data recorded on magnetic tape. After further processing by program LISTPARM, a list of parameters and associated values in engineering units are output in ASCII form. Each channel has a recording width of 4000 computer units and calibrations were conducted to establish the relationship between computer units and engineering units. A typical calibration is shown in Figure A1. Extraction of data at ARL is carried out on the EDS VAX 750 computer and the procedures involved are best illustrated through the use of an example and reference to Figure A2.

For the purpose of this exercise the manoeuvre selected occurred on the first flight of the second phase of tests and is event 72. From the flight test report it is established that event 72 commenced at approximately 1040.0 seconds and finished at about 1109.0 seconds. From Table A1 it can be seen that the data are stored on ARL tape 1153 and the data are from the first flight of a possible 3 on this tape.

After logging onto the VAX 750 computer at ARL and with tape 1153 mounted on drive MTBO:, the following commands are given to assign devices: (note that all user responses are prefixed by a > symbol)

```plaintext
> mount /foreign/blocksize=15100 mtb0:
%MOUNT-I-WRITELOCK, volume is write locked
%MOUNT-I-MOUNTED, mounted on _MTBO:
> ass mtb0: for001
> ass mtb0: for002
> ass mtb0: tape
```

Set default directory to [ae_drobik.aftras.vax.indata] and create the data input file P2F1E72.IN. This file contains the following details of the data to be extracted:

- The number of channels to be extracted (33)
- Time interval (0.01667 or \(\frac{1}{60}\) th of a second)
- Start of extraction (1040 seconds)
- Finish of extraction (1109 seconds)
- Channels and calibration versions to be selected (BI-170 calibration 4 to BI-031 calibration 1)
Shown below is file P2F1E72.IN

33 0.01667
1040.00 1109.000
BI 170 4
BI 171 4
BI 172 5
BI 173 2
BI 174 3
BI 175 3
BI 160 8
BI 201 7
BI 184 8
BI 023 1
BI 025 2
BI 40 4
BI 176 1
BI 177 1
BI 214 4
BI 215 4
BI 39 4
BI 41 1
BI 55 1
BI 43 2
BI 44 3
BI 45 2
BI 178 1
BI 53 2
BI 54 2
BI 238 5
BI 190 8
BI 195 8
BI 237 5
BI 188 4
BI 166 1
BI 028 1
BI 031 1

Table A2 lists the relevant channels in the order to be extracted (1 to 33) and gives the calibrations to be used. The order of the extracted channels is important and several points need to be considered when extracting data:

- Channel 7 should be selected according to the altitude of the case considered. For example BI-164-7 would be selected for a phase 1 40000 feet case.
• Channel 8 should be selected according to the Mach number of the case considered. For example, BI-202-8 would be selected for a phase 2 Mach 1.2 case.

• Channels 10 and 11, the angle of attack $\alpha$ and angle of sideslip $\beta$ should be selected according to the phase. BI-237 and BI-188 for phase 1 CADS $\alpha$ and $\beta$, or BI-023 and BI-025 for phase 2 NBTU $\alpha$ and $\beta$.

• Phase 1 flights need only the first 28 channels to be extracted.

• Phase 2 flights have a total of 33 channels with NBTU $\alpha$ and $\beta$ signals being selected in channels 10 and 11.

• For phase 2 flights channel 31 must contain the crew module accelerometer BI-31-01 signal. The output is in computer units and a calibration is applied during the flight data processing stage. If this channel is to be used instead of the C of G normal accelerometer (phase 2 flights 2 and 3) there is no need to place this signal in channel 1 because the selection of normal accelerometer to be used is carried out in the FDP stage.

Set default directory to [ae_drobik.aftras.vax.extract] and run command file EXTRACT.COM as shown below:

```
> set def [ae_drobik.aftras.vax.extract]
> list extract.com

$ set noverify
$ WRITE SYS$OUTPUT " AFTRAS EXTRACT PROGRAM "
$ WRITE SYS$OUTPUT " "
$ WRITE SYS$OUTPUT " NB. Filenames fully qualified eg. [twp.ts1672]fred.dat"
$ INQUIRE q4 "ENTER THE MAG TAPE DRIVE e.g. MTAO: "
$ INQUIRE q1 "ENTER THE INPUT filename (.inl) "
$ inquire Q2 "ENTER THE OUTPUT WORKING filename (.oul) "
$ inquire q3 "Enter flight number of the file on the archive tape (1-3) "
$ ru [ae_drobik.AFTRAS.vax.extract]EXTRACT/PARAMETER=('Q1','q2','q3','q4')
$ WRITE SYS$OUTPUT " no Batch Job submitted"
$ WRITE SYS$OUTPUT " - output logfile in your root directory "
$ EXIT
```

Shown below are the commands and responses to commence the extract and rewind the tape on MTB0:

```
> ru extract
F111C EXTRACT PROCESSING PROGRAM
```
Enter file code name, (eg:P3F2E101) > P2FIE72
Enter the tape sequence No. > 1

Infile=[- .INDATA]P2F1E72.IN
Outfile=[]P2F1E72.OUT

READING ARCHIVE MAG TAPE
READ CALIBRATION FILE, NOW CHECKING INDATA

ACCEL VERT "G" BI- 170- 4
ACCEL LAT "G" BI- 171- 4
ACC LNG CG "G" BI- 172- 6
PITCH RATE DEG/SEC BI- 173- 2
ROLL RATE DEG/SEC BI- 174- 3
YAW RTE CG DEG/SEC BI- 175- 3
HPF < 5K FEET BI- 160- 8
MACH < .7 MACH BI- 201- 7
CAS FINE T KCAS BI- 184- 8
NBTU ALPHA DEGREES BI- 23- 1
NBTU BETA DEGREES BI- 26- 2
STAB RH DEGREES BI- 40- 4
PTCHACC CG RAD/SEC BI- 176- 1
ROLLACC CG RAD/SEC BI- 177- 1
ADI PITCH DEGREES BI- 214- 4
ADI BANK DEGREES BI- 216- 4
STAB LH DEGREES BI- 39- 4
RUD POSN DEGREES BI- 41- 1
RPEDAL POS INCHES BI- 55- 1
SPL LH O/B DEGREES BI- 43- 2
SPL RH O/B DEGREES BI- 44- 3
WNGSWPXDCR DEGREES BI- 45- 2
YWANG ACC RAD/SEC BI- 178- 1
STK POS LG INCHES BI- 53- 2
STK POS LT INCHES BI- 54- 2
AOACADS-VE DEGREES BI- 238- 6
ALT CRSCAD FEET BI- 190- 8
CADS M CSE MACH BI- 195- 8
AOACADS+VE DEGREES BI- 237- 5
BETA CADS DEGREES BI- 188- 4
CM ACC VRT "G" BI- 166- 1
ACC-X NBTU "G" BI- 28- 1
NBTU A TMP DEGREES CBI- 31- 1

FORTRAN STOP
A binary file of calibrated measurands in engineering units has now been created. This file has to be converted to ASCII code and transferred to the ELXSI 6400 computer for pre analysis processing. The program used for this purpose is called LISTPARM and is invoked from the directory [ae.drobik.aftras.vax.listparm]. Shown below are the commands and responses to run LISTPARM:

> SET MAG/REW NTBO:

A binary file of calibrated measurands in engineering units has now been created. This file has to be converted to ASCII code and transferred to the ELXSI 6400 computer for pre analysis processing. The program used for this purpose is called LISTPARM and is invoked from the directory [ae.drobik.aftras.vax.listparm]. Shown below are the commands and responses to run LISTPARM:

> RU LISTPARM

AFTRAS LIST PARAMETERS PROGRAM
version 2.1 july 85
AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

PLEASE ENTER AFTRAS OUT FILENAME
> [-.EXTRACT]P2F1E72.OUT

TYPE 1 IF PRINTING BY EVENTS,
  2 IF PRINTING AT TIME INCREMENTS,
  3 IF PRINTING AVERAGES BETWEEN CONSECUTIVE EVENTS
  4 IF PRINTING 'ABOUT' EVENTS
  5 IF PRINTING ENTIRE FILE CONTENTS
  6 OUTPUT DEVICE IS : SCREEN , SELECT TO CHANGE
  7 CHANGE OUTPUT MEASURANDS
  8 TO FINISH

> 6

TYPE 1 IF PRINTING BY EVENTS,
  2 IF PRINTING AT TIME INCREMENTS,
  3 IF PRINTING AVERAGES BETWEEN CONSECUTIVE EVENTS
  4 IF PRINTING 'ABOUT' EVENTS
  5 IF PRINTING ENTIRE FILE CONTENTS
  6 OUTPUT DEVICE IS : PRINTER , SELECT TO CHANGE
  7 CHANGE OUTPUT MEASURANDS
  8 TO FINISH

> 5

FORTRAN STOP

Output from program LISTPARM is written to the file LISTPARM.DAT and this file is renamed to identify the particular case extracted eg. P2F1E72.DAT. This file is copied to the ELXSI by logging onto the ELXSI and using the netcopy command.

19
Flight data is now in ASCII format on the ELXSI and can be plotted using programs TRPLOT and TRANS. Reference [18] details the TRANS plotting program. TRPLOT converts ASCII data to ELXSI binary in a format suitable for TRANS and is run by:

```
> TRPLOT
   INPUT DATA FILENAME = > P2F1E72.DAT
   Read in VBLES etc---beginning numerical data
   Finished with data--TRFINI then end
   Fortran program executed STOP statement 0
```

Now run TRANS to create a device independent metafile plot file.

```
> TRANS
   [TRANS version date 11-MAR-86]
   I/P FILENAME = plots
   TS       1691   01   A088-132   008
   I/P FILE RECORDED ON 27-Jul-90 AT 09:53:54
   INTEGN INT = .0000E+00; RUN CPU TIME = 25.84 SEC.
   TIME FROM 4.6800E+02 TO 4.9094E+02 IN STEPS OF 1.6670E-02
   > PLS
   IS GRAPHICS OUTPUT TO SCREEN REQUIRED :
   > N
   [PLS/O Output, for this run, going to DSK:plots.PL6 ]
   STRIP PLOTS :
   BLKS
   > AV
   TO SPECIFY NO. OF X UNITS/INCH, TYPE 0 FOR X
   LENGTH OF AXES IN INCHES; X, Y =
   > 10.5
   ARE SYMBOLS REQRD FOR PLOTS :
   > N
```
A metafile PLOTS.PL6 has now been created and can be viewed using a metafile translator on any graphics device. Any channel can be plotted out at the ARL computer center. The file is renamed and plotted using the following instructions:

```
> COPY PLOTS.PL6 PLT.P2F1E71
> PLOT.ZT8 PLT.P2F1E72 PICNO= 1 FRAME=634,267
> PLOT.ZT8 PLT.P2F1E72 PICNO= 31 FRAME=634,267
```
Table A1: Data Storage

### Phase 1 Flights

<table>
<thead>
<tr>
<th>Flight No.</th>
<th>Serials</th>
<th>ARDU Tape (segment)</th>
<th>ARL Tape (segment)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shake 1</td>
<td>RDUVX2(1)</td>
<td>1043(1)</td>
<td>Shake down flight 1</td>
</tr>
<tr>
<td>2</td>
<td>Shake 2</td>
<td>RDUVX3(1)</td>
<td>1044(1)</td>
<td>Shake down flight 2</td>
</tr>
<tr>
<td>3</td>
<td>1,2</td>
<td>RXWX2(1)</td>
<td>1045(1)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>3,4</td>
<td>RXWX2(2)</td>
<td>1045(2)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5,6,7</td>
<td>RDUVX4(1)</td>
<td>1046(1)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>10,11</td>
<td>RDUVX4(2)</td>
<td>1046(2)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>8,9</td>
<td>RDUVX4(3)</td>
<td>1046(3)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>12,13</td>
<td>RDUVX2(2)</td>
<td>1043(2)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>14,15</td>
<td>RDUVX2(3)</td>
<td>1043(3)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>RDUVX3(2)</td>
<td>1044(2)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>18,17</td>
<td>RDUVX3(3)</td>
<td>1044(3)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>18 repeat</td>
<td>RDUVX5(1)</td>
<td>1129(1)</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>16 repeat</td>
<td>RDUVX5(2)</td>
<td>1129(2)</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>17 repeat</td>
<td>RDUVX5(3)</td>
<td>1129(3)</td>
<td></td>
</tr>
</tbody>
</table>

### Phase 2 Flights

<table>
<thead>
<tr>
<th>Flight No.</th>
<th>Serials</th>
<th>ARDU Tape (segment)</th>
<th>ARL Tape (segment)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 to 10</td>
<td>JD01(1)</td>
<td>1153(1)</td>
<td>Normal accelerometer at CofG unavailable, use accelerometer in crew module</td>
</tr>
<tr>
<td>2</td>
<td>11 to 16</td>
<td>JD01(2)</td>
<td>1153(2)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16,17,18,29,30,31</td>
<td>JD02(1)</td>
<td>1067(1)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>21 to 26,31</td>
<td>JD02(2)</td>
<td>1067(2)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>27,28,33,37</td>
<td>JD04(1)</td>
<td>1182(1)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>19,20,34,35,36,2 to 7</td>
<td>JD04(2)</td>
<td>1182(2)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>27,28,33,37</td>
<td>JD04(3)</td>
<td>1182(3)</td>
<td></td>
</tr>
</tbody>
</table>
## Table A2: Instrumentation Calibrations

<table>
<thead>
<tr>
<th>Channel</th>
<th>No.</th>
<th>Order</th>
<th>Channel Calibration Number</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration vert.</td>
<td>170</td>
<td>1</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>acceleration lat.</td>
<td>171</td>
<td>2</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>acceleration long.</td>
<td>172</td>
<td>3</td>
<td>4455555555555555555</td>
<td>5555555555</td>
<td></td>
</tr>
<tr>
<td>Pitch rate</td>
<td>173</td>
<td>4</td>
<td>2222222222222222222</td>
<td>2222222222</td>
<td></td>
</tr>
<tr>
<td>Roll rate</td>
<td>174</td>
<td>5</td>
<td>3333333333333333333</td>
<td>3333333333</td>
<td></td>
</tr>
<tr>
<td>Yaw rate</td>
<td>175</td>
<td>6</td>
<td>3333333333333333333</td>
<td>3333333333</td>
<td></td>
</tr>
<tr>
<td>Height &lt; 5 k</td>
<td>160</td>
<td>7</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>Mach &lt; 0.7</td>
<td>201</td>
<td>8</td>
<td>6666666666666666666</td>
<td>7777777777</td>
<td></td>
</tr>
<tr>
<td>CAS fine</td>
<td>184</td>
<td>9</td>
<td>6666666666666666666</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>AoA CADS +ve</td>
<td>237</td>
<td>10</td>
<td>444444444444444444</td>
<td>5555555555</td>
<td></td>
</tr>
<tr>
<td>Beta CADS</td>
<td>188</td>
<td>11</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>Right stab</td>
<td>040</td>
<td>12</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>Pitch acceleration</td>
<td>176</td>
<td>13</td>
<td>1111111111111111111</td>
<td>1111111111</td>
<td></td>
</tr>
<tr>
<td>Roll acceleration</td>
<td>177</td>
<td>14</td>
<td>1111111111111111111</td>
<td>1111111111</td>
<td></td>
</tr>
<tr>
<td>ADI pitch</td>
<td>214</td>
<td>15</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>ADI bank</td>
<td>215</td>
<td>16</td>
<td>444444444444444444</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>Left stab</td>
<td>039</td>
<td>17</td>
<td>3333333333333333333</td>
<td>4444444444</td>
<td></td>
</tr>
<tr>
<td>Rudder position</td>
<td>041</td>
<td>18</td>
<td>1111111111111111111</td>
<td>1111111111</td>
<td></td>
</tr>
<tr>
<td>Rudder pedal posn.</td>
<td>055</td>
<td>19</td>
<td>1111111111111111111</td>
<td>1111111111</td>
<td></td>
</tr>
<tr>
<td>Spoiler LH O/B</td>
<td>043</td>
<td>20</td>
<td>2222222222222222222</td>
<td>2222222222</td>
<td></td>
</tr>
<tr>
<td>Spoiler RH O/B</td>
<td>044</td>
<td>21</td>
<td>3333333333333333333</td>
<td>3333333333</td>
<td></td>
</tr>
<tr>
<td>Wing sweep</td>
<td>045</td>
<td>22</td>
<td>2222222222222222222</td>
<td>2222222222</td>
<td></td>
</tr>
<tr>
<td>Yaw acceleration</td>
<td>178</td>
<td>23</td>
<td>1111111111111111111</td>
<td>1111111111</td>
<td></td>
</tr>
<tr>
<td>Long. stick posn.</td>
<td>053</td>
<td>24</td>
<td>2222222222222222222</td>
<td>2222222222</td>
<td></td>
</tr>
<tr>
<td>Lat. stick posn.</td>
<td>054</td>
<td>25</td>
<td>2222222222222222222</td>
<td>2222222222</td>
<td></td>
</tr>
<tr>
<td>AoA CADS -ve</td>
<td>238</td>
<td>26</td>
<td>444444444444444444</td>
<td>5555555555</td>
<td></td>
</tr>
<tr>
<td>Alt coarse</td>
<td>190</td>
<td>27</td>
<td>6666666666666666666</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>CADS Mach coarse</td>
<td>195</td>
<td>28</td>
<td>6666666666666666666</td>
<td>8888888888</td>
<td></td>
</tr>
</tbody>
</table>

### Additional Channels for Phase 2 Flights

<table>
<thead>
<tr>
<th>Channel</th>
<th>No.</th>
<th>Order</th>
<th>Channel Calibration Number</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBTU alpha</td>
<td>029</td>
<td>29</td>
<td>00000000000000000000</td>
<td>0000000000</td>
<td></td>
</tr>
<tr>
<td>NBTU beta</td>
<td>030</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew module acc.</td>
<td>031</td>
<td>31</td>
<td>00000000000000000000</td>
<td>0000000000</td>
<td></td>
</tr>
<tr>
<td>Accel. NBTU vert</td>
<td>032</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NBTU temperature</td>
<td>033</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Available Height and Mach Range Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>No.</th>
<th>Channel Calibration Number</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height &lt; 5 k</td>
<td>160</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>5k &lt; Height &lt; 15k</td>
<td>162</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>15k &lt; Height &lt; 25k</td>
<td>162</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>25k &lt; Height &lt; 35k</td>
<td>163</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
<tr>
<td>35k &lt; Height &lt; 45k</td>
<td>164</td>
<td>6666666666666666666</td>
<td>7777777777</td>
<td></td>
</tr>
<tr>
<td>45k &lt; Height &lt; 55k</td>
<td>164</td>
<td>6666666666666666666</td>
<td>7777777777</td>
<td></td>
</tr>
<tr>
<td>Mach &lt; 0.7</td>
<td>201</td>
<td>6666666666666666666</td>
<td>7777777777</td>
<td></td>
</tr>
<tr>
<td>0.69 &lt; Mach &lt; 1.8</td>
<td>202</td>
<td>7777777777777777777</td>
<td>8888888888</td>
<td></td>
</tr>
</tbody>
</table>
Figure A1: Example of Instrumentation Calibration
Magnetic Tape Containing Flight Test Results → Data file Containing Extract Information

**PROGRAM EXTRACT**
Purpose: To extract from the flight test tape the measurands as specified in the input file, and to apply instrument calibrations

Output file in binary format in engineering units

**PROGRAM LISTPARM**
Purpose: To convert output from program EXTRACT to ASCII format

ASCII data files containing data in engineering units

Transfer to ELXSI 6400

**PROGRAMS TRPLOT and TRANS**
Purpose: To convert 'LISTPARM' files into ELXSI binary format and produce device independent metafiles

Device Independent METAFILES

Figure A2: Extracting Flight test data
Appendix B Mass Characteristics Program CGCALCP1OR3

Computer program CGCALC_P1OR3 is written in the computer language FORTRAN 77 and uses manufacturers and experimental data to calculate the aircraft’s mass characteristics. Figure B1 gives an outline of the program. At run time the user has a number of options available including:

- Phase 1 or phase 2 flight
- CADS or NBTU \( \alpha \) and \( \beta \) measurement to be used for analysis. This information is required to allow calculation of the distance between the location of the transducers and the C of G.
- Source of normal accelerometer measurement.
- A normal accelerometer signal was available from 3 sources, C of G, crew module or from the nose boom in phase 2 flights and like the \( \alpha \) and \( \beta \) signals, its position relative to the C of G has to be calculated.
- Slat retracted or extended
- Flap extension. Note that if flaps are extended, the slats will also be extended.
- Method of fuel contents calculation: Either total fuel contents along with the automatic fuel schedule, or the indicated fuel contents of the forward and aft tanks corrected with fuel calibration data, to calculate actual fuel tank contents. Table B1 shows the automatic fuel schedule followed if this option is used.

A typical run of program CGCALC_P1OR3 is shown below and user inputs are indicated as >

```plaintext
> CGCALC_P1OR3
  WING SWEEP ANGLE IS
  > 16
  PHASE 1 OR 2 FLIGHT [1 OR 2]
  > 2
  SPECIFY IF CADS OR NBTU *ALPHA* MEASUREMENT TO BE USED
    [RESPONSE IS EITHER CADS OR NBTU]
  > NBTU
  SPECIFY IF CADS OR NBTU *BETA* MEASUREMENT TO BE USED
    [RESPONSE IS EITHER CADS OR NBTU]
  > NBTU
  SPECIFY WHERE THE NORMAL ACCELEROMETER IS LOCATED AT
    THE CG, ON THE NBTU OR IN THE CREW MODULE
    [RESPONSE IS CG, NBTU OR CREW]
```
CREW ARE SLATS EXTENDED [RESPONSE IS YES or NO]

YES

FLAP DEFLECTION

26.0

DO YOU WANT TO SPECIFY INDICATED FUEL TANK CONTENTS FOR AIRCRAFT A8-132 [Y OR N]

Y

FORWARD FUEL TANK READING IS [LBS]

14300

AFT FUEL TANK READING IS [LBS]

6000

AIRCRAFT CONFIGURATION WITH INDICATED FUEL

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Delta X</th>
<th>Delta Y</th>
<th>Delta Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC AIRCRAFT</td>
<td>40073.6</td>
<td>529.1</td>
<td>.0</td>
<td>180.2</td>
</tr>
<tr>
<td>SWEPT WING</td>
<td>7174.4</td>
<td>523.7</td>
<td>40.0</td>
<td>176.2</td>
</tr>
<tr>
<td>PILOT</td>
<td>215.0</td>
<td>249.7</td>
<td>-13.0</td>
<td>184.2</td>
</tr>
<tr>
<td>NAVIGATOR</td>
<td>215.0</td>
<td>249.7</td>
<td>13.0</td>
<td>184.2</td>
</tr>
<tr>
<td>OIL (UNUSED)</td>
<td>99.0</td>
<td>885.9</td>
<td>.0</td>
<td>154.6</td>
</tr>
<tr>
<td>OIL (USEABLE)</td>
<td>12.0</td>
<td>885.9</td>
<td>.0</td>
<td>158.3</td>
</tr>
<tr>
<td>WATER (AIR CON)</td>
<td>41.7</td>
<td>470.0</td>
<td>.0</td>
<td>155.0</td>
</tr>
<tr>
<td>PYROTECHNICS</td>
<td>24.8</td>
<td>801.1</td>
<td>.0</td>
<td>192.0</td>
</tr>
<tr>
<td>OXYGEN CONVERTER</td>
<td>25.0</td>
<td>162.8</td>
<td>.0</td>
<td>157.0</td>
</tr>
<tr>
<td>CONVERTER</td>
<td>17.0</td>
<td>162.8</td>
<td>.0</td>
<td>157.0</td>
</tr>
<tr>
<td>CREW MODUAE BALLAST</td>
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<td>.0</td>
<td>170.0</td>
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<td>WINDSHEILD WASH FLUID</td>
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<td>.0</td>
<td>143.0</td>
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<td>EMG OXY AND COMP AIR</td>
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<td>282.9</td>
<td>.0</td>
<td>207.6</td>
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<td>MISSION DATA PROV.</td>
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<td>257.9</td>
<td>.0</td>
<td>179.0</td>
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<tr>
<td>CHAFF</td>
<td>37.0</td>
<td>801.1</td>
<td>.0</td>
<td>192.0</td>
</tr>
<tr>
<td>GUN (EMPTY)</td>
<td>1061.8</td>
<td>385.6</td>
<td>.0</td>
<td>152.0</td>
</tr>
<tr>
<td>FORWARD TANKS</td>
<td>14449.3</td>
<td>400.6</td>
<td>.0</td>
<td>191.5</td>
</tr>
<tr>
<td>AFT TANKS</td>
<td>6933.6</td>
<td>634.8</td>
<td>.0</td>
<td>179.9</td>
</tr>
<tr>
<td>WING TANKS TOTAL</td>
<td>.0</td>
<td>616.9</td>
<td>.0</td>
<td>194.8</td>
</tr>
<tr>
<td>WEAPON BAY TANK</td>
<td>.0</td>
<td>392.0</td>
<td>.0</td>
<td>145.4</td>
</tr>
<tr>
<td>FUEL IN LINE</td>
<td>184.0</td>
<td>615.5</td>
<td>.0</td>
<td>184.0</td>
</tr>
<tr>
<td>UNUSEABLE FUEL</td>
<td>292.0</td>
<td>494.5</td>
<td>.0</td>
<td>179.3</td>
</tr>
<tr>
<td>SPARE1</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
</tr>
<tr>
<td>SPARE2</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
</tr>
<tr>
<td>SPARE3</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
<td>.0</td>
</tr>
</tbody>
</table>

FWD TANKS CONTAIN 8615.72363 POUNDS OF FUEL MORE THAN AFT
FORWARD FUEL GAUGE READING = 14300.0 POUNDS
ACTUAL FORWARD FUEL = 14449.291 POUNDS
AFT FUEL GAUGE READING = 6000.0 POUNDS
ACTUAL AFT FUEL = 5933.56738 POUNDS

FUEL USED = 14199.1408 POUNDS

HORZ. POSITION OF CG = 24.4684524 PERCENT OF MAC
HORZ. POSITION OF CG = 507.008697 FUSESTAX

VERTICAL POSITION OF CG = 3.83693528 PERCENT OF MAC
VERTICAL POSITION OF CG = 181.551803 WATERLNZ

TOTAL USEABLE FUEL WEIGHT = 20382.8693 POUNDS
TOTAL WEIGHT OF AIRCRAFT = 69900.8593 POUNDS

FLAP DEFLECTION = 25.0

****** INERTIA DATA ******

IXX = 73343.6718 SLUGS FT-SQ
IYY = 344665.781 SLUGS FT-SQ
IZZ = 411017.062 SLUGS FT-SQ
IXZ = 3976.7871 SLUGS FT-SQ

IXZ/IXX = -5.42212724E-02
IZZ/IXZ = -9.67547949E-03

********** INSTRUMENT OFFSET DATA **********

XALF = 45.5107 YALF = .0000 ZALF = 2.5535
XB = 44.7032 YB = .0000 ZB = 3.0518
XAX = 2.5241 YAX = -2.4308 ZAX = 1.3877
XAY = 2.4216 YAY = -2.4583 ZAY = 1.3877
XAN = 20.6674 YAN = .0000 ZAN = 1.6610
Table B1: Automatic Fuel Schedule

<table>
<thead>
<tr>
<th>TANK</th>
<th>Fuel Used In Segment (lbs)</th>
<th>Total fuel used (lbs)</th>
<th>Fuel to Burn (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Fuel Load</td>
<td>0</td>
<td>0</td>
<td>34582</td>
</tr>
<tr>
<td>Primary Weapon</td>
<td>1852</td>
<td>1852</td>
<td>32730</td>
</tr>
<tr>
<td>Bay Fuel Tank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing tanks</td>
<td>5060</td>
<td>2760</td>
<td>27670</td>
</tr>
<tr>
<td>Forward 1 tank</td>
<td>712</td>
<td>7624</td>
<td>26958</td>
</tr>
<tr>
<td>Forward 1 tank &amp; Aft 2 tank until Aft 2 tank empty</td>
<td>4868</td>
<td>12492</td>
<td>22090</td>
</tr>
<tr>
<td>Forward 1 tank &amp; Aft 1 tank until Forward 1 tank empty</td>
<td>9142</td>
<td>21634</td>
<td>12948</td>
</tr>
<tr>
<td>Forward 2 tank &amp; Aft 1 tank until Aft 1 tank empty</td>
<td>4564</td>
<td>26198</td>
<td>8384</td>
</tr>
<tr>
<td>Forward 2 tank until empty</td>
<td>5743</td>
<td>31941</td>
<td></td>
</tr>
<tr>
<td>Reserve</td>
<td>2457</td>
<td>34398</td>
<td>184</td>
</tr>
<tr>
<td>Fuel in Lines</td>
<td>184</td>
<td>34582</td>
<td>0</td>
</tr>
</tbody>
</table>
User input includes:
1) Wing sweep
2) alpha and beta CADS or NBTU
3) Normal accelerometer location
4) Slat and flap extensions
5) Indicated fuel and use calibration or total fuel and use fuel schedule

Baseline aircraft data
Data base containing C of G, inertia, flap, slat extension information

Program CGCALC_P1OR3

Calculate individual fuel tank contents if using fuel schedule or apply calibration to indicated fuel tank readings

Calculate C of G of empty wing

Calculate C of G of following fuel tanks: Wing
Primary weapon bay
Forward
Aft

Calculate C of G change if slats and flaps are extended

Add component contributions to basic aircraft weight and C of G and calculate overall AUW and C of G

Calculate instrumentation reference data

Calculate moments and products of inertia for various components about their own C of G and then calculate overall values

OUTPUT:
Files required for use in Flight Data Processing and parameter estimation

Figure B1: Mass Characteristics Calculation
Appendix C - Flight Data Processing Program FDP

The flight data processing program FDP reads in flight data obtained from the APTRAS program LISTPARM and processes it into files formatted for use in a variety of analysis software programs. Using the manoeuvre given in Appendix B, an example of running FDP is shown below. A flow diagram showing the program steps is given in Figure C1. (note that all user responses are prefixed by a >):

> FD

**** WELCOME TO F111C FLIGHT DATA PROCESSING PROGRAM - FDP ****

******* RUNNING PROGRAM FDP TO PROCESS FLIGHT DATA ********

Enter listparm input 'ile name in full

> P2F1E72.DAT

Using the instrument position information contained in the file MMLE3.PARA, which is an output from program CGCALC.P1OR3, the instrument options are displayed and can be used to check that all required options are correct. If the case to be processed is from a phase 2 flight, the phase 2 pressure error correction will be applied. Also printed out are the start and finishing times of the extracted data and the data channels and their respective calibrations. A check should be made at this stage to ensure that the required channels have been extracted.

NBTU Alpha instrument is being used
NBTU Beta instrument is being used
Crew module Normal Accel instrument is being used
Phase 2 PE Corrections Applied

INFORMATION ABOUT DATASET
--------------------- ------- -------
NO. OF INC. START TIME END TIME
MEASURANDS

33  1.666999998E-02  1040.0  1109.0

DATASET DESCRIPTION
TRIAL ID TRIAL PHASE A/C ID FLIGHT NO.
TS 1616 02 AOBB-132 001

NO. SHORT SHORT MEASURAND

33
<table>
<thead>
<tr>
<th>TITLE</th>
<th>UNITS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCEL VERT</td>
<td>&quot;G&quot;</td>
<td>BI-170-4</td>
</tr>
<tr>
<td>ACCEL LAT</td>
<td>&quot;G&quot;</td>
<td>BI-171-4</td>
</tr>
<tr>
<td>ACC LNG CG</td>
<td>&quot;G&quot;</td>
<td>BI-172-5</td>
</tr>
<tr>
<td>PITCH RATE</td>
<td>DEG/SEC</td>
<td>BI-173-2</td>
</tr>
<tr>
<td>ROLL RATE</td>
<td>DEG/SEC</td>
<td>BI-174-3</td>
</tr>
<tr>
<td>YAW RTE CG</td>
<td>DEG/SEC</td>
<td>BI-175-3</td>
</tr>
<tr>
<td>HPF &lt; 6K</td>
<td>FEET</td>
<td>BI-160-8</td>
</tr>
<tr>
<td>MACH &lt; .7</td>
<td>MACH</td>
<td>BI-201-7</td>
</tr>
<tr>
<td>CAS FINE T</td>
<td>KCAS</td>
<td>BI-184-8</td>
</tr>
<tr>
<td>NBTU ALPHA</td>
<td>DEGREES</td>
<td>BI-23-1</td>
</tr>
<tr>
<td>NBTU BETA</td>
<td>DEGREES</td>
<td>BI-26-2</td>
</tr>
<tr>
<td>STAB RH</td>
<td>DEGREES</td>
<td>BI-40-4</td>
</tr>
<tr>
<td>PITCH ACC CG</td>
<td>RAD/SEC</td>
<td>BI-176-1</td>
</tr>
<tr>
<td>ROLL ACC CG</td>
<td>RAD/SEC</td>
<td>BI-177-1</td>
</tr>
<tr>
<td>ADI PITCH</td>
<td>DEGREES</td>
<td>BI-214-4</td>
</tr>
<tr>
<td>ADI BANK</td>
<td>DEGREES</td>
<td>BI-216-4</td>
</tr>
<tr>
<td>STAB LH</td>
<td>DEGREES</td>
<td>BI-39-4</td>
</tr>
<tr>
<td>RUD POSN</td>
<td>DEGREES</td>
<td>BI-41-1</td>
</tr>
<tr>
<td>R P EDAL POS</td>
<td>INCHES</td>
<td>BI-55-1</td>
</tr>
<tr>
<td>SPL LH O/B</td>
<td>DEGREES</td>
<td>BI-43-2</td>
</tr>
<tr>
<td>SPL RH O/B</td>
<td>DEGREES</td>
<td>BI-44-3</td>
</tr>
<tr>
<td>WNGSX PXD CR</td>
<td>DEGREES</td>
<td>BI-46-2</td>
</tr>
<tr>
<td>YWANG ACC</td>
<td>RAD/SEC</td>
<td>BI-178-1</td>
</tr>
<tr>
<td>STK POS LG</td>
<td>INCHES</td>
<td>BI-53-2</td>
</tr>
<tr>
<td>STK POS LT</td>
<td>INCHES</td>
<td>BI-54-2</td>
</tr>
<tr>
<td>AGACADS-VE</td>
<td>DEGREES</td>
<td>BI-238-6</td>
</tr>
<tr>
<td>ALT CRSCAD</td>
<td>FEET</td>
<td>BI-190-8</td>
</tr>
<tr>
<td>CADS M CSE</td>
<td>MACH</td>
<td>BI-195-8</td>
</tr>
<tr>
<td>AGACADS+VE</td>
<td>DEGREES</td>
<td>BI-237-6</td>
</tr>
<tr>
<td>BETA CADS</td>
<td>DEGREES</td>
<td>BI-189-4</td>
</tr>
<tr>
<td>CM ACC VRT</td>
<td>&quot;G&quot;</td>
<td>BI-166-1</td>
</tr>
<tr>
<td>ACC-X NBTU</td>
<td>&quot;G&quot;</td>
<td>BI-28-1</td>
</tr>
<tr>
<td>NBTU A TMP</td>
<td>DEGREES C</td>
<td>BI-31-1</td>
</tr>
</tbody>
</table>

The option is available at this stage to select different portions of the extracted time histories for analysis.

Do you wish to delete data from start of time history?

> Y

Enter Aftras tape time to begin time history
Do you wish to delete data from end of time history?

> Y

Enter Aftras tape time for data cut-off

> 1080

Type of phase lags to be used

Do you want standard Channel lags?
For standard Phase 1 lags type .......... [P1]
For standard Phase 2 lags type .......... [P3]
For standard Phase 2 lags with the crew module norm accelerometer type .......... [CM]
For non standard lags type ................ [N]

> CM

Standard Phase 2 Crew Module lags applied

** Flight Data now being processed **

The processing of the raw flight data now commences and several files are created for use in the analysis as shown below:

- FPR.LON and FPR.LAT. These files provide the input data for the flight path reconstruction programs ARLFPR1ON2 and ARLFPR1LAT which are used to calculate the flow vane calibration constants. Note: the data for these programs are required in the following units. Lengths in meters, angles in degrees, angular rates in radians per second, velocity (VTAS) in meters per second and accelerations at the centre of gravity in meters per second per second. Because the instrumentation package was not located at the centre of gravity, corrections have to be made to the measured signals to give the C of G values. Using Figure C2 and the equations given below the C of G offset corrections are made.

\[
a_{z_{eq}} = a_{zm} - \frac{\Delta z\dot{q}}{g} + \frac{\Delta y\dot{r}}{g} + \frac{\Delta zq^2}{g} + \frac{\Delta zr^2}{g}
\]
\[
a_{vy} = a_{ym} - \frac{\Delta z\dot{r}}{g} + \frac{\Delta z\dot{p}}{g} + \frac{\Delta y\dot{r}^2}{g} + \frac{\Delta y\dot{p}^2}{g}
\]
\[
a_{xz} = a_{zm} - \frac{\Delta z\dot{q}}{g} + \frac{\Delta y\dot{r}}{g} - \frac{\Delta y\dot{q}^2}{g} - \frac{\Delta z\dot{p}^2}{g}
\]

- MMLE3.DAT. This is the raw data file required for use in the parameter identification program MMLE3. The data for this program are required in the following units:
  
  angles in degrees, angular rates in radians per second (VTAS) and accelerations in 'g' measured at that instrumentation pack.

- F-111C.dat. This file can be used to provide control input time histories into a six degree of freedom model of the F111-C enabling comparisons to be made between the calculated response of the aircraft during the flight test manoeuvre and the actual measured response.

Have a glorious day in Melbourne!

******* FLIGHT DATA PROCESSING COMPLETE  **************

The flight data processing has been completed and analysis can commence.
Initial input options include:

- NBTU or CADS alpha and beta
- C of G, Crew module or NBTU normal accelerometer
- Phase 2 Pressure Error Corrections

**PROGRAM FDP**

Read in data

**Input options:**

- Time of start and finish
- Phase lag type
- If phase 2 PEC correction is to be applied

Apply: PEC correction

- Scale altitude correction
- Phase lags
- Crew module calibration, if being used

Write out files for Flight Path Reconstruction and parameter identification in suitable formats

---

**Figure C1: Flight Data Processing**
Figure C2: Notation for Linear and Angular Accelerometers
Appendix D - Pressure Error Correction

For the manoeuvres flown with the NBTU fitted a correction is required to the data calculated by the Central Air Data System due to the change in the static pressure source. This correction has to include the differences between the static pressures at the two locations and also the in-built corrections which are used by the CADS system for data from the aircraft system. A calibrated Mirage chase aircraft was used to establish the magnitude of the error of the static pressure source for aircraft A8-132 with the NBTU fitted. The static and impact pressures can be calculated from the following equations taken from Reference [19]. The static air pressure \( p_s \) for the pacer Mirage aircraft at a level \( h_{\text{pacer}} \) is given by:

\[
p_s = p_0 \left( \frac{T_0 - L h_{\text{pacer}}}{T_0} \right) T_0^{\gamma} \]

The ambient pressure \( p_0 \) can be then calculated using the known pressure error correction from the pacer aircraft.

For the F-111C aircraft with an indicated altitude of \( h \), the static pressure \( p_s \) is calculated from:

\[
p_s = p_0 \left( \frac{T_0 - L h}{T_0} \right) T_0^{\gamma} \]

The differential pressure \( \Delta p \) is

\[
\Delta p = p_s - p_0
\]

From the F-111C's indicated airspeed, VIAS the indicated impact pressure \( q_{ci} \) is calculated

\[
q_{ci} = p_0 \left[ 1 + \frac{(\gamma - 1)}{2} \left( \frac{V \text{IAS}}{a_0} \right)^2 \right]^{\frac{\gamma - 1}{\gamma}} - 1
\]

The chase and F-111C aircraft were flown in close formation at various values of VIAS and the indicated altitude from the two aircraft was recorded.

This data was analysed by ARDU using the known pressure correction of the chase aircraft to give the static pressure corrections shown in Table D1. Measurements were not made at supersonic speeds. Data from the subsonic tests were extrapolated to supersonic speeds using information from tests on similar installations.

The corrections to velocity and altitude are calculated using the values of \( \Delta p/q_{ci} \) given in Table D1 by the following method:

For the given indicated pressure height \( h \), calculate the static pressure \( p_s \) using the following equations:

For \( H_i \leq 36,089.0 \) feet

\[
p_s = p_0 \left( \frac{T_0 - L h}{T_0} \right) T_0^{\gamma}
\]

39
For \( H_i > 36089.0 \) feet

\[
p_s = p_1 e^{\frac{RT_i}{g}(h-h_1)}
\]

where \( T_1 \) and \( p_1 \) are the temperature and static pressure at 36089 feet.

Given the indicated airspeed \( V_{IAS} \), the indicated impact pressure is calculated using the following equation:

\[
q_{ci} = p_0 \left[ 1 + \frac{(\gamma - 1)}{2} \left( \frac{V_{IAS}}{a_0} \right)^{\frac{\gamma}{\gamma - 1}} - 1 \right]
\]

Using \( q_{ci} \) and \( p_s \) calculated above, the indicated Mach number \( M_i \) is calculated:

\[
M_i = \left[ \frac{2}{\gamma - 1} \left( \frac{q_i}{p_s} + 1 \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]^{0.5}
\]

From Table D1 for any given value of \( M_i \) interpolate for a value of \( \Delta p/q_{ci} \) from which:

\[
\Delta p = \Delta p/q_{ci} \times q_{ci}
\]

can be calculated. The actual impact pressure is calculated to be:

\[
q_c = q_{ci} + \Delta p
\]

Using this calibrated impact pressure calculate the calibrated airspeed \( V_{CAS} \)

\[
V_{CAS} = a_0 \left[ \left( \frac{2}{\gamma - 1} \right) \left( \frac{q_c}{p_0} + 1 \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]^{0.5}
\]

The ambient calibrated pressure is:

\[
p_a = p_s - \Delta p
\]

And the calibrated pressure altitude is:

For \( H_i \leq 36089.0 \) feet

\[
h_{pc} = \frac{T_0 - T_0 \left( \frac{p_a}{p_0} \right)^{\frac{L}{g}}}{L}
\]

For \( H_i > 36089.0 \) feet

\[
h_{pc} = \frac{RT_1}{g} \log \left( \frac{p_s}{p_1} \right) + 36089
\]

Where \( T_1 \) and \( p_1 \) are the temperature and static pressure at 36089 feet.

40
## Table D1: Pressure Error Correction Data

<table>
<thead>
<tr>
<th>Mach No.</th>
<th>Alt</th>
<th>$V_i$</th>
<th>$q_{ci}$</th>
<th>$\Delta P$</th>
<th>$\Delta P/q_{ci}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>1000</td>
<td>325</td>
<td>379.71</td>
<td>16.127</td>
<td>0.0425</td>
</tr>
<tr>
<td>0.60</td>
<td>1000</td>
<td>390</td>
<td>561.26</td>
<td>28.956</td>
<td>0.0516</td>
</tr>
<tr>
<td>0.70</td>
<td>1000</td>
<td>456</td>
<td>791.64</td>
<td>45.215</td>
<td>0.0571</td>
</tr>
<tr>
<td>0.80</td>
<td>1000</td>
<td>520</td>
<td>1066.0</td>
<td>68.611</td>
<td>0.0644</td>
</tr>
<tr>
<td>0.90</td>
<td>1000</td>
<td>588</td>
<td>1420.0</td>
<td>112.000</td>
<td>0.0787</td>
</tr>
<tr>
<td>0.95</td>
<td>1000</td>
<td>620</td>
<td>1613.0</td>
<td>145.000</td>
<td>0.0902</td>
</tr>
</tbody>
</table>
Appendix E - Scale Altitude Correction

Scale altitude error is the term used to describe the difference between calibrated airspeed VCAS, which is the indicated airspeed VIAS corrected for any pressure errors, and instrumentation errors, and the equivalent airspeed VEAS. The difference between VCAS and VEAS occurs because airspeed measuring instrument calibrations are simplified by assuming a constant value of unity for the pressure ratio $\delta = p/p_0$ in part of the calibration equation. This error can be neglected at low speeds and low altitudes but is significant at high Mach numbers and high altitudes.

Bernoulli's equation for the total pressure in compressible flow can be expressed as a function of Mach number in the absence of any shock wave as:

$$p_t = p \left[1 + \frac{(\gamma - 1)}{2} M^2\right]^{\frac{1}{\gamma}}$$  \hspace{1cm} (E1)

which is the pitot pressure $p_p$ sensed by a pitot tube in subsonic flow. For supersonic flow, the pitot pressure is modified by the presence of a normal shock at the mouth of the pitot tube. The ratio of total pressure across a shock is given by:

$$\frac{p_t}{p_i} = \left[1 + \frac{2\gamma}{(\gamma + 1)} (M^2 - 1)\right]^{\frac{1}{\gamma - 1}}$$ \hspace{1cm} (E2)

Therefore for $M \leq 1.0$, $p_p = p_t$

$$\frac{P_t}{p} = \left[1 + \frac{(\gamma - 1)}{2} M^2\right]^{\frac{1}{\gamma - 1}}$$ \hspace{1cm} (E3)

and for $M \geq 1.0$, $p_p \neq p_t$

$$\frac{P_t}{p} = \frac{p_t}{p_i} \times \frac{p_t}{p} = \left[1 + \frac{2\gamma}{(\gamma + 1)} (M^2 - 1)\right]^{\frac{1}{\gamma - 1}} \left[\frac{(\gamma + 1)}{2} M^2\right]^{\frac{1}{\gamma - 1}}$$ \hspace{1cm} (E4)

The impact pressure, which is the difference between pitot and stagnation pressure is given by the relationship:

$$q_c = p_p - p$$ \hspace{1cm} (E5)

Calibrated airspeed VCAS is obtained from the indicated airspeed, corrected for any pressure measurement errors that have been introduced by the air data system and for any mechanical errors in the instrument. VCAS is the airspeed that would be required at sea-level in a standard atmosphere to give the same impact pressure as that sensed at the particular height and true airspeed considered. For a sea level ISA atmosphere:

When $VCAS/a_0 \leq 1.0$

$$\frac{q_c}{p_0} = \frac{p_p - p}{p_0} = \left[1 + \frac{(\gamma - 1)}{2} \left(\frac{VCAS}{a_0}\right)^2\right]^{\frac{1}{\gamma - 1}} - 1$$ \hspace{1cm} (E6)
When \( \frac{VCAS}{a_0} > 1.0 \)

\[
\frac{q_0}{p_0} = \frac{P - P_0}{p_0} = \left[ 1 + \frac{2 \gamma}{(\gamma + 1)} \left( \frac{(VCAS)^2}{a_0} - 1 \right) \right]^{\frac{\gamma}{\gamma - 1}} \left[ \frac{\gamma + 1}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1 \ldots (E7)
\]

To find the relationship between calibrated airspeed and Mach number we can equate the above expressions using the substitution

\[
\delta = \frac{P}{p_0}
\]

Note: Three cases have to be considered: For \( \frac{VCAS}{a_0} \leq 1.0 \) and \( M \leq 1.0 \) equating E6 and E3

\[
\left[ 1 + \frac{(\gamma - 1)}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1 = \delta \left[ 1 + \frac{2 \gamma}{(\gamma + 1)} (M^2 - 1) \right]^{\frac{1}{\gamma - 1}} \left[ \frac{\gamma + 1}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1
\]

For \( \frac{VCAS}{a_0} \leq 1.0 \) and \( M > 1.0 \) equating E6 and E4

\[
\left[ 1 + \frac{(\gamma - 1)}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1 = \delta \left[ 1 + \frac{2 \gamma}{(\gamma + 1)} (M^2 - 1) \right]^{\frac{1}{\gamma - 1}} \left[ \frac{\gamma + 1}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1
\]

For \( \frac{VCAS}{a_0} > 1.0 \) and \( M > 1.0 \) equating E7 and E4

\[
\left[ 1 + \frac{2 \gamma}{(\gamma + 1)} \left( \frac{VCAS}{a_0} \right)^2 - 1 \right]^{\frac{1}{\gamma - 1}} \left[ \frac{\gamma + 1}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1 = \delta \left[ 1 + \frac{2 \gamma}{(\gamma + 1)} (M^2 - 1) \right]^{\frac{1}{\gamma - 1}} \left[ \frac{\gamma + 1}{2} \left( \frac{VCAS}{a_0} \right)^2 \right]^{\frac{1}{\gamma - 1}} - 1
\]

Because \( \delta \) is a function of pressure height, i.e., \( p \) is the ambient pressure at a given height, the above equations show that there is a relationship between \( VCAS, M \) and pressure height. Given

\[
VEAS = VTAS (\frac{P}{p_0})^{\frac{1}{2}}
\]

and

\[
a = \frac{\gamma p}{\rho}
\]

\[
a_0 = \frac{\gamma p_0}{\rho}
\]

then

\[
VEAS = Ma (\frac{P}{p_0})^{\frac{1}{2}}
\]
Substituting for $VEAS = a_0 M \delta^{\frac{3}{2}}$ and $\gamma = 1.4$ the relationships between VCAS, VEAS and pressure height can be developed for the three cases.

For $VCAS/a_0 \leq 1.0$ and $VEAS/\left(\frac{a_0}{\gamma}\right)^0.8 \leq 1.0$ then

$$\left[1 + 0.2 \left(\frac{VCAS}{a_0}\right)^2\right]^{3.5} = 1 \left[1 + \frac{0.2}{\delta} \left(\frac{VCAS}{a_0}\right)^2\right]^{3.5} - 1$$

For $VCAS/a_0 \leq 1.0 < VCAS/\left(\frac{a_0}{\gamma}\right)^0.5$ then

$$\left[1 + 0.2 \left(\frac{VCAS}{a_0}\right)^2\right]^{3.5} = \delta \left[\frac{1.2 \times 5^{2.5} \left(\frac{VEAS}{a_0}\right)^2}{\delta} \left(\frac{a_0}{\gamma}\right)^{2.5} - 1\right]$$

For $VCAS/a_0 > 1.0$ and $VCAS/\left(\frac{a_0}{\gamma}\right)^0.5 > 1.0$ then

$$\left[1.26 \times 5^{2.5} \left(\frac{VCAS}{a_0}\right)^2\right]^{2.5} - 1 = \delta \left[\frac{1.26 \times 5^{2.5} \left(\frac{VEAS}{a_0}\right)^2}{\delta} \left(\frac{a_0}{\gamma}\right)^{2.5} - 1\right]$$

From the above expressions the difference between calibrated airspeed VCAS and the equivalent air speed VEAS can be calculated. At sea level $\delta = 1$ so the values of VCAS and VEAS are identical. At higher altitudes where $\delta \neq 1.0$ the difference between the two increases. This difference has been called scale altitude error. Figure E1 shows the value of scale altitude error as a function of pressure height and Mach number. For airspeed measurement purposes it is necessary to make an adjustment to VCAS especially at high altitudes and Mach numbers.
Figure E1: Scale Altitude Correction to VCAS
Appendix F - Flight Path Reconstruction Programs

The programs used are described in detail in References [12] and [13] and in this section an example will be used to illustrate how they are run on the ELXSI computer. The first step is to set up the data input table 'DATIN.DAT' and this is done using program FPRSORT. As with previous examples user input is prefixed by a > symbol.

> fprsort
NAME OF INPUT FILE
datin.long

**LONGITUDINAL CASE**

**TABLE 1 : STATE VARIABLES**

<table>
<thead>
<tr>
<th>1</th>
<th>U</th>
<th>YES</th>
<th>2</th>
<th>V</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>W</td>
<td>YES</td>
<td>4</td>
<td>PHI</td>
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</tr>
<tr>
<td>5</td>
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<td>6</td>
<td>PSI</td>
<td>NO</td>
</tr>
<tr>
<td>7</td>
<td>H</td>
<td>YES</td>
<td>8</td>
<td>BAX</td>
<td>YES</td>
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<td>9</td>
<td>BAY</td>
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<td>10</td>
<td>BAZ</td>
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<tr>
<td>11</td>
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<td>12</td>
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<td>BALP</td>
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<tr>
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<td>BPHI</td>
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<td>24</td>
<td>BTHE</td>
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<tr>
<td>25</td>
<td>BPSI</td>
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<td>26</td>
<td>BH</td>
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</tr>
<tr>
<td>27</td>
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<td>28</td>
<td>LBET</td>
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<td>33</td>
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**TABLE 2 : INPUTS**

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<tbody>
<tr>
<td>3</td>
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<tr>
<td>6</td>
<td>Q</td>
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<td>R</td>
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**TABLE 3 : OUTPUTS**

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<th>2</th>
<th>BET</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>ALP</td>
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<td>4</td>
<td>PHI</td>
<td>NO</td>
</tr>
<tr>
<td>6</td>
<td>THE</td>
<td>YES</td>
<td>6</td>
<td>PSI</td>
<td>NO</td>
</tr>
<tr>
<td>7</td>
<td>H</td>
<td>YES</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The state variables, inputs and outputs to be used for analysis are displayed and can be changed. For this case (a longitudinal pitch up manoeuvre), the option for changing the states variable inputs and outputs are not exercised.

> 0

The start and finishing times are displayed along with the position (in meters) of the angle of attack $\alpha$ and angle of sideslip $\beta$ measurement devices. In the listing below the finishing time TEND is changed to 6.49 seconds and the distance to the $\alpha$ measuring device XALP is increased to 13.862 meters.

1 TO .00000E+00
2 TEND .40000E+02
3 DT .60000E+02
4 XALP .45000E+01
5 YALP .00000E+00
6 XBET .00000E+00
7 ZBET .00000E+00

NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE
2 6.49
1 TO .00000E+00
2 TEND .64000E+01
3 DT .60000E+02
4 XALP .45000E+01
5 YALP .00000E+00
6 XBET .00000E+00
7 ZBET .00000E+00

NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE
4 13.862
1 TO .00000E+00
2 TEND .64000E+01
3 DT .60000E+02
4 XALP .13862E+01
5 YALP .00000E+00
6 XBET .00000E+00
7 ZBET .00000E+00

48
NO. AND VALUE TO CHANGE (EG. 3 .01) OR 0 0 TO TERMINATE

0 0

1. NPAS No of passes through data
2. ITER No of local iterations
3. NDEX No of samples before averaging
4. IFIL filtering of inputs write to FILINP.DAT
5. ICYL samples between writes to the output files
6. IRES residuals & S.D. written to RES.DAT & SDEV.DAT
7. IBIAS inst. param. written to PARAM.DAT on last pass

NO. AND VALUE TO CHANGE (EG. 3 3800) OR 0 0 TO TERMINATE
THE LAST FOUR PARAMETERS ARE TRUE OR FALSE SWITCHES

0 - FALSE 1 - TRUE

0 0

For longitudinal manoeuvres the program ARLFPR2LON is used and for lateral cases program ARLFPRLAT is used. For the program to commence running type:

> arlfpr2lon

Shown below is part of the files DATOUT.DAT which summarises the results obtained:

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
FLIGHT PATH RECONSTRUCTION: PROGRAM ARLFPR RUN 1
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

** PARAMETERS OF THE FILTERING PROCEDURE **

START TIME = .00000E+00 SECS ** FINAL TIME = .64000E+01 SECS

DATA SAMPLING PERIOD = .16667E-01 SECS

POSITION OF THE SIDESLIP AND INCIDENCE ANGLE SENSORS

XBETA = .00000E+00 ZBETA = .00000E+00
XALPHA = .13862E+02 YALPHA = .00000E+00
** INITIAL STATE ESTIMATE **

<table>
<thead>
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<th>ESTIMATE</th>
<th>VARIANCE</th>
</tr>
</thead>
<tbody>
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<tr>
<td>W</td>
<td>1.43420E+02</td>
<td>4.0000E+01</td>
</tr>
<tr>
<td>THET</td>
<td>1.11880E+00</td>
<td>4.0000E-03</td>
</tr>
<tr>
<td>H</td>
<td>3.92650E+03</td>
<td>4.0000E+01</td>
</tr>
</tbody>
</table>

** INITIAL ESTIMATE OF PARAMETERS **

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<th>VARIANCE</th>
<th>NOISE VARIANCE</th>
</tr>
</thead>
<tbody>
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<td>5.0000E-01</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>BAZ</td>
<td>0.0000E+00</td>
<td>5.0000E-01</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>BP</td>
<td>0.0000E+00</td>
<td>5.0000E-03</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>BVEL</td>
<td>0.0000E+00</td>
<td>1.0000E+01</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>BALP</td>
<td>0.0000E+00</td>
<td>5.0000E-03</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>BTHE</td>
<td>0.0000E+00</td>
<td>5.0000E-03</td>
<td>0.0000E+00</td>
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<tr>
<td>BH</td>
<td>0.0000E+00</td>
<td>1.0000E+01</td>
<td>0.0000E+00</td>
</tr>
<tr>
<td>LALP</td>
<td>0.0000E+00</td>
<td>5.0000E-03</td>
<td>0.0000E+00</td>
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</tbody>
</table>
** DATA PROCESSING NO. 5 **

** PARAMETERS ESTIMATE **

<table>
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<tr>
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<td>-2.0941E-01</td>
<td>9.96E-03</td>
</tr>
</tbody>
</table>
Appendix G - A priori Data from Six Degree of Freedom Flight Dynamic Model

The six degree of freedom flight dynamic mathematical model of the F-111C is used to obtain a priori values of the aerodynamic stability and control derivatives for use in the parameter estimation techniques. This program stores the aerodynamic data in data tables in both derivative and coefficient form. The coefficient form is employed where the aerodynamic forces are non-linear. Additional subroutines were developed to extract local derivatives from the non-linear model using the ACSL simulation language Jacobian analysis facility. Details of this procedure are given in References [21] and [22]. Configuration data and initial conditions for the simulation are contained in file TABLEE.NEW shown below. The aircraft's mass characteristics obtained from program CGCALC_P10R3 described in Appendix B, are presented in the first part of the table.

WEIGHTS AND INERTIAS

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<th>VALUE(F)</th>
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<td>344865.000000</td>
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<tr>
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<td>73343.000000</td>
<td>IZZ</td>
<td>411017.000000</td>
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<tr>
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INITIAL CONDITIONS (ALFW IS OVERWRITTEN BY TRIM ROUTINE)

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<th>VALUE(F)</th>
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<tbody>
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<td>ALFW</td>
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<tr>
<td>BETAO</td>
<td>.0000000</td>
<td>RO</td>
<td>.0000000</td>
</tr>
<tr>
<td>TRACKO</td>
<td>.0000000</td>
<td>XO</td>
<td>.0000000</td>
</tr>
<tr>
<td>PHIDO</td>
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<td>YO</td>
<td>.0000000</td>
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<td>XMACHO</td>
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<td>VWE</td>
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AIRCRAFT GEOMETRY

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<td>.0000000</td>
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</table>
With file TABLEE.NEW altered to suit the particular case, running of the model can commence (> indicates user response):

> fillalong

Information describing the aerodynamic data base used in the simulation is output to the screen and the ACSL commands and flags required to be set by the user are provided. These included the commands required to set up the initial run time parameters and, for the example shown, to set the flap deflection to 25 degrees, the trim flag to true to ensure the equations are trimmed in equilibrium, and the derivative finder option to true.

> S CMD = 10
> S FLAPS = 25.
> S CTRIM = .T.
> S DEFIND = .T.
> START

The current status of the main switches and flags defining the control system settings, the analysis facilities, and the configuration is presented below: The CONVERGENCE signal indicates that trimming of the aircraft has taken place.

*************************************************************
* CURRENT STATUS OF SET UP SWITCHES                      *
*************************************************************
* CONTROLS SYSTEM SWITCHES                               *
*************************************************************
* RDAMP * ROLL DAMPER * F * 
* PDAMP * PITCH DAMPER * F * 
* YDAMP * YAW DAMPER * F * 
* RCAUG * ROLL CONTROL AUGMENTATION * F * 
* PCaug * PITCH CONTROL AUGMENTATION * F * 
* STA * SERIES TRIM ACTUATOR * F * 
*************************************************************
GENERAL SET UP SWITCHES

RADAPT * ROLL ADAPTIVE GAIN FINDER * F *
PADAPT * PITCH ADAPTIVE GAIN FINDER * F *
DEFIND * AERODYNAMIC DERIVATIVE FINDER * T *
FLTDAT * FLIGHT DATA INPUT * F *
CTRIM * TRIM AIRCRAFT WITH THRUST * T *
PTRIM * TRIM AIRCRAFT WITH ELEVATORS * F *
RTRIM * TRIM WITH STEADY SIDESLIP * F *
DUMP * GENERATE DEBUG OUTPUT * F *
PLOTFL * PRODUCE 3-D GRAPICS FILE * F *

IMPORTANT CONSTANTS

XCG * CENTRE OF GRAVITY POSITION * .24468 *
RFB * ROLL CONTROL FEEDBACK * 1.00000 *
AYFB * LATERAL ACCELEROMETER F/BACK * 1.00000 *

TAKE OFF AND LANDING CONFIGURATION

LANDGR * LANDING GEAR DOWN * F *
SPEEDB * SPEED BRAKE DOWN * F *
SLATS * LEADING EDGE SLATS EXTENDED * T *
GRDEFF * IN GROUND EFFECT * F *
FLAPS * TRAILING EDGE FLAPS EXTENSION * 25.00000 *

CONVERGENCE

> STOP

File F111DERV.OUT shown below contains the a priori derivatives calculated by the simulation program in a format suitable for use in the input file FAR01.DAT used by program MMLE3.

**********NON-DIMENSIONAL LONGITUDINAL AERODYNAMIC DERIVATIVES. **********

<p>| | |</p>
<table>
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<th></th>
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</thead>
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<tr>
<td>CLv</td>
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<tr>
<td>CDv</td>
<td>- .2937219</td>
</tr>
<tr>
<td>CMv</td>
<td>- .0108612</td>
</tr>
</tbody>
</table>
CL\alpha = 0.1316468
CD\alpha = 0.3009140
CM\alpha = -0.0191155
CL\delta\alpha = 2.5420000
CM\delta\alpha = -4.6251057
CL\eta = 5.7770989
CM\eta = -14.2470031

*********NON-DIMENSIONAL LATERAL AERODYNAMIC DERIVATIVES. *********
C\beta = -1.0751711
C\delta\beta = -0.0471412
CN\beta = -0.0671741
C\gamma_p = -0.0695050
C\gamma_p = -0.4218597
CN_p = 0.0151035
C\gamma_r = 0.3232533
C_r = 0.0426392
CN_r = -0.1817579
C\gamma_{dbeta} = -0.1191400
CL_{dbeta} = -0.0100330
CN_{dbeta} = 0.0351486

*********NON-DIMENSIONAL LATERAL CONTROL DERIVATIVES. *********
C_{\gamma_{aileron}} = 0.0726516
C_{\delta_{aileron}} = -0.0346603
CN_{aileron} = -0.0397724
C_{\gamma_{rudder}} = 0.0846688
C_{\delta_{rudder}} = 0.0097033
CN_{rudder} = -0.0227910
C_{\gamma_{spoiler}} = 0.0046761
C_{\delta_{spoiler}} = -0.0386813
CN_{spoiler} = -0.0094143
Appendix H - Parameter Identification Program MMLE3

The data processing described in previous Appendices is carried out to prepare the flight data for use by the parameter identification program MMLE3. Considerable background knowledge is needed to apply the program. Only the program operation procedures will be covered in this Appendix. A detailed description of the program MMLE3 is given in Reference [15]. Shown below is an example of an input file FAR01.DAT which provides all the data required for the third run of a phase 2 flight, event 72, along with a brief comment.

STANDARD AIRCRAFT ROUTINES
END ONCE
NEW
H1620035.OV3 16 TS1691 MMLE3 F111C LONG STAB P2F1E72 RUN 3 SLATS 36 FLAPS
$WIND,
AREA=550,CHORD=8.8,SPAN=70.0,
CG= .24509,
STAB=T,
PRINT =F,

Angle of attack scale factor $K_A$ and instrument locations

$K_{ALF}=1.08,$
$X_{ALF} = 45.5107,$  $Y_{ALF} = .0000,$  $Z_{ALF} = 2.5535$
$X_B = 44.7032,$  $Y_B = .0000,$  $Z_B = 3.0518$
$X_{AX} = 2.5241,$  $Y_{AX} = -2.4308,$  $Z_{AX} = 1.3877$
$X_{AY} = 2.4216,$  $Y_{AY} = -2.4583,$  $Z_{AY} = 1.3877$
$X_{AN} = 20.6674,$  $Y_{AN} = .0000,$  $Z_{AN} = 1.6610$
$END$
0.
0.
0.

A priori aerodynamic information including matrix element positions and values
The default longitudinal AN matrix is

\[
\begin{bmatrix}
C_{L_o} & C_{L_4} & 0 \\
C_{m_o} & C_{m_4} & 0 \\
0 & 0 & 0
\end{bmatrix}
\]

The default lateral AN matrix is
\[
\begin{bmatrix}
C_{Y_p} & C_{Y_f} & C_{Y_r} & 0 \\
C_{l_p} & C_{l_f} & C_{l_r} & 0 \\
C_{n_p} & C_{n_f} & C_{n_r} & 0 \\
0 & 0 & 0 & 0
\end{bmatrix}
\]

The default longitudinal BN matrix is

\[
\begin{bmatrix}
C_{L_{ax}} \\
C_{m_{tx}} \\
0
\end{bmatrix}
\]

The default lateral BN matrix is

\[
\begin{bmatrix}
C_{Y_{ax}} & C_{Y_{tx}} \\
C_{l_{ax}} & C_{l_{tx}} \\
C_{n_{ax}} & C_{n_{tx}} \\
0 & 0
\end{bmatrix}
\]

CMA  LONG  AN(2,1)  -.01912
CMQ  LONG  AN(2,2)  -14.24700
CMAD LON   GN(2,1)  -.62511
CMDE LON   BN(2,1)  -.03534
CMAT LON   CN(4,1)  .13166
CMAT LON   CN(4,2)  5.77710
CMDE LON   DN(4,1)  .01746
END

H1620035.OV3  16 TS1691 M4LE3 F111C LONG STAB P3F1E72 RUN 3 SLATS 36
FLAPS
$USER LONG =T,
KALF=1.06
W= 60000.85030 ,CG= .24468,
IX= 73343.67180 ,IY= 344865.78100,
IZ=411017.06200 ,IXZ= 3976.78710,
XALF = 45.5107, YALF = .0000 , ZALF = 2.5535
XB = 44.7032, YB = .0000 , ZB = 3.0518
XAX = 2.5241, YAX = -2.4308 , ZAX = 1.3877

58
\[
X_{AY} = 2.4216, \quad Y_{AY} = -2.4583, \quad Z_{AY} = 1.3877 \\
X_{AN} = 20.6674, \quad Y_{AN} = 0.0000, \quad Z_{AN} = 1.6610 \\
\]

Namelist INPUT is described in detail in Reference [15] section 3.3.8 with most of the variables being equal to a real or integer type number.

\[
\$INPUT \text{ CARD=T, NREC=24, ERRTH=F,} \\
\text{NUPLT=1, NEXPLT=6,} \\
\text{ERRMAX=10.E+30} \\
\text{TINVAR=T,} \\
\text{SPS=60, TEST=F,} \\
\text{MZ=4,} \\
\text{MU=1,} \\
\text{MX=3,} \\
\text{NOITER=29,} \\
\text{ITG=30,} \\
\text{WAPR=1.0,} \\
\text{ITAPR=20,} \\
\text{ZSCALE(6)=57.295} \\
\text{ZSCALE(1)=1.0} \\
\$END \\
100000000 \quad 1000000000
\]

Some of the aerodynamic parameters are linked through hard constraints to reduce the number of independent variables and to improve the identification process. For the longitudinal motion the following constraints based on the \textit{a priori} model values were used:

\[
C_{m_a} = 0.32464 \times c_{m_y} \\
C_{l_q} = 330.86868 \times C_{n_{\delta_e}} \\
C_{L_{\text{delta}}} = C_{N_{\text{delta}}} \\
C_{L_\alpha} = C_{N_\alpha}
\]

\text{HARD} 5

\text{HARD} 5

\text{RN}(2,1) = \text{AN}(2,2) \ast 0.32464 \\
\text{AN}(1,2) = \text{DN}(4,1) \ast 330.86868 \\
\text{CN}(4,2) = \text{DN}(4,1) \ast 330.86868 \\
\text{BN}(1,1) = \text{DN}(4,1) \ast 1.0
\[ AN(1,1) = CN(4,1) \times 1.0 \]

**END**

Flight data is provided in the following order:

- \( t \), \( \alpha \), \( q \), \( V \), \( \theta \), \( \alpha_n \), \( q \), \( a_z \), \( \delta_e \), \( \delta_c \), \( \delta_{1,\text{longitudinal}} \), \( \delta_{2,\text{longitudinal}} \), \( \phi \), \( h \), \( M \), \( q \), \( p \), \( r \), \( a_y \), \( \rho \), \( \dot{r} \), \( \delta_x \), \( \delta_r \), \( \delta_{1,\text{lateral}} \), \( \delta_{2,\text{lateral}} \)

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100000000</td>
<td>2.5800</td>
<td>.0948</td>
<td>356.6670</td>
<td>1.1361</td>
<td>1.0559</td>
</tr>
<tr>
<td></td>
<td>-.0338</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>146.0993</td>
<td>-.4976</td>
<td>.0000</td>
<td>.0000</td>
<td>.0000</td>
<td>-1.6664</td>
</tr>
<tr>
<td></td>
<td>.2061</td>
<td>-1.1277</td>
<td>-.5927</td>
<td>-.0210</td>
<td>1.4067</td>
</tr>
<tr>
<td></td>
<td>-.5241</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100000001</td>
<td>2.0532</td>
<td>.0423</td>
<td>356.2252</td>
<td>1.1361</td>
<td>1.0285</td>
</tr>
<tr>
<td></td>
<td>-.0331</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>146.7467</td>
<td>-.5087</td>
<td>.0000</td>
<td>.0000</td>
<td>.0000</td>
<td>1.6664</td>
</tr>
<tr>
<td></td>
<td>-.0578</td>
<td>-1.1277</td>
<td>-.5927</td>
<td>-.0247</td>
<td>1.0315</td>
</tr>
<tr>
<td></td>
<td>-.4115</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100000034</td>
<td>1.9216</td>
<td>.0948</td>
<td>356.6670</td>
<td>1.2242</td>
<td>1.0161</td>
</tr>
<tr>
<td></td>
<td>-.0346</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results of the identification process are written into file FAR03.DAT and shown below are the results obtained after 12 iterations:

**WEIGHTED ERRORS**

**ERROR SUM = 3.0000**

<table>
<thead>
<tr>
<th>ALPHA</th>
<th>Q</th>
<th>THETA</th>
<th>AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>.0000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**DET (RSQ) = -3.494288**

<table>
<thead>
<tr>
<th>AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>.1202</td>
</tr>
<tr>
<td>-.1916E-01</td>
</tr>
<tr>
<td>.0000</td>
</tr>
</tbody>
</table>

60
BN
3 BY 1
.2190E-01
-.3046E-01
.0000

SN
3 BY 1
.7031
-.7449E-01
.0000

CN
4 BY 3
1.150 62.34 .0000
.0000 1.000 .0000
.0000 .0000 1.000
.1702 6.609 .0000

DN
4 BY 1
.0000
.0000
.0000
.2190E-01

HN
4 BY 1
.0000
.0000
.0000
.7113

WEIGHTED ERRORS
ERROR SUM = 2.0984

ALPHA   Q   THETA   AN
1.008   1.021  .0000  .9691

DET (RSQ) = -3.485601

GGI
4 BY 4
4.685   .0000  .0000  .0000
.0000  1.185  .0000  .0000
.0000  .0000  .0000  .0000
.0000  .0000  .0000  434.5

ITERATION 12 COMPLETED. H1620035.OV3 16 TS1691 M06E3 F111C LONG STAB P3F1E72 RUN 3 SLATS 35 FLAPS

COST FUNCTION CONVERGED WITHIN .10E-02 BOUND.

WEIGHTED ERRORS
ERROR SUM = 3.0000

61
<table>
<thead>
<tr>
<th>ALPHA</th>
<th>Q</th>
<th>THETA</th>
<th>AN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

\[
\text{DET (RSQ)} = -3.486601
\]

Cramer-Rao bounds.

\[
\begin{array}{ccc}
\text{AC} & 3 \times 3 \\
0.000 & 0.000 & 0.000 \\
0.1363E-03 & 0.7636 & 0.000 \\
0.000 & 0.000 & 0.000 \\
\text{BC} & 3 \times 1 \\
0.000 & 0.3763E-03 & 0.000 \\
\text{SC} & 3 \times 1 \\
0.8623E-02 & 0.1971E-02 & 0.000 \\
\text{CC} & 4 \times 3 \\
0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.000 \\
0.8890E-03 & 0.000 & 0.000 \\
\text{DC} & 4 \times 1 \\
0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.8684E-03 \\
\text{HC} & 4 \times 1 \\
0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.5932E-02 \\
\end{array}
\]
Appendix I - Longitudinal Equations of Motion

State variables \( z = (\alpha, q, \theta) \)

Control variables \( u = (\delta) \)

Observation variables \( z = (\alpha_m, q_m, \theta_m, a_{nm}, a_z, \dot{q}_m) \)

The nonlinear longitudinal state equations are:

\[
\dot{\alpha} = -\frac{\dot{q}S}{mV}R(C_L + \ddot{\alpha}_0) + q + \frac{q}{V}R(\cos \theta \cos \alpha + \sin \alpha \sin \theta) - \frac{T}{mV}R \sin \alpha
\]

\[
I_{yy} \dot{q} = \dot{q}ScRC_m
\]

\[
\dot{\theta} = q + \dot{\theta}_0
\]

The \( \dot{\alpha}_0 \) and \( \dot{\theta}_0 \) are included to allow for instrument biases.

The longitudinal observation equations are:

\[
\alpha_m = K_{\alpha}(\alpha - \frac{x_a}{V}q)
\]

\[
q_m = q
\]

\[
\theta_m = \theta
\]

\[
a_{nm} = \frac{\dot{q}S}{mg}C_N + \frac{x_{an}}{gR} \dot{q} + \frac{x_{a2}}{R^2} q^2
\]

\[
a_z = -\frac{\dot{q}S}{mg}C_A + \frac{x_{az}}{gR} \dot{q} - \frac{x_{a2}}{R^2} q^2 + \frac{T}{mg}
\]

\[
\dot{q}_m = \dot{q} + \dot{q}_0
\]

The \( \dot{q}_0 \) is the instrument bias on \( \dot{q} \).
The expansions of the longitudinal force and moment coefficients are:

\[ C_N = C_{N_o} \alpha + C_{N_o} \frac{q_c}{2V_R} + C_{N_o} \delta_e + C_{N_o} \]

\[ C_m = C_{m_o} \alpha + C_{m_o} \frac{q_c}{2V_R} + C_{m_o} \delta_e + C_{m_o} + C_{m_o} \frac{\dot{\alpha}}{2V_R} \]

\[ C_A = C_{A_o} \alpha + C_{A_o} \frac{q_c}{2V_R} + C_{A_o} \delta_e + C_{A_o} \]

\[ C_L = C_N \cos \alpha - C_A \sin \alpha \]
Appendix J - Lateral Equations of Motion

State variables \( x = (\beta, p, r, \phi) \)

Control variables \( u = (\delta_a, \delta_r, \delta_{sy}) \)

Observation variables \( z = (\beta_m, p_m, r_m, \phi_m, a_y) \)

The nonlinear lateral-directional state equations are:

\[
\begin{align*}
\dot{\beta} &= \frac{qS}{mV} R(C_{\gamma} + \dot{\beta}_0) + \frac{g}{V} R \cos \theta \sin \phi + p \sin \alpha - r \cos \alpha \\
\dot{p} I_z - \dot{p} I_2 &= q S b R C_{\gamma} + \frac{q \tau}{R} (I_y - I_z) + pq \frac{I_z}{R} \\
\dot{r} I_z - \dot{p} I_2 &= q S b R C_{\alpha} + \frac{p q}{R} (I_z - I_y) - qr \frac{I_z}{R} \\
\dot{\phi} &= p + r \cos \phi \tan \theta + q \sin \phi \tan \theta + \phi_0
\end{align*}
\]

The terms \( \dot{\beta}_0 \) and \( \dot{\phi}_0 \) are included to allow for instrument biases.

The lateral observation equations are:

\[
\begin{align*}
\beta_m &= K_{\beta} (\beta - \frac{x_{\beta}}{V} p + \frac{x_{\beta}}{V} r) \\
p_m &= p \\
r_m &= r \\
\phi_m &= \phi \\
a_{y_m} &= \frac{\dot{q} S}{mg} C_{\gamma} - \frac{x_{a_{\gamma}}}{g R} \dot{p} + \frac{x_{a_{\gamma}}}{g R} \dot{r} - \frac{y_{a_{\gamma}}}{R^2 g} (p^2 + r^2) \\
\dot{p}_m &= \dot{p} + \dot{p}_0 \\
\dot{r}_m &= \dot{r} + \dot{r}_0
\end{align*}
\]

The terms \( \dot{p}_0 \) and \( \dot{r}_0 \) are the instrument biases on \( \dot{p} \) and \( \dot{r} \).

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The expansions of the lateral force and moment coefficients are:

\[ C_Y = C_{Y_0} + C_{Y_0} \frac{pb}{2VR} + C_{Y_0} \frac{rb}{2VR} + C_{Y_1} \delta + C_{Y_0} \]

\[ C_l = C_{l_0} \beta + C_{l_0} \frac{pb}{2VR} + C_{l_0} \frac{rb}{2VR} + C_{l_0} \delta + C_{l_0} + C_{l_0} \frac{\delta b}{2VR} \]

\[ C_n = C_{n_0} \beta + C_{n_0} \frac{pb}{2VR} + C_{n_0} \frac{rb}{2VR} + C_{n_0} \delta + C_{n_0} + C_{n_0} \frac{\delta b}{2VR} \]

where the \( \delta \) term is summed over all controls. For the 50° and 72.5° sweeps, the aileron (\( \delta_a \)) and rudder (\( \delta_r \)) are used. For sweeps less than or equal to 47°, the spoilers (\( \delta_s \)) are also operative.
Appendix K - Output File Notation

The notation for naming and cataloging MMLE3 results uses the following information: case type, sweep, altitude, Mach number and version.

\[ \text{case type} \quad \text{sweep} \quad \text{Mach number} \quad \text{version} \]

\[ A \quad 50 \quad H30 \quad M1.2 \quad V2 \]

Case type
- A: Longitudinal MMLE3
- B: Lateral MMLE3
- C: Longitudinal MMLE3P
- D: Lateral MMLE3P
- E: Longitudinal MODEL
- F: Lateral MODEL

Where MMLE3 is the standard parameter estimation program. MMLE3P is a version with fixed weightings and MODEL contains the a priori results obtained from the six degree of freedom flight dynamic model of the F-111C.

Sweep
- 16: 16 degrees
- 26: 26 degrees
- 35: 35 degrees
- 45: 45 degrees
- 50: 50 degrees
- 72: 72.5 degrees

Height
- H05: 5000 feet
- H10: 10000 feet
- H20: 20000 feet
- H30: 30000 feet
- H40: 40000 feet
- H50: 50000 feet
Version longitudinal
1 Phase 1 +ve g pullup
2 Phase 1 -ve g pushover
3 Phase 2 +ve g pullup
4 Phase 2 -ve g pushover
5 Phase 1 +ve g pullup repeat
6 Phase 1 -ve g pushover repeat
7 Phase 2 +ve g pullup repeat
8 Phase 2 -ve g pushover repeat

lateral
1 Phase 1 initial roll to the right
2 Phase 1 initial roll to the left
3 Phase 2 initial roll to the right
4 Phase 2 initial roll to the left
5 Phase 1 initial roll to the right repeat
6 Phase 1 initial roll to the left repeat
7 Phase 2 initial roll to the right repeat
8 Phase 2 initial roll to the left repeat

Longitudinal Analysis

Shown below is a typical longitudinal output file produced by MMLE3 with the following information:
File designation, title, flag to indicate Cm has been corrected for C of G position, actual sweep angle, actual Mach number, actual altitude, actual all up weight in pounds, C of G as a % of mean aerodynamic chord.

A50H30M1.2V2 50 TS1691 MMLE3 F111C LONG STAB L8E01 RUN 8_NG
CMACORR 60 +1.2287 +30076.6113 +74812.8250 +0.2978

Estimates for the longitudinal stability and control derivatives are presented followed by their Cramer-Rao bounds.

\[
\begin{bmatrix}
Cl_a & Cl_b \\
Cm_a & Cm_b \\
Cm_a & Cm_b \\
Cl_a & Cm_b \\
\end{bmatrix}
\]

\[+
0.0747 \quad +5.7827 \\
-0.0565 \quad -17.0710 \\
\]

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The last line contains the weightings for the output variables $\alpha, q, \theta, a_n$ used in the cost function equation.

$+23.2331 +16.0489 +0.0000 +1081.3801$

**Lateral Analysis**

Shown below is a typical lateral output file produced by MMLE3 with the following information:
File designation, title, actual sweep angle, actual Mach number, actual altitude, actual all up weight in pounds.

D72h20m1.5v2 72.5 pif1le4a
72.5  +1.52387714  +20538.5234  +72698.5

Estimates for the lateral stability and control derivatives are presented followed by their Cramer-Rao bounds.

$$
\begin{bmatrix}
C_{Y\alpha} & C_{Yq} & C_{Y\theta} \\
C_{I\alpha} & C_{Iq} & C_{I\theta} \\
C_{n\alpha} & C_{nq} & C_{n\theta} \\
C_{Y\alpha} & C_{Yq} & C_{Y\theta} \\
C_{I\alpha} & C_{Iq} & C_{I\theta} \\
C_{n\alpha} & C_{nq} & C_{n\theta}
\end{bmatrix}
$$

$$
\begin{bmatrix}
-8.4877523E-03 & -3.59000004E-02 & +0.285699993 \\
-6.61816797E-04 & -4.74088229E-02 & +2.65999995E-02 \\
+6.76631927E-04 & +2.00000009E-03 & -0.184223115 \\
+1.58686506E-03 & +7.39969198E-04 & +0.0 \\
-8.60938453E-04 & +4.41243264E-06 & +0.0 \\
-1.13605608E-04 & -4.27318154E-04 & +0.0 \\
+1.06449871E-04 & +0.0 & +0.0 \\
+8.6398003E-06 & +4.21156204E-04 & +0.0
\end{bmatrix}
$$
The last line contains the weightings for the output variables $\beta, p, r, \phi$ and $a_y$ in the cost function equation.

\begin{align*}
+6.00899982 &+0.400000005 \quad +15.0 \quad +0.0 \quad +15000.0
\end{align*}

**Take-Off and Landing Analysis**

The notation for the take-off and landing configuration is as follows:

\[
\begin{array}{ccc}
\text{sweep} & \text{flapsetting} \\
\text{case type} & \text{VIAS} & \text{knots} & \text{version} \\
H & 16 & 240 & 25.0 & V1 \\
\end{array}
\]

- **Case type**
  - H: Longitudinal MMLE3
  - I: Lateral MMLE3
  - J: Longitudinal MMLE3P
  - K: Lateral MMLE3P
  - L: Longitudinal MODEL
  - M: Lateral MODEL

- **VIAS**
  - 150: 150 knots indicated
  - 160: 160 Knots indicated
  - 180: 180 Knots indicated
  - 200: 200 Knots indicated
  - 215: 215 Knots indicated
  - 240: 240 Knots indicated

- **Flap setting**
  - 00: 0 flaps, slats extended
  - 15: 15 degrees flap, slats extended
  - 25: 25 degrees flap, slats extended
  - 35: 35 degrees flap, slats extended

Version designation is identical for the clean aircraft configuration and the take off and landing configuration.
Table 1: Instrumentation Channels used for Flight Dynamic Analysis

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Units</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCEL LONG CG*</td>
<td>(a_x)</td>
<td>g</td>
<td>±5</td>
<td>±0.05</td>
</tr>
<tr>
<td>ACCEL LAT CG</td>
<td>(a_y)</td>
<td>g</td>
<td>±5</td>
<td>±0.05</td>
</tr>
<tr>
<td>ACCEL VERT CG†</td>
<td>(a_z)</td>
<td>g</td>
<td>±10</td>
<td>±0.05</td>
</tr>
<tr>
<td>ROLL RATE</td>
<td>(p)</td>
<td>deg/sec</td>
<td>±300</td>
<td>±3</td>
</tr>
<tr>
<td>PITCH RATE</td>
<td>(q)</td>
<td>deg/sec</td>
<td>±100</td>
<td>±1</td>
</tr>
<tr>
<td>YAW RATE</td>
<td>(r)</td>
<td>deg/sec</td>
<td>±50</td>
<td>±0.5</td>
</tr>
<tr>
<td>ROLL ACC CG</td>
<td>(\dot{p})</td>
<td>rad/sec^2</td>
<td>±10</td>
<td>±0.05</td>
</tr>
<tr>
<td>PITCH ACC CG</td>
<td>(\dot{q})</td>
<td>rad/sec^2</td>
<td>±5</td>
<td>±0.05</td>
</tr>
<tr>
<td>YAW ACC CG</td>
<td>(\dot{r})</td>
<td>rad/sec^2</td>
<td>±5</td>
<td>±0.05</td>
</tr>
<tr>
<td>ROLL ANGLE</td>
<td>(\phi)</td>
<td>deg.</td>
<td>±180</td>
<td>±0.5</td>
</tr>
<tr>
<td>PITCH ANGLE</td>
<td>(\theta)</td>
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* NBTU measurements available in Phase 2
† Altitude and Mach no. coarse and fine readings available
‡ Crew module normal accelerometer used in flights 2 and 3 of Phase 2 because of a fault in the CG accelerometer signal
Table 2: Matrix of Test Points for Phase 1 and Phase 2

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- Phase 1
- Phase 2
Table 3: Take-Off and Landing Aircraft Configurations

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<th>Manoeuvre</th>
<th>Phase</th>
<th>Altitude (ft.)</th>
<th>Mach no./ KCAS</th>
<th>Sweep (deg.)</th>
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<td>165 kn.</td>
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Take Off Configuration

25° flap

| Phase | Altitude (ft.) | Mach no./ KCAS | Sweep (deg.) |
|-------|----------------|----------------|--------------|--------------|
| 1     | 1000           | 158 kn.        | 16           |
| 2     | 1000           | 165 kn.        | 16           |
Table 4: Supplementary Manoeuvres

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<th>Manoeuvre</th>
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<th>Altitude (ft.)</th>
<th>Mach no./KCAS</th>
<th>Sweep (deg.)</th>
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Table 5: Weighing Information for Phase 1 Aircraft, 16° Sweep Flaps Down

Configuration

Wing Sweep: 16 Degrees
Flaps: Fully extended
Slats: Fully extended
Gear: Down

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<th>Moment (lb-in)</th>
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</table>

Table 6: Weighing Information for Phase 1 Aircraft, 16° Sweep

Configuration

Wing Sweep: 16 Degrees
Flaps: Up
Slats: Up
Gear: Down

<table>
<thead>
<tr>
<th>Support Points</th>
<th>Weight (lb)</th>
<th>Support Point Total</th>
<th>Weight (lb)</th>
<th>Arm (in)</th>
<th>Moment (lb-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port</td>
<td>22207</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Starboard</td>
<td>22242</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nose</td>
<td>6158</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main</td>
<td></td>
<td></td>
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<td>24953669</td>
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<td></td>
<td></td>
<td>6158</td>
<td>264.8</td>
<td>1630638</td>
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<td>Total</td>
<td></td>
<td></td>
<td>50607</td>
<td>525.3</td>
<td>26584307</td>
</tr>
</tbody>
</table>
Table 7: Weighing Information for Phase 1 Aircraft, 26° Sweep

Configuration

Wing Sweep: 26 Degrees
Flaps: Up
Slats: Up
Gear: Down

<table>
<thead>
<tr>
<th>Support Points</th>
<th>Weight (lb)</th>
<th>Support Point Total</th>
<th>Weight (lb)</th>
<th>Arm (in)</th>
<th>Moment (lb-in)</th>
</tr>
</thead>
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Table 8: Weighing Information for Phase 1 Aircraft, 35° Sweep

Configuration

Wing Sweep: 35 Degrees
Flaps: Up
Slats: Up
Gear: Down

<table>
<thead>
<tr>
<th>Support Points</th>
<th>Weight (lb)</th>
<th>Support Point Total</th>
<th>Weight (lb)</th>
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<th>Moment (lb-in)</th>
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<tr>
<td>Port</td>
<td>22631</td>
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Table 9: **Weighing Information for Phase 1 Aircraft, 50° Sweep**

**Configuration**
- Wing Sweep: 50 Degrees
- Flaps: Up
- Slats: Up
- Gear: Down

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<th>Support Points</th>
<th>Weight (lb)</th>
<th>Support Point</th>
<th>Weight (lb)</th>
<th>Arm (in)</th>
<th>Moment (lb-in)</th>
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</thead>
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<tr>
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<td>45407</td>
<td>561.4</td>
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<tr>
<td>Nose</td>
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<td>Total</td>
<td>50640</td>
<td>530.8</td>
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</table>

Table 10: **Weighing Information for Phase 2 Aircraft, 26° Sweep**

**Configuration**
- Wing Sweep: 26 Deg
- Flaps: Up
- Slats: Up
- Gear: Down
- NBTU installed

<table>
<thead>
<tr>
<th>Support Points</th>
<th>Weight (lb)</th>
<th>Support Point</th>
<th>Weight (lb)</th>
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<th>Moment (lb-in)</th>
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<tr>
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<td>6555</td>
<td>Misc.</td>
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**Note:**
- Misc. refers to an adjustment that has to be made to the final weight and moment arm of the aircraft to compensate for
  - Any items weighed but are not part of the basic configuration.
  - Items that are part of the basic configuration that were not in the aircraft when it was weighed.
Table 11: Instrumentation Lags

<table>
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<tr>
<th>Channel</th>
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<td>$a_{n+1}$</td>
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Figure 1: Instrumented F-111C Aircraft (A8-132) Operated by ARDU for Flight Trial
Flight data on AFTRAS tape

Extract test point measurands (VAX 750) Programs EXTRACT and LISTPARM

Transfer to ELXSI 6400

C of G and inertia calculations for particular flight condition, pressure error correction, scale altitude error, time shifts Program FDP

Files for data processing

Flight path reconstruction (estimation program FPR)  $\alpha$ and $\beta$ vane calibration

A priori derivative calculation

Trim and run F-111C flight dynamic model

Parameter estimation, (maximum likelihood estimation MMLE3) Aerodynamic and control derivatives

Least squares fit to flight test data Final derivatives stored in data-base

Figure 3: Summary of Flight Data Processing and Analysis Procedures
Figure 4: Summary of Computer Programs, Input and Output File Names
## Figure 5: Summary of Computer Programs, Input and Output File Names (continued)

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**Pitch Doublets**

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**Roll Inputs**

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**Pitch Doublets**

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**Roll Inputs**

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</tbody>
</table>

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Figure 6: Typical Pilot's Test Card
Control input \rightarrow \text{Test aircraft} \rightarrow \text{Noise Measured response} \rightarrow \text{Estimated response} \rightarrow \text{Mathematical model of aircraft} \rightarrow \text{Gauss-Newton computational algorithm} \rightarrow \text{Maximum likelihood cost function} \rightarrow \text{Maximum likelihood estimate of aircraft parameters}

Figure 7: Block Diagram of Maximum Likelihood Estimation Procedure
## AERODYNAMIC DERIVATIVES
used in Linear Identification Models

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<tr>
<th>Static Derivatives</th>
<th>Longitudinal</th>
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Importance of derivatives to aircraft motion.
- Prime
- Secondary
- Least

---

**Figure 8:** Summary of Aerodynamic Parameters Used in Linear Identification Models
Figure 9: Example Time Histories for Longitudinal Manoeuvres

87
Figure 10: Curve Fitting Procedure for Derivatives
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C.A. Martin

**Corporate Author and Address:**
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506 Lorimer Street
Fishermens Bend VIC 3207

**Abstract:**
A series of flight trials was performed on the F-111C aircraft at the RAAF's Aircraft Research and Development Unit in February and October 1987. Data obtained from the tests were analysed at the Aeronautical Research Laboratory to determine the aircraft aerodynamic and control derivatives. This report describes the methods and computer programs which are used to process and analyse the flight test data. Data handling procedures, pre-analysis flight data processing and the methods used to make corrections to air sensor measurements are described. Although the test programme was conducted on a F-111C aircraft, with minor alterations the computer programs and procedures can be used for other aircraft test programmes.
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#### COMPUTER PROGRAMS USED

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#### ADDITIONAL INFORMATION (AS REQUIRED)