AR-009-955

DSTO-TR-0463

Australian Airborne Trials of the Sikorsky S-70B-2 Helicopter: Part 1 – Performance Measurements

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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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Air Operations Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Airborne tests have been conducted using an instrumented Sikorsky S-70B-2 helicopter. These tests were flown by a Royal Australian Navy Test Pilot and were primarily aimed at establishing limits for the S-70B-2 when operating from an 'Adelaide' class FFG-7 frigate. While the aircraft was instrumented, the opportunity was taken to fly a series of performance and flight dynamic tests to establish baseline data that will be used to further develop a mathematical model of the helicopter. This report details the scope of the performance tests, describes data processing procedures, and presents results of the tests.

RELEASE LIMITATION

Approved for public release

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

Published by

DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001

Telephone: (03) 9626 8111
Fax: (03) 9626 8999

AR No. 009-955
January 1997

APPROVED FOR PUBLIC RELEASE

Australian Airborne Trials of the Sikorsky S-70B-2 Helicopter: Part I - Performance Measurements

Executive Summary

From 4 to 30 March 1994, the First of Class Flight Trial (FOCFT) for the Sikorsky S-70B-2 helicopter on the 'Adelaide' class of FFG-7 frigate was conducted aboard HMAS SYDNEY. The aircraft was instrumented to record flight control positions and flight dynamic parameters. The ship was instrumented to record motion and wind velocity parameters. The purpose of this trial was to develop new Ship Helicopter Operating Limits (SHOLs) for operational use. This trial was performed by the Aircraft Maintenance and Flight Trials Unit (AMAFTU) of the Royal Australian Navy (RAN) with the aid of Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO).

AOD has been developing a computer model of the dynamic interface for the S-70B-2 helicopter and the 'Adelaide' class of FFG-7 frigates in order to investigate operational problems and limits for the RAN. While the aircraft was configured with instrumentation for the FOCFT, the opportunity was taken to conduct a series of performance and flight dynamic tests to determine baseline data that could then be used to further develop the model of the S-70B-2 helicopter.

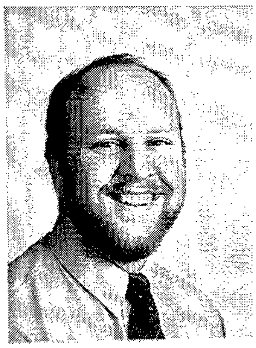
A contract with The Sir Lawrence Wackett Centre for Aerospace Design was negotiated entitled 'Data Processing and Development of Associated Software'. As part of this contract, processing of the aforementioned performance data has been carried out, with modifications made to the associated software. The contract also included the processing of data for the flight dynamic tests and the FOCFT, the results of which will be published at a later date.

This report gives a summary of the performance tests, details of modifications made to existing data processing software, a description of the data processing procedures, and presents time histories of the measured data. Helicopter performance data are then determined by taking the mean of the time history data over a time period during which the aircraft was trimmed.

This work will enable further development of a mathematical model of the S-70B-2 helicopter. A fully developed model will provide guidance on the outer boundaries of SHOLs, which will allow further FOCFTs to extend the SHOLs and thus give the fleet greater operational flexibility. The model will also allow the assessment of what effect different helicopter roles and role equipment will have. The Defence outcomes of this work are progress towards safe extensions of the operational capability of the S-70B-2 helicopter in embarked operations, and improvements in ability to model and plan helicopter maritime missions.

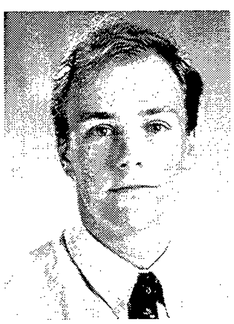
Authors

A. M. Arney
Air Operations Division



Ashley Arney graduated from the University of Sydney in 1981, having obtained an Aeronautical Engineering Degree, with honours. Since commencing employment at the then Aeronautical Research Laboratory in 1982, he has been involved with the mathematical modelling of the performance and flight dynamics of a wide range of helicopters. He has also obtained extensive experience in trials, data processing, and the use of such data for development of models. More recently he has been involved in modelling the helicopter-ship dynamic interface, and gathering data for development purposes.

I. Fieldhouse
The Sir Lawrence Wackett Centre for Aerospace Design



Ian Fieldhouse graduated from the Royal Melbourne Institute of Technology in 1994, having obtained a Bachelor of Engineering in Aerospace Engineering, with honours. He commenced employment with the Sir Lawrence Wackett Centre for Aerospace Design in 1994 providing technical service support to the Air Operations Division of the Aeronautical and Maritime Research Laboratory. In this position he has been involved in the helicopter flight dynamics area, processing and analysing flight data.

CONTENTS

1. INTRODUCTION

From 4 to 30 March 1994, the First of Class Flight Trial (FOCFT) for the Sikorsky S-70B-2 helicopter on the 'Adelaide' class of FFG-7 frigate was conducted aboard HMAS SYDNEY (Ref. 1). The aircraft was instrumented to record flight control positions and flight dynamic parameters. The ship was instrumented to record motion and wind velocity parameters. The purpose of this trial was to develop new Ship Helicopter Operating Limits (SHOLs) for operational use. This trial was performed by the Aircraft Maintenance and Flight Trials Unit (AMAFTU) of the Royal Australian Navy (RAN) with the aid of Air Operations Division (AOD) of the Defence Science and Technology Organisation (DSTO).

AOD has been developing a computer model of the dynamic interface for the S-70B-2 helicopter and the 'Adelaide' class of FFG-7 frigates in order to investigate operational problems and limits for the RAN. While the aircraft was configured with instrumentation for the FOCFT, the opportunity was taken to conduct a series of performance and flight dynamic tests to determine baseline data that could then be used to further develop the model of the S-70B-2 helicopter.

A contract with The Sir Lawrence Wackett Centre for Aerospace Design was negotiated entitled 'Data Processing and Development of Associated Software'. As part of this contract, processing of the aforementioned performance data has been carried out, with modifications made to the associated software. The contract also included the processing of data for the flight dynamic tests (Ref. 2) and the FOCFT (Ref. 3).

This report gives a summary of the performance tests, details of modifications made to existing data processing software, a description of the data processing procedures, and presents time histories of the measured data. Helicopter performance data are then determined by taking the mean of the time history data over a time period during which the aircraft was trimmed.

Imperial units are adopted throughout this document because (a) they are used exclusively by workers in the US with whom AOD is collaborating, (b) the S-70B-2 is built in the US to imperial specifications, and (c) the RAN work in imperial units when dealing with this helicopter.

2. SCOPE OF PERFORMANCE TESTS

The aircraft was instrumented by AMAFTU and data gathered using the data acquisition system developed by AOD, known as Data Acquisition Real-Time Hardware (DARTH, Ref. 4), which was a successor to the Versatile Airborne Data Acquisition and Replay (VADAR, Ref. 5) system. The DARTH system allows up to 56 channels to be used. Of these, 32 are analogue inputs (A), eight are digital inputs (DI), eight are digital outputs (DO), two are digital-analogue outputs (DA), and six are synchro (S) inputs. Table 1 lists the measurements recorded and their respective channel allocations.

The pilot controls (shown as 'Pre-Mix' in Table 1) and Automatic Flight Control System outputs (shown as 'AFCS' in Table 1) feed into a mixing unit, which then controls movement of the primary jacks. The mixing unit outputs (shown as 'Post-Mix' in Table 1) have physical stops that do not necessarily correspond to the physical stops of the pilot controls (due to AFCS inputs and mechanical mixing). Thus both mixer unit outputs and pilot controls are used to determine the amount of control travel available (Ref. 6). The travel available for the post-mix cyclic controls are calculated real-time by the DARTH system (Channels 49 and 50) and indicated to the pilot by console mounted displays. The primary jack displacements were recorded to enable main rotor blade angles to be determined directly. By recording all these quantities, a level of redundancy was able to be achieved.

For example, if the AFCS roll instrumentation failed (Channel 11), the AFCS roll may be deduced from the other control quantities.

Table 1. Summary of Data Recording Channels

Channel No.	Type	Variable	Channel No.	Type	Variable
1	A	Pitch Rate	22	A	No. 2 Engine Torque
2	A	Roll Rate	23	A	Weight on Wheels
3	A	Yaw Rate	24	A	Radar Altitude
4	A	Lateral Acc	25	A	Air Speed
5	A	Longitudinal Acc	26	A	Post-Mix; Yaw
6	A	Vertical Acc	27	A	Post-Mix; Pitch Aft
7	A	Longitudinal Doppler	28	A	Post-Mix; Pitch Forward
8	A	Lateral Doppler	29	A	Post-Mix; Roll Aft
9	A	Vertical Doppler	30	A	Post-Mix; Roll Forward
10	A	AFCS Pitch	31	A	Pitch Bias Actuator
11	A	AFCS Roll	32	A	Event Marker
12	A	AFCS Collective	33-40	DI	Not Used
13	A	AFCS Yaw	41-48	DO	Not Used
14	A	Forward Primary Jack	49	DA	Pitch Post-Mix
15	A	Aft Primary Jack	50	DA	Roll Post-Mix
16	A	Lateral Primary Jack	51	S	Not Used
17	A	Cyclic Long. Pre-Mix	52	S	Not Used
18	A	Cyclic Lateral Pre-Mix	53	S	Heading (AHRS[1])
19	A	Collective Pre-Mix	54	S	Stabilator Angle
20	A	Pedals Pre-Mix	55	S	Pitch Attitude (Gyro)
21	A	No. 1 Engine Torque	56	S	Roll Attitude (Gyro)

Executive computer programs were developed by AMAFTU to operate the data acquisition software originally developed by AOD. These programs required the DARTH operator to input a sortie number for each aircraft flight. Sorties 1 to 23 were used during the FOCFT, and Sorties 98 and 99 were allocated to the performance and flight dynamic tests respectively. As the software was developed specifically for FOCFTs, it was only capable of labelling recorded data files in terms of engine startup, shutdown, aircraft take-off, and landing. Each individual test (known as an 'evolution') could thus be labelled either AU, AD, AT, or AL respectively for aircraft data, or SU, SD, ST, or SL respectively for ship data. During the FOCFT, the standard procedure was to number the recorded take-off and landing files consecutively. At the end of Sortie 23, the total number of take-offs and landings was 198 and 193 respectively.[2] All the evolutions during Sortie 98 were labelled as take-offs, beginning with AT800. For Sortie 99, all the evolutions were labelled as landings, beginning with AL800.

1 Attitude and Heading Reference System.

2 The number of take-offs does not equal the number of landings because not every take-off and landing was recorded.

Also developed by AMAFTU, as part of this software, was the use of administration files ('.ADM' extensions). Prior to each sortie, the DARTH operator entered information such as basic aircraft weight,[3] then immediately before each evolution he would input the fuel weight (as read from the aircraft fuel gauge) and atmospheric conditions. The aircraft weight, *cg*, and atmospheric density ratio were then calculated and written to the '.ADM' file corresponding to that evolution. For example, Evolution AT800 has acquired data stored in file AT800.DAT and administration information in file AT800.ADM. A typical administration file for Sortie 98 is shown in Appendix A. The atmospheric conditions included in the '.ADM' file were the outside air temperature (OAT), wind speed, wind direction, and pressure altitude.[4]

The majority of the performance tests were conducted during Sortie 98 on 6 April, upon return from the FOCFT, under nominally still air conditions (< 3 kn). Other performance tests were conducted on an opportunity basis over a number of sorties during the FOCFT. A limited study of ground effect was performed that involved hovering at different heights and hovering at the same heights over both land and the flight deck of an FFG-7. Since the rotor diameter of the S-70B-2 is greater than the width of an FFG-7 flight deck, it would be expected that the aircraft would be influenced by 'partial ground effect' (PGE). The PGE caused by the ship flight deck, which may be a significant factor in 'power limited' landings,[5] is yet to be adequately determined. During the FOCFT, a stable hover was established above the bullseye (for 10 and 15 ft above the flight deck) for zero wind-over-deck and two weights (referred weights[6] of 17000 and 19400 lbf). During Sortie 98, a stable hover was established in ground effect (IGE) at 10 and 15 ft above the ground for nominally the same referred weights used at sea. This enables direct comparison of PGE with full IGE data even though the tests were done under different atmospheric conditions.

Table 2 summarises the performance tests. Except where otherwise specified, all tests were done at an altitude ≥ 100 ft, i.e. out of ground effect (OGE). Evolutions conducted IGE are shown at heights above ground level (AGL) or above the flight deck (AFD). For all test points, the aircraft was in steady trimmed flight and data were recorded for a period of not less than 10 s.

After Sortie 98 had been completed, the weight and *cg* information recorded in the administration files was found to be inconsistent with the weight and balance chart for that sortie. The discrepancy was attributed to an incorrect 'Basic Weight' being entered into the '.ADM' file prior to the sortie. Also, the weight entered into the AL174.ADM file during Sortie 21 was identical to that for AL173.ADM, and was assumed incorrect. This

---

3 Although it would be more appropriate to measure the mass, which remains constant with varying gravitational acceleration (g), rather than weight, which varies with g, the weight is used throughout this report assuming the standard value for g. Since g is a function of distance from the centre of the earth, the weight will vary with latitude and altitude. The standard value for g is defined at the earth's surface at 45° latitude. At an altitude of 10000 ft for a latitude of 45°, g is reduced by about 0.10 %. On the earth's surface at the equator, g is reduced by about 0.26 %, and at the poles g is increased by about 0.27 %.

4 The aircraft altimeter is set to International Standard Atmosphere (ISA) sea-level pressure (29.92 inHg), so that the indicated aircraft pressure altitude will enable determination of the standard atmospheric pressure ratio. In conjunction with the OAT, the air density may then be determined from standard atmosphere relationships.

5 Parts of the SHOL may be defined when the power margin is reduced to 5% (day) or 10% (night), i.e. 'power limited'.

6 During flight tests, the ratio of weight to density ratio (W/σ, known as 'referred weight') is used so that test data may be referred back to standard atmospheric conditions. The density ratio is given by $\sigma = \rho/\rho_o$, where ρ is the ambient density and ρ_o is the sea level density for an ISA+5°C atmosphere ($\rho_o = 0.002336$ slug/ft^3).

discrepancy was attributed to an incorrect fuel weight being entered into the '.ADM' file prior to the evolution. The weight corrections for all these evolutions are detailed in Appendix B.

Along with information recorded using the DARTH system and administration files, comments were hand written into a log sheet during each evolution. For Sorties 98 and 99, these comments were made by the DSTO observer aboard the aircraft, and for the sorties at sea, by various members of the trials team (usually the test pilot). The performance evolution log, which contains the individual evolution designation, atmospheric data, corrected weight and *cg* position, and comments, is given in Appendix C.

Table 2. Summary of Performance Flight Tests

File #	Evolution	File#	Evolution
Hover		**Forward Climb/Descent**	
AT800	3 ft AGL - IGE	AT828	Climb 40 kn
AT801	10 ft AGL - IGE	AT829	Descent 40 kn
AT802	15 ft AGL - IGE	AT830	Climb 80 kn
AT803	20 ft AGL - IGE	AT831	Descent 80 kn
AT804	30 ft AGL - IGE	AT832	Climb 120 kn
AT805	40 ft AGL - IGE	AT833	Descent 120 kn
AT806	50 ft AGL - IGE	**Autorotation**	
AT807	100 ft AGL - OGE	AT834	0 kn
Low Airspeed		AT835	80 kn
AT808	Forward 15 kn	AT836	100 kn
AT809	Forward 30 kn	**Ground Effect Study**	
AT810	Aft 15 kn	*Hovering Above Ground*	
AT811	Aft 30 kn	AT816	10 ft AGL, W/σ=19396 lbf
AT812	Port 15 kn	AT817	15 ft AGL, W/σ=19396 lbf
AT813	Port 30 kn	AT837	10 ft AGL, W/σ=17000 lbf
AT814	Starboard 15 kn	AT838	15 ft AGL, W/σ=17000 lbf
AT815	Starboard 30 kn	AT839	100 ft AGL, W/σ=17000 lbf
Level Flight		*Hovering Over Flight Deck*	
AT821	40 kn	AL100	3 ft AFD, W/σ= 19232 lbf
AT822	80 kn	AL151	15 ft AFD, W/σ= 17163 lbf
AT823	120 kn	AL152	10 ft AFD, W/σ= 17076 lbf
AT824	140 kn	AL158	10 ft AFD, W/σ= 17000 lbf
Vertical Climb/Descent		AL159	15 ft AFD, W/σ= 16922 lbf
AT818	Climb 600 fpm	AL173	10 ft AFD, W/σ= 19217 lbf
AT819	Climb 1200 fpm	AL174	10 ft AFD, W/σ= 19138 lbf
AT819	Climb 1200 fpm		
AT820	Climb 1800 fpm		
AT825	Descent 600 fpm		
AT826	Descent 3300 fpm		
AT827	Descent 3300 fpm		

3. MODIFICATIONS TO DATA PROCESSING SOFTWARE

3.1 *Refine* Program

The data processing program *S70B2Refine* is available for running on Macintosh computers and has been developed from *JBFOCFTRefine,* which was developed to process data acquired during the Black Hawk FOCFT aboard the training ship HMAS JERVIS BAY. This program had been developed from program *MacShipRefine* (Ref. 7), which was developed from program *Refine* (Refs 8 and 9). Changes made to *MacShipRefine* to obtain *JBFOCFTRefine* included calculation of aircraft and ship angular accelerations, aircraft Euler angles, and channel specific modifications required for the specific trial.

This section details modifications made to *JBFOCFTRefine* that resulted in program *S70B2Refine*. The modules that make up *S70B2Refine* are listed in Table 3. Those modules with the 'S70B2' prefix were those modified to create *S70B2Refine.* These modifications are discussed further below.

Table 3. Program *S70B2Refine* Modules

S70B2R1.f	ChkUpr.f
S70B2R2.f	Ding.f
ShipR3.f	TSub87.f
S70B2R4.f	SPreNotch.f
ShipR5.f	NotchFilter.f
S70B2R6.f	Gillfix.f
Rename.f	FindStartTime.f
Rextra.f	

3.1.1 S70B2R1.f

For the HMAS JERVIS BAY trial, the ship yaw attitude (Channel 51) was forced to range between ±180° rather than 0 to 360°. This channel was changed initially to Channel 53, which is the aircraft compass heading for the S-70B-2 trials, but was later commented out of the code as it was considered unnecessary.

For the S-70B-2 trials, the aircraft stabilator angle, heading, gyro pitch, and roll attitude measurements were recorded on synchro channels and all other data recorded on analogue channels. The DARTH system conducts signal processing on the analogue channels only, which results in a delay in those measurements. Program variable `TDELAY` was thus set to correct the delayed channels by a total of 0.1 s (Section 4.3).

3.1.2 S70B2R2.f

An updated Fortran compiler found that parameter `PD2` was found to be declared as a double precision variable twice, which resulted in a compilation error. This parameter is now correctly declared only once. Previous and current results are unaffected.

3.1.3 S70B2R4.f

A large section of the code in this module related to an earlier undercarriage trial (Ref. 10) and used Channels 19 to 27 to calculate parameters specific to that trial. This section of code was deleted.

One of the modifications made to create JBFOCFTR4.f was to allow for 'signed' synchro channels. A 'signed' synchro parameter may have positive or negative values (e.g. roll attitude), whereas an 'unsigned' parameter (e.g. heading) is always positive. The 'signed' parameters are defined in a DARTH '.SET' file, which was named FOCFT_L.SET (Appendix D) for the S-70B-2 trials. For the HMAS JERVIS BAY trial, aircraft Channels 51, 52, 53, and 54 were 'signed' channels, but for the S-70B-2 trials, aircraft Channels 54, 55, and 56 were 'signed' channels.

Also, for the HMAS JERVIS BAY trial, the aircraft heading (Channel 55) required a saw-toothed calibration rather than the linear calibration required for the S-70B-2 trial.

Note that, although Channel 46 has not been used for data acquisition, it is still defined in this module to be the actual start time. When running *S70B2Refine* (see Section 4), if the user replies Y to the question 'IS THE EXACT START TIME REQUIRED :', the exact time will be output to Channel 46. This facility has been retained so that if data are acquired in a future trial from two synchronised DARTH units, the exact time difference in the data may be determined. For the S-70B-2 FOCFT trial, the DARTH units could not be synchronised.

3.1.4 S70B2R6.f

Calculation of the Euler yaw and roll angles (ψ and ϕ respectively) requires the aircraft gyro pitch, roll, and heading measurements. For the HMAS JERVIS BAY trial, the aircraft gyro pitch, roll, and heading measurements were Channels 53, 54, and 55 respectively, whereas for the S-70B-2 trials, they were Channels 55, 56, and 53 respectively.

Calculations of the angular accelerations are also conducted in this module, thus requiring changes to the channel numbers for the angular rates. For the HMAS JERVIS BAY trial, the aircraft pitch, roll, and yaw rate measurements were Channels 2, 3, and 4 respectively, whereas for the S-70B-2 trials, they were Channels 1, 2, and 3 respectively. Channels 40, 41, and 42 were assigned to the calculated yaw, roll, and pitch accelerations respectively.

3.2 *Convert* Programs

The output from program *S70B2Refine* was post-processed by program *MacTrans* (Ref. 11) to display data either graphically or in tabular form. In order to convert the tabular data from *MacTrans* '.COL' files into a multi-column format suitable for input into other programs, the program *JBFOCFTConvert(ac)* had been written for an earlier trial. This program was modified to allow for channel numbers specific to this trial and named *S70B2Convert(ac)*.

The main change to the program involved rearranging and increasing the number of channels. Program *JBFOCFTConvert(ac)* only output 20 channels, whereas program *S70B2Convert(ac)* outputs all 44 channels from *S70B2Refine*. Several channels were converted either from kn to ft/s or from a unit including degrees to one using radians (e.g. deg/s to rad/s). The output files are named after the *MacTrans* '.COL' input file, replacing the '.COL' extension with an ' Out' extension.

Two sections of code were no longer necessary in the program. The first calculated the distance covered by the helicopter and was deleted. The second ensured the aircraft yaw attitude ranged between -180^{o} and +180^{o} and has been commented out.

Program *Compat* was used to determine time delays associated with the DARTH system signal conditioning of the analogue channels (Section 4.3). Program *S70B2Convert(ac)-C* is a modification of *S70B2Convert(ac)* that reads in *MacTrans* '.COL' files and then writes out motion data in a format suitable for input to *Compat* (Table 4). The output files are named after the *MacTrans* '.COL' input file, replacing the '.COL' extension with a '.Motion' extension. In Table 4, subscript 'm' denotes a measured quantity, and no subscript indicates a quantity calculated from measured data.

Table 4. Input Format Required by *Compat*

Column	Variable	Comments
1	*Time*	
2-4	$a_{x_m}, a_{y_m}, a_{z_m}$	Linear Accelerations (ft/s^2)
5-7	p_m, q_m, r_m	Angular Rates (rad/s)
8-10	$\dot{p}, \dot{q}, \dot{r}$	Angular Accelerations (rad/s^2)
11-13	U_m, V_m, W_m	Doppler Velocities (ft/s)
14-16	ϕ_m, θ_m, ψ_m	Euler Angles (rad)
17-19	X_m, Y_m, Z_m	X_m, Y_m set to zero; Z_m is Rad Alt (ft)

4. DATA PROCESSING PROCEDURES

The DARTH system recorded the raw data in IBM binary format ('`.DAT`' files) and saved them to 3.5 inch floppy disks. The data acquired during the S-70B-2 flying trials were transferred from the floppy disks to a Macintosh magneto-optical disk and a Digital Data Storage (DDS) 4 mm data cartridge (DDS tape). These data were then transferred via a Macintosh computer to a RISC machine so that the data could be converted to ASCII format ('`.con`' files) that are in the form required as input to program *S70B2Refine.* Program *convdata* was used to convert the '`.DAT`' files to '`.con`' files. These files were then transferred back to the Macintosh and stored on compact disk and a DDS tape using program *Retrospect* (© Dantz Development Corporation). An example of running *convdata* is shown below. In examples throughout this document, bold italic type indicates user inputs and <CR> denotes a carriage-return.

```
<anne /home/arneya/tmp> convdata AL10.DAT -n > AL10.con
```

During a landing aboard ship, all channels were likely to measure variations, as opposed to the performance tests where the aircraft was in steady trimmed flight. Thus, to check all data processing software was working correctly, a landing evolution during Sortie 2 was chosen to be processed (`AL10.con`). Also, past experience with the VADAR system has shown that the data of some channels can contain 'noise' below the cut-off frequencies used by the DARTH signal conditioning. This can adversely affect any post-processing of the measurements, such as differentiation of the angular rates. *S70B2Refine* has the capability to perform digital filtering of the data to remove this noise (Ref. 8). The sections below discuss checking the data processing software and determining required digital filtering characteristics, instrument and analogue filter delays, and instrument calibration offset errors in doppler velocity data. An example of processing the data is also given.

4.1 Checking Data Processing Software

Program *S70B2Refine* was first used to process the data, and time history plots were then created using program *MacTrans*. These plots were then compared to the similar output produced by the IBM PC programs *SpltData* and *UPltData* associated with the DARTH software.

In order to run *S70B2Refine*, a calibration file that contains instrument calibration factors and offsets was required. The DARTH file `FOCFT_L.SET`, containing instrument calibration factors and offset values for each channel, was defined prior to each sortie.[7] The instrument calibration scale factors and offsets from the `FOCFT_L.SET` file for Sortie 2 (Appendix D) were used to create a temporary calibration file, `TEMPCAL`.

Evolution AL10, Sortie 2, was a landing during the FOCFT that was chosen to check the processing software, as variation of the measured parameters would show faulty data more obviously than the trimmed performance data.

S70B2Refine was run as shown below, with the input data file and calibration file required to be in the same directory as the program.

```
***************************************************
* Program to process data obtained from S-70B-2   *
* Performance, Dynamic and First of Class Flight  *
* Trials held March-April 1994 using PC-based Data *
* Acquisition System.                             *
* Data files must have ".con"  extensions         *
***************************************************

Input Data Filename (w/o ".Con" extension) = AL10
Is this an aircraft data file (default N): Y
".DAT" OUTPUT FILENAME (w/o ext) = S2AL10
TITLE (2 lines of 60 chrs)
:S-70B-2 Trials - Sortie 2 Landing 10
:Test File
ARE ASSIGNED BLK NUMBERS REQRD : N
CALIBRATION FILENAME = TEMPCAL
Day Number (Default is other than Day 1) = <CR>
IS PRE-PROCESSING WITH A NOTCH FILTER REQRD : N
OUTPUT INTERVAL (in 20'ths of sec; e.g. 40 for 2 sec) = <CR>
IS THE EXACT START TIME REQUIRED : N
STARTING TIME DELAY = <CR>
TIME LIMIT = <CR>
IS FILTERING REQRD : N
IS SMOOTHING REQRD : N
ARE INSTRUMENT & ANALOGUE FILTER DELAY ADJUSTMENTS REQRD : N
ARE SCALES AND OFFSETS REQRD : Y
ARE PLOT LIMITS REQRD : N
ARE DROP-OUTS TO BE CORRECTED : N
ARE ALL CHANNELS REQRD : Y
DATE = 20-SEP-94
TIME = 09:22:33

No. time corrections =   0
No. blocks replaced =   0
No. drop-out corrections =   0

STOP 1
```

Program *S70B2Refine* produced an output file with a '`.DAT`' extension. To avoid confusion with the original DARTH system raw data file (also with a '`.DAT`' extension), this file was named with the prefix `S2` to indicate the file was from Sortie 2. For the example above, the DARTH raw data file was named `AL10.DAT`, the output from program *convdata* was named

[7] The calibration factors and offsets for the AFCS output channels (10-13) varied between some sorties. This variation was due to failures of the instrumentation fit. The AFCS channels were recalibrated after each failure, thus a different `FOCFT_L.SET` file was required for each sortie where variations occurred. Due to the unreliability of the instrumentation, the data from these channels should be treated with caution.

AL10.con, and the output file from *S70B2Refine* was named S2AL10.DAT. This output file was used as input to program *MacTrans* (Ref. 11), which was used to produce plots of the time histories for all recorded channels. An example of running *MacTrans* for Channel 56 (roll attitude) is shown below. The input file is required to be in the same directory as the program.

```
[TRANS version date 12-FEB-91]

GO STRAIGHT TO EVENT LOOP? N
I/P FILENAME = S2AL10
S-70B-2 Trials - Sortie 2 Landing 10
Test File

I/P FILE RECORDED ON 20-SEP-94   AT 09:22:33

INTEGN INT = 0.0000E+00; RUN CPU TIME =    2 MIN. 31.87 SEC.

TIME FROM 0.0000E+00 TO 5.4650E+01 IN STEPS OF 5.0000E-02

*PLS
IS GRAPHICS OUTPUT TO SCREEN REQUIRED :
[PLS/O Output, for this run, going to DSK:S2AL10.PLT     ]

STRIP PLOTS :

BLKS
56

TO SPECIFY NO. OF X UNITS/INCH, TYPE 0 FOR X

LENGTH OF AXES IN INCHES; X, Y = 5,6
ARE SYMBOLS REQRD FOR PLOTS : N
LINE KEY (0 GIVES DEFAULT) = <CR>
THE CURRENT LINE COLOURS ARE:
0 & 1    2        3        4
BLACK    RED      GREEN    BLUE
5        6        7        8
CYAN     MAGENTA  YELLOW   ORANGE
AVAILABLE COLOURS :
BLACK, RED, GREEN, LTGREEN, BLUE, LTBLUE, CYAN,
MAGENTA, PURPLE, YELLOW, ORANGE.
DO YOU WISH TO CHANGE THE COLOURS? : N
*GOE
*EXI

STOP
```

Program *SoftPC* (©Insignia Solutions) was used on a Macintosh computer to emulate an IBM PC, so that DARTH programs *SpltData* and *UPltData* could be used to view time histories of the raw data. Program *SpltData* creates ASCII data files containing the raw data for each of the channels in imperial units. An example of running *SpltData* for Evolution AL10 is shown below.

```
> SPLTDATA AL10.DAT -n
```

File AL10.001 contains data for Channel 1, AL10.002 contains data for Channel 2, etc. Time data are contained in file AL10.098. Program *UPltData* then uses these ASCII data files to plot time histories to the screen. An example of running *UPltData* for Evolution AL10 is shown below.

```
> UPLTDATA AL10.DAT -x -j
```

Hard copies of these plots were obtained by taking a snapshot of the screen. Program *MacDrawPro* (©Claris Corporation) was then used to print the snapshot. A comparison was then made of the output using *UPltData* with that obtained using *MacTrans*, and is shown in Figure 1 for the roll attitude channel. The vertical scales for the two plots in Fig. 1 have been offset to facilitate comparison. The two plots are not identical because *MacTrans* does not draw every data point and thus contains fewer spikes. However, the comparison of all channels confirmed that *S70B2Refine* was working correctly.

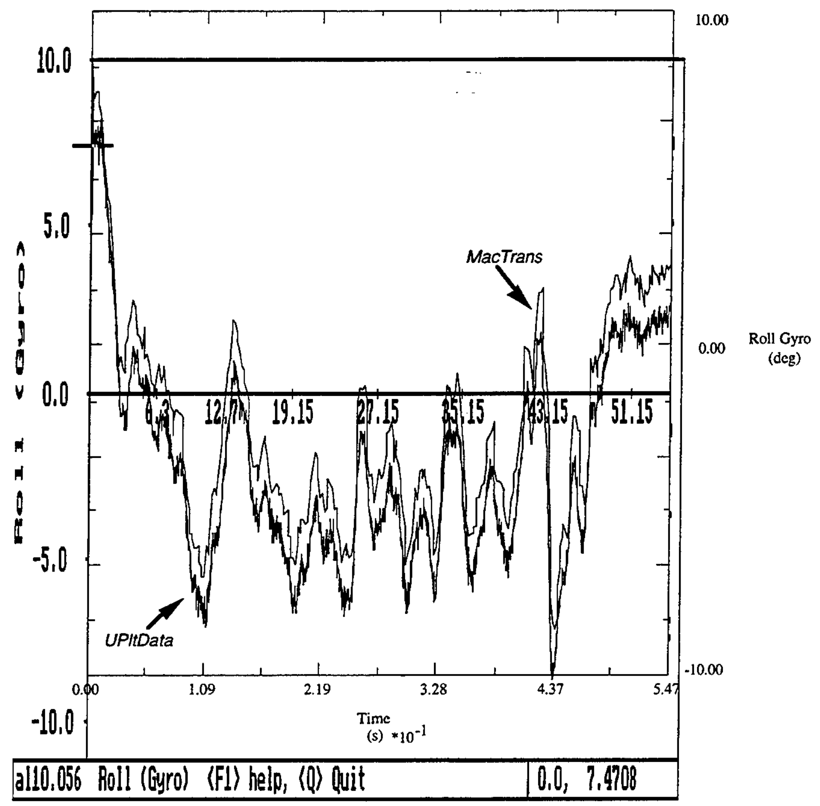


Figure 1. Comparison of Roll Attitude Data Using *UPltData* and *MacTrans* (*MacTrans* Plot Vertically Offset)

The complicated procedure of running programs *convdata*, *S70B2Refine*, and *MacTrans* in order to achieve a time history that can be more easily obtained using programs *SpltData* and *UPltData* is only necessary if the measured data contain errors or noise. Program *S70B2Refine* has the capability to correct commonly encountered errors and digitally filter noisy data, as demonstrated in the following sections.

4.2 Determination of Digital Filtering Characteristics

The DARTH system used an 8 pole Elliptic filter with a 12.5 Hz cut-off frequency to condition the data acquired using the 32 analogue channels (Appendix D). Neither the digital channels nor the synchro channels underwent any signal conditioning. Experience with the DARTH system has shown that the signal conditioning has not always eliminated all the significant noise present on some channels. In particular, any noise on the angular rate channels can adversely affect the result of differentiating the data to obtain angular accelerations. A spectral analysis was performed for all channels to determine the frequency at which any noise was present, so that suitable digital filtering charateristics may be determined.

Program *spectrum* was available on a RISC 6000 machine and requires the input file to be in four columns. The first column is time and the three remaining columns are the variables to be analysed. To obtain the data in column format, program *MacTrans* was first used to obtain data in imperial units, and program *S70B2Convert(ac)* was then used to convert these data to multi-column format. The input files for *spectrum* were created by editing the ' `Out`' file from *S70B2Convert(ac)* using program *Kaleidagraph* (© Abelbeck Software). The input files were then transferred to the RISC 6000 machine and processed by *spectrum*. An example of running *MacTrans* is shown below.

```
 [TRANS version date 12-FEB-91]

GO STRAIGHT TO EVENT LOOP? <CR>
I/P FILENAME = S2AL10
S-70B-2 Trials - Sortie 2 Landing 10
Test File

I/P FILE RECORDED ON 20-SEP-94   AT 09:22:33

INTEGN INT = 0.0000E+00; RUN CPU TIME =    2 MIN. 31.87 SEC.

TIME FROM 0.0000E+00 TO 5.4650E+01 IN STEPS OF 5.0000E-02

*prc
PRINTING IN COLUMNS :

BLKS
a
IS O/P TO TTY REQRD :
*goe
** RUNNING **
*exi

STOP
```

The *MacTrans* output from the example above was file `S2AL10.COL`. When *S70B2Convert(ac)* was run, the user was prompted for an input file, which in this case was `S2AL10.COL`. File `S2AL10 Out` was created and then edited accordingly to produce an input file for *spectrum* in the format previously described. For the three linear acceleration measurements, file `s2al10ACCEL` was created from `S2AL10 Out`. This file was then transferred to a RISC 6000 and *spectrum* was run as shown below.

```
<anne /home/arneya/tmp> spectrum
 Input File :s2al10ACCEL
<anne /home/arneya/tmp>
```

Program *spectrum* produced the output file `FFT.OUT`, which had the format of data in four columns. The first column was frequency and the remaining three columns were the power spectral densities for the three variables in the input file. For this example, the output file was renamed to `s2al10ACCEL.out` and transferred to the Macintosh, where the spectral densities were plotted using *Kaleidagraph*. The spectral analysis for the lateral acceleration measurements is shown in Figure 2.

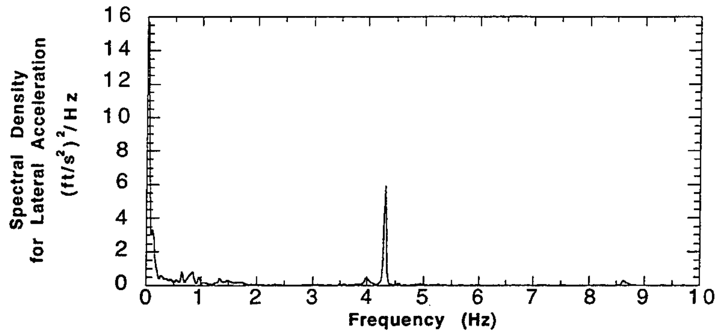


Figure 2. Spectral Density of Lateral Acceleration Measurements

The example in Fig. 2 clearly shows that noise is present between 4 and 4.5 Hz that corresponds with the main rotor frequency (main rotor rotational speed is nominally 27 rad/s = 4.3 Hz). Spectral densities for all the channels were obtained and indicated that the measurements of the angular rates and linear accelerations contained similar spikes between 4 and 4.5 Hz, and thus needed further digital filtering. A 5-pole Butterworth filter with cut-off frequency of 4 Hz and 50 dB attenuation was chosen to filter these channels. The filter characteristics are included in the calibration file for *S70B2Refine*, called `SHAWKCAL` (Appendix E). To include digital filtering of the angular rate and linear acceleration measurements and correct for resulting phase lags, program *S70B2Refine* was run as in Section 4.1, with the following changes in responses.

```
IS FILTERING REQRD :  Y
IS OUTPUT OF FILTER CHARACTERISTICS REQRD :  N
ARE DIGITAL FILTER DELAY ADJUSTMENTS REQRD  :  Y
```

A comparison of the filtered and unfiltered data for the lateral acceleration is shown in Figure 3.

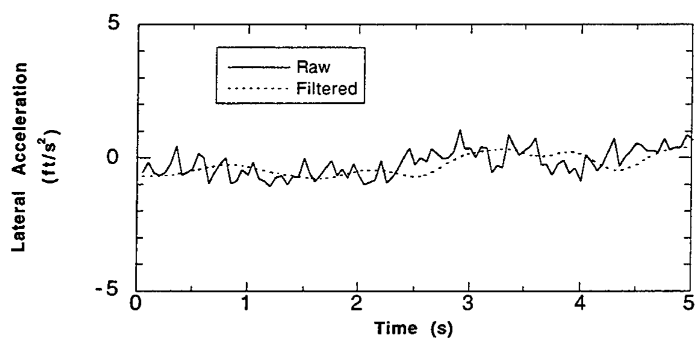


Figure 3. Comparison of Lateral Acceleration Raw Measurements with Digitally Filtered Data

4.3 Determination of Instrument and Analogue Filter Delays

As mentioned in Section 4.2, the measurements using the 32 analogue channels have all been conditioned using an analogue filter. This analogue filtering causes a time delay to the measurements from the conditioned channels when compared with measurements obtained from the unconditioned synchro channels. Program *Compat* was used to identify instrument and analogue filter delays in the measurements. *Compat* is a compatibility checking program that enables comparison of measured quantities with those calculated by integrating the rigid body kinematic equations of motion. In this way, instrumentation scaling factor and offset errors may be determined. Ref. 12 gives further information on *Compat*. By comparing the pitch attitude measured using a synchro channel with the calculated value from the equations of motion, which use data from the filtered analogue channels, any time delays may also be determined.

The data used for this analysis were acquired during the S-70B-2 dynamic trials (Ref. 2), and are summarised in Table 5. These data were chosen as they provided substantial variation in the aircraft attitude with time, as opposed to the performance data where the aircraft was in trimmed flight.

Table 5. Evolutions Analysed To Establish Time Delays

Evolution	Airspeed (kn)	Control Input
AL800	0	Step Cyclic Forward
AL802	0	Step Cyclic Left
AL803	0	Step Cyclic Right
AL806	0	Step Pedal Left
AL820	40	Step Cyclic Left
AL824	40	Step Pedal Left
AL859	120	Pulse Cyclic Forward
AL860	120	Pulse Cyclic Aft

An example of running *Compat* to calculate the aircraft attitudes is shown below. The `COMDAT.002` file used as input was identical to that used in Ref. 12. The input file `S99AL860.Motion` was created using program *S70B2Convert(ac)-C* (Section 3.2). Note that for this example, only the attitude information is actually used by *Compat*.

```
<anne /home/arneya/tmp/compat> Compat
COMDAT.xxx File Number?
2
 COMDAT.002 opened.

 Input File?
S99AL860.Motion
 S99AL860.Motion    opened.

 ***** NNo > Data file size - Data array reduced from 2500 to 185 points
  ITERATION NUMBER  0
  ITERATION NUMBER  1
...............
  ITERATION NUMBER  24
<anne /home/arneya/tmp/compat>
```

The output file `var.dat` contained the calculated aircraft attitudes. Comparison of the measured and calculated data, for the evolutions in Table 5, indicated that a time delay of about 0.1 s occurred. This delay is assumed to apply to all data acquired from the 32 analogue channels during the S-70B-2 trials. The comparison of the measured and calculated pitch attitude for Evolution AL860 is shown in Figure 4.

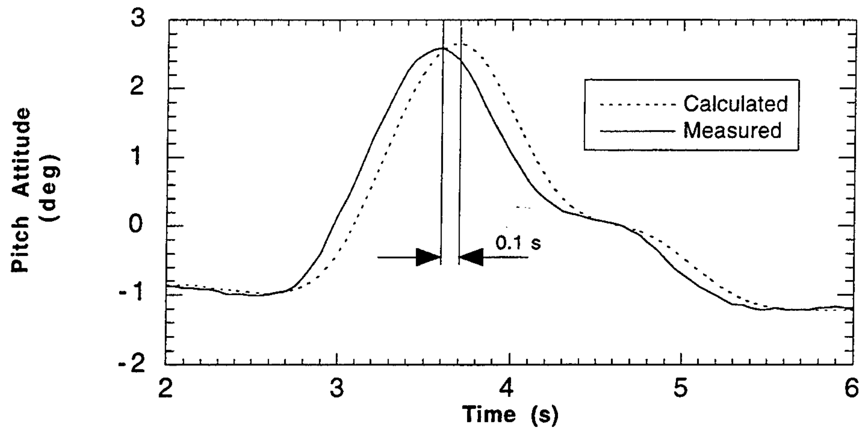


Figure 4. Comparison of Measured with Calculated Pitch Attitude

Program *S70B2Refine* was modified to incorporate this time delay (Section 3.1.1). To include this correction when processing the data, the following change in response was required.

```
ARE INSTRUMENT & ANALOGUE FILTER DELAY ADJUSTMENTS REQRD : Y
```

4.4 Offset Errors in Doppler Velocity Data

Examination of the raw data for the hover evolutions (AT800 - AT807) indicated that an offset error was present in the doppler velocity channels. For all these evolutions, the doppler velocities consistently indicated a ground speed of about 3 ft/s backwards and about 3 ft/s upwards, which was inconsistent with the Rad Alt indication and comments in the evolution log (Appendix C).

Further examination of the hover data indicated that the aircraft was not perfectly trimmed during the recording runs, i.e. the aircraft was pitching, rolling, or yawing at a small angular rate. Because hover Evolutions AT801 and AT803 had the lower angular rates, program *Compat* (Ref. 12) was used for these evolutions to determine instrument offset errors. The mean errors for these evolutions were then used to adjust the offset values of the calibrations for the doppler velocities in the `FOCFT_L.SET` file, resulting in those shown in the SHAWKCAL calibration file (Appendix E) used by *S70B2Refine*.

Program *Compat* was run according to the method described in Ref. 12, but with some differences, which are discussed further below. Firstly, as in Ref. 12, since angular terms in the rigid body kinematic equations of motion used for compatibility checking are independent of the linear terms, the angular rate instrument offsets (b_p, b_q, and b_r) were determined. Secondly, the measured aircraft velocities in body axes (u_m, v_m, and w_m) were replaced with a constant value of zero (as these would be the actual body velocities in a perfect hover) and the offset errors in the accelerometers (b_{ax}, b_{ay}, and b_{az}) were determined. Finally, the measured doppler velocities were used for the aircraft velocities in body axes, and the doppler velocity offsets (b_u, b_v, and b_w) were determined. Table 6 presents the offset errors estimated by *Compat* and the associated Cramer-Rao (C-R) bounds for the angular rate gyros, the accelerometers, and the doppler velocities. As a general rule, if the C-R bound is less than one tenth of the estimated parameter, then a high level of confidence can be attached to the estimate. As can be seen in Table 6, a high degree of confidence is associated with the estimates for the accelerometer offsets, and a good degree of confidence associated with the angular rates and longitudinal and vertical doppler velocities. However, the lateral doppler velocity offset is not estimated with a high level of confidence. This is assumed to be because the offset error is small, i.e. the original calibration for the lateral doppler is reasonably accurate, and possibly within the accuracy of the device. Similarly, the C-R bound for b_q, Evolution AT801, is about one fifth of the estimate, although for AT803 it is about one fifteenth. This variation is attributed to the estimates of b_q being small.

Table 6. Instrument Offset Errors

Parameter		AT801	AT803	Mean
b_p (rad/s)	Estimate	-0.001081	-0.000722	-0.0009
	C-R Bound	0.000167	0.000191	
b_q (rad/s)	Estimate	0.000515	0.001002	0.0008
	C-R Bound	0.000101	0.000067	
b_r (rad/s)	Estimate	0.005890	0.005402	0.0056
	C-R Bound	0.000117	0.000075	
b_{a_x} (ft/s^2)	Estimate	-0.534655	-0.657509	-0.60
	C-R Bound	0.002614	0.002227	
b_{a_y} (ft/s^2)	Estimate	0.557048	0.495849	0.53
	C-R Bound	0.003201	0.007004	
b_{a_z} (ft/s^2)	Estimate	0.309407	0.239789	0.27
	C-R Bound	0.013513	0.007136	
b_u (ft/s)	Estimate	-3.339330	-3.034545	-3.19
	C-R Bound	0.082872	0.160176	
b_v (ft/s)	Estimate	0.014445	0.585442	0.30
	C-R Bound	0.108046	0.157710	
b_w (ft/s)	Estimate	-3.064116	-2.853874	-2.96
	C-R Bound	0.059965	0.110058	

As mentioned previously, the mean offset values in Table 6 were used to adjust the original offset factors in the `FOCFT_L.SET` files to obtain the final calibration file SHAWKCAL shown in Appendix E. Figure 5 shows a comparison of the calculated body velocities for AT803 obtained using optimised offset values for that evolution (from *Compat*) and using the mean offset values. Similar results were obtained using AT801. The variation using the optimised and mean values suggests that the mean values are a reasonable compromise to use for all the data.

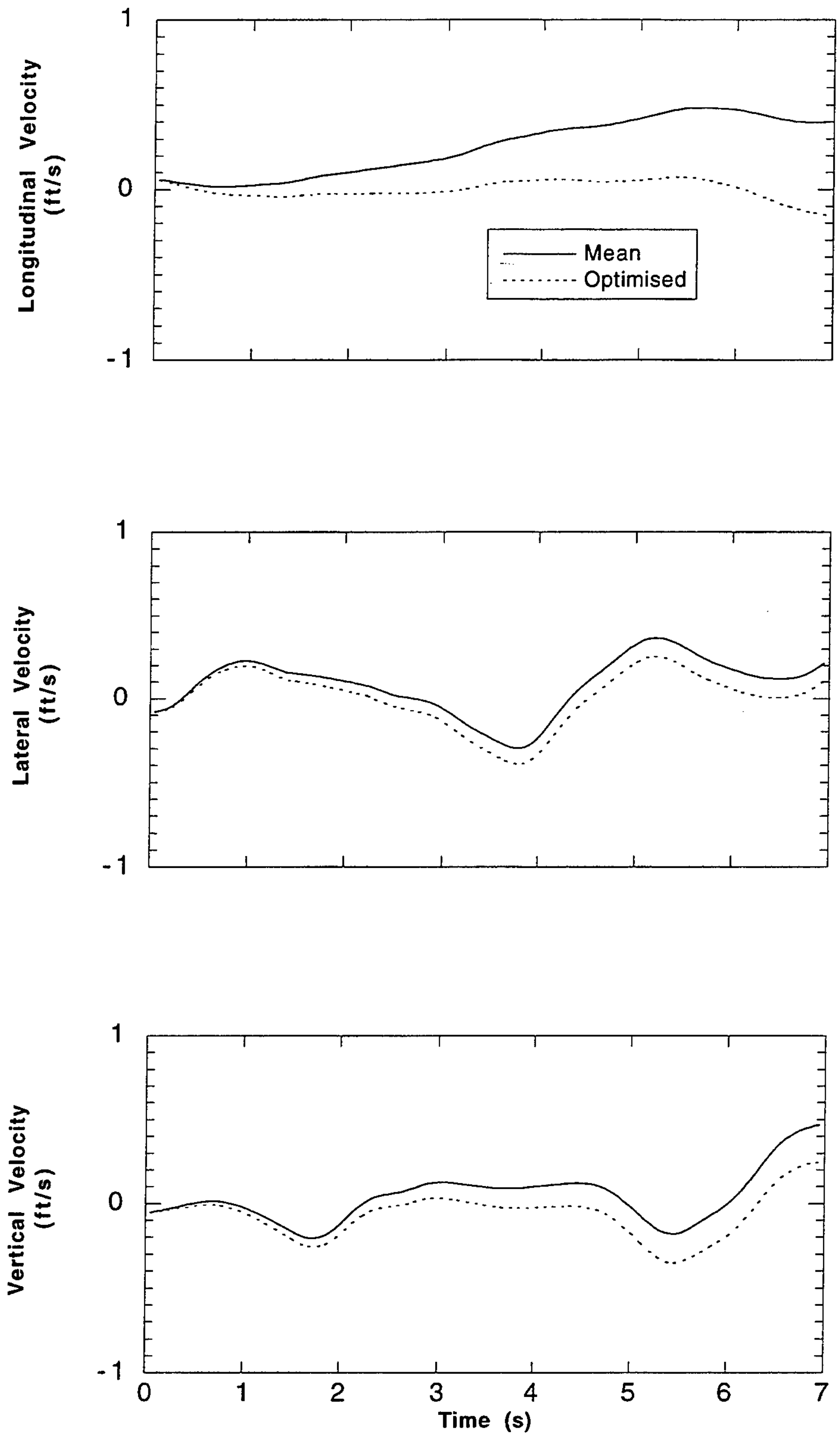


Figure 5. Comparison of Calculated Velocities Using Mean Offsets and Optimised Offsets for AT803

4.5 Processing Data

Program *S70B2Refine* was used to process the raw data which had been converted to ASCII format ('.con' files). A number of responses required in running *S70B2Refine* had changed, compared to those in the example in Section 4.1, due to digital filtering and analogue filter delay adjustments (Sections 4.2 and 4.3). The calibration file used by *S70B2Refine* for processing the data was named SHAWKCAL (Appendix E). This calibration file includes digital filtering characteristics and corrected instrument calibration and offset factors (Sections 4.2 and 4.4). An example of how *S70B2Refine* was run for all of the performance data is shown below.

```
*****************************************************
* Program to process data obtained from S-70B-2     *
* Performance, Dynamic and First of Class Flight    *
* Trials held March-April 1994 using PC-based Data  *
* Acquisition System.                               *
* Data files must have ".con"  extensions           *
*****************************************************

Input Data Filename (w/o ".con" extension) = AT800
Is this an aircraft data file (default N): Y
".DAT" OUTPUT FILENAME (w/o ext) = S98AT800
TITLE (2 lines of 60 chrs)
: S98 AT800 Hover 3ft AGL IGE
: Hp=210ft Ta=17degC; Stable hover,little movement
ARE ASSIGNED BLK NUMBERS REQRD : N
CALIBRATION FILENAME = SHAWKCAL
Day Number (Default is other than Day 1) = <CR>
IS PRE-PROCESSING WITH A NOTCH FILTER REQRD : N
OUTPUT INTERVAL (in 20'ths of sec; e.g. 40 for 2 sec) = <CR>
IS THE EXACT START TIME REQUIRED : N
STARTING TIME DELAY = <CR>
TIME LIMIT = <CR>
IS FILTERING REQRD : Y
IS OUTPUT OF FILTER CHARACTERISTICS REQRD :  N
ARE DIGITAL FILTER DELAY ADJUSTMENTS REQRD   :  Y
IS SMOOTHING REQRD : N
ARE INSTRUMENT & ANALOGUE FILTER DELAY ADJUSTMENTS REQRD : Y
ARE SCALES AND OFFSETS REQRD : Y
ARE PLOT LIMITS REQRD : N
ARE DROP-OUTS TO BE CORRECTED : N
ARE ALL CHANNELS REQRD : Y
DATE = 05-SEP-94
TIME = 13:37:13

No. time corrections =    0
No. blocks replaced =   0
No. drop-out corrections =    0

STOP 1
```

The program *S70B2Refine* produces a '.DAT' output file as described in Section 4.1. The '.DAT' file was the input file for program *MacTrans* which produced time history plots for all parameters (reproduced in the accompanying microfiche) and a '.COL' output file containing a listing of the data in imperial units.

The commands to produce the time history plots are shown below.

```
[TRANS version date 12-FEB-91]

GO STRAIGHT TO EVENT LOOP? N
I/P FILENAME = S98AT800
S98 AT800 Hover 3ft AGL IGE
Hp=210ft Ta=17degC; Stable hover,little movement

I/P FILE RECORDED ON 05-SEP-94   AT 13:37:13

INTEGN INT = 0.0000E+00; RUN CPU TIME =    2 MIN. 54.53 SEC.

TIME FROM 0.0000E+00 TO 2.3650E+01 IN STEPS OF 5.0000E-02

*PLS
IS GRAPHICS OUTPUT TO SCREEN REQUIRED :
[PLS/O Output, for this run, going to DSK:S98AT800.PLT      ]

STRIP PLOTS :

BLKS
A
TO SPECIFY NO. OF X UNITS/INCH, TYPE 0 FOR X

LENGTH OF AXES IN INCHES; X, Y = 0,1
MIN X, NO. OF X UNITS/INCH = 0,5
ARE SYMBOLS REQRD FOR PLOTS : N
LINE KEY (0 GIVES DEFAULT) = <CR>
THE CURRENT LINE COLOURS ARE:
0 & 1    2        3        4
BLACK    RED      GREEN    BLUE
5        6        7        8
CYAN     MAGENTA  YELLOW   ORANGE
AVAILABLE COLOURS :
BLACK, RED, GREEN, LTGREEN, BLUE, LTBLUE, CYAN,
MAGENTA, PURPLE, YELLOW, ORANGE.
DO YOU WISH TO CHANGE THE COLOURS? : N
*GOE
*EXI

STOP
```

The plot files are automatically named by replacing the '.DAT' extension of the input file with a '.PLT.?' extension. The ? is a,b,c,d,e, or f, signifying the order in which the plots were produced. Each file contains a plot of up to eight variables. As an example, the file name containing time histories for the first eight variables, using as input the file S98AT800.DAT, would be S98AT800.PLT.a. The time history plots for AT800 are shown in Appendix F.

The output files containing numerical data in imperial units have a '.COL' extension. For example, using the input file S98AT800.DAT, the output file is named S98AT800.COL. An example of the commands for *Mactrans* to produce a '.COL' file is shown below. Part of file S98AT800.COL is shown in Appendix G.

The '.COL' file stores all 44 parameters in *MacTrans* column format. This file is used as an input file to program *S70B2Convert(ac)*, which converts the *MacTrans* column format to multi-column format that is more easily read in by other programs. The output file is renamed using the first eight characters from the name of the input file combined with the extension ' Out'. For example, when the input file is S98AT800.COL, the output file is named S98AT800 Out. When *S70B2Convert(ac)* was run, the user was prompted for an input file, which in this case was S98AT800.COL.

```
[TRANS version date 12-FEB-91]

GO STRAIGHT TO EVENT LOOP? N
I/P FILENAME = S98AT800
S98 AT800 Hover 3ft AGL IGE
Hp=210ft Ta=17degC; Stable hover,little movement

I/P FILE RECORDED ON 05-SEP-94   AT 13:37:13

INTEGN INT = 0.0000E+00; RUN CPU TIME =    2 MIN. 54.53 SEC.

TIME FROM 0.0000E+00 TO 2.3650E+01 IN STEPS OF 5.0000E-02

*PRC
PRINTING IN COLUMNS :

BLKS
A
IS O/P TO TTY REQRD :
*GOE
** RUNNING **
*EXI

STOP
```

All data were stored on a DDS tape and a compact disk. A complete explanation of the data storage procedures is given in Appendix H.

5. RESULTS

For Sortie 98, the airfield tower indicated an initial wind velocity of 2 kn from 300°. The hover and low airspeed evolutions were conducted at low altitude in the vicinity of the airfield at the beginning of the sortie. The level flight, climbs, descents, and autorotations were all conducted at higher altitude away from the airfield. For these evolutions, the aircraft systems were used to determine the ambient wind velocity, which was then noted in the Evolution Log (Appendix C). Upon return to the airfield for the lower weight ground effect evolutions, a circuit was performed at low altitude to again allow use of the aircraft systems to determine the ambient wind speed. For the evolutions at sea, the wind velocity relative to the ship was indicated by the ship anemometer, and is indicated in Appendix C.

The time histories of all the performance data were examined and the time period for each evolution during which the aircraft was nominally trimmed was determined. Mean values for all channels for each evolution were calculated for this time period and are presented in Appendix I.

The DARTH system analogue channels have a maximum resolution of ± 2048 counts. The maximum value that could be recorded for a particular channel could be found by applying the calibration and offset factors in the FOCFT_L.SET file. For the Rad Alt, this 'calibration' limit was about 200 ft, even though the Rad Alt instrument itself was effective at greater altitudes. Similarly, the calibration limit for the longitudinal and lateral doppler velocity was about 124 kn, and the calibration limit for the vertical doppler was about 41 kn (~4150 ft/min). These calibration limits were caused by instrumentation deficiencies, which could not be rectified in the time available. For the FOCFT evolutions (Ref. 3), none of these limits were exceeded, although for Sorties 98 and 99, the majority of the evolutions were conducted at altitudes higher than 200 ft. Also, during some of the high speed evolutions, the ground speed exceeded 124 kn and the rate of descent exceeded 4150 ft/min. Table 7 details the evolutions during which the doppler velocity calibration limits were exceeded.

Table 7. Evolutions That Exceeded Doppler 'Calibration' Limits

Evolution	Planned Event	Doppler Exceeded
AT824	140 kn Level Flight	Longitudinal
AT826	Descent 3300 fpm	Longitudinal
AT827	Repeat of AT826	Vertical
AT832	Climb 120 kn	Longitudinal
AT833	Descent 120 kn	Longitudinal
AT834	0 kn Autorotation	Vertical
AT835	80 kn Autorotation	Vertical
AT836	100 kn Autorotation	Vertical

Another problem with the doppler velocity channels was found to occur on Evolutions AT826, AT827, and AT834. The common factor with these evolutions is that they were all done at high altitude and all achieved high rates of descent. Examining the time histories of the performance data shows that for Evolutions AT826 and AT827, the lateral doppler measurements were uncharacteristically constant at values well below the calibration limit (~15.3 ft/s for AT826 and ~-7.6 ft/s for AT827). In addition, for AT826, the vertical doppler was reading an out-of-range value of incorrect sign (about -71.6 ft/s). The autorotation of AT834 may offer some clues for this behaviour as the data recording was continued during the recovery. The time histories show that during the descent, the longitudinal and lateral dopplers were reading constant values below the calibration limit (about 20.3 ft/s and 12.1 ft/s respectively) and the vertical doppler calibration limit had been exceeded. During the initial recovery, indicated by the rapid lowering of the aircraft pitch attitude to increase airspeed, the three doppler velocities began to read non-constant values, but as the aircraft airspeed increased, the pitch attitude was increased to arrest the descent and the dopplers again started to record constant values (about 78.4 ft/s, 8.7 ft/s, and 42.1 ft/s for the longitudinal, lateral, and vertical dopplers respectively). This suggests that a combination of high altitude, high rate of descent, and high aircraft attitude may render the doppler measurements unreliable. Further investigation would be required to confirm this.

Examination of the hover data indicated that a possible error in the calibration factors for the stabilator angle measurements was present. In hover, the stabilator angle should read -40°, but the data indicated about -36.4°. This offset was not noticed until after the data processing had been completed, so the archived stabilator angle measurements, those data presented in Appendix F, and the accompanying microfiche should all be corrected, as detailed in Appendix J. However, it should be noted that the mean stabilator angle data presented in Appendix I have been corrected.

Except for the evolutions noted above, the time histories show that the data are of good quality and reliability. The low wind speed conditions at the beginning of the sortie were ideal for the hover and low airspeed evolutions in particular, since the aircraft systems are incapable of determining the true airspeed below about 30 kn airspeed, i.e. the dopplers were used to indicate groundspeed which was about the same as the airspeed. For the higher speed evolutions, the ambient wind is less critical and the airspeed is more accurately indicated by the aircraft instruments.

6. CONCLUDING REMARKS

Measurements have been gathered representing the performance characteristics of the Sikorsky S-70B-2 helicopter. These measurements have been examined and shown to be generally of good quality and reliability. A spectral analysis has been conducted to identify the frequency of noise present in the recorded data. Offset errors in some of the instrumentation calibrations have been resolved, and phase lags due to instrumentation filters have been determined. The data processing software has been modified to account for the effects outlined above, as well as specific changes required for the particular trial, and has been shown to be working correctly. All the data have been processed and archived in a form suitable for future use in developing a mathematical model of the S-70B-2 helicopter. The low speed data in particular are expected to be of good quality, as the atmospheric conditions of the day were ideal for this kind of testing.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to Rodd Perrin, a member of AOD at the time, for extracting the stabilator scheduling equations from program *GenHel*, and creating the Microsoft *Excel* spreadsheet which used these equations to determine the stabilator angles.

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APPENDIX A - ADMINISTRATION FILE 'AT800.ADM'

```
    S-70B-2 / FFG FOCFT FEB94

    Aircraft Admin File

  Sortie......................  98
  Evolution...................  T800
  Pilot Rating................  1
  Time........................  07:10:55

AIRCRAFT PARAMETERS:

  Basic Weight...............  15928
  Basic Moment...............  5654691
  Total Fuel.................  3670
      Internal...............  3670
      External (Port)........  0
      External (Stbd)........  0
  Total Ballast..............  420
      Ballast Blocks.........  10
  Total Weight...............  20018

  Target Weight (Corrected)..  18000
  Actual Weight (Corrected)..  19964
  Percent Error in W/Sigma ..  10.9

  Max forward CofG...........  346.8
  Max aft CofG...............  364
  Target CofG................  359
  Actual CofG................  362.0

ENVIRONMENTAL CONDITIONS:

  OAT........................  17
  Pressure Altitude..........  210
  Sigma......................  1.0027
  Wind Direction.............
  Wind Speed.................
  Sea State..................  0
  Day/Night..................  Day

EVOLUTION PARAMETERS:

  Ships Pitch................  0
  Ships Roll.................  0
  Target Q/Sigma.............  106
  Average Torque.............  0
  Average Torque (Corrected).  0
  Maximum Torque.............  0
  Maximum Torque (Corrected).  0

SORTIE PARAMETERS:

  Sortie Date................  06-04-94
  Sortie Start Time..........  07:10:08

OTHER INFORMATION:

  Last Landing...............  L192
  Last Takeoff...............  T198
  Last Startup...............  U64
  Last Shutdown..............
  Configuration file.........  FOCFT_L.SET

COMMENTS:
```

APPENDIX B - WEIGHT CORRECTIONS

Corrections to the weight and *cg* calculations for Sortie 98 and Evolution AL174 of Sortie 21 are given here. These corrections were required because of incorrect weight figures in the respective '.ADM' files.

Before each sortie, AMAFTU personnel determined a weight and balance chart for the helicopter. Table B1 is a reproduction of the chart for Sortie 98. Some of the terms used in the weight and balance charts and the '.ADM' files are not consistent. The main differences are listed in Table B2. This appendix will use the terms from the weight and balance chart.

Table B1. S-70B-2 Weight and Balance Chart for Sortie 98

SEAHAWK WEIGHT AND BALANCE CALCULATIONS

SORTIE NO: 98
CONFIG: 19000

DATUM WEIGHT	Max Aft CofG	Max Fwd CofG
19244	364.0	346.8

Maximum shipborne weight is 20800 lbf

Item	Wt	Arm	Inc	Tot. Wt	Moment
Basic Weight (Incl. Inst)	13501	361.8	1	13501	4884993
Aircrewman's Seat (RH Aft)	16	363.0	1	16	5808
Ballast Box (Fwd Cabin)	547	275.0	1	547	150425
Sonobuoy Launcher Ballast	290	267.8	1	290	77662
Fwd Port Ext. Stores Ballast	592	320.0	0	0	0
Port PDT	495	366.2	0	0	0
STBD PDT	495	397.7	0	0	0
Port Ext Fuel Tank	124	365.9	0	0	0
STBD Ext Fuel Tank	124	397.4	0	0	0
CREW					
Pilot & Copilot	200	227.1	2	400	90840
VADAR Operator	200	363.2	1	200	72640
Aircrewman	200	363.2	1	200	72640
Fuel Empty Zero Variable Ballast Weight & Moment			**15154**	**5355008**	
VARIABLE BALLAST					
Ballast Weights	42	275.0	10	420	115500
Fuel Empty Gross Weight & Moment				15574	5470508
FUEL					
Fuel (Int)	3670	402.5	1	3670	1477175
Fuel (Ext Port)	0	365.9	0	0	0
Fuel (Ext STBD)	0	397.4	0	0	0
Total Fuel				3670	1477175
DATUM ALL UP WEIGHT AND MOMENT			19244	6947683	
DATUM CG POSITION	**361.0**				

Table B2. Equivalent Terms in '.ADM' Files and Weight and Balance Charts

'.ADM' File	Weight and Balance Chart
Basic Weight	Fuel Empty Zero Variable Ballast Weight
Basic Moment	Fuel Empty Zero Variable Ballast Moment
Total Weight	All Up Weight

B1. Corrections For Sortie 98

Prior to Sortie 98, two torpedos (PDT in Table B1) were carried, but no aircrewman. For Sortie 98, the torpedos were removed and an aircrewman added, but the 'Fuel Empty Zero Variable Ballast Weight' entered in the '.ADM' file remained unchanged. Thus the calculated values for the weight and *cg* in the '.ADM' files for Sortie 98 are incorrect. Below is a calculation showing that the incorrect 'Fuel Empty Zero Variable Ballast Weight' entered in the '.ADM' file and the correct 'Fuel Empty Zero Variable Ballast Weight' from Table B1 are consistent with the items added and removed.

Incorrect Fuel Empty Zero Variable Ballast Weight	= 15928† lbf
Torpedo Weight (2 off)	= 990‡ lbf
Aircrewman Weight	= 200‡ lbf
Aircrewman's Seat	= 16‡ lbf
Corrected Fuel Empty Zero Variable Ballast Weight	= 15928 - 990 + 200 + 16
	= 15154 lbf

The 'All Up Weight' and *cg* were recalculated for all evolutions in Sortie 98 and are given in Appendix C. An example of the calculation is shown below for Evolution AT800.

Item	Weight (lbf)	Arm (in)	Moment (lbf.in)
Fuel Empty Gross Weight & Moment	15574‡		5470508‡
Fuel	3670†	402.5‡	1477175
All Up Weight & Moment	**19244**		**6947683**

CG Position = 6947683/19244 = **361.0**

B2. Corrections For Evolution AL174 Sortie 21

For Evolution AL174 in Sortie 21, the fuel weight recorded in the '.ADM' file was the same as for Evolution AL173 and was assumed to have been incorrectly input by the DARTH operator. A correction was made by estimating fuel flow between Evolutions AL171 and

† Value from '.ADM' file (Appendix A).

‡ Value from weight and balance chart (Table B1).

AL173,[1] taking the time elapsed between Evolutions AL173 and AL174, then calculating the amount of fuel used. For the calculations below, the fuel used and time elapsed between Evolutions AL171 and AL174 were obtained from the respective '.ADM' files.

STEP 1. Calculate Fuel Flow Rate.

Time between Evolutions AL171 and AL173	= 1758 s
Fuel used between Evolutions AL171 and AL173	= 350 lb
Fuel Flow Rate = 350/1758	= **0.20** lb/s

STEP 2. Calculate Fuel Used.

Time between Evolutions AL173 and AL174	= 393 s
Fuel used between Evolutions AL173 and AL174 = 393 x 0.2	= **79** lb

As fuel quantities were always rounded to the nearest 10 lb, the fuel usage was set to 80 lb.

STEP 3. Calculate Weights and Moments for Evolution AL174.

Item	**Weight (lbf)**	**Arm (in)**	**Moment (lbf.in)**
Fuel - AL173	2770		
Fuel Used AL173 - AL174	- 80		
Fuel - AL174	2690	402.5	1082725
From weight and balance chart for Sortie 21,			
Fuel Empty Gross Weight & Moment	+ 16726		+ 5874141
All Up Weight & Moment - AL174	**19416**		**6956866**

CG Position = 6956866/19416 = **358.3**

---

1 Evolution AL172 was skipped in calculating the average fuel flow rate in order that an average over a longer period of time could be found.

APPENDIX C - PERFORMANCE EVOLUTION LOG

This appendix contains atmospheric data, corrected weight and *cg* position, and comments made for all performance evolutions. The pressure altitude (H_p) was read from the aircraft altimeter and the ambient temperature (T_a) was read from the aircraft Outside Air Temperature (OAT) gauge.

Table C1. Hover

File #	Time	Height AGL (ft)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT800	7:10:55	3 IGE	210	17	1.0027	19244	361.0	Stable Hover - little movement.
AT801	7:12:47	10 IGE	210	17	1.0027	19194	360.9	Stable Hover - little movement.
AT802	7:14:07	15 IGE	210	17	1.0027	19174	360.9	Some rocking and rolling.
AT803	7:15:13	20 IGE	210	17	1.0027	19154	360.8	Some rocking and rolling.
AT804	7:16:10	30 IGE	210	16	1.0062	19134	360.8	Stable Hover - little movement.
AT805	7:17:26	40 IGE	210	16	1.0062	19104	360.7	Stable Hover - little movement.
AT806	7:18:23	50 IGE	210	16	1.0062	19094	360.7	Stable Hover - little movement.
AT807	7:19:43	100 OGE	210	16	1.0062	19064	360.6	Stable Hover - little movement.

Table C2. Low Airspeed

File #	Time	Airspeed (KIAS)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT808	7:23:06	15 Fwd	380	18	0.9931	18994	360.5	High nose up.
AT809	7:25:08	30 Fwd	380	18	0.9931	18964	360.4	High nose up; vibration apparent.
AT810	7:27:12	15 Aft	380	18	0.9931	18924	360.3	High nose up; vibration apparent (more than 30 kn fwd).
AT811	7:29:00	30 Aft	380	18	0.9931	18864	360.2	High nose up; vibration apparent (less than 15 kn aft).
AT812	7:31:00	15 Port	380	18	0.9931	18854	360.2	Relatively less vibration;some rock & roll (lots of right pedal).
AT813	7:32:50	30 Port	380	18	0.9931	18814	360.1	Much smoother than others.
AT814	7:34:48	15 Stbd	380	18	0.9931	18764	360.0	Smooth (much smoother than left).
AT815	7:36:39	30 Stbd	380	18	0.9931	18744	359.9	Vibration as in transition.

Table C3. Vertical Climb/Descent

File #	Time	RoC/D (fpm)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT818	7:47:17	600	1000	20	0.9644	18584	359.6	(approx 90% Q) Climb begins very low at 40 ft, Heading 330 & going backwards to zero wind. Recordings begin at approx 150 ft - finished at 1000ft - wind 9 kn at 330.
AT819	7:50:01	1200	1000	20	0.9644	18544	359.5	(approx 98% Q) Very stable climb.
AT820	7:52:37	1800	1000	20	0.9644	18514	359.4	(approx 106% Q) Stable climb.
AT825	8:06:08	600	1500	20	0.9467	18304	358.9	Descents away from airfield (beginning at 4000 ft); at 1500, Wind 320 at 6 kn. Recording beginning at 1700 ft; comfortable descent.
AT826	8:14:48	3300	2500	19	0.9160	18164	358.6	Atmospherics at 2500, Wind 17 kn (backwards to nill wind). Setting up at 5000 ft (at 4000 things happen too quickly) - start with an autorotation then bring back to zero airspeed, then pull in power (avoids vortex ring) - airspeed too high (try again AT827).
AT827	8:19:15	3300	2500	19	0.9160	18104	358.4	V. bumpy & beginning to get vortex ring; otherwise good datum.

Table C4. Level Flight

File #	Time	Airspeed (KIAS)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT821	7:56:11	40	1500	20	0.9470	18444	359.2	Stable, not much vibration (<30 kn).
AT822	7:57:50	80	1500	20	0.9470	18424	359.2	Wind indicating 6kn from 320. Stable -some rock & roll - little vibration (<40 kn).
AT823	7:59:36	120	1500	20	0.9470	18404	359.1	Bumpy - more rock & roll (smoother towards end of run).
AT824	8:01:36	140	1500	21	0.9437	18364	359.0	Bumpy in parts (smoother at start of run). Vh limited due to chicken sticks in place of radome.

Table C5. Forward Climb / Descent

File #	Time	Airspeed (KIAS)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT828	8:22:54	40	1500	20	0.9470	18064	358.3	Climb; stable, smooth.
AT829	8:24:21	40	1500	20	0.9470	18044	358.3	Descent; vibration upon entry (before recording), otherwise smooth.
AT830	8:26:32	80	1500	20	0.9470	18014	358.2	Climb; Recordings attempted at datum height (1500 ft) climb very smooth.
AT831	8:28:32	80	1500	20	0.9470	17984	358.1	Descent; very smooth.
AT832	8:30:49	120	1500	20	0.9470	17954	358.1	Climb; smooth - a little bumpy towards end.
AT833	8:33:09	120	1500	20	0.9470	17914	358.0	Descent smooth.

Table C6. Autorotation - All at H_p 1500 ft

File #	Time	Airspeed (KIAS)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT834	8:36:41	0	3800	20	0.9470	17854	357.8	Nr101 good - recording began 2000 ft; pitch, pull (Nr went to 94) and flare (fairly violent). Vert auto uncomfortable - need 1000 ft to recover airspeed. 3800 ft/min descent.
AT835	8:39:53	80	2500	20	0.9470	17814	357.7	Nr 102 - 101, reduced to 93 in pull out. Airspeed to 20 kn, 2500 ft/min descent.
AT836	8:43:39	100	2900	20	0.9470	17754	357.6	Nr 101, reduced to 98 in pull out, 2900 ft/min descent.

Table C7. Ground Effect Study - Over Land

File #	Time	Height AGL (ft)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AT816	7:39:09	10	210	17	1.0027	18714	359.9	Smooth hover.
AT817	7:40:16	15	210	17	1.0027	18684	359.8	Some rock and roll.
AT837	9:33:11	10	220	22	0.9854	16154	353.1	4 kn backwards to compensate for wind.
AT838	9:34:51	15	220	22	0.9854	16094	352.9	4 kn backwards to compensate for wind.
AT839	9:36:39	100	400	22	0.9790	16084	352.9	4 kn backwards to compensate for wind.

Table C8. Ground Effect Study - At Sea

File #	Time	Height AFD (ft)	H_p (ft)	T_a (°C)	σ	Weight (lbf)	*cg* (in)	Comments
AL100	12:35:13	5	-180	14	1.0276	19762	359.6	Sortie 12, relative wind 6 kn from 160°.
AL151	17:39:50	15	-400	16	1.0286	17654	360.3	Sortie 17, relative wind 1 kn from 155°.
AL152	17:46:13	15	-400	16	1.0286	17564	360.1	Sortie 17, relative wind 1 kn from 150°.
AL158	19:19:00	10-15	-420	16	1.0293	17498	360.4	Sortie 18,light spray, relative wind 1 kn from ahead.
AL159	19:25:43	10-15	-420	16	1.0293	17418	360.2	Sortie 18,light spray, relative wind 2 kn from 350°.
AL173	22:14:45	10	-400	20	1.0145	19496	358.5	Sortie 21, 9 ft hover, 10 s, relative wind 1 kn from 255°.
AL174	22:21:18	10	-400	20	1.0145	19416	358.3	Sortie 21, 10 ft hover, 20 s, relative wind 0.5 kn from 250°.

APPENDIX D - DARTH SET-UP FILE 'FOCFT_L.SET' FOR SORTIE 2

The DARTH set-up files are of the form of a single column. For the purpose of this report, the file has been split into two columns.

```
2.0
-5V to +5V
Twos complement
 7/03/94
 5:37:57.72
A01
Pitch Rate
20
 2.14999999999918E-0001
-1.95310000000006E-0002
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A02
Roll Rate
20
-1.00000000000023E-0001
 1.95310000000006E-0002
 0.00000000000000E+0000
1
-7.89999999999509E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A03
Yaw Rate
20
-4.00000000000091E-0001
 1.95310000000006E-0002
 0.00000000000000E+0000
1
-4.00000000000205E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A04
Lateral Acceleration
20
-5.00000000000000E-0001
 2.09299999999928E-0002
 0.00000000000000E+0000
1
 4.00000000000205E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A05
Longitudinal Acceleration
20
 1.39999999999964E+0000
 2.09299999999928E-0002
 0.00000000000000E+0000
1
-7.89999999999509E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A06
Vertical Acceleration
20
-3.21500000000233E+0001
-2.09299999999928E-0002
 0.00000000000000E+0000
1
-3.76199999999881E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A07
Doppler - Longitudinal Velocity
20
-2.79999999999927E+0000
 6.10350000000039E-0002
 0.00000000000000E+0000
1
-4.00000000000205E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A08
Doppler - Lateral Velocity
20
-1.20000000000073E+0000
 6.10351000000264E-0002
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A09
Doppler - Vertical Velocity
20
-2.50000000000000E+0000
 2.03449999999918E-0002
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A10
AFCS Output - Pitch
20
 4.70000000000000E+0001
 1.08899999999949E-0001
 0.00000000000000E+0000
2
-1.54399999999987E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A11
AFCS Output - Roll
20
 5.05000000000000E+0001
 1.08899999999949E-0001
 0.00000000000000E+0000
2
-1.66300000000047E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A12
AFCS Output - Collective
20
 7.50000000000000E+0001
 1.08899999999949E-0001
 0.00000000000000E+0000
2
-1.42599999999948E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
```

```
A13
AFCS Output - Yaw
20
 5.80000000000000E+0001
 1.08899999999949E-0001
 0.00000000000000E+0000
2
-1.34599999999955E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A14
Primary Jack - Fwd
20
 4.93064000000013E+0001
-3.00200000000075E-0002
 2.09900000000020E-0007
2
-2.37600000000020E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A15
Primary Jack - Aft
20
 5.25100000000093E+0001
 2.64229999999941E-0002
-3.46599999999798E-0007
2
-2.45500000000175E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A16
Primary Jack - Lateral
20
 4.97689999999711E+0001
-2.96789999999874E-0002
-1.02590000000007E-0007
2
-3.00999999999840E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A17
Cyclic Longitudinal - Pre-Mix
20
 5.08400000000256E+0001
 3.22118000000273E-0002
-1.91920000000090E-0007
2
-2.45500000000175E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A18
Cyclic Lateral  - Pre-Mix
20
 5.02000000000116E+0001
 2.92975000000126E-0002
 3.53550000000216E-0007
2
-2.49499999999898E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A19
Collective - Pre-Mix
20
 5.03379999999888E+0001
 3.19979999999873E-0002
 1.05870000000063E-0006
2
-2.25700000000143E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A20
Pedals - Pre-Mix
20
 4.69000000000233E+0001
 4.98039999999946E-0002
-2.49999999999903E-0006
2
-2.33599999999933E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A21
No 1 Engine Torque
20
 0.00000000000000E+0000
 6.69000000000324E-0002
 0.00000000000000E+0000
1
-4.00000000000205E-0002
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A22
No 2 Engine Torque
20
 0.00000000000000E+0000
 6.69000000000324E-0002
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A23
Weight on Wheels
20
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
1
-5.06900000000314E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A24
Radar Altitude
20
-5.17600000000093E+0001
 1.21700000000033E-0001
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A25
Air Speed
20
 6.50999999999767E+0001
 3.08259999999905E-0002
 0.00000000000000E+0000
1
-4.98999999999796E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A26
Yaw - Post-Mix
20
 5.04130000000005E+0001
 2.88879999999949E-0002
-9.73600000000671E-0007
2
-2.37600000000020E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
```

```
A27
Post Mix - Pitch Aft
20
 3.08120000000054E+0000
 9.75000000000392E-0004
 0.00000000000000E+0000
2
-2.25700000000143E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A28
Post Mix - Pitch Fwd
20
 6.22080000000278E+0000
 7.24650000000437E-0004
 0.00000000000000E+0000
2
-1.18800000000010E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A29
Post Mix - Roll Aft
20
 6.10050000000047E+0000
 9.80070000000666E-0004
 0.00000000000000E+0000
2
-2.49499999999898E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A30
Post Mix - Roll Fwd
20
 5.44819999999891E+0000
 9.75500000000018E-0004
 0.00000000000000E+0000
2
-2.25700000000143E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A31
Pitch Bias Actuator
20
 3.25700000000070E+0001
 4.09670000000233E-0002
 0.00000000000000E+0000
1
-4.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
A32
Event Marker
20
-1.00000000000023E-0001
 2.50000000000128E-0003
 0.00000000000000E+0000
1
 0.00000000000000E+0000
12.5 Hz, 8 Pole, Elliptic (LTC-1064-1)
DI1
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI2
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI3
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI4
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI5
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI6
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI7
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DI8
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO1
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO2
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO3
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO4
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO5
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
```

```
DO6
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO7
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DO8
Ch Not Used
0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
DA1
Pitch - Post-Mix (%)
20
 0.00000000000000E+0000
 4.88520000000108E-0002
 0.00000000000000E+0000
DA2
Roll - Post-Mix (%)
20
 0.00000000000000E+0000
 4.88520000000108E-0002
 0.00000000000000E+0000
SY1

0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
Unsigned
SY2

0
 0.00000000000000E+0000
 1.00000000000000E+0000
 0.00000000000000E+0000
Unsigned
SY3
Heading (AHRS)
20
 0.00000000000000E+0000
 5.49319999999653E-0003
 0.00000000000000E+0000
Unsigned
SY4
Stabilator Angle
20
 0.00000000000000E+0000
 5.49319999999653E-0003
 0.00000000000000E+0000
Signed
SY5
Pitch (Gyro)
20
 0.00000000000000E+0000
-5.49319999999653E-0003
 0.00000000000000E+0000
Signed
SY6
Roll (Gyro)
20
 0.00000000000000E+0000
 5.49319999999653E-0003
 0.00000000000000E+0000
Signed
```

APPENDIX E - CALIBRATION FILE SHAWKCAL

TITLE (2 lines of 60 chrs)
Aircraft calibration file for S70B2 Performance Trial
August 1994 (Trials March 1994)
[Channel no. -1 denotes time]

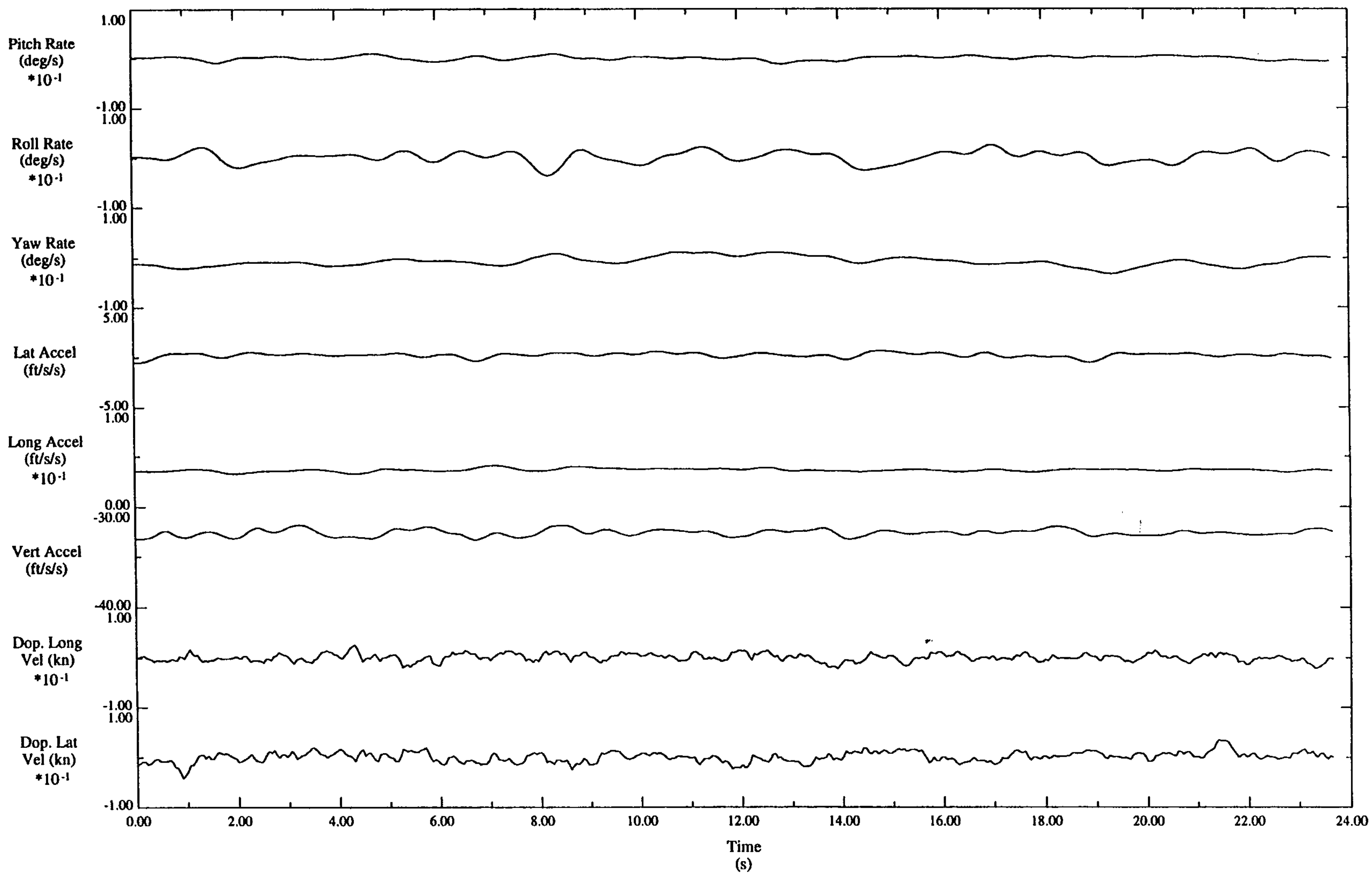
Channel No.	Label	Cal Factor, Offset	Filter Characteristics Assigned No.	Plot Limits (Lower,Upper)	Smoothing Characteristics (Freq, Atten) (No. Poles)	Notch Filter Characteristics (No. Pts Smoothed) (No. Params)	(Alpha, dF) (Min Freq., Max Freq., Exp Freq.)
-1	Time	5.0000E-02					
	(s)	0.0000E+00					0.0000E+00 0.0000E+00
1	Pitch Rate	-1.9531E-02	0	-5.0000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(deg/s)	1.6916E-01		2.5000E+02	5		0.0000E+00 0.0000E+00
2	Roll Rate	1.9531E-02	0	-1.0000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(deg/s)	-4.8430E-02		1.0000E+01	5		0.0000E+00 0.0000E+00
3	Yaw Rate	1.9531E-02	0	-1.0000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(deg/s)	-7.2086E-01		1.0000E+01	5		0.0000E+00 0.0000E+00
4	Lat Accel	2.0929E-02	0	-1.0000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(ft/s/s)	-1.0300E+00		1.0000E+01	5		0.0000E+00 0.0000E+00
5	Long Accel	2.0929E-02	0	2.5000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(ft/s/s)	1.9999E+00		4.5000E+01	5		0.0000E+00 0.0000E+00
6	Vert Accel	-2.0929E-02	0	-1.0000E+01	4.0000E+00 5.0000E+01		0.0000E+00 0.0000E+00 0.0000E+00
	(ft/s/s)	-3.2420E+01		1.0000E+01	5		
7	Dop. Long	6.1035E-02	0	-1.0000E+01			
	Vel (kn)	-9.0983E-01		1.0000E+01			
8	Dop. Lat	6.1035E-02	0	-1.0000E+02			
9	Vel (kn)	-1.3778E+00		1.0000E+02			
	Dop. Vert	2.0345E-02	0	-1.0000E+02			
	Vel (kn)	-7.4620E-01		1.0000E+02			
10	AFCS Pitch	1.0889E-01	0	-1.0000E+02			
	(%)	1.1200E+02		1.0000E+02			
11	AFCS Roll	1.0889E-01	0	0.0000E+00			
	(%)	8.8500E+01		1.0000E+02			
12	AFCS Coll	1.0890E-01	40	-5.0000E+00			
	(%)	9.2500E+01		5.0000E+00			
13	AFCS Yaw	1.0890E-01	19	-5.0000E+00			
	(%)	1.4600E+02		5.0000E+00			
14	Prim Jack	-3.0020E-02	20	-5.0000E+00			
	Fwd (%)	4.9306E+01		5.0000E+00			
15	Prim Jack	2.6422E-02	21	-5.0000E+00			
	Aft (%)	5.2510E+01		5.0000E+00			
16	Prim Jack	-2.9679E-02	2	0.0000E+00			
	Lat (%)	4.9769E+01		2.0000E+02			
17	Cyc Long	3.2212E-02	0	0.0000E+00			
	PreMix (%)	5.0840E+01		2.0000E+02			
18	Cyc Lat	2.9296E-02	0	0.0000E+00			
	PreMix (%)	5.0200E+01		1.5000E+02			

19	Collective PreMix (%)	3.1998E-02 5.0338E+01	0	0.0000E+00 1.5000E+02
20	Pedals (%) Pre-Mix	4.9804E-02 4.6900E+01	1	-4.0000E+01 4.0000E+01
21	Engine 1 Torque (%)	6.6900E-02 0.0000E+00	2	-5.0000E+00 5.0000E+00
22	Engine 2 Torque (%)	6.6900E-02 0.0000E+00	3	2.0000E+01 5.0000E+01
23	Wt-Wheels)	1.0000E+00 0.0000E+00	4	-2.0000E+01 2.0000E+01
24	Rad Alt (ft)	1.2170E-01 -5.1760E+01	5	-2.0000E+01 2.0000E+01
25	Air Speed (kn)	3.0826E-02 6.5099E+01	6	-2.0000E+01 2.0000E+01
26	Yaw PostM (%)	2.8888E-02 5.0413E+01	7	0.0000E+00 5.0000E+01
27	Pitch Aft PostM(in)	9.7500E-04 3.0812E+00	8	-1.0000E+03 1.0000E+03
28	Pitch Fwd PostM (in)	7.2465E-04 6.2208E+00	9	-5.0000E+00 5.0000E+00
29	Roll Aft PostM (in)	9.8007E-04 6.1005E+00	30	0.0000E+00 1.0000E+02
30	Roll Fwd PostM (in)	9.7550E-04 5.4482E+00	31	0.0000E+00 1.0000E+02
31	Pitch Bias Acuatr (%)	4.0967E-02 3.2570E+01	601	0.0000E+00 5.0000E+01
32	Event Marker	2.5000E-03 -1.0000E-01	602	5.0000E+02 7.0000E+02
33	Not Used	1.0000E+00 0.0000E+00	10	-5.0000E+00 5.0000E+00
34	Not Used	1.0000E+00 0.0000E+00	11	-5.0000E+00 5.0000E+00
35	Not Used	1.0000E+00 0.0000E+00	12	-5.0000E+00 5.0000E+00
36	Not Used	1.0000E+00 0.0000E+00	13	-5.0000E+00 5.0000E+00
37	Not Used	1.0000E+00 0.0000E+00	14	-5.0000E+00 5.0000E+00
38	Not Used	1.0000E+00 0.0000E+00	15	-5.0000E+00 5.0000E+00
39	Not Used	1.0000E+00 0.0000E+00	16	-5.0000E+00 5.0000E+00
40	Yaw Acc (deg/s/s)	1.0000E+00 0.0000E+00	17	-5.0000E+00 5.0000E+00
41	Roll Acc (deg/s/s)	1.0000E+00 0.0000E+00	603	-5.0000E+00 5.0000E+00
42	Pitch Acc (deg/s/s)	1.0000E+00 0.0000E+00	604	-5.0000E+00 5.0000E+00
43	Not Used	1.0000E+00 0.0000E+00	605	-5.0000E+00 5.0000E+00
44	Phi (deg)	1.0000E+00 0.0000E+00	606	-5.0000E+00 5.0000E+00
45	Psi (deg)	1.0000E+00 0.0000E+00	607	-5.0000E+00 5.0000E+00
46	Start Time	1.0000E+00 0.0000E+00	608	-5.0000E+00 5.0000E+00
47	Not Used	1.0000E+00 0.0000E+00	609	-5.0000E+00 5.0000E+00
48	Not Used	1.0000E+00 0.0000E+00	610	-5.0000E+00 5.0000E+00
49	Pitch PM (%)	4.8852E-02 0.0000E+00	611	-5.0000E+00 5.0000E+00
50	Roll PM (%)	4.8852E-02 0.0000E+00	612	-5.0000E+00 5.0000E+00
51	Not Used	1.0000E+00 0.0000E+00	0	-1.0000E+01 1.0000E+01
52	Not Used	1.0000E+00 0.0000E+00	0	-1.0000E+01 1.0000E+01
53	Heading AHRS (deg)	5.4932E-03 0.0000E+00	0	-1.0000E+01 1.0000E+01
54	Stab Angle (deg)	5.4932E-03 0.0000E+00	0	-1.0000E+01 1.0000E+01
55	Pitch Gyro (deg)	-5.4932E-03 0.0000E+00	0	-1.8000E+02 1.8000E+02
56	Roll Gyro (deg)	5.4932E-03 0.0000E+00	617	-5.0000E+00 5.0000E+00
57	Not Used	1.0000E+00 0.0000E+00	60	-5.0000E+00 5.0000E+00
58	Not Used	1.0000E+00 0.0000E+00	618	-5.0000E+00 5.0000E+00

EXCEPTIONS

Channel No.	Flight No.	Cal Factor	Offset

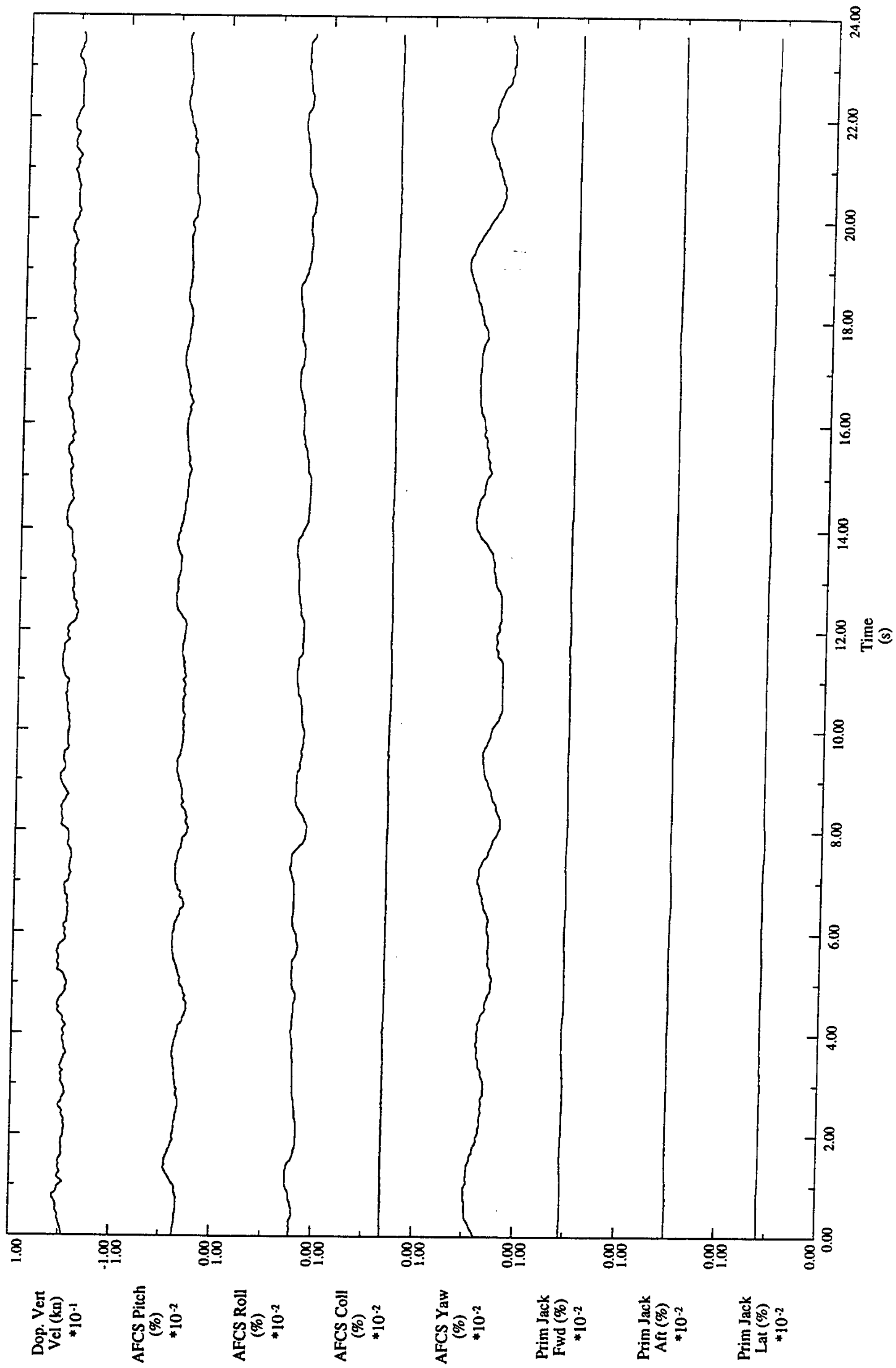
APPENDIX F - *MACTRANS* PLOT, EVOLUTION AT800



S98 AT800 Hover 3 ft AGL IGE; New Offsets

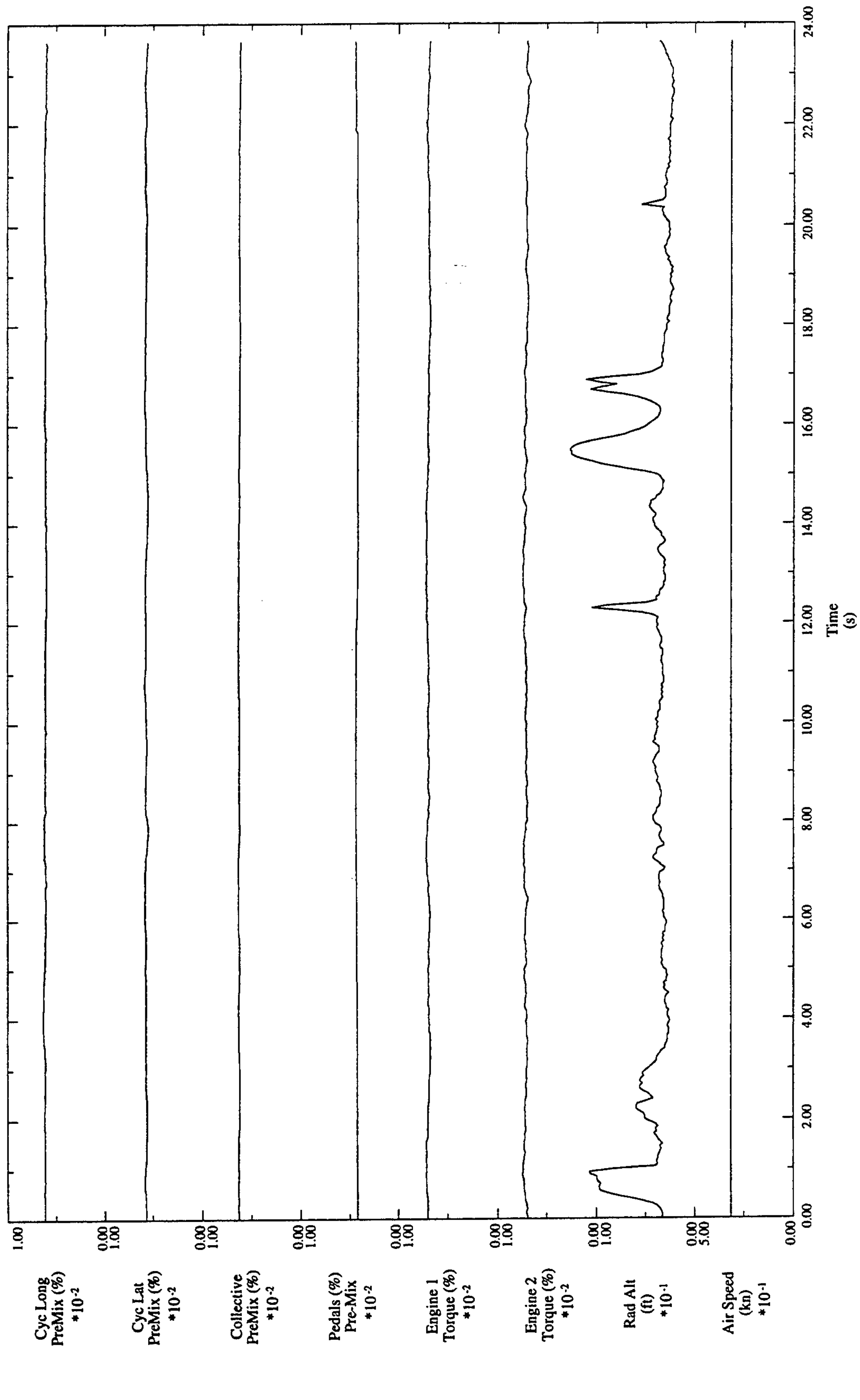
Hp=210 ft Ta=17degC; Stable hover, little movement

05-SEP-94 13:37:13



S98 AT800 Hover 3 ft AGL IGE; New Offsets
Hp=210 ft Ta=17degC; Stable hover, little movement

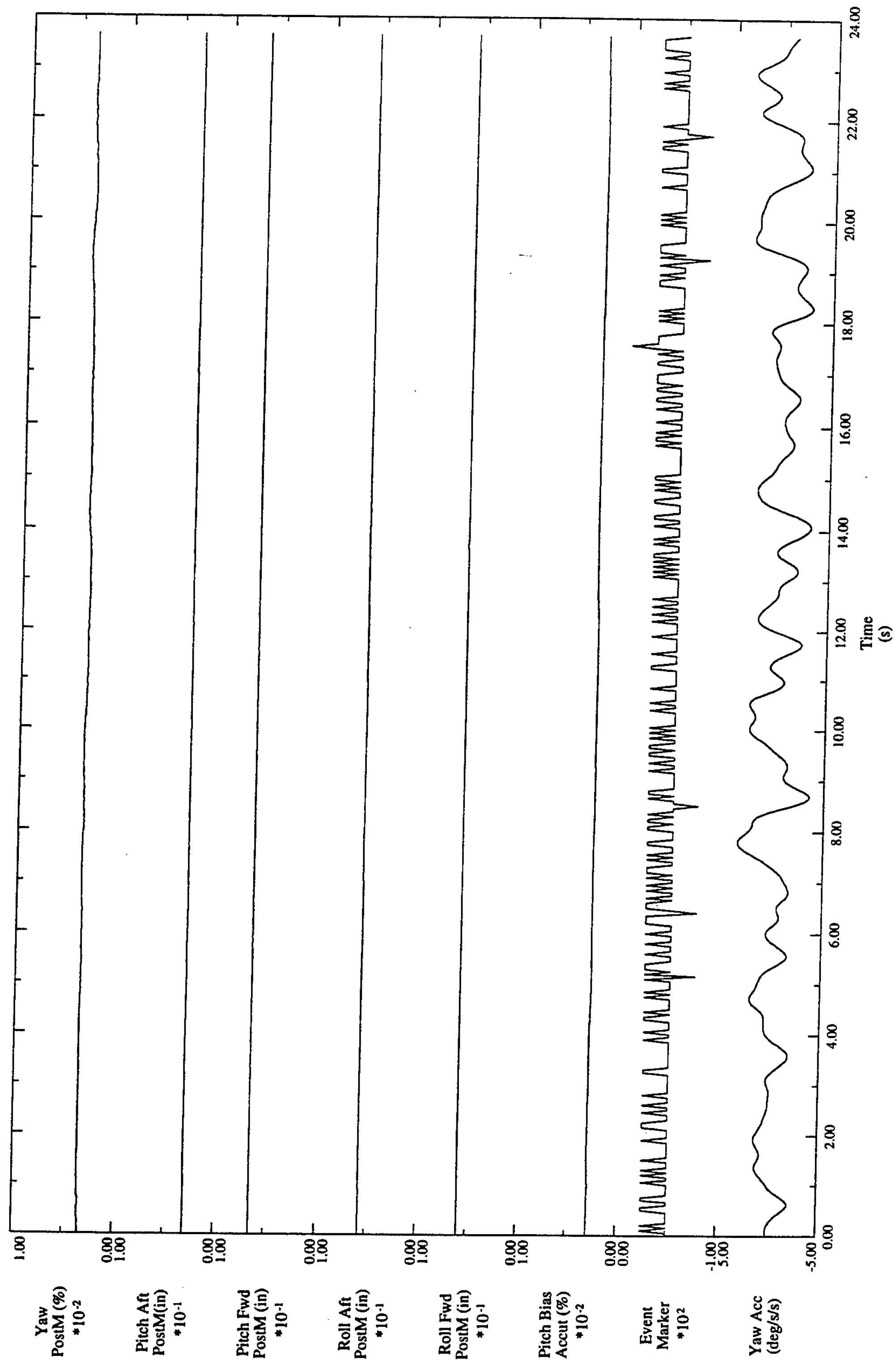
05-SEP-94 13:37:13



05-SEP-94 13:37:13

S98 AT800 Hover 3 ft AGL IGE; New Offsets

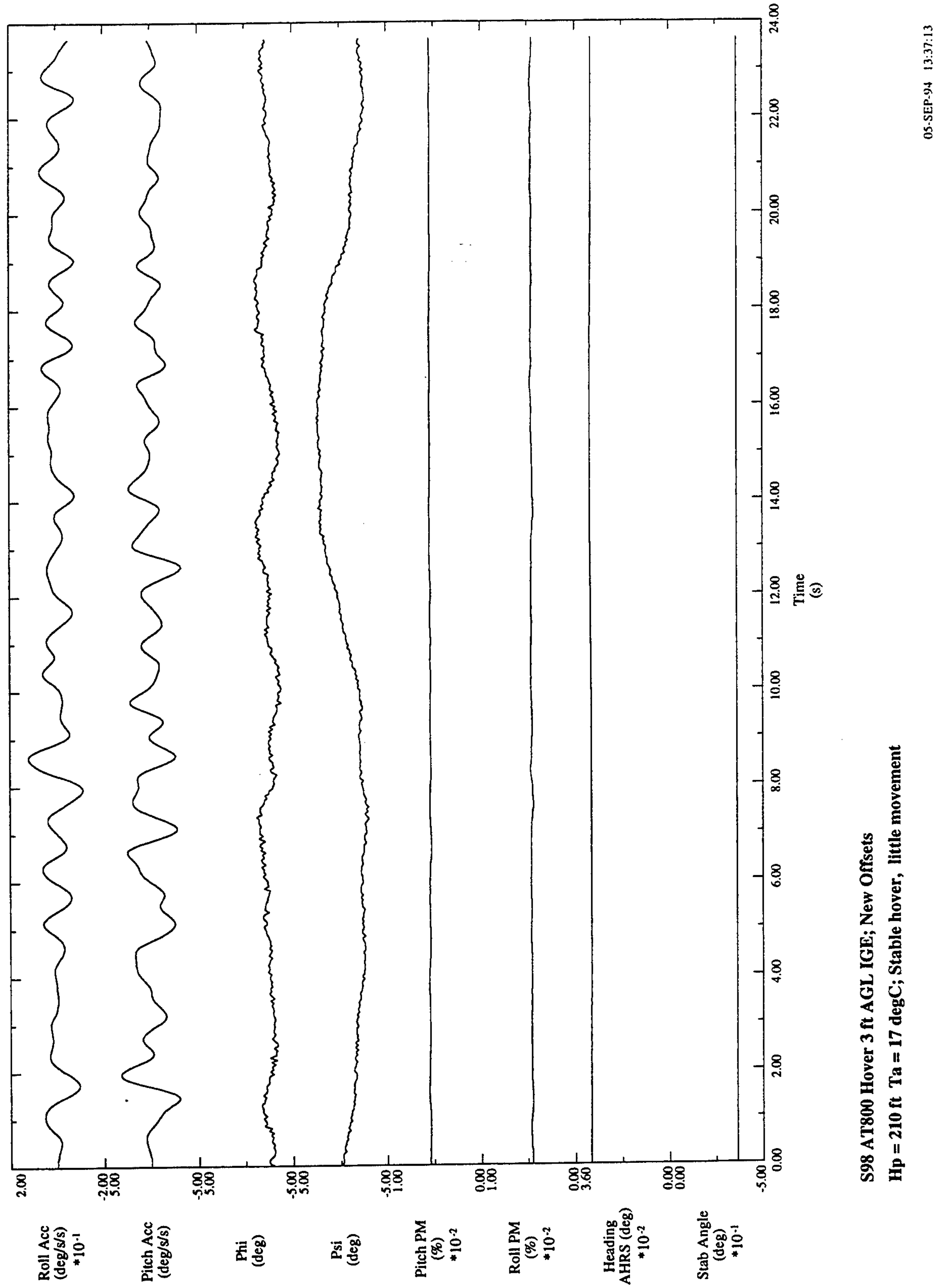
Hp = 210 ft Ta = 17 degC; Stable hover, little movement



S98 AT800 Hover 3 ft AGL IGE; New Offsets

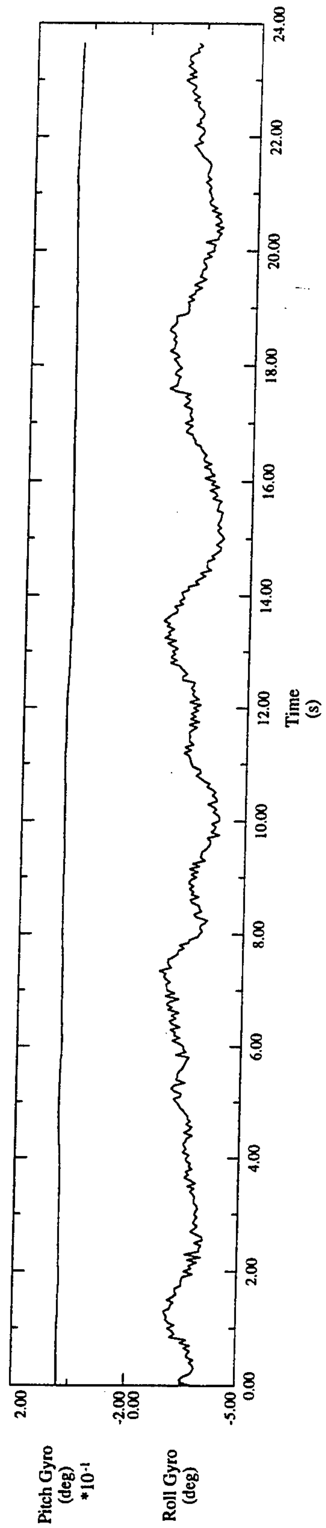
Hp = 210 ft Ta = 17 degC; Stable hover, little movement

05-SEP-94 13:37:13



S98 AT800 Hover 3 ft AGL IGE; New Offsets

Hp = 210 ft Ta = 17 degC; Stable hover, little movement



S98 AT800 Hover 3 ft AGL IGE ; New Offsets

Hp = 210 ft Ta = 17 degC; Stable hover, little movement

05-SEP-94 13:37:13

APPENDIX G - *MACTRANS* PRINT FILE, EVOLUTION AT800

Shown below is part of the *MacTrans* file S98AT800.COL showing the column format of the data. The data are written in up to six columns broken up with titles at regular intervals.

```
1 S98 AT800 Hover 3ft AGL IGE; New Offsets
  Hp=210ft Ta=17degC; Stable hover,little movement

  RECORDED ON 05-SEP-94   AT 13:37:13   INTEGN INT = 0.0000E+00
                                          RUN CPU TIME =   2 MIN. 54.53 SEC.

  BLK NUMBER =      1          2          3          4          5
  Time         Pitch Rate  Roll Rate  Yaw Rate   Lat Accel  Long Accel
  (s)           (deg/s)     (deg/s)    (deg/s)    (ft/s/s)   (ft/s/s)
  0.0000E+00  1.6916E-01  2.4453E-01 -1.1505E+00 -4.6492E-01  3.5696E+00
  5.0000E-02  1.6917E-01  2.4436E-01 -1.1506E+00 -4.6472E-01  3.5695E+00
  1.0000E-01  1.6925E-01  2.4296E-01 -1.1510E+00 -4.6286E-01  3.5685E+00
  1.5000E-01  1.6976E-01  2.3760E-01 -1.1529E+00 -4.5467E-01  3.5652E+00
                                    |
                                    |
  2.4500E+00  1.8384E-01 -1.1307E+00 -7.8874E-01  4.5324E-01  3.4873E+00
  2.5000E+00  1.8618E-01 -1.0035E+00 -7.8410E-01  4.1716E-01  3.5103E+00

1 BLK NUMBER =      1          2          3          4          5
  Time         Pitch Rate  Roll Rate  Yaw Rate   Lat Accel  Long Accel
  (s)           (deg/s)     (deg/s)    (deg/s)    (ft/s/s)   (ft/s/s)
  2.5500E+00  2.0276E-01 -8.9162E-01 -7.8191E-01  3.7867E-01  3.5285E+00
  2.6000E+00  2.3309E-01 -7.9235E-01 -7.8111E-01  3.4207E-01  3.5413E+00
  2.6500E+00  2.7356E-01 -7.0026E-01 -7.8121E-01  3.1040E-01  3.5494E+00
                                    |
                                    |
2.3550E+01 -7.1166E-01  7.0883E-01  1.6801E-01  6.6052E-02  3.6273E+00
  2.3600E+01 -7.0672E-01  4.9252E-01  1.3405E-01  1.0324E-02  3.6157E+00
1 S98 AT800 Hover 3ft AGL IGE; New Offsets
  Hp=210ft Ta=17degC; Stable hover,little movement

  RECORDED ON 05-SEP-94   AT 13:37:13   INTEGN INT = 0.0000E+00
                                          RUN CPU TIME =   2 MIN. 54.53 SEC.

  BLK NUMBER =      6          7          8          9          10
  Time         Vert Accel  Dop. Long  Dop. Lat   Dop. Vert  AFCS Pitch
  (s)           (ft/s/s)   Vel (kn)   Vel (kn)   Vel (kn)    (%)
  0.0000E+00 -3.3194E+01 -1.1637E-01 -1.3778E+00 -6.6482E-01  3.6430E+01
  5.0000E-02 -3.3194E+01  5.6950E-03 -1.2557E+00 -6.8517E-01  3.5886E+01
  1.0000E-01 -3.3194E+01  3.1087E-01 -8.8952E-01 -5.2241E-01  3.6104E+01
  1.5000E-01 -3.3190E+01  2.4984E-01 -8.8952E-01 -4.8172E-01  3.5668E+01
                                    |
                                    |
1 S98 AT800 Hover 3ft AGL IGE; New Offsets
  Hp=210ft Ta=17degC; Stable hover,little movement

  RECORDED ON 05-SEP-94   AT 13:37:13   INTEGN INT = 0.0000E+00
                                          RUN CPU TIME =   2 MIN. 54.53 SEC.

  BLK NUMBER =     54          55          56
  Time         Stab Angle  Pitch Gyro  Roll Gyro
  (s)            (deg)       (deg)      (deg)
  0.0000E+00 -3.6365E+01  3.8672E+00 -3.0103E+00
  5.0000E-02 -3.6365E+01  3.8892E+00 -2.5708E+00
  1.0000E-01 -3.6365E+01  3.9112E+00 -2.4829E+00
  1.5000E-01 -3.6365E+01  3.9112E+00 -2.6367E+00
                                    |
                                    |
  2.3550E+01 -3.6387E+01  3.7793E+00 -2.0435E+00
  2.3600E+01 -3.6387E+01  3.7573E+00 -2.2852E+00
```

APPENDIX H - ARCHIVE INFORMATION

H1. Hardware

The computer used to store data was an Apple Macintosh IIsi, using System Software Z1-7.1 (©Apple Computer, Inc). All processed data have been stored on a 4 mm Digital Data Storage (DDS) tape and a compact disk (CD). The data stored on the DDS tape and CD are identical, thus providing two copies of all data and software on two different media.

H2. Software

Program *Retrospect* was used to store data on the DDS tape. *Retrospect* creates a storage set to label and catalogue the DDS tape. The name of the storage set for the DDS tape containing the data is `S70B2 Processd Flt Data`. Fig. H1 shows a 'Files Report' from *Retrospect* for the DDS tape used. Each time data is stored, *Retrospect* catalogues the data in a session. Four sessions were used to store the data and software and these are shown in Fig. H1, reading from top to bottom, in the reverse order that they were stored. Session `S70B2 Converted Data` contains all the '`.con`' files for Sortie 98, as well as those for Sortie 99 (Ref. 2) and the FOCFT sorties (Ref. 3). Session `S70B2 SetUp Data` contains all data files produced in checking that the data processing software was working correctly as described in Section 4.1. Session `Performance Data` contains all data produced in processing Sortie 98 and the ground effect trials at sea (Table 2), and session `Software` contains the data processing software.

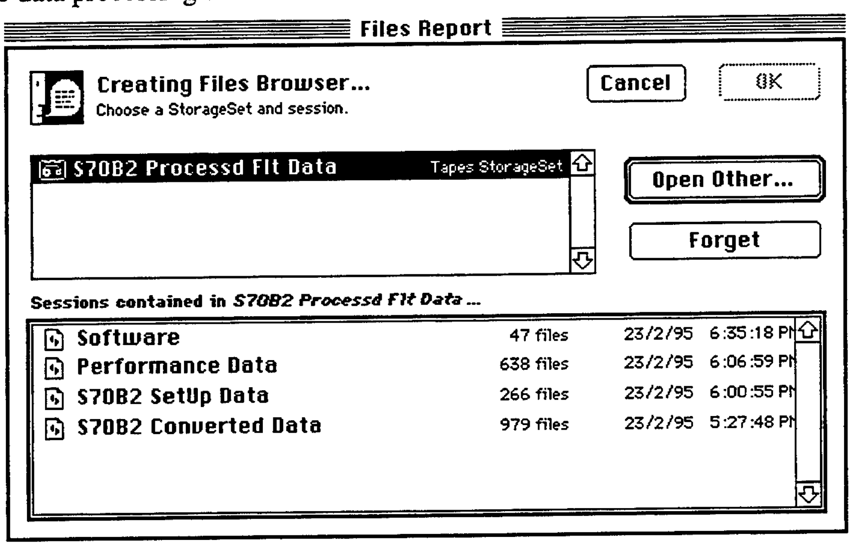


Figure H1. Files Report From *Retrospect*

The data were written to the CD by using a Pinnacle Micro recordable CD drive (RCD-1000) with RCD-MAC software. The data were stored using the Hierarchical File System format that allows the CD (named 'S70B2 Flight Data') to be read by any Macintosh with a CD-ROM drive. The same data as contained in the *Retrospect* storage set are stored on the CD in directories with the same names as the sessions. An explanation of the directory structure is given in Section H3.

H3. Directory Structure

The directory structure in the three sessions used by *Retrospect* is the same as that stored on the CD, and is detailed in the following sub-sections.

H3.1 S70B2 Converted Data

All the '.con' files are stored in session S70B2 Converted Data on the DDS tape and the directory of this name on the CD. Files are stored in individual sortie directories labelled S??Processed, where ?? is the sortie number. For example, the performance data are stored in the directory named S98Processed.

H3.2 S70B2 SetUp Data

The directory structure for S70B2 SetUp Data is shown in Fig. H2. All directory structure figures in this appendix show file names in bold print.

The files in S2AL10 DATA are the input, output and calibration files for the data processing software as used in Section 4.1. The significance of file extensions is detailed in Section 4.5. Files beginning with an 'f' are those that have had digital filtering included using filter characteristics determined in Section 4.2. The sub-directories are explained as follows.

S2AL10 uplt graphs contains the graphs of the raw data as displayed by the program *UPltData* (Section 4.1). Each channel has an individual file, which is a snapshot of the screen, and is labelled according to the channel name. For example Channel 12 recorded the AFCS Collective and the snapshot is labelled AFCS Coll. Using *MacDraw Pro* the snapshots were combined in groups of four and labelled appropriately. For example Combined 1-4 is a *MacDraw Pro* file displaying Channels 1 to 4.

S2Al10KGspect contains the files produced using program *Kaleidagraph*, to be used as input to program *spectrum* as described in Section 4.2. The files are labelled as a description of the three channels included in each file. For example s2al10ACCEL includes the three channels recording the linear accelerations, whereas s2al10-10-12 includes Channels 10 to 12. s2al10-56 contains only the one channel, but contains two dummy parameters to satisfy the format requirements of *spectrum*.

S2Al10spect contains the output files from *spectrum* ('.out' extension) and the same files converted for use by *Kaleidagraph* ('KG' suffix replacing '.out' extension). These files retain the descriptive part of the name as given to the *spectrum* input files. Spectral density plots of each channel created using *Kaleidagraph* are individually named in a similar manner to the snapshots of the *UPltData* graphs.

S2AL10TRANS contains all time histories produced by *MacTrans*, as described in Sections 4.1 and 4.5. Plots are included for both filtered and unfiltered data.

fs2al10KGspect is the same as S2Al10KGspect but using filtered data.

fs2al10spect is the same as S2Al10spect but using filtered data. Only the six filtered channels and three doppler channels were plotted.

Aircraft Delays contains the data used to establish the instrument and analogue filter delays (Section 4.3). Sub-directories are labelled by evolution designation, but only evolutions listed in Table 5 were used. The files contained in each sub-directory are similar to those described in sub-directory AL800, but for the corresponding evolution. The files for AL800 are explained as follows.

Al800.con, Al800.DAT, Al800.COL and Al800.Motion are files produced by the data processing software. Digital filtering was included.

THIST.dat and var.dat are output files from program *Compat*, and THIST.datKG and var.datKG are the corresponding files converted for use by program *Kaleidagraph*.

THETA - AL800 is a *Kaleidagraph* plot of the pitch attitude using the calculated and measured data from the two *Compat* files mentioned above.

H3.3 Performance Data

The first two levels of the `Performance Data` directory structure are shown in Fig. H3. The file `S98SHAWKCAL` is the calibration file used by program *S70B2Refine* for processing data from Sortie 98.

`Sortie 98` has three sub-directories (Fig. H3) that are further subdivided (Fig. H4). A description of the contents of the three main sub-directories follows.

`S98ADMfiles` contains the '`.ADM`' files recorded before each evolution (Section 2). Also included are the files `FOCFT_L.SET`, `FOCFT_L.LMT` and `ASORTIE.LOG`. These files were recorded only once for the sortie.

`S98FILES` contains eight sub-directories which have been labelled according to the phase of the performance flight tests (Table 2) for which they contain data. The hover phase has two directories labelled `HOVER` and `HoverNewOff`. The former contains data produced before the offset corrections were determined (Section 4.4), and the latter has the new offsets included. All other phases included the offset corrections. All eight sub-directories contain the appropriate `?????Files` sub-directories as described further below.

`S98Means` contains nine sub-directories. The first seven directories are labelled according to the different flight test phases (Table 2). For example, `LowAirspeed` contains data for the Low Airspeed test phase. These directories contain the appropriate output files from *S70B2Convert(ac)* ('` Out`' files), converted for use by *Kaleidagraph*, hence the '`kg`' suffix. For example `S98AT808 Outkg` is a *Kaleidagraph* file containing the data output by *S70B2Convert(ac)* for Evolution AT808. The two remaining files in the example directory are named `Low AS Means` and `LowASMeansTab`. The first is a *Kaleidagraph* file containing means for all channels from each evolution in the flight test phase, while the second is a *Word* (©Microsoft Corporation) document containing the same information in table format. Two sub-directories contain means for the data obtained in the hover phase. `Hover Aves` contains means determined prior to the calculation of the doppler offset errors (Section 4.4), hence the name of the other sub-directory `Hover New`. The last sub-directory is `Means Tables` and contains *Word* documents based on those in the previous seven directories. These documents present the quantities rearranged in a more logical order than in channel sequence, and form the basis of Appendix I. The files containing these rearranged tables have an '`R`' added to the name, e.g. `LowASMeansTabR`.

`IGE Study at Sea Files` has nine sub-directories (Fig. H3) as follows.

`AL100FILES` - `AL174Files` (seven directories) are similar to that described below for `AT800FILES`

`IGEatSeaMeans` contains *Kaleidagraph* and *Word* files used to produce the means tables as shown in Appendix I. The files are named along the same lines as those in `S98 Means`

`IGESeaADM` contains the '`.ADM`' files recorded before each evolution (Section 2).

```
S70B2 SetUp Data
      - S2AL10 DATA
            - AL10.con
            - s2al10 Out
            - s2al10.COL
            - s2al10.DAT
            - fs2al10. Out
            - fs2al10.COL
            - FS2AL10.DAT
            - S2SHAWKCAL
            - S2AL10 uplt graphs
                  - AFCS Coll
                  ..........
                  - Yaw Rate
                  - Combined 1-4
                  ..........
                  - Combined 55/6-98/9
            - S2Al10KGspect
                  - s2al10ACCEL
                  ..........
                  - s2al10-56
            - S2Al10spect
                  - s2al10ACCEL.out
                  - s2al10ACCELKG
                  ..........
                  - s2al10-56.out
                  - s2al10-56KG
                  - AFCSColl
                  ..........
                  - YawPos
            - S2AL10TRANS
                  - s2al10.PLT.a
                  ..........
                  - fs2al10.PLT.f
            - fs2al10KGspect
                  - fs2al10-Acc
                  ..........
                  - fs2al10-56
            - fs2al10spect
                  - fs2al10-Acc.out
                  - fs2al10-AccKG
                  ..........
                  - fs2al10-56.out
                  - fs2al10-56KG
                  - DopVx
                  ..........
                  - YawRate
      - Aircraft Delays
            - AL800
                  - AL800.con
                  - AL800.DAT
                  - AL800.COL
                  - AL800.Motion
                  - THIST.dat
                  - THIST.datKG
                  - var.dat
                  - var.datKG
                  - THETA - AL800
            - AL802
            - AL803
            - AL806
            - AL820
            - AL824
            - AL859
            - AL860
```

Figure H2. Directory Structure For S70B2 SetUp Data

```
Performance Data
        - S98SHAWKCAL
        - Sortie98
                - S98ADMfiles
                - S98FILES
                - S98Means
        - IGE Study at Sea Files
                - AL100FILES
                - AL151Files
                - AL152Files
                - AL158Files
                - AL159Files
                - AL173Files
                - AL174Files
                - IGEatSeaMeans
                - IGESeaADM
                        - AL100.ADM
                        ..........
                        - AL174.ADM
```

Figure H3. Upper Level Directory Structure For `Performance Data`

As can be seen from Figs H3 and H4, the majority of sub-directories in `Performance Data` are labelled `?????Files` or `?????FILES` , where `?????` is the evolution designation. An example of this is `AT800FILES` which contains the files produced by the data processing software for Evolution AT800 (Fig. H4). A description of these files is given below.

`AT800.con` - the raw data file converted from IBM binary to ASCII format (program *convdata*).

`S98AT800.DAT` - the output from *S70B2Refine*, which has the S98 prefix added so as not to be confused with the raw data file `AT800.DAT`. Also used as input to *MacTrans*.

`S98AT800.COL` - *MacTrans* output file containing all parameters in five columns. Input file into *S70B2Convert(ac)*

`S98AT800 Out` - Output from *S70B2Convert(ac)* containing all parameters in individual columns.

`S98AT800.PLT.?` - time history plots produced from *MacTrans*, where ? is a, b, c, d, e or f.

```
- S98ADMfiles
      - AT800.ADM
      ..........
      - AT839.ADM
      - FOCFT_L.SET
      - FOCFT_L.LMT
      - ASORTIE.LOG
- S98FILES
      - HOVER
            - AT800FILES
                  - AT800.con
                  - S98AT800.DAT
                  - S98AT800.COL
                  - S98AT800 Out
                  - S98AT800.PLT.a
                  - S98AT800.PLT.b
                  - S98AT800.PLT.c
                  - S98AT800.PLT.d
                  - S98AT800.PLT.e
                  - S98AT800.PLT.f
            - AT801 FILES to AT807FILES
      - HoverNewOff
            - AT800FILES to AT807FILES
      - Low Airspeed
            - AT808FILES to AT815FILES
      - Vert Clb/Desc
            - AT818FILES to AT820FILES
      - Level Flight
            - AT821FILES to AT824FILES
            - AT825FILES to AT827FILES
      - Fwd Climb/Desc
            - AT828FILES to AT833FILES
      - AutoRot
            - AT834FILES to AT836FILES
      - Grnd Eff
            - AT816FILES to AT817FILES
            - AT837FILES to AT839FILES
- S98Means
      - Hover New
      - LowAirspeed
            - S98AT808 Outkg
            ............
            - S98AT815 Outkg
            - Low AS Means
            - LowASMeansTab
      - Vert Clb/Des
      - Lev Flight
      - Fwd C/D
      - Autorot
      - Grd Eff
      - Hover Aves
      - Means Tables
```

Figure H4. Lower Level Directory Structure For Sortie 98

H3.4 Software

The `Software` directory structure is shown in Fig. H5.

`Software` contains two sub-directories which contain the files necessary to compile three of the data processing programs. The files in sub-directory `S70B2Refine ƒ` are those required for program *S70B2Refine*. The files in sub-directory `S70B2Convert ƒ` are those required for programs *S70B2Convert(ac)* and *S70B2Convert(ac)-C*. A number of files with the same extensions are contained in these directories. These files are explained as follows using the files from `S70B2Refine ƒ` as examples.

`S70B2Refine` - no extension indicates the executable code.

`S70B2Refine.make` - file containing compiler directives.

`S70B2Refine.SYM` - file containing symbolic debugger information.

`S70B2Refine.rsrc` - resource file.

`S70B2R1.f` - file containing Fortran source code. A number of source modules are used for program *S70B2Refine* (Table 3. Ref. 1), but only one source file is used for each of programs *S70B2Convert(ac)* and *S70B2Convert(ac)-C*.

`S70B2Refine.f.o` - object file produced when program is compiled.

```
Software
     - S70B2Refine ƒ
          - S70B2Refine
          - S70B2Refine.make
          - S70B2Refine.SYM
          - S70B2Refine.rsrc
          - S70B2R1.f
          - S70B2R1.f.o
          ...................
          - FindStartTime.f
          - FindStartTime.f.o
     - S70B2Convert ƒ
          - S70B2Convert(ac)
          - S70B2Convert(ac).f
          - S70B2Convert(ac).f.o
          - S70B2Convert(ac).make
          - S70B2Convert(ac).SYM
          - S70B2Convert(ac).rsrc
          - S70B2Convert(ac)-C
          - S70B2Convert(ac)-C.f
          - S70B2Convert(ac)-C.f.o
          - S70B2Convert(ac)-C.make
          - S70B2Convert(ac)-C.SYM
```

Figure H5. Directory Structure for `Software`

APPENDIX I - MEAN VALUES FOR TRIMMED FLIGHT

Table I1. Hover

Variable	File AT800 (13-18s)		File AT801 (7-14s)		File AT802 (6-14s)		File AT803 (9-15s)		File AT804 (7-12s)		File AT805 (2-8s)		File AT806 (7-12s)		File AT807 (15-20s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	60.7	0.5	57.1	1.3	58.4	0.8	58.3	0.7	58.0	1.1	59.2	1.1	59.9	0.4	59.8	0.2
PreCycLat (%)	56.7	1.1	56.0	0.4	55.4	0.6	54.9	0.3	55.1	0.2	54.5	0.2	55.2	0.2	52.2	0.1
PreColl (%)	62.5	0.5	66.1	0.4	67.2	0.3	68.2	0.3	69.5	0.3	70.2	0.6	71.3	0.6	70.2	0.6
PrePedals(%)	41.9	0.1	39.5	0.1	39.6	0.2	39.2	0.1	38.9	0.4	40.4	0.3	39.1	0.1	41.4	0.1
AFCS Pit (%)	36.8	3.0	34.2	4.2	32.2	4.8	35.0	1.8	36.3	1.6	37.7	3.0	36.9	3.4	37.7	2.0
AFCS Roll (%)	21.2	4.0	20.5	1.8	18.7	3.3	19.2	1.7	19.8	1.8	17.4	1.5	18.4	0.9	18.6	1.4
AFCS Coll (%)	31.5	0.4	29.1	0.7	28.9	0.5	29.0	0.3	29.4	0.3	29.0	0.6	28.8	0.7	29.4	0.6
AFCS Yaw (%)	41.7	5.7	31.1	8.5	33.0	7.8	34.7	6.1	32.7	6.2	29.8	4.7	34.5	8.6	33.9	5.0
PitchPstM (%)	54.3	0.3	51.1	0.6	51.4	0.8	52.1	0.5	52.4	0.2	52.6	0.4	52.7	0.4	52.5	0.3
RollPstM (%)	45.6	0.8	44.2	0.5	43.4	0.8	43.9	0.5	43.7	0.6	44.0	0.9	42.6	0.4	40.9	0.4
YawPostM (%)	34.4	0.7	29.8	0.9	29.6	0.8	28.8	0.5	28.3	0.6	27.9	0.7	26.9	1.0	29.3	0.6
PrJck Fwd (%)	53.3	0.3	53.2	0.4	54.1	0.6	55.2	0.3	56.3	0.2	56.8	0.3	57.5	0.4	56.8	0.4
PrJck Aft (%)	50.2	0.3	46.6	0.5	46.2	0.5	46.1	0.4	45.6	0.3	45.4	0.4	44.8	0.5	45.3	0.3
PrJck Lat (%)	57.7	0.3	59.3	0.2	59.9	0.3	60.5	0.3	61.5	0.2	61.7	0.3	62.4	0.4	60.7	0.3
Pit Bias (%)	28.6	0.3	26.0	0.4	26.1	0.6	26.6	0.1	26.8	0.2	26.9	0.3	27.1	0.2	26.8	0.2
Stab Ang (deg)	-40.0	0.0	-40.0	0.0	-40.0	0.0	-40.0	0.0	-40.0	0.0	-40.0	0.0	-40.0	0.0	-40.0	0.0
Theta (deg)	3.9	0.2	5.9	0.3	5.8	0.4	5.4	0.1	5.2	0.1	5.1	0.2	5.0	0.2	5.2	0.1
Phi (deg)	-2.4	0.8	-1.5	0.2	-1.8	0.5	-1.7	0.3	-2.0	0.5	-2.4	0.2	-2.1	0.2	-2.1	0.2
Roll (deg)	-2.4	0.8	-1.5	0.2	-1.8	0.5	-1.8	0.3	-2.0	0.5	-2.4	0.2	-2.1	0.2	-2.1	0.2
Psi (deg)	2.0	0.2	-0.7	0.7	1.6	0.3	0.3	0.4	-4.2	0.7	0.6	0.2	1.1	0.5	-1.0	0.4
Heading (deg)	303.3	0.2	301.8	0.7	301.9	0.3	300.6	0.4	295.6	0.7	298.9	0.2	300.3	0.5	298.3	0.4
Q (deg/s)	-0.2	0.4	-0.2	0.4	0.1	0.5	-0.1	0.2	0.0	0.1	0.0	0.2	-0.1	0.4	0.0	0.2
P (deg/s)	0.2	1.4	0.1	0.5	0.1	1.2	0.2	0.6	0.4	0.4	0.0	0.4	0.2	0.3	0.2	0.3
R (deg/s)	-0.5	0.6	-0.5	0.8	-0.4	0.7	-0.8	0.5	-1.2	0.6	-0.3	0.3	-0.7	0.7	-0.8	0.3
QDot (deg/s^2)	0.3	1.0	-0.1	0.9	0.0	1.8	-0.1	0.9	0.0	0.4	0.0	0.6	-0.3	1.1	0.0	0.7
PDot (deg/s^2)	-0.1	3.4	-0.1	1.8	-0.5	3.3	-0.1	1.9	-0.2	1.5	0.0	1.0	0.3	1.4	-0.1	1.1
RDot (deg/s^2)	-0.3	1.3	-0.1	1.8	-0.1	2.1	0.1	1.5	-0.2	2.1	0.1	0.9	-0.3	1.4	0.1	0.7
Ax (ft/s^2)	3.5	0.1	4.5	0.1	4.4	0.2	4.3	0.1	4.1	0.1	4.0	0.1	4.0	0.1	4.1	0.1
Ay (ft/s^2)	0.2	0.2	-0.2	0.2	0.0	0.3	0.0	0.2	0.0	0.2	0.0	0.1	0.1	0.1	0.1	0.1
Az (ft/s^2)	-32.6	0.2	-32.6	0.3	-32.6	0.3	-32.5	0.3	-32.6	0.2	-32.6	0.2	-32.7	0.4	-32.3	0.3
DopVx (ft/s)	-0.3	1.3	-0.1	1.0	0.2	1.3	0.4	2.0	0.3	2.4	1.4	1.7	0.2	1.6	-0.1	1.4
DopVy (ft/s)	0.1	1.7	-0.3	1.3	1.0	2.0	0.2	2.0	-0.2	1.8	-0.6	2.3	-0.1	1.6	0.1	1.4
DopVz (ft/s)	0.1	0.9	-0.2	0.8	0.1	0.8	0.1	1.3	-0.1	1.3	0.0	1.3	-1.0	1.7	0.2	1.5
U (ft/s)	53.1	0.0	53.1	0.0	53.1	0.0	53.1	0.0	53.1	0.0	53.1	0.0	53.0	0.0	53.0	0.0
Z (ft)	-5.2	2.8	-11.8	0.4	-15.4	0.8	-22.4	0.2	-31.9	1.2	-41.2	1.3	-49.2	0.8	-108.4	1.2
Engine1 (%)	70.1	1.0	77.5	1.1	79.4	0.9	81.4	0.7	83.3	0.6	83.9	1.0	86.1	1.5	82.4	0.9
Engine2 (%)	71.9	1.0	79.2	1.3	81.0	0.9	82.9	1.0	84.7	0.6	85.5	1.1	87.4	1.5	84.0	1.0
PitAftPstM (in)	3.0	0.0	2.9	0.0	2.9	0.0	2.9	0.0	2.9	0.0	2.9	0.0	2.9	0.0	2.9	0.0
PitFwdPstM (in)	6.5	0.0	6.5	0.0	6.5	0.0	6.6	0.0	6.6	0.0	6.6	0.0	6.6	0.0	6.6	0.0
RolAftPstM (in)	5.7	0.0	5.7	0.0	5.7	0.0	5.7	0.0	5.7	0.0	5.7	0.0	5.7	0.0	5.7	0.0
RolFwdPstM (in)	5.9	0.0	5.9	0.0	6.0	0.0	5.9	0.0	6.0	0.0	6.0	0.1	6.0	0.0	6.0	0.0

Table I2. Low Airspeed

Variable	File AT808 (3-8s)		File AT809 (11-16s)		File AT810 (4-10s)		File AT811 (7-12s)		File AT812 (13-20s)		File AT813 (6-11s)		File AT814 (4-9s)		File AT815 (6-12s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	49.3	0.6	50.1	0.2	65.5	0.2	69.2	1.1	70.4	0.6	74.5	0.6	54.3	0.2	50.0	0.4
PreCycLat (%)	44.3	0.6	45.5	0.2	66.6	0.2	71.8	0.6	50.1	1.6	47.7	1.0	69.5	0.3	71.7	0.5
PreColl (%)	63.5	0.4	56.7	0.2	68.2	0.1	57.8	0.7	65.2	0.1	62.3	0.7	65.1	0.3	54.2	0.2
PrePedals(%)	44.5	0.1	47.2	0.1	41.4	0.3	40.7	1.7	45.6	1.7	52.5	1.2	32.6	0.6	28.9	0.2
AFCS Pit (%)	34.4	3.4	40.2	1.5	27.6	1.2	13.5	3.8	29.5	7.0	12.9	4.3	30.5	2.8	15.9	2.5
AFCS Roll (%)	19.1	2.5	26.5	1.1	17.0	1.1	18.0	2.2	18.3	6.6	17.1	5.1	45.6	3.0	30.6	2.4
AFCS Coll (%)	20.6	3.2	47.3	2.5	41.4	3.3	23.5	6.5	40.2	4.5	31.3	9.9	43.7	2.1	32.4	1.4
AFCS Yaw (%)	31.4	4.4	34.4	1.9	35.0	5.0	35.5	10.8	38.1	16.9	35.4	15.2	31.4	7.0	24.2	3.3
PitchPstM (%)	41.6	0.3	45.5	0.2	55.1	0.3	56.8	0.6	59.4	1.2	57.7	0.5	50.0	0.3	46.9	0.3
RollPstM (%)	32.9	0.4	35.1	0.2	54.4	0.2	61.0	0.7	39.2	1.3	37.9	1.1	54.8	0.3	60.9	0.6
YawPostM (%)	35.9	0.4	43.5	0.4	31.5	0.5	35.7	0.8	37.5	3.2	45.2	2.4	23.5	0.8	23.4	0.5
PrJck Fwd (%)	46.2	0.3	43.3	0.3	57.4	0.3	53.7	0.5	58.9	1.1	56.8	0.7	51.7	0.3	43.1	0.2
PrJck Aft (%)	41.3	0.2	47.9	0.2	48.0	0.3	53.2	0.4	52.0	0.7	51.6	0.4	46.9	0.3	49.5	0.2
PrJck Lat (%)	54.0	0.3	48.7	0.2	64.9	0.3	61.9	0.3	56.9	0.6	55.4	0.5	62.4	0.2	58.3	0.2
Pit Bias (%)	23.7	0.3	28.9	0.2	24.9	0.1	21.9	0.5	27.5	0.7	25.6	0.6	26.1	0.3	24.7	0.3
Stab Ang (deg)	-40.0	0.0	-39.8	0.0	-39.8	0.0	-39.8	0.0	-39.9	0.0	-39.9	0.0	-39.8	0.0	-39.6	0.0
Theta (deg)	7.6	0.2	3.7	0.2	6.2	0.1	8.6	0.4	4.3	0.5	5.8	0.4	5.5	0.2	6.6	0.2
Phi (deg)	-1.3	0.3	-0.6	0.2	-3.4	0.3	-2.0	0.3	-7.5	0.8	-9.4	0.4	1.7	0.5	-0.5	0.3
Roll (deg)	-1.3	0.3	-0.6	0.2	-3.5	0.3	-2.1	0.3	-7.5	0.8	-9.5	0.4	1.7	0.5	-0.5	0.3
Psi (deg)	1.0	0.2	-3.1	0.5	0.8	0.5	1.5	0.6	1.4	0.9	3.9	0.5	-0.5	0.4	-3.5	0.5
Heading (deg)	298.3	0.2	296.5	0.5	126.3	0.5	126.0	0.6	27.3	0.9	30.9	0.5	211.0	0.4	214.3	0.5
Q (deg/s)	-0.1	0.3	-0.0	0.1	-0.1	0.1	-0.3	0.3	-0.2	0.8	-0.1	0.8	-0.1	0.2	-0.2	0.2
P (deg/s)	0.1	0.6	0.2	0.2	0.3	0.4	0.0	0.7	0.7	2.4	-0.2	2.2	-0.1	0.7	0.1	0.7
R (deg/s)	-0.3	0.4	-0.7	0.1	-0.6	0.5	-0.3	1.0	-0.9	2.0	-0.1	1.8	-0.6	0.6	-0.1	0.2
QDot (deg/s^2)	-0.0	0.7	0.0	0.5	0.0	0.3	-0.2	0.7	0.0	2.3	-0.0	2.9	-0.1	0.8	0.0	0.6
PDot (deg/s^2)	0.2	1.8	0.0	0.6	-0.1	1.7	-0.2	3.0	-0.2	9.5	0.4	9.7	0.0	2.4	0.3	3.5
RDot (deg/s^2)	-0.1	0.7	0.0	0.2	-0.3	1.0	-0.5	1.0	-0.7	5.1	0.1	5.0	0.1	1.4	0.1	0.8
Ax (ft/s^2)	5.3	0.1	3.3	0.1	4.9	0.1	5.7	0.2	3.6	0.2	4.3	0.3	4.1	0.1	4.5	0.1
Ay (ft/s^2)	-0.2	0.0	-0.7	0.0	0.6	0.1	0.2	0.1	3.0	0.3	4.2	0.3	-2.3	0.1	-1.8	0.1
Az (ft/s^2)	-32.6	0.2	-32.5	0.1	-32.4	0.2	-32.9	0.3	-32.3	0.6	-32.3	0.6	-32.2	0.2	-32.5	0.3
DopVx (ft/s)	26.0	0.8	53.2	1.1	-23.1	0.7	-55.3	1.4	-0.3	1.5	-1.3	1.8	1.2	1.3	0.9	1.9
DopVy (ft/s)	-0.7	1.1	3.3	1.5	1.2	1.1	3.7	2.0	-29.5	1.1	-53.7	1.6	29.9	1.0	56.7	2.0
DopVz (ft/s)	4.8	0.4	5.0	0.7	-4.5	0.5	-13.6	1.7	-5.6	0.8	-15.3	1.1	-1.1	0.8	1.1	1.0
U (ft/s)	53.0	0.2	55.9	0.2	52.9	0.4	52.8	0.3	52.8	0.0	52.8	0.0	52.7	0.0	52.7	0.0
Z (ft)	-102.0	1.5	-104.9	1.4	-95.1	1.4	-90.6	1.1	-94.4	1.4	-90.6	2.7	-96.7	1.3	-94.1	1.0
Engine1 (%)	72.4	0.5	58.4	0.6	76.8	0.7	64.2	1.1	72.8	2.2	69.7	1.5	73.3	1.0	60.3	0.4
Engine2 (%)	74.1	0.4	59.2	1.2	78.3	1.0	65.2	1.4	72.5	2.2	70.5	1.4	75.2	0.8	61.8	0.4
PitAftPstM (in)	2.6	0.0	2.8	0.0	3.0	0.0	3.1	0.0	3.2	0.0	3.1	0.0	2.9	0.0	2.8	0.0
PitFwdPstM (in)	6.4	0.0	6.3	0.0	6.6	0.0	6.4	0.0	6.6	0.0	6.5	0.0	6.5	0.0	6.3	0.0
RolAftPstM (in)	5.9	0.0	6.0	0.0	5.4	0.0	5.4	0.0	5.8	0.0	5.8	0.0	5.5	0.0	5.4	0.0
RolFwdPstM (in)	5.9	0.0	5.8	0.0	6.0	0.0	5.8	0.0	5.9	0.0	5.9	0.0	5.9	0.0	5.7	0.0

Table I3. Vertical Climb/Descent

Variable	File AT818 (0-10s)		File AT819 (12-18s)		File AT820 (20-25s)		File AT825 (3-8s)		File AT825 (20-25s)		File AT826 (2-6s)		File AT827 (2-8s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	62.7	0.8	64.1	0.4	64.3	0.4	49.7	1.4	55.0	0.7	64.6	1.0	55.5	2.6
PreCycLat (%)	52.6	0.3	54.3	0.3	54.7	0.1	43.6	0.2	44.5	0.2	38.2	0.9	42.4	2.1
PreColl (%)	73.3	0.1	75.5	0.0	78.5	0.0	64.3	0.1	64.4	0.0	30.7	0.3	43.2	0.6
PrePedals(%)	39.3	0.3	37.6	0.6	35.4	0.0	37.2	0.2	39.5	0.3	52.5	0.2	44.3	1.9
AFCS Pit (%)	39.6	4.0	30.6	1.9	27.9	1.2	33.5	4.8	28.8	4.6	13.8	6.5	29.1	19.0
AFCS Roll (%)	16.2	1.6	16.3	1.2	15.5	2.1	17.8	1.2	20.5	2.6	51.1	5.4	39.1	15.3
AFCS Coll (%)	30.1	0.3	28.0	0.4	26.1	0.4	24.1	0.5	24.8	0.5	28.8	0.9	26.9	1.5
AFCS Yaw (%)	30.9	5.3	24.1	3.9	28.0	3.0	26.2	5.5	29.4	5.6	38.3	13.4	29.0	18.0
PitchPstM (%)	55.5	0.4	55.3	0.3	55.2	0.2	44.3	0.8	47.0	0.7	53.0	1.2	49.9	4.5
RollPstM (%)	40.5	0.3	41.8	0.3	41.6	0.1	33.6	0.2	34.1	0.4	30.3	0.8	34.2	2.9
YawPostM (%)	26.2	0.4	22.4	0.3	18.1	0.3	29.4	0.5	32.1	0.5	60.6	1.8	46.4	3.9
PrJck Fwd (%)	61.5	0.3	63.1	0.1	64.8	0.1	48.5	0.6	50.5	0.4	35.9	0.8	40.3	3.1
PrJck Aft (%)	45.5	0.3	44.1	0.1	42.5	0.1	43.0	0.6	44.7	0.4	65.6	0.7	57.5	2.5
PrJck Lat (%)	63.0	0.2	65.2	0.1	67.2	0.0	54.1	0.2	54.5	0.2	30.4	0.4	39.7	1.0
Pit Bias (%)	28.1	0.4	26.4	0.2	26.0	0.1	24.1	0.4	24.4	0.5	23.8	0.8	27.4	1.8
Stab Ang (deg)	-39.8	0.0	-39.8	0.0	-39.7	0.0	-39.9	0.0	-39.8	0.0	-39.7	0.0	-39.6	0.0
Theta (deg)	3.7	0.3	5.0	0.2	5.1	0.1	7.1	0.3	6.7	0.4	7.5	0.6	4.2	1.3
Phi (deg)	-4.4	0.4	-3.0	0.4	-2.3	0.2	-1.3	0.3	-1.1	0.4	2.7	0.6	1.3	1.9
Roll (deg)	-4.4	0.4	-3.1	0.4	-2.3	0.2	-1.4	0.3	-1.1	0.4	2.7	0.6	1.3	1.9
Psi (deg)	0.2	0.5	-0.2	0.3	-1.3	0.4	-2.6	0.4	-5.3	0.4	1.9	0.4	0.2	2.4
Heading (deg)	329.0	0.5	330.5	0.3	333.5	0.4	321.3	0.4	318.5	0.4	316.1	0.4	298.0	2.4
Q (deg/s)	-0.1	0.4	-0.1	0.2	-0.1	0.1	-0.0	0.5	-0.2	0.5	0.1	0.9	-0.8	2.5
P (deg/s)	0.2	0.4	0.2	0.3	0.1	0.2	0.1	0.3	-0.0	0.3	0.2	2.0	-0.1	3.2
R (deg/s)	-0.5	0.4	-0.4	0.4	-0.7	0.2	-0.5	0.5	-0.0	0.5	-0.2	1.5	0.6	3.4
QDot (deg/s^2)	-0.0	0.7	0.0	0.4	0.1	0.3	0.0	1.3	-0.1	0.8	0.1	2.8	0.5	7.4
PDot (deg/s^2)	-0.0	1.1	-0.0	0.9	0.0	0.6	-0.0	1.3	0.0	1.1	0.1	8.5	0.1	10.5
RDot (deg/s^2)	-0.1	0.6	0.3	0.5	0.1	0.3	-0.2	1.2	-0.2	1.0	-0.3	4.9	1.5	6.7
Ax (ft/s^2)	3.7	0.1	3.8	0.1	4.0	0.0	4.8	0.2	4.5	0.1	3.2	0.3	3.5	0.9
Ay (ft/s^2)	1.3	0.1	0.9	0.1	0.8	0.1	-0.6	0.1	-0.4	0.1	-1.6	0.3	-1.1	0.7
Az (ft/s^2)	-32.5	0.1	-32.4	0.1	-32.4	0.1	-32.2	0.2	-32.0	0.1	-32.3	0.5	-32.9	1.1
DopVx (ft/s)	-16.8	1.0	-14.3	1.0	-18.8	1.1	-3.5	0.5	-5.7	0.7	209.3	0.0	11.2	0.1
DopVy (ft/s)	1.8	1.0	-4.1	1.0	0.8	1.4	0.5	0.6	0.1	0.5	-15.3	0.1	-7.7	0.1
DopVz (ft/s)	-17.6	0.6	-38.5	0.5	-54.3	0.5	13.9	0.3	20.4	0.4	-71.6	0.0	69.0	0.0
U (ft/s)	52.6	0.3	52.5	0.0	52.4	0.0	52.2	0.0	52.2	0.0	52.1	0.2	52.0	0.2
Z (ft)	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0
Engine1 (%)	90.9	0.3	98.1	0.3	105.0	0.3	67.9	0.6	65.7	0.4	17.7	0.5	34.1	3.2
Engine2 (%)	91.2	0.5	97.2	0.4	104.5	0.3	69.5	0.7	67.3	0.4	18.8	1.1	36.0	3.2
PitAftPstM (in)	3.0	0.0	3.0	0.0	3.0	0.0	2.7	0.0	2.8	0.0	3.2	0.0	3.0	0.1
PitFwdPstM (in)	6.7	0.0	6.7	0.0	6.8	0.0	6.5	0.0	6.5	0.0	6.0	0.0	6.1	0.0
RolAftPstM (in)	5.7	0.0	5.6	0.0	5.6	0.0	5.9	0.0	5.9	0.0	6.4	0.0	6.1	0.1
RolFwdPstM (in)	6.1	0.0	6.1	0.0	6.2	0.0	5.9	0.0	5.9	0.0	5.4	0.0	5.5	0.0

Table I4. Level Flight

Variable	File AT821 (15-20s)		File AT822 (12-22s)		File AT823 (15-30s)		File AT824 (12-17s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	51.4	0.1	48.8	0.2	45.3	0.2	39.0	0.3
PreCycLat (%)	48.0	0.2	52.2	0.2	56.3	0.2	58.6	0.2
PreColl (%)	52.4	0.1	50.1	0.3	63.5	0.4	78.0	0.4
PrePedals(%)	48.8	0.2	57.8	0.4	62.7	0.3	58.8	0.2
AFCS Pit (%)	36.8	2.3	33.0	3.8	34.1	4.6	32.4	4.1
AFCS Roll (%)	33.2	2.9	36.4	2.1	31.3	3.0	27.8	2.3
AFCS Coll (%)	24.4	0.8	33.6	2.9	32.6	4.1	14.5	1.3
AFCS Yaw (%)	28.3	2.3	38.1	3.6	36.8	3.6	35.6	2.9
PitchPstM (%)	46.6	0.3	39.1	0.6	35.7	0.8	30.2	0.8
RollPstM (%)	38.4	0.4	43.2	0.4	45.3	0.6	44.3	0.5
YawPostM (%)	46.5	0.2	57.6	0.4	54.3	0.4	43.4	0.5
PrJck Fwd (%)	42.7	0.3	36.7	0.5	42.5	0.5	48.9	0.4
PrJck Aft (%)	49.8	0.2	47.2	0.4	37.9	0.6	26.6	0.7
PrJck Lat (%)	48.1	0.2	48.4	0.2	59.1	0.3	70.4	0.4
Pit Bias (%)	30.0	0.2	29.4	0.3	41.0	0.3	48.4	0.3
Stab Ang (deg)	-35.9	0.0	-8.1	0.1	-5.4	0.2	-4.9	0.2
Theta (deg)	2.1	0.2	2.7	0.2	-0.8	0.2	-3.6	0.3
Phi (deg)	0.0	0.3	0.3	0.3	-0.3	0.6	-0.4	0.3
Roll (deg)	0.0	0.3	0.3	0.3	-0.3	0.6	-0.4	0.3
Psi (deg)	-6.8	0.1	1.5	0.3	-2.7	0.5	0.1	0.2
Heading (deg)	32.9	0.1	36.1	0.3	34.6	0.5	39.0	0.2
Q (deg/s)	-0.2	0.2	-0.1	0.4	-0.1	0.5	-0.0	0.4
P (deg/s)	0.2	0.4	0.2	0.5	0.1	0.9	0.1	0.7
R (deg/s)	0.0	0.2	0.1	0.4	-0.1	0.4	0.0	0.5
QDot (deg/s^2)	0.1	0.3	-0.1	1.5	-0.0	2.6	-0.0	2.3
PDot (deg/s^2)	0.2	1.5	0.0	2.2	0.1	4.2	-0.1	2.9
RDot (deg/s^2)	0.1	0.5	-0.0	1.1	-0.0	1.3	0.1	1.2
Ax (ft/s^2)	-0.4	0.1	-0.8	0.1	-0.7	0.2	-0.7	0.2
Ay (ft/s^2)	1.8	0.1	1.7	0.1	-0.4	0.2	-1.5	0.1
Az (ft/s^2)	-32.1	0.2	-32.2	0.5	-32.3	1.2	-32.5	0.9
DopVx (ft/s)	75.6	1.4	138.5	2.8	203.4	2.2	209.3	0.0
DopVy (ft/s)	13.8	1.6	12.5	2.8	20.8	2.3	24.6	2.6
DopVz (ft/s)	7.2	0.9	12.8	1.5	-3.9	2.7	-25.8	2.0
U (ft/s)	67.7	0.6	128.9	0.7	194.4	1.6	216.4	0.0
Z (ft)	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0
Engine1 (%)	50.3	0.5	42.0	0.4	58.6	0.8	87.4	1.4
Engine2 (%)	51.8	0.6	43.5	0.4	60.0	1.0	87.3	1.0
PitAftPstM (in)	2.8	0.0	2.6	0.0	2.4	0.0	2.3	0.0
PitFwdPstM (in)	6.3	0.0	6.2	0.0	6.4	0.0	6.8	0.0
RolAftPstM (in)	5.9	0.0	5.8	0.0	5.7	0.0	5.6	0.0
RolFwdPstM (in)	5.7	0.0	5.6	0.0	5.9	0.0	6.3	0.0

Table I5. Forward Climb/Descent

Variable	File AT828 (10-18s)		File AT829 (6-12s)		File AT830 (10-18s)		File AT831 (10-20s)		File AT831 (35-45s)		File AT832 (0-15s)		File AT833 (0-24s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	52.0	0.6	51.5	1.1	47.5	0.5	51.5	0.3	50.7	0.2	45.7	0.3	45.6	0.3
PreCycLat (%)	53.2	0.2	43.3	0.1	53.4	0.1	50.8	0.3	50.9	0.4	58.0	0.2	57.0	0.2
PreColl (%)	65.5	0.0	36.0	0.1	62.4	0.0	36.6	0.1	32.5	0.1	74.4	0.0	49.2	0.2
PrePedals(%)	37.7	0.5	54.3	0.0	50.9	0.2	62.8	0.3	61.9	0.1	56.8	1.3	61.1	2.7
AFCS Pit (%)	29.8	4.9	33.5	4.3	37.8	3.4	39.0	2.0	38.9	2.3	35.2	3.2	39.7	2.6
AFCS Roll (%)	27.0	3.0	37.3	1.9	26.9	2.6	32.3	1.8	36.4	3.4	37.5	2.3	40.7	2.5
AFCS Coll (%)	23.8	0.9	26.9	0.5	24.1	0.4	29.0	0.5	29.3	0.3	25.2	0.4	28.8	0.5
AFCS Yaw (%)	35.4	6.5	34.7	2.5	35.1	3.0	35.8	1.6	38.2	2.6	35.6	3.6	38.3	3.1
PitchPstM (%)	45.0	0.5	43.5	0.3	39.5	0.4	40.9	0.3	40.3	0.3	35.5	0.6	38.9	0.4
RollPstM (%)	42.3	0.5	37.2	0.3	44.8	1.0	44.9	0.3	45.1	0.3	44.0	0.4	48.6	0.6
YawPostM (%)	31.7	0.6	59.2	0.3	45.7	0.1	69.5	0.2	70.6	0.2	44.7	0.3	62.6	0.5
PrJck Fwd (%)	49.8	0.3	33.0	0.3	44.5	0.4	31.9	0.2	29.5	0.3	49.6	0.4	36.7	0.3
PrJck Aft (%)	42.7	0.3	57.7	0.2	40.7	0.2	55.8	0.2	58.1	0.3	32.1	0.4	47.1	0.3
PrJck Lat (%)	58.6	0.1	36.7	0.1	57.5	0.1	40.6	0.1	37.9	0.2	66.5	0.2	50.7	0.2
Pit Bias (%)	27.5	1.1	28.4	0.5	29.7	0.4	30.0	0.3	30.2	0.3	41.0	0.2	41.7	0.2
Stab Ang (deg)	-36.2	0.7	-35.1	0.4	-11.7	0.2	-5.2	0.1	-5.2	0.1	-7.0	0.2	-3.0	0.1
Theta (deg)	4.3	0.9	3.7	0.4	2.6	0.3	2.2	0.2	2.0	0.2	-0.9	0.2	-1.3	0.2
Phi (deg)	-0.2	0.4	0.3	0.3	-0.3	0.4	-0.3	0.3	0.1	0.4	0.5	0.4	0.2	0.4
Roll (deg)	-0.2	0.4	0.3	0.3	-0.3	0.4	-0.3	0.3	0.1	0.4	0.5	0.4	0.2	0.4
Psi (deg)	5.4	0.6	-0.0	0.4	-0.5	0.5	0.8	0.3	4.6	0.2	0.5	0.4	-0.3	0.5
Heading (deg)	227.2	0.6	237.4	0.4	238.0	0.5	41.4	0.3	45.2	0.2	43.8	0.4	235.1	0.5
Q (deg/s)	0.2	0.3	0.1	0.2	0.1	0.3	-0.1	0.2	-0.0	0.3	-0.1	0.4	-0.1	0.3
P (deg/s)	0.3	0.6	0.1	0.4	-0.0	0.6	0.1	0.3	0.2	0.7	0.1	0.5	0.1	0.6
R (deg/s)	-0.1	0.6	-0.2	0.3	-0.0	0.4	-0.0	0.3	0.2	0.4	0.1	0.5	0.1	0.4
QDot (deg/s^2)	-0.0	0.9	-0.0	0.4	0.1	0.8	0.0	0.5	-0.0	1.0	0.1	1.6	-0.0	1.3
PDot (deg/s^2)	-0.2	2.3	-0.1	1.6	0.1	2.0	0.0	1.2	0.0	3.0	-0.0	2.6	0.0	2.9
RDot (deg/s^2)	-0.2	1.7	-0.2	0.5	0.2	1.0	-0.1	0.5	-0.1	0.8	-0.1	1.1	0.0	1.0
Ax (ft/s^2)	-0.5	0.1	-0.8	0.1	-0.7	0.1	-0.4	0.1	-0.6	0.1	-0.6	0.3	-0.7	0.2
Ay (ft/s^2)	2.4	0.1	2.2	0.1	1.3	0.1	1.0	0.1	1.3	0.1	-0.8	0.1	-0.9	0.1
Az (ft/s^2)	-32.5	0.3	-32.4	0.2	-32.6	0.3	-32.1	0.3	-32.3	0.4	-32.2	0.7	-32.2	0.6
DopVx (ft/s)	74.9	1.5	74.6	1.0	140.5	2.2	145.5	2.4	141.9	2.1	205.3	2.5	208.6	1.3
DopVy (ft/s)	-14.8	1.8	-36.4	1.6	-20.3	2.4	15.9	2.2	7.0	2.8	16.4	3.5	-27.2	4.3
DopVz (ft/s)	-23.2	1.2	37.7	1.1	-19.0	1.0	36.5	1.5	42.1	1.1	-35.0	1.8	20.0	2.1
U (ft/s)	70.5	2.5	67.6	1.0	131.8	0.7	132.8	0.8	129.8	1.1	195.6	1.7	194.6	1.2
Z (ft)	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0	-197.4	0.0
Engine1 (%)	74.9	0.3	25.1	0.2	64.8	0.3	23.0	0.4	18.7	0.2	80.6	0.5	38.4	0.5
Engine2 (%)	76.6	0.3	26.5	0.2	66.4	0.3	24.6	0.3	20.0	0.3	82.1	0.5	40.0	0.5
PitAftPstM (in)	2.7	0.0	2.9	0.0	2.6	0.0	2.9	0.0	2.9	0.0	2.4	0.0	2.6	0.0
PitFwdPstM (in)	6.5	0.0	6.0	0.0	6.4	0.0	6.0	0.0	6.0	0.0	6.7	0.0	6.2	0.0
RolAftPstM (in)	5.7	0.0	6.1	0.0	5.7	0.0	6.0	0.0	6.0	0.0	5.6	0.0	5.7	0.0
RolFwdPstM (in)	5.9	0.0	5.4	0.0	5.8	0.0	5.4	0.0	5.3	0.0	6.1	0.0	5.6	0.0

Table I6. Autorotation

Variable	File AT834 (1-6s)		File AT835 (5-25s)		File AT836 (5-25s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	52.3	1.4	47.1	0.5	44.4	1.3
PreCycLat (%)	41.0	0.9	51.6	0.3	54.5	0.6
PreColl (%)	13.1	0.3	16.3	0.1	16.2	1.4
PrePedals(%)	55.5	0.3	50.9	2.6	55.9	1.2
AFCS Pit (%)	15.0	7.9	37.6	3.0	42.7	4.8
AFCS Roll (%)	42.1	5.6	42.1	2.6	44.7	2.6
AFCS Coll (%)	29.7	1.5	29.5	0.7	29.9	0.6
AFCS Yaw (%)	34.9	8.5	51.0	2.4	46.0	3.1
PitchPstM (%)	37.5	1.3	38.5	0.4	37.3	0.3
RollPstM (%)	37.7	0.9	48.0	0.4	50.6	0.5
YawPostM (%)	73.3	0.6	72.4	0.2	73.5	0.4
PrJck Fwd (%)	19.6	0.9	21.8	0.3	21.1	0.6
PrJck Aft (%)	68.6	0.8	67.2	0.3	66.6	1.0
PrJck Lat (%)	22.4	0.5	28.6	0.1	29.7	0.9
Pit Bias (%)	24.3	0.8	30.5	1.2	34.3	0.8
Stab Ang (deg)	-39.5	0.0	-3.8	0.6	-0.7	0.2
Theta (deg)	6.9	0.6	2.4	0.9	1.0	0.8
Phi (deg)	0.8	0.5	1.3	0.4	1.5	0.4
Roll (deg)	0.8	0.5	1.3	0.4	1.5	0.4
Psi (deg)	-1.0	0.9	-0.5	0.9	0.9	0.6
Heading (deg)	320.2	0.9	318.4	0.9	330.3	0.6
Q (deg/s)	-0.1	1.1	-0.2	0.3	-0.3	0.3
P (deg/s)	0.3	1.4	0.2	0.5	0.2	0.5
R (deg/s)	-0.8	0.8	-0.4	0.4	-0.1	0.4
QDot (deg/s^2)	0.0	2.8	0.0	0.7	-0.0	0.8
PDot (deg/s^2)	0.3	6.8	0.0	1.6	0.0	2.1
RDot (deg/s^2)	-0.4	2.2	-0.0	0.7	0.0	0.8
Ax (ft/s^2)	-2.3	0.3	-1.8	0.1	-1.5	0.1
Ay (ft/s^2)	3.1	0.3	1.8	0.1	1.0	0.1
Az (ft/s^2)	-31.2	0.4	-32.2	0.4	-31.9	0.6
DopVx (ft/s)	20.3	0.1	103.7	3.8	148.3	5.0
DopVy (ft/s)	12.1	0.1	-6.2	2.4	-3.7	5.3
DopVz (ft/s)	69.0	0.0	69.0	0.0	69.0	0.0
U (ft/s)	51.9	0.0	127.3	2.4	158.4	2.7
Z (ft)	-197.4	0.0	-197.4	0.0	-197.4	0.0
Engine1 (%)	1.0	0.1	0.8	0.2	1.7	0.7
Engine2 (%)	1.0	0.1	0.8	0.1	1.9	0.5
PitAftPstM (in)	3.2	0.0	3.2	0.0	3.1	0.0
PitFwdPstM (in)	5.7	0.0	5.8	0.0	5.8	0.0
RolAftPstM (in)	6.5	0.0	6.2	0.0	6.2	0.0
RolFwdPstM (in)	5.1	0.0	5.1	0.0	5.0	0.0

Table I7. Ground Effect Study - Over Land

Variable	File AT816 (20-25s)		File AT817 (10-20s)		File AT837 (7-12s)		File AT838 (15-20s)		File AT839 (20-30s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	58.5	0.3	59.0	0.4	65.0	0.2	64.6	0.4	68.1	0.5
PreCycLat (%)	55.8	0.6	55.0	0.4	56.7	0.2	55.9	0.8	55.8	0.1
PreColl (%)	64.2	0.8	66.2	0.5	60.2	0.2	60.7	0.6	65.2	0.0
PrePedals(%)	39.2	1.1	39.4	0.3	37.5	0.4	38.6	1.2	41.7	0.8
AFCS Pit (%)	36.2	3.1	35.2	4.4	31.2	4.0	36.8	2.9	34.6	3.3
AFCS Roll (%)	18.9	3.2	17.4	2.8	17.3	1.4	16.1	2.4	18.1	0.8
AFCS Coll (%)	33.5	0.3	33.2	0.3	22.1	0.4	22.0	0.6	22.6	2.7
AFCS Yaw (%)	30.0	6.7	30.2	6.9	37.7	4.6	30.4	6.8	27.5	5.4
PitchPstM (%)	52.4	0.7	52.5	0.8	58.3	0.5	58.7	0.3	59.7	0.5
RollPstM (%)	47.1	1.2	45.4	0.9	51.1	0.8	49.4	1.3	46.3	0.2
YawPostM (%)	31.6	0.3	30.6	0.6	32.8	0.4	33.5	0.7	33.0	0.7
PrJck Fwd (%)	53.6	0.5	54.6	0.6	56.3	0.4	57.0	0.3	60.5	0.5
PrJck Aft (%)	48.1	0.6	47.3	0.6	53.4	0.3	53.3	0.4	51.8	0.4
PrJck Lat (%)	58.8	0.6	59.6	0.3	57.8	0.2	57.9	0.4	60.4	0.2
Pit Bias (%)	26.6	0.2	26.5	0.4	28.2	0.3	29.1	0.8	29.3	0.3
Stab Ang (deg)	-39.5	0.0	-39.5	0.0	-39.4	0.0	-39.4	0.0	-39.5	0.0
Theta (deg)	5.2	0.1	5.3	0.2	3.4	0.2	2.7	0.6	2.6	0.3
Phi (deg)	-1.7	0.4	-2.0	0.4	-2.0	0.4	-2.6	0.6	-2.5	0.4
Roll (deg)	-1.7	0.4	-2.0	0.4	-2.0	0.4	-2.6	0.6	-2.5	0.4
Psi (deg)	-4.2	0.9	-0.7	0.3	4.6	0.5	-3.3	0.2	-1.1	0.6
Heading (deg)	295.6	0.9	298.0	0.3	314.5	0.5	321.5	0.2	326.2	0.6
Q (deg/s)	-0.2	0.4	-0.1	0.5	-0.1	0.5	0.2	0.3	-0.1	0.4
P (deg/s)	0.1	0.9	0.0	0.8	0.2	0.4	-0.2	1.0	0.2	0.3
R (deg/s)	-1.2	0.5	-0.4	0.7	-0.5	0.5	-0.3	0.6	-0.3	0.5
QDot (deg/s²)	0.2	0.9	0.2	1.9	-0.5	1.1	-0.0	1.6	0.2	0.7
PDot (deg/s²)	-0.0	3.2	-0.1	2.8	-0.0	1.5	0.2	3.1	-0.0	1.1
RDot (deg/s²)	-0.0	1.2	-0.1	1.2	0.1	1.3	0.1	0.8	-0.0	0.8
Ax (ft/s²)	-0.2	0.1	-0.0	0.2	0.1	0.1	0.2	0.4	0.2	0.1
Ay (ft/s²)	4.0	0.2	4.0	0.2	2.6	0.1	2.5	0.1	2.2	0.1
Az (ft/s²)	-32.4	0.5	-32.5	0.4	-32.2	0.3	-32.3	0.4	-32.4	0.2
DopVx (ft/s)	0.4	1.2	-0.6	1.2	-5.9	0.5	-8.2	0.6	-5.3	1.1
DopVy (ft/s)	0.6	1.1	-0.2	1.6	0.2	0.5	1.8	0.7	0.3	1.0
DopVz (ft/s)	-0.0	1.0	-0.2	1.1	-1.2	0.4	-1.0	0.3	-0.6	0.5
U (ft/s)	52.7	0.0	52.7	0.0	51.8	0.0	51.8	0.1	51.8	0.0
Z (ft)	-10.3	0.7	-16.2	1.0	-9.6	0.7	-15.1	0.9	-95.1	1.1
Engine1 (%)	73.0	1.4	76.1	1.1	64.0	0.6	65.5	1.0	70.7	0.6
Engine2 (%)	74.4	1.8	77.6	1.4	65.8	0.9	66.8	1.1	72.3	0.8
PitAftPstM (in)	3.0	0.0	3.0	0.0	3.1	0.0	3.2	0.0	3.2	0.0
PitFwdPstM (in)	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.6	0.0
RolAftPstM (in)	5.7	0.0	5.7	0.0	5.6	0.0	5.6	0.0	5.6	0.0
RolFwdPstM (in)	5.8	0.1	5.9	0.0	5.7	0.0	5.7	0.0	5.9	0.0

Table I8. Ground Effect Study at Sea $\frac{W}{\sigma} \approx 17000$ lbf

Variable	File AL151 (18-25s)		File AL151 (40-50s)		File AL152 (12-22s)		File AL152 (40-50s)		File AL152 (60-66s)		File AL158 (27-37s)		File AL158 (45-55s)		File AL159 (30-40s)		File AL159 (48-58s)		File AL159 (85-95s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	61.6	2.3	61.3	1.4	64.1	2.8	61.0	1.8	61.1	3.7	57.5	2.2	59.0	1.9	57.6	2.9	58.4	2.3	59.8	3.2
PreCycLat (%)	55.9	2.2	55.0	1.2	55.7	2.0	54.5	2.2	56.1	2.6	56.8	2.4	56.8	3.1	56.7	2.6	56.3	2.1	58.0	2.0
PreColl (%)	63.6	1.6	64.0	1.0	63.6	1.7	63.8	2.5	64.0	2.6	63.0	2.1	63.0	2.4	63.4	2.7	63.4	1.6	65.4	1.7
PrePedals(%)	39.6	1.3	39.3	1.6	39.0	1.8	40.4	0.9	38.8	1.1	36.4	1.6	37.9	2.0	38.8	2.1	36.5	2.6	37.5	2.3
AFCS Pit (%)	29.5	12.3	33.9	7.2	18.3	13.6	36.2	9.9	31.6	14.1	42.7	11.9	40.3	12.5	46.5	14.1	47.3	10.8	44.5	16.3
AFCS Roll (%)	24.6	5.6	23.8	3.9	23.8	5.5	22.9	5.7	25.1	9.0	24.9	7.2	25.7	9.0	24.1	9.3	23.8	5.1	22.4	6.1
AFCS Coll (%)	29.6	1.0	29.2	0.9	28.7	1.2	28.7	1.2	28.7	1.8	28.6	1.4	28.7	1.4	28.7	1.6	28.5	1.2	28.6	1.4
AFCS Yaw (%)	45.7	2.3	46.1	2.6	46.4	3.2	46.1	2.3	46.8	2.0	45.8	2.7	46.3	3.0	45.4	2.9	45.1	2.3	46.6	2.8
PitchPstM (%)	53.8	1.7	54.1	1.7	53.7	2.9	54.2	1.8	53.6	3.3	53.6	2.0	53.7	2.3	53.3	2.4	54.3	1.9	54.3	2.8
RollPstM (%)	46.3	1.6	45.7	1.3	47.1	1.6	45.6	2.2	46.8	2.1	47.2	2.0	47.0	2.6	46.9	2.5	46.6	1.8	48.1	1.9
YawPostM (%)	31.3	1.5	31.4	1.5	31.5	2.0	32.4	2.3	31.4	2.5	29.3	3.0	31.3	3.1	31.7	2.6	30.4	2.4	30.9	1.8
PrJck Fwd (%)	54.9	1.0	55.3	1.0	54.8	1.6	55.3	1.7	55.1	2.8	54.7	1.5	54.8	1.5	54.8	1.4	55.4	1.5	56.7	2.0
PrJck Aft (%)	49.2	1.7	49.2	1.4	49.0	2.4	49.2	1.8	48.8	2.3	49.3	1.9	49.2	2.3	48.8	2.6	49.5	1.6	48.4	2.1
PrJck Lat (%)	58.9	1.3	58.8	0.8	59.0	1.4	58.9	1.8	59.4	1.7	58.9	1.7	59.0	1.9	59.3	2.1	59.1	1.1	61.1	1.3
Pit Bias (%)	26.3	1.6	26.7	0.6	25.2	1.7	27.0	1.1	26.7	1.6	27.1	1.2	26.9	1.1	26.7	1.6	27.0	1.2	27.2	1.8
Stab Ang (deg)	-39.4	0.0	-39.4	0.0	-39.5	0.0	-39.5	0.0	-39.5	0.0	-39.5	0.0	-39.5	0.0	-39.5	0.0	-39.4	0.0	-39.5	0.0
Theta (deg)	5.2	1.2	4.9	0.4	6.0	1.2	4.6	0.9	4.9	1.1	4.5	0.8	4.7	0.8	4.7	1.1	4.6	0.8	4.6	1.2
Phi (deg)	-2.6	1.4	-2.3	0.6	-2.7	0.9	-2.9	0.9	-3.0	1.7	-2.1	1.2	-2.4	1.7	-2.4	1.6	-2.4	1.0	-3.6	1.2
Roll (deg)	-2.6	1.4	-2.3	0.6	-2.7	0.9	-2.9	0.9	-3.0	1.7	-2.2	1.2	-2.4	1.7	-2.5	1.6	-2.4	1.0	-3.6	1.2
Psi (deg)	-2.8	0.7	-8.8	0.8	-3.9	4.2	-25.3	1.5	-24.9	0.9	0.6	0.9	-4.5	1.6	-9.2	1.4	-12.0	0.9	-17.8	1.0
Heading (deg)	218.7	0.7	212.7	0.8	218.7	4.2	197.3	1.5	197.7	0.8	194.4	0.9	189.2	1.6	188.9	1.4	186.1	0.9	180.3	1.0
Q (deg/s)	-0.4	1.2	-0.1	0.8	-0.1	1.7	-0.1	1.0	-0.2	1.6	-0.0	1.2	-0.0	1.3	0.1	1.6	-0.1	1.4	0.0	2.1
P (deg/s)	0.3	2.7	0.2	1.8	0.1	2.3	0.1	3.0	1.0	4.0	0.3	2.8	0.3	3.6	-0.4	3.8	0.2	2.3	0.0	2.8
R (deg/s)	0.1	1.0	-0.1	1.2	-0.2	1.7	-0.5	1.1	-0.5	0.9	-0.3	1.3	-0.5	1.6	-0.1	1.5	0.2	1.2	-0.2	1.5
QDot (deg/s^2)	0.1	3.1	0.0	3.0	0.0	4.4	0.1	3.2	0.3	5.4	-0.1	3.1	-0.0	3.7	0.0	3.6	0.1	3.4	0.1	5.0
PDot (deg/s^2)	0.0	9.2	0.0	8.9	-0.1	7.4	-0.6	13.2	-1.2	14.3	0.2	10.5	0.3	12.5	-0.5	17.4	-0.0	8.4	0.1	12.6
RDot (deg/s^2)	-0.1	2.3	-0.1	3.3	0.1	4.4	-0.1	3.3	-0.2	2.1	0.1	3.3	-0.1	4.6	-0.1	3.9	-0.0	2.6	-0.4	3.5
Ax (ft/s^2)	0.0	0.4	0.0	0.4	0.1	0.4	0.2	0.4	0.2	0.5	0.1	0.5	0.1	0.5	0.2	0.5	0.2	0.3	0.5	0.4
Ay (ft/s^2)	3.7	0.5	3.7	0.4	3.7	0.6	3.6	0.5	3.7	0.7	3.6	0.5	3.6	0.6	3.7	0.6	3.5	0.5	3.3	0.7
Az (ft/s^2)	-32.0	1.4	-32.4	0.7	-32.4	1.2	-32.2	1.8	-31.8	1.8	-32.2	1.4	-32.4	1.5	-32.3	1.9	-32.3	1.2	-32.3	1.2
DopVx (ft/s)	-0.0	1.2	-0.2	0.8	2.8	2.6	-0.1	0.8	-0.9	1.2	-0.1	1.1	-0.1	0.8	-0.5	0.9	0.0	1.0	-0.4	0.9
DopVy (ft/s)	0.3	1.4	0.2	1.1	0.3	1.3	0.4	1.3	0.6	0.9	0.3	1.3	0.0	1.3	0.3	1.3	0.1	1.3	0.9	1.3
DopVz (ft/s)	-0.3	1.2	-0.1	0.8	0.9	1.4	-0.1	1.3	0.2	1.0	-0.0	1.0	-0.1	1.1	-0.0	1.0	0.0	0.8	0.4	1.0
U (ft/s)	52.2	0.0	52.2	0.0	52.2	0.0	52.2	0.1	52.2	0.0	52.0	0.0	52.0	0.0	52.0	0.0	52.0	0.0	52.0	0.0
Z (ft)	-15.3	0.6	-14.4	0.3	-14.1	1.4	-14.5	0.9	-11.2	0.3	-10.6	0.5	-12.1	0.8	-13.5	0.6	-13.7	0.6	-12.4	0.6
Engine1 (%)	74.5	3.4	74.3	1.5	73.8	3.4	73.8	5.7	74.6	6.2	73.7	5.1	74.1	5.9	74.0	5.4	74.3	4.6	76.7	3.5
Engine2 (%)	75.0	3.3	76.1	1.8	75.1	3.6	74.9	6.4	76.9	6.5	75.5	6.1	75.7	6.3	75.3	6.0	76.0	4.6	78.3	3.5
PitAftPstM (in)	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1	3.0	0.1
PitFwdPstM (in)	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0	6.5	0.0
RolAftPstM (in)	5.6	0.0	5.7	0.0	5.6	0.0	5.7	0.0	5.6	0.0	5.6	0.1	5.6	0.1	5.6	0.1	5.6	0.0	5.6	0.0
RolFwdPstM (in)	5.9	0.0	5.9	0.0	5.8	0.0	5.9	0.1	5.9	0.1	5.9	0.0	5.9	0.0	5.9	0.1	5.9	0.0	5.9	0.0

Table I9. Ground Effect Study at Sea $\frac{W}{\sigma} \approx 19000$ lbf

Variable	File AL100 (35-45s)		File AL173 (30-35s)		File AL174 (30-40s)		File AL174 (45-55s)	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
PreCycLon (%)	59.8	1.2	65.9	3.7	62.1	1.4	62.5	1.1
PreCycLat (%)	57.3	3.4	56.0	3.0	54.4	1.6	55.1	2.9
PreColl (%)	66.1	1.8	67.1	1.5	66.6	1.1	67.3	1.3
PrePedals(%)	38.9	1.5	38.1	1.5	38.4	1.2	39.0	1.5
AFCS Pit (%)	32.4	7.7	16.6	13.4	35.2	5.8	35.2	5.0
AFCS Roll (%)	28.6	10.9	13.5	10.8	13.1	7.5	12.2	8.6
AFCS Coll (%)	26.8	0.8	29.2	1.2	29.4	0.9	29.4	0.7
AFCS Yaw (%)	44.7	2.8	19.5	11.1	17.9	10.8	15.0	9.8
PitchPstM (%)	54.0	1.2	54.5	2.7	55.2	1.0	55.6	1.2
RollPstM (%)	46.0	2.2	45.2	3.1	44.4	1.3	45.0	2.3
YawPostM (%)	30.0	2.0	28.6	2.7	29.1	1.2	28.9	1.5
PrJck Fwd (%)	56.4	1.0	57.9	2.0	58.2	0.9	58.8	1.1
PrJck Aft (%)	47.9	1.4	47.5	1.9	48.1	0.9	48.0	1.2
PrJck Lat (%)	60.8	1.5	61.4	1.3	60.7	1.0	61.4	1.3
Pit Bias (%)	27.6	0.8	25.4	2.7	27.2	0.8	27.2	0.5
Stab Ang (deg)	-39.5	0.0	-39.5	0.0	-39.5	0.0	-39.6	0.0
Theta (deg)	3.7	0.6	5.7	2.0	4.3	0.6	4.3	0.4
Phi (deg)	-1.4	2.1	-1.4	1.1	-1.9	1.4	-2.1	1.4
Roll (deg)	-1.4	2.1	-1.4	1.1	-1.9	1.4	-2.1	1.4
Psi (deg)	-4.1	0.8	3.3	0.4	-4.4	0.7	-4.2	1.0
Heading (deg)	6.3	0.8	256.0	0.4	242.7	0.7	242.9	1.0
Q (deg/s)	-0.1	0.7	0.7	1.8	-0.0	0.6	-0.2	0.6
P (deg/s)	0.4	3.4	0.2	3.4	0.3	1.6	-0.1	2.7
R (deg/s)	-0.1	1.4	0.2	1.0	-0.2	1.0	0.3	1.0
QDot (deg/s^2)	0.1	2.1	-0.0	4.0	0.1	1.8	-0.0	1.8
PDot (deg/s^2)	0.7	11.2	-2.1	13.0	-0.0	5.6	0.4	9.6
RDot (deg/s^2)	-0.1	3.9	-0.3	2.3	-0.1	2.6	-0.1	2.7
Ax (ft/s^2)	-0.1	0.5	-0.0	0.5	-0.0	0.3	0.0	0.4
Ay (ft/s^2)	3.7	0.4	3.2	0.6	3.3	0.3	3.2	0.3
Az (ft/s^2)	-32.2	1.2	-32.2	0.8	-32.1	0.8	-32.1	0.9
DopVx (ft/s)	-0.5	0.9	3.9	1.3	-0.2	1.0	-0.3	0.9
DopVy (ft/s)	-0.1	1.2	-1.2	1.0	0.1	1.2	0.2	1.2
DopVz (ft/s)	-0.2	1.1	1.7	0.8	-0.1	0.7	-0.2	0.8
U (ft/s)	52.2	0.1	51.9	0.0	51.8	0.0	51.8	0.2
Z (ft)	-3.2	0.6	-8.4	0.7	-9.8	0.4	-8.3	0.4
Engine1 (%)	80.5	5.3	84.3	4.7	81.3	2.0	81.5	2.3
Engine2 (%)	81.1	5.3	81.7	4.6	81.8	2.5	83.5	2.3
PitAftPstM (in)	3.0	0.0	3.0	0.1	3.0	0.0	3.0	0.0
PitFwdPstM (in)	6.5	0.0	6.6	0.0	6.6	0.0	6.6	0.0
RolAftPstM (in)	5.6	0.1	5.6	0.1	5.6	0.0	5.6	0.1
RolFwdPstM (in)	5.9	0.0	6.0	0.0	6.0	0.0	6.0	0.0

APPENDIX J - CALIBRATION CORRECTION FOR STABILATOR ANGLES

Observations of the flight data showed that the measured stabilator angle for all hover cases indicated about -36.4°. However, the true angle of the stabilator in hover is known to be -40°. This discrepancy could be due to an error in either the calibration scale or offset factors, or both.

Program *GenHel* (Refs 13,14) was originally obtained from the Naval Air Warfare Center (NAWC) under the auspices of The Technical Cooperation Panel. *GenHel,* which uses a blade element model to represent the rotor aerodynamics, has been tested for validity by Ballin (Ref. 15) at NASA Ames for the US UH-60A Black Hawk (or S-70A-1), and has been shown to represent the aircraft flight behaviour reasonably well. Preliminary comparisons between *GenHel* and the performance data show that the model also predicts the behaviour of the S-70B-2 reasonably well (Ref. 16). The *GenHel* equations were used to determine the correct stabilator angle for a given flight condition. A Microsoft *Excel* spreadsheet that used the *GenHel* equations for the stabilator scheduling, which is a function of airspeed, collective stick position, pitch rate, and lateral acceleration, was created. For the hover and level flight evolutions, the mean airspeed, collective stick position, pitch rate, and lateral acceleration were input to the spreadsheet and stabilator angles were calculated.

Program *Kaleidagraph* was used to plot the *GenHel* stabilator angles against the measured stabilator angles and determine a best fit straightline. However, in order to force the best fit equation to give a stabilator angle of -40° when the measured data indicated -36.4°, the measured data were first incremented by 36.4°. By plotting this offset data against the *GenHel* data, an equation of the form $y = mx' - 40$ was fitted, where x' was the measured stabilator angle + 36.4° and y was the *GenHel* stabilator angle (Fig. J1). The measured, offset, and *GenHel* stabilator angles are shown in Table J1.

Table J1. Measured and Calculated Stabilator Angles

Evolution	Level Flight Airspeed (kn)	Measured Stab Angle (deg)	Offset Measured Stab Angle (deg)	*GenHel* Stab Angle (deg)
AT807[1]	0	-36.4	0	-40.0
AT821	40	-32.6	3.8	-35.3
AT822	76	-6.9	29.5	-9.7
AT823	115	-4.4	32.0	-4.6
AT824	128	-3.9	32.5	-4.3

From Fig. J1, the equation for the stabilator angle is

$$y = 1.0809x' - 40$$

where $x' = x + 36.4$ and x is the measured stabilator angle. Thus

$$\begin{aligned} y &= 1.0809(x + 36.4) - 40 \\ &= 1.0809x - 0.65524 \end{aligned}$$

[1] AT807 was chosen to represent the hover data, although all the IGE hovers AT800 to AT806 indicated a stabilator angle of -36.4°.

For future data processing of aircraft data (Refs 2,3), the calibration file (Appendix E) needs to be modified so that the calibration factor for the stabilator angle (Channel 54) becomes $1.0809(5.4932E-03) = 5.9376E-03$, and the offset factor becomes -0.65524.

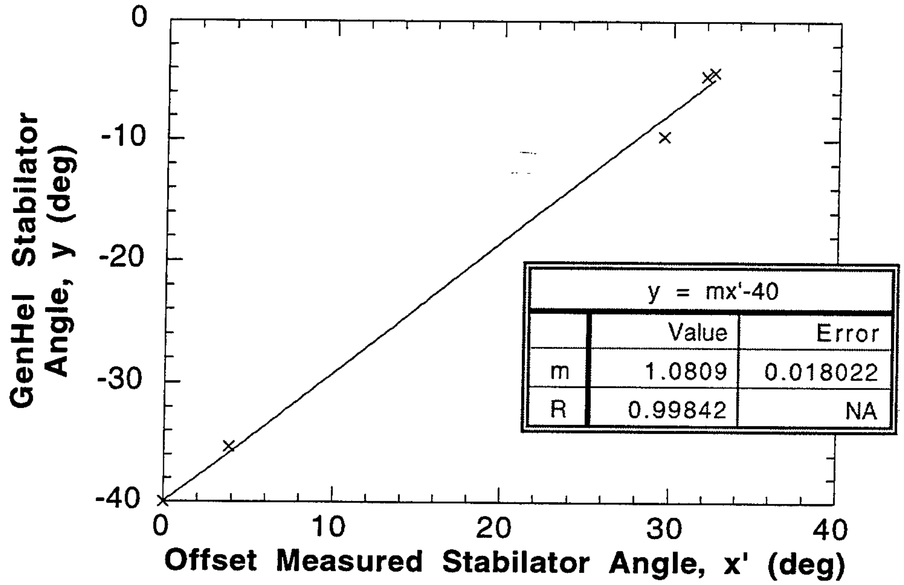


Figure J1. Curve Fit for Offset Measured Stabilator Angle vs *GenHel* Angle

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2. TITLE Australian Airborne Trials of the Sikorsky S-70B-2 Helicopter: Part I - Performance Measurements			3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)	
4. AUTHOR(S) A. M. Arney and I. Fieldhouse			5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory PO Box 4331 Melbourne Vic 3001	
6a. DSTO NUMBER DSTO-TR-0463	6b. AR NUMBER AR-009-955		6c. TYPE OF REPORT Technical Report	7. DOCUMENT DATE January 1997
8. FILE NUMBER M1/8/882	9. TASK NUMBER NAV 95/183	10. TASK SPONSOR DAVENG-N	11. NO. OF PAGES 72	12. NO. OF REFERENCES 16
13. DOWNGRADING/DELIMITING INSTRUCTIONS None			14. RELEASE AUTHORITY Chief, Air Operations Division	

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

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17. CASUAL ANNOUNCEMENT Yes

18. DEFTEST DESCRIPTORS

Flight tests, Sikorsky helicopters, Oliver Hazard Class Perry frigates, performance tests, flight dynamics, mathematical models

19. ABSTRACT

Airborne tests have been conducted using an instrumented Sikorsky S-70B-2 helicopter. These tests were flown by a Royal Australian Navy Test Pilot and were primarily aimed at establishing limits for the S-70B-2 when operating from an 'Adelaide' class FFG-7 frigate. While the aircraft was instrumented, the opportunity was taken to fly a series of performance and flight dynamic tests to establish baseline data that will be used to further develop a mathematical model of the helicopter. This report details the scope of the performance tests, describes data processing procedures, and presents results of the tests.

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