To the Graduate Council:

I am submitting herewith a thesis written by Joseph Benson Sudderth entitled "Instrumentation of the United States Forest Service Baron 58P N132Z for Flight Testing." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Ralph D. Kimberlin

Dr. Ralph Kimberlin, Major Professor

We have read this thesis
and recommend its acceptance:

Charles J. N. Baldwin

Uwe Peter Solies

Accepted for Council:

Lew Minkel

Associate Vice Chancellor
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Joseph B Swedlund

Date 8-21-92

INSTRUMENTATION OF THE UNITED STATES FOREST SERVICE BARON 58P N132Z FOR FLIGHT TESTING

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Joseph Benson Sudderth

December 1992

DEDICATION

TO MY FAMILY

WHOSE LOVE AND

ENCOURAGEMENT PROVIDED ME

WITH THE STRENGTH NEEDED

TO COMPLETE THIS PROGRAM

ACKNOWLEDGEMENTS

The author would like to thank Dr. Ralph D. Kimberlin, advisor and chairman of the thesis committee, for his support when it was needed most. The author would also like to thank the other committee members, Dr. Charles T. N. Paludan and Dr. Uwe Peter Solies and for their advice and assistance in the completion of this thesis.

The author thanks Paul Sims and Bob Jones for sharing their expertise in the field of instrumentation. Thanks to Betsy Smith for taking care business and Roy Smith for keeping the planes in the air.

ABSTRACT

This thesis describes the instrumentation package used to collect and reduce the data acquired while flight testing the United States Forest Service's Beechcraft Baron 58P N132Z.

The system consisted of sensing instruments, a signal conditioner, a personal computer and appropriate software. Power to the sensors and the computer was controlled by the flight test engineer. Data were collected for twenty minutes and stored in the computers memory. At the end of twenty minutes the data were downloaded to a floppy disk. The data on the floppy disk were manipulated on a separate personal computer's for analysis once on the ground. The system was reliable and provided a quick and easy way to interpret the data.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	Background Information	1
	Lead Plane Maneuver	2
II.	DESCRIPTION OF TEST ARTICLE	3
	Aircraft Description	3
	Vortex Generators	4
III.	TEST OBJECTIVES	6
	Safe Operating Range	6
	Vortex Generator Effectiveness Test	6
IV.	DESCRIPTION OF AIRCRAFT INSTRUMENTATION	8
	Alpha and Beta	8
	Aileron Position	10
	Rudder Position	12
	Elevator Position	13
	Airspeed and Altitude	13
	Angles of Pitch and Roll	16
	Rates of Pitch, Roll and Yaw	18
	Acceleration along the X,Y, and Z axis	19
	Instrumentation Container	20
	Time	20
	Thermocouple	21
	Signal Conditioner	21

CHAPTER PAGE

IV. (Continued)

Computer 22

Wing Tufts 23

Calibration Methods 23

V. SOFTWARE 28

Labtech Notebook Version XE 28

Smart 3.0 28

Slidewrite Plus Four 4.0 29

Mathcad 3.0 29

VI. ANALYSIS AND DISCUSSION 30

Euler Angles 30

Noise 30

VII. SYSTEM OPERATION AND RESULTS 34

VIII. CONCLUSIONS 35

IX. RECOMMENDATIONS 36

LIST OF REFERENCES 37

APPENDICES 39

APPENDIX A 40

APPENDIX B 43

APPENDIX C 48

VITA 65

LIST OF FIGURES

FIGURE	PAGE
1. Baron 58P Three View Drawing	5
2. Alpha and Beta Boom and Boom Mount	9
3. Block Diagram of a Potentiometer	11
4. Block Diagram of a Wheatstone Bridge	14
5. Block Diagram of a Vertical Gyroscope	17
6. Flow Visualization Tufts	24
7. Euler Angle Analysis.	31
8. Noise Reduction	33
A.1 Power Distribution	41
A.2 Signal Conditioner and Computer	42
B.1 Lead Plane Maneuver with VGs Installed	44
B.2 Lead Plane Maneuver with VGs Removed and Installed	45
B.3 Lead Plane Maneuver with VGs Removed	46
B.4 Lead Plane Maneuver with VGs Removed	47
C.1 Differential Pressure Transducer Calibration	49
C.2 Absolute Pressure Transducer Calibration.	50
C.3 Roll Rate Calibration	51
C.4 Pitch Rate Calibration.	52
C.5 Yaw Rate Calibration	53
C.6 Roll Angle Calibration.	54
C.7 Pitch Angle Calibration	55
C.8 N_z Calibration	56
C.9 N_x Calibration	57

FIGURE PAGE

C.10 N_y Calibration 58

C.11 Elevator Position Calibration 59

C.12 Aileron Position Calibration 60

C.13 Rudder Position Calibration 61

C.14 Beta Calibration 62

C.15 Alpha Calibration 63

C.16 Baron Airspeed Indicator Instrument Correction . 64

CHAPTER I

INTRODUCTION

A. Background Information

The University of Tennessee Space Institute was awarded a contract on March 9, 1992 to investigate the safety of the Lead Plane Maneuver performed by the Forest Service in their Beechcraft B-58P Barons. The investigation was deemed necessary after two Barons departed controlled flight while performing the Lead Plane Maneuver.

The National Transportation Safety Board (NTSB) acknowledged that the Baron would enter a flat spin at high asymmetric power settings and low speed. The NTSB has sent safety recommendations to the FAA requesting that all Barons be retrofitted with aerodynamic air flow kits to reduce the hazardous single engine stall characteristics (1).

VG Systems, Inc. of Saint Paul, Minnesota, manufactures Vortex Generators (VGs) that are advertised to comply with NTSB recommendations for the Baron, and has offered to outfit the Forest Service's 20 Barons used to perform the Lead Plane Maneuver (2).

The Forest Service has contracted with the Space Institute to establish a safe envelope for the Lead Plane Maneuver, and to determine if the benefits derived from the installation of the VGs justify their cost.

B. Lead Plane Maneuver

During the Lead Plane Mission the pilot must scout the drop zone and determine the target area for the fire retardant drop. The pilot then intercepts the tanker and leads it to the target area. Once over the target the pilot marks the drop zone for the tanker by pulling up and continues the Lead Plane Maneuver in order to evaluate the drop. The maneuver consists of an ascending left bank turn with power added for best climb performance. The maneuver is entered at an indicated airspeed between 140 and 150 knots. The lead plane pilot must be aware of air traffic and ground personnel position in order to ensure a safe drop. Low visibility due to smoke, varying terrain and turbulence increase the difficulty of the maneuver. The lead plane pilot cannot add power too soon or the tanker will lose visual contact. Once the mission is complete the lead plane pilot must critique the drop and determine the next drop position (3). A comprehensive description of the Lead Plane Mission can be found in "A Flight Test Evaluation of the Beechcraft 58p Lead Plane Mission Profile for the Forest Service" , a thesis written by Joseph Sedor (4).

CHAPTER II

DESCRIPTION OF TEST ARTICLE

A. Aircraft Description

The Beechcraft Baron 58P is a low wing light twin powered by two horizontally opposed Teledyne Continental TSIO-520-WB six-cylinder engines. The engines are direct-drive, turbocharged and fuel injected, each rated at 325 horsepower at 2700 RPM and a manifold pressure of 39.5 inches of mercury. The engines drive two McCauley constant speed, three bladed propellers using 3AF32C511 hubs with 82NEA-4 blades. The 58P has 172 gallon total fuel capacity with 166 of usable fuel on board. The Baron tested is serial number TJ-284 and was manufactured in May of 1980. The type certificate number is A23CE and the registration number is N132Z. The plane belongs to the United Sates Forest Service and was delivered with 3344.7 hours total time. As of June 3, 1991 the plane had a weight of 4496.70 pounds corresponding to a center of gravity 75.50 inches aft of the datum point producing a moment of 339500 inch pounds. The plane, in its test condition, weighed 5550 pounds with 996 pounds of that being fuel weight. The Baron has a wing area of 188.131 square feet over a span of 37 feet and 10 inches. The maximum take off weight is 6200 pounds and the zero fuel weight is 5700 pounds. The test center of gravity was calculated with a 200 pound pilot and a 40 pound pack in front. A three view diagram of the Baron is shown in Figure 1 (5).

B. Vortex Generators

The Baron arrived at the Space Institute with Vortex Generators installed. The Vortex Generators (VGs) were installed per Supplemental Type Certificate number is SA4016NM issued February 26, 1988 (6). The VGs kit consisted of 111 VGs, 34 outboard of the engine nacelle, four inboard of the engine nacelle on top of the leading edge of each wing and 35 on the left leading edge of the vertical stabilizer.

The VGs create counter rotating vortices that add energy to the boundary layer by mixing the high energy freestream flow with the low energy boundary layer. The increased boundary layer energy results in the boundary layer remaining attached to the wing at higher angles of attack than is possible without the VGs (4).

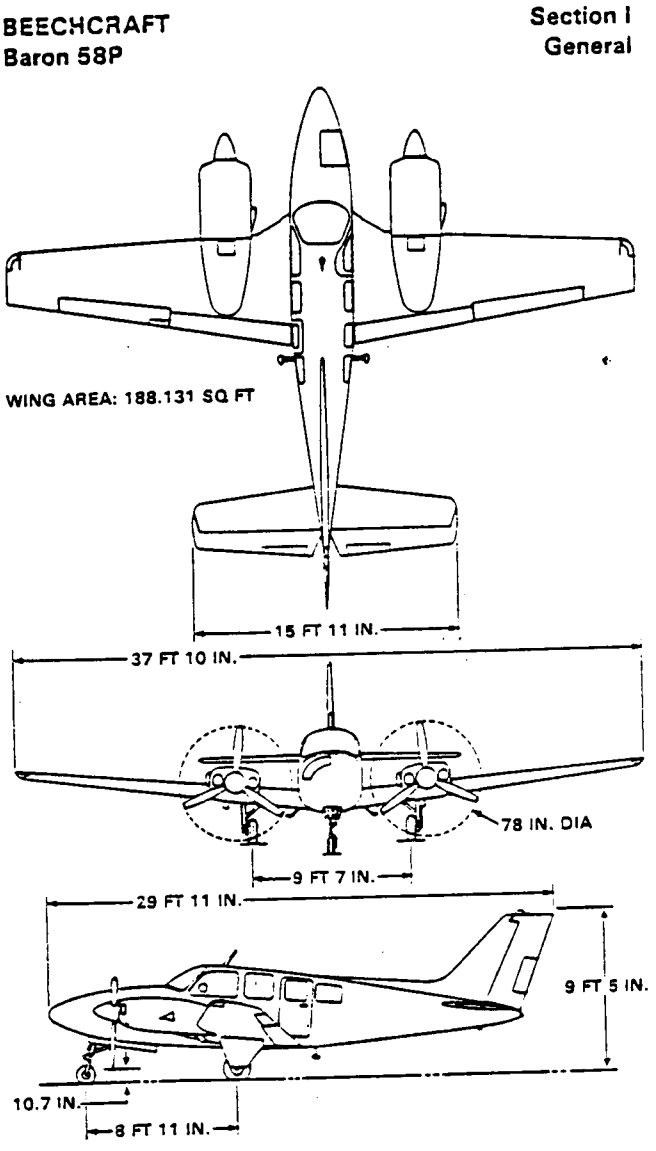


Figure 1.- Baron 58P Three view

Source: Beechcraft Pressurized Baron 58P Pilot's Operating Handbook FAA Approved Airplane Flight Manual. Kansas: Commercial Publications, 1990.

CHAPTER III

Test Objectives

A. Safe Operation Range

The objectives of the flight tests were to determine if the Lead Plane Maneuver is safe and determine if the margin of safety can be increased by installing VGs on the lead plane. To determine the safety of the Lead Plane Maneuver it was necessary to determine minimum entry speeds, maximum load factors and maximum bank angles. A fuel unporting test was also performed to determine if the risk of performing the maneuver was increased with minimum fuel in one wing. A comprehensive Flight Test plan can be found in Joseph Sedor's Thesis (4).

B. Vortex Generator Effectiveness

The testing of the VGs included the determination of loss of level flight performance due to increased drag, the decrease in stall speed due to delayed separation of the high energy boundary layer, and improved stall characteristics due to the airflow over the ailerons remaining attached at higher angles of attack. Power off and power on level stalls were performed with the VGs installed, with only the VGs in board of the nacelle removed and all the VGs removed. The stalls were performed to determine the VGs' effects on stall speed and stall characteristics. Level Flight Performance Tests

were performed with the VGs installed and removed to determine loss of excess power due to increased drag.

CHAPTER IV

Description of Aircraft Instrumentation

In order to establish an envelope of safe operating ranges for the Lead Plane Maneuver, and any increased safety due to the VGs, the following parameters were monitored.

A. Alpha and Beta

Angle of attack, alpha and sideslip angle, beta were measured using two vanes driving dial potentiometers mounted ninety degrees to each other on a boom that was secured to the tip of the left wing. The boom is shown in Figure 2. The alpha and beta potentiometers were powered by five volts DC supplied by a DC to DC converter. The DC to DC converter was powered by the ship's 28 volts DC power supply. The alpha potentiometer was calibrated between the range of positive and negative 20 degrees, producing a linear output voltage between plus or minus one volt DC, with nose up being the positive sense. The beta potentiometer was calibrated between the range positive and negative 20 degrees, producing a linear output between plus or minus one volt DC, with nose right being the positive sense. Both potentiometers were five kilohms with a non-linearity of plus or minus one percent.

The boom was constructed of a titanium conduit with a wooden beam cut to conform to fit the under side of the left wing tip. The wooden base was mounted to the wing with a

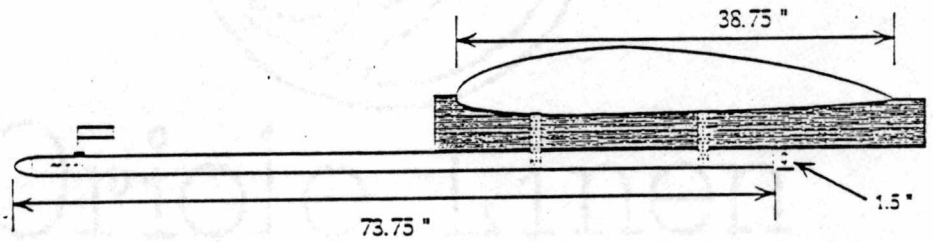


Figure 2.- Alpha and Beta Boom and Boom Mount

five eighths inch stainless steel band that ran over the wing and under the base placing the wood in compression. Mounted to the base of the boom was a 73.75 inch titanium pipe one and a half in diameter. The shaft was secured to the base with two five eighths inch stainless bands 32.75 inches apart.

The boom was mounted to the wing so the vanes were at least one chord length in front of the leading to minimize distortions of the free stream. The vanes were six and a half inches by an inch and a half and attached to the potentiometers on four inch metal stems. The electrical cables for the flow angle sensors were wired inside the wing along a wing stiffener and then through the flap housing, under the fuselage into the rear compartment. It then continued through the modified rear pressure bulkhead and into the signal conditioner. The boom weighed seven pounds. Figure 3 shows a block diagram of a potentiometer.

B. Aileron Position

The aileron position was measured by a linear potentiometer mounted inside the left wing and connected to the belcrank for the aileron cable. The potentiometer used was a slide type with a total resistance of five kilohms plus or minus 20 percent with a non-linearity of plus or

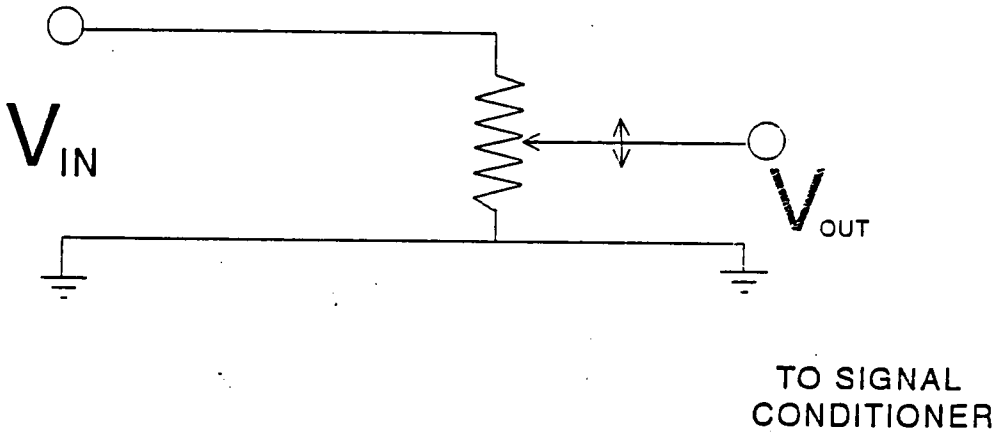


Figure 3. Block diagram of a potentiometer.

minus one percent. A five volts DC to DC converter powered the sensor. The potentiometer was calibrated through the aileron's full range of travel of positive 20 degrees and negative 18 degrees with the left trailing edge down being the positive sense. This range of travel produced a linear output between positive 4.07 volts DC and minus 2.29 volts DC. The potentiometer's electrical cable was routed beside the boom wire through the flap housing, under the fuselage and through the modified rear pressure bulkhead to the signal conditioner.

C. Rudder Position

The slide type potentiometer used to measure rudder position was mounted in the tail cone and connected to the rudder at the point where the cable meets the rudder. This potentiometer had a five kilohms resistance plus or minus 20 percent with a non-linearity of one percent. It was powered by five volts DC supplied by the DC to DC converter. The potentiometer was calibrated through the rudder's full range of positive 20 degrees and negative 19 degrees with trailing edge left being the positive sense. This range of travel produced a linear output between positive 6.6 volts DC and negative 1.44 volts DC. The potentiometer's electrical cable was routed along a fuselage stiffener through the modified rear pressure bulkhead and into the signal conditioner.

D. Elevator Position

A slide type potentiometer mounted in the aft fuselage and attached to the elevator cable was used to measure elevator position. This potentiometer had five kilohms resistance plus or minus 20 percent and a non-linearity of plus or minus one percent. It was powered by five volts DC supplied by the DC to DC converter. The potentiometer was calibrated through the elevators full range of positive 24 and negative 14 degrees with the trailing edge up being the positive sense. This range of travel produced a linear output between positive 5.46 volts DC and negative 1.45 volts DC. The potentiometer's electrical cable was routed through the modified rear pressure bulkhead to the signal conditioner.

E. Airspeed and Altitude

Airspeed was measured using a Microswitch differential pressure transducer serial number 0126-0019. The transducer was a Wheatstone bridge with two active arms etched in silicone. The bridge was positioned on a diaphragm that deformed as either static or pitot pressure changed. The deformation of the diaphragm caused the resistance of the active arms to change. This resulted in an unbalanced bridge. Figure 4 is a block diagram of the Wheatstone bridge. The transducer was powered by 12 volts DC

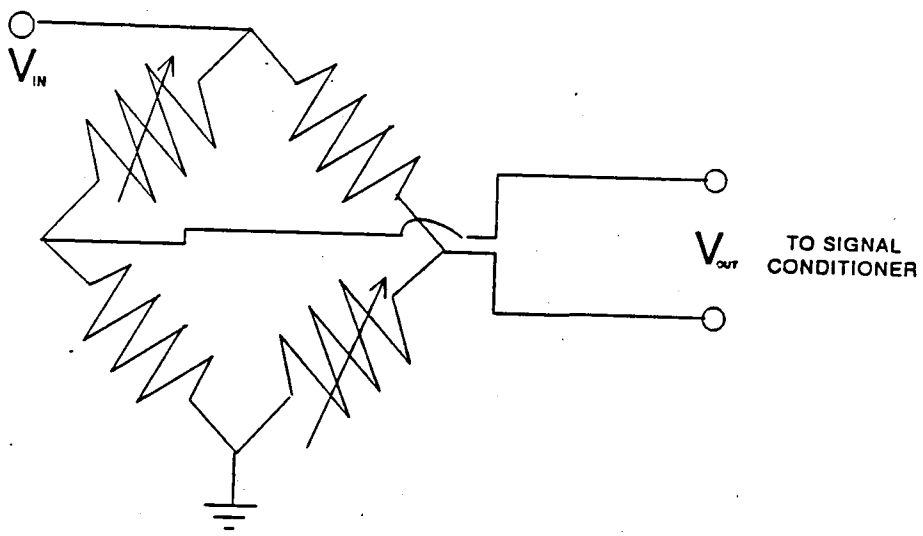


Figure 4.- Block diagram of a Wheastone Bridge

supplied by a DC to DC converter which was powered by the ship's 28 volt power supply. The transducer used to measure airspeed was connected to the pitot source with a modified T fitting connected to the airspeed indicator, and a quarter inch polyethylene hose running to the transducer. The static pressure was supplied by the ship's static source. The transducer was calibrated using a water manometer simulating pressure between zero and 200 knots producing a nonlinear output of 1.59 volts DC at zero knots and 8.91 volts DC at 200 knots. The transducer was mounted in the instrumentation container and wired to the signal conditioner.

Altitude was measured using a Microswitch absolute pressure transducer serial number 0280-0014. The absolute pressure transducer was a single active arm Wheatstone bridge etched in silicone. As the static pressure changes the active resistor deforms, therefore changing the resistance of the active arm creating an output voltage across the bridge.

The absolute pressure transducer was calibrated between 1500 and 20000 feet using a mercury manometer to simulate pressure. It produced a nonlinear output of 8.425 volts DC at 1500 feet and 5.007 volts DC at 20000 feet. The transducer was mounted in the instrumentation container and wired to the signal conditioner.

Calibration of the ship's airspeed indicator showed a negative five knot error between 60 and 160 knots that

increased to a negative 10 knot error between 170 and 230 knots.

A leak check performed on the ships pitot-static system showed a leak of 800 feet per minute at 2000 feet differential pressure. The leak was found in the autopilot interface to the static system and corrected before the flight tests were undertaken.

F. Angles of Pitch and Roll

The pitch and roll angles were measured by a Humphrey's vertical gyroscope with potentiometric pickoffs model Vg-24-0809-5, serial number 40. The gyroscope was powered by 115 volts AC at 400 Hz supplied by a inverter powered by the ship's 28 volt electrical system. The vertical gyroscope was calibrated for pitch angle measurements using a tilt table between positive and negative 40 degrees, with pitch up being the positive sense. These pitch angles produced a linear output of positive 3.97 volts DC at positive 40 degrees and positive 0.95 volts DC at negative 40 degrees. The vertical gyroscope was calibrated for roll angle using the tilt table between positive and negative 60 degrees, with roll left being the positive sense. These roll angles produced a linear output of 4.21 volts DC at positive 60
degrees and 0.79 volts DC at negative 60 degrees. Roll left

Figure 5.-Block diagram of a vertical gyroscope.

Source: Paludan, Ted. Measurement Science 1. Lecture Notes, The University of Tennessee Space Institute. Tullahoma, TN (7).

was chosen for the positive sense because the Lead Plane Maneuver consisted of a left banking turn. The vertical gyroscope was mounted in the instrumentation container, and the output was connected to the signal conditioner. Figure 5 shows a vertical gyroscope (7).

G. Rates of Pitch, Roll and Yaw

The pitch, roll and yaw rates were measured by Humphrey's rate gyroscopes with potentiometric pickoffs powered by the ship's 28 volt DC power supply. Yaw rate and pitch rate were measured by a Humphrey's rate gyroscope model number was SBU-13/A serial number 93322-7902976. Roll rate was measured by a Humphrey's rate gyroscope model number RG51-0115-1 serial number H26. Both gyroscopes were calibrated on a rate table between zero degrees and 1800 degrees per minute. This was accomplished by turning to the right and to the left for yaw and roll rates and up and down for pitch rate. Nose right was the positive sense during the yaw rate calibration. The calibration yielded positive 3.069 volts DC at 1800 degrees per minute to the right and negative 3.053 volts DC at 1800 degrees per minute yaw to the left. The output was linear.

Pitch down was the positive sense for the pitch rate calibration. The calibration yielded negative 3.5053 volts DC at 1800 degrees per minute pitch up and positive 3.033 volts DC at 1800 degrees per minute pitch down. The output

was linear. Roll right was the positive sense for the roll rate calibration. The calibration yielded positive 4.20 volts DC at 1800 degrees per minute to the right and positive 0.82 volts DC at 1800 degrees per minute roll left. The output was linear. Both gyroscopes were mounted in the instrumentation container and wired to the signal conditioner.

H. Acceleration along the X,Y and Z Axis N_x, N_y, N_z

The normalized acceleration in Z direction was measured by a TRU-106/A accelerometer. It was powered by 28 volts DC supplied by the aircraft's electrical system. The accelerometer was calibrated on a tilt table and the output was read after it was passed through the signal conditioner. The acceleration due to gravity was calibrated between zero and 180 degrees. Zero degrees corresponds to positive one G and 180 degrees corresponds to negative one G. The output at zero degrees was one volt DC, the output one 180 degrees was negative 1.53 volts DC. The output was linear. A panel mounted accelerometer that measured acceleration in the Z direction was installed to the pilot's instrument panel in order to enable the test pilot to accurately fly the mission maneuvers.

The normalized acceleration in the X direction was measured by a suspended mass accelerometer type TRU-107 powered by the ship's twenty-eight volts DC. The calibration was done on the tilt table between positive and negative 60

degrees, producing linear output ranging from positive 4.41 volts DC at positive 60 degrees and negative 4.45 volts DC at negative 60 degrees. Positive 60 degrees corresponds to positive 0.87 G and negative 60 degrees corresponds to negative 0.87 G.

Acceleration in the Y direction was measured using a Statham model number A5TC b-1-350 strain gauge accelerometer serial number 6952. The 10 volt excitation for the strain gauge bridge is provided by the signal conditioning block. The accelerometer was calibrated on the tilt table between positive and negative 60 degrees, producing linear output ranging from positive 1.71 volts DC at positive 60 degrees to negative 1.73 volts DC at negative 60 degrees.

I. Instrumentation Container

The instrumentation container was an all metal box mounted on the tracks that normally hold the center seats. The computer was mounted on top of the instrumentation container.

J. Time

The elapsed time during the maneuvers was kept by the computer's internal clock operating at a speed of 12 megahertz.

K. Thermocouple

A T type thermocouple was installed in the cockpit outside air temperature port in order to read outside air temperature. The electrical wiring for thermocouple was routed under the pilot's seat into the instrumentation container. The thermocouples reference junction was supplied by the signal conditioner.

L. Signal Conditioner

The outputs from all previously discussed sensing equipment, with the exception of time, were sent to signal conditioners before reaching the computer.

Three types of signal conditioners were used to convert the low level input of the transducers, potentiometers, accelerometers, and the thermocouple to an output between positive and negative 10 volts. All three types were powered by the ship's 28 volt DC electrical supply. The absolute and differential pressure transducer, accelerometers Nx and NZ and the potentiometer outputs were connected to separate Analog Devices model 3B10 signal conditioners. The 3B10 accepted an input ranging from plus to minus five volts. The signals were then amplified, filtered and an output between plus or minus 10 volts was sent to the analog to digital converter. The result was a voltage output that was proportional to the input voltage. The voltage output could be calibrated using the zero and span trim potentiometers (8).

The outputs from the Ny accelerometer was conditioned by Analog Devices 3B16. The 3B16 accepted inputs from the four arm strain gauge bridge and provided constant ten volts excitation to the bridge. The input signal was amplified, filtered and an output between positive and negative 10 volts was sent to the analog to digital converter.

The thermocouple signal was input into an Analog Devices 3B37. The 3B37 provided a synthetic ground as well as a reference temperature for the thermocouple. The 3B37 accepted a millivolt input from the thermocouple, and produced a filtered output between zero and 10 volts.

L. Computer

From the signal conditioner the signals were sent to the computer, a Dell System Model 220 with an Intel 286 central processing unit, where the analog signals were converted to digital and stored in the memory. The analog to digital converter used was a RTI-800. A direct memory access card allowed the data to be sent directly from the converter to the memory. The data collection was activated by the flight test engineer with a remote switch that activated the computer. Once the computer was activated the Labtech Notebook program automatically booted and data collection would begin.

M. Wing Tufts

Both wings were tufted in order to visualize the flow separation during a stall. The tufts were 10 inch strands of black yarn folded in half and taped to the wings with speed tape. The strands were positioned in four rows. The first row began approximately 12 inches from the leading edge with the remaining three rows positioned six inches behind the previous row. The tufts in each row were placed six to 10 inches apart. Each row contained approximately twenty tufts. Figure 6 shows the tufts taped to the wings.

N. Calibration Methods

All calibrations outputs were read through the signal conditioners. The through the loop calibrations allowed for the potentiometers to be zeroed at the level flight position of the control surfaces and alpha and beta vanes. Aileron and elevator position were calibrated using a bubble protractor. The control surfaces were placed in their trim position and the bubble protractor was placed on them and zeroed. The surfaces were then moved through their full range of motion in five degree increments. The outputs were recorded as the trailing edged was moved full up, back to zero, full down and back to zero. The outputs were recorded

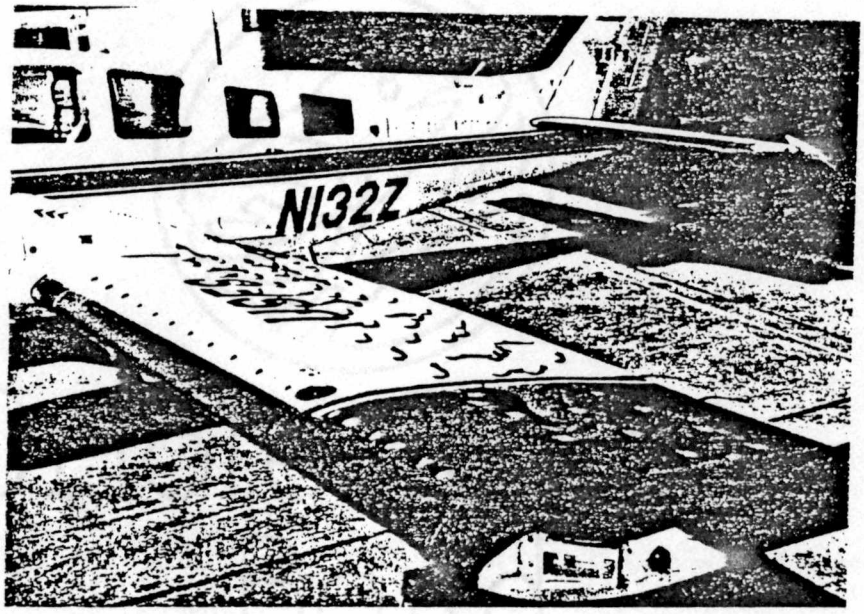


Figure 7.- Flow visualization tufts.

in both directions in order to determine the internal resistance, or hysterisis in the sensors.

Rudder position was calibrated by hanging a plumb bob from the trailing edge, and a protractor template under the plumb bob on the ground. The outputs were measured in five degree increments as the trailing edge was moved through its full range of motion. First from left to right and then right to left in order to determine the potentiometer's hysterisis.

Alpha was calibrated with the bubble protractor through positive and negative 20 degrees. Beta was calibrated with a small protractor template placed under the vane on the boom. A pointer was taped to the vane and angle of deflection was read from the template. The outputs were recorded in five degree intervals moving the vanes in both directions through the full 20 degrees in order to determine hysterisis in the sensors.

The accelerometers for Nx and Nz were calibrated on a tilt table, as was the strain gauge accelerometer used to measure Ny. For the Nz calibration zero degrees on the tilt table corresponded to one G, 90 degrees on the tilt table corresponded to zero G's and one 180 degrees on the tilt table corresponded to negative one G. The Nx and Ny accelerometers were calibrated between positive and negative 60 degrees. Positive 60 degrees corresponded to positive 0.87 G and negative 60 degrees corresponded to negative 0.87 G. The Nz outputs were recorded moving the table from zero to one 180

degrees and back to zero in order to determine the hysterisis in the sensor. Nx and Ny outputs were recorded moving the table from zero degrees to positive 60 degrees through zero to negative 60 degrees and back to zero in order to determine the hyterysis in the sensors.

The vertical gyroscope was calibrated on the tilt table between positive and negative 40 degrees for the pitch angle and positive and negative 60 degrees for roll angle. In both case outputs were read in five degree increments. The outputs were recorded moving the table through the ranges ascending and descending in order to determine the hysterisis of the gyroscope.

Both rate gyroscopes were calibrated on the rate table between positive and negative 1800 degrees per minute, or 30 degrees per second. The outputs were recorded starting at zero, moving to 30 degrees per second, back through zero to negative 30 degrees per second, and then back to zero. Outputs were measured ascending and descending through the rates in order to determine the hysterisis of the rate gyroscope.

The absolute pressure transducer was calibrated using a Hoss mercury manometer. As a vacuum was pulled on the static port of the sensor, outputs were recorded to correspond to between 1000 and 20000 feet and back to 1000 feet. The hysterisis of the transducer is determined in this manner.

The differential pressure transducer was calibrated by sealing the static port and connecting the total pressure port

to a water manometer. The transducer outputs were recorded between 50 and 200 knots with increasing and decreasing airspeed. This determined the hysterisis of the transducer.

The Baron's airspeed indicator was calibrated by the same means used in calibrating the differential pressure transducer. The ship's static port was sealed and the ship's pitot source was connected to the water manometer. The indicator was calibrated between 50 and 200 knots indicated airspeed. This test revealed significant error in the airspeed indicator.

The thermocouple was factory calibrated, and the signal conditioner provided the reference temperature and a synthetic ground.

All calibration curves can be found in appendix C. The outputs were read from a Fluke multimeter, hand recorded and entered into Slidewrite for production of calibration curves.

CHAPTER V

Software

A. Labtech Notebook version XE

Labtech Notebook is a registered trademark of Laboratory Technologies Corporation. The software is designed to simplify data acquisition in the laboratory environment. The program catalogs data received from the analog to digital converter. The program was initialized by the flight observer on the test flights when he activated the computer. Once the computer was activated Notebook began sampling data at four Hertz. Notebook sampled data for 20 minutes, and wrote the data to memory. Once the data acquisition ended, Notebook would down load the data from memory to a three and a half inch floppy disk in the three and one half inch disk drive (9).

B. Smart 3.0

The spreadsheet application of the Smart 3.0 program was used to format the data read from the three and one half inch floppy disk. Smart is a registered trademark of Innovative Software, Inc. The Smart software was used to view the raw data and delete the portion of the data in which a maneuver was not performed. Smart was also used to strip the data of commas that were written in by Notebook. The data that were acquired during the maneuvers were written to a floppy disk

and then read by either Slidewrite or Mathcad for the final data reductions.

C. Slidewrite Plus Four

Slidewrite Plus 4.0 is a registered trademark of the Advanced Graphics Software, Inc. Slidewrite was used to produce the final graphs for the Forest Service report. Once the data were properly formatted using Smart, the pertinent data were written to a floppy disk and loaded into the Slidewrite spreadsheet. Once in the spreadsheet the data points were plotted versus time (10).

D. Mathcad 3.0

Mathcad 3.0 was used to reduce the data as soon as the flights were completed. Mathcad is a registered trademark of Mathsoft, Inc. Mathcad allowed for quick and easy comparison of the plane performance from one flight to the next. Mathcad was also used to do an Euler angle analysis on the data.

CHAPTER VI

Analysis and Discussion

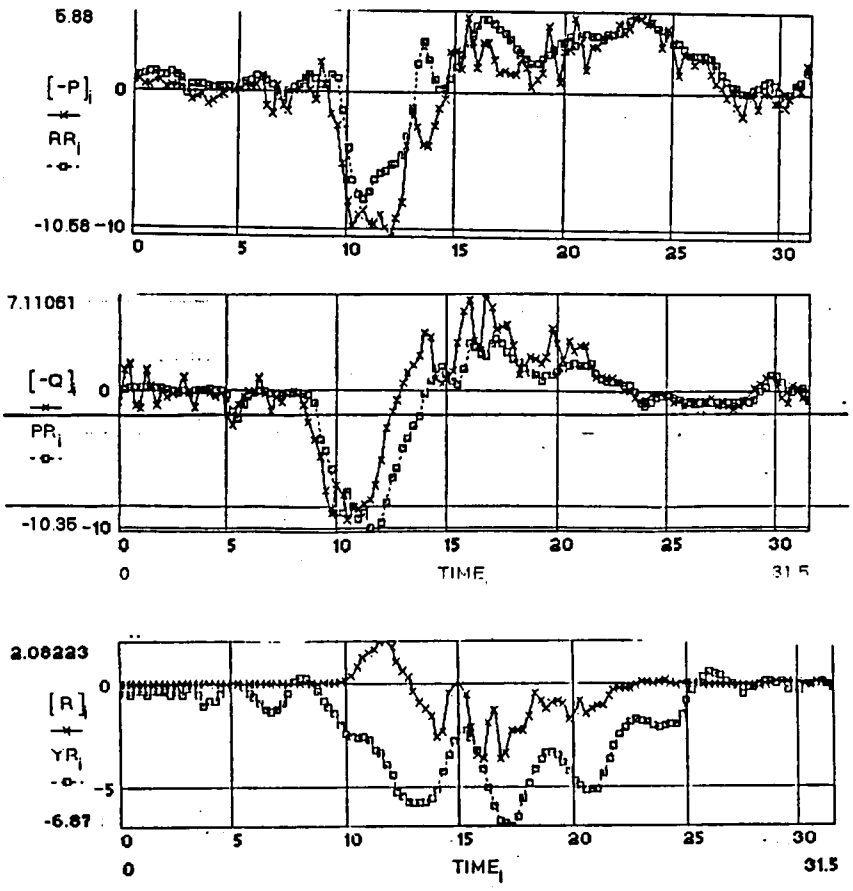
A. Euler Angle Analysis

The orientation of an aircraft during flight relative to a fixed frame of reference can be described by three consecutive rotations. The final orientation is dependent on the order of rotation. These angles of rotation are called the Euler angles (11).

Data obtained from the gyroscopic instruments were used to calculate final orientation of the aircraft. The calculated aircraft position was then compared to actual measured aircraft position as a means of ensuring accurate data. The comparisons of calculated position and actual position are shown in Figure 7.

B. Noise Reduction

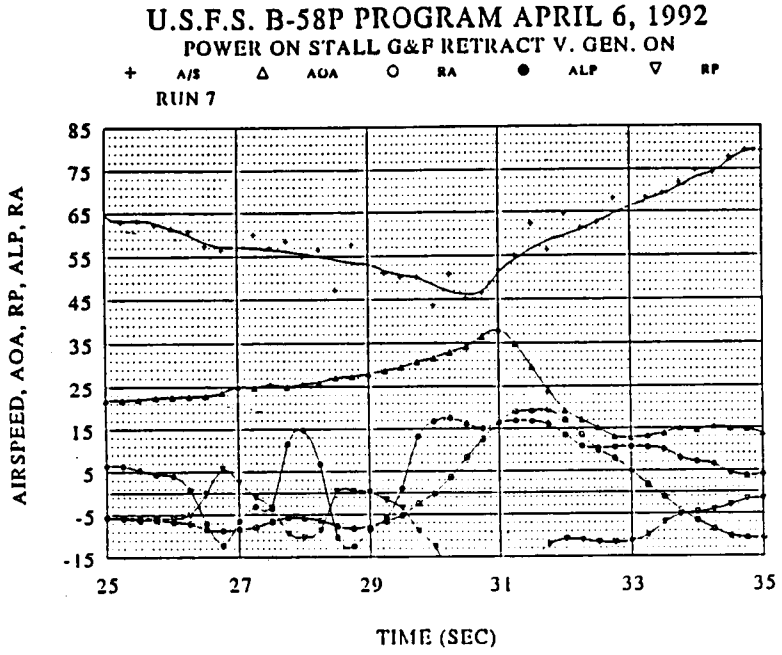
The data scatter indicated noise ranging from 10 to 20 percent of actual values. The 400 hertz, 115 volt AC inverter was suspected of creating most of the noise that appeared in the data. The signal from the sensors was filtered by the signal conditioner; therefore it was assumed the noise was entering the system between the signal conditioner and the computer. The problem was addressed by wrapping the bus that ran from the signal conditioner to the computer with 50 turns of 20 gauge magnet wire. The magnetic wire acted as a ground plane filtering the AC signal from the 400 hertz inverter.



P = RR - YR sin PA
Q = PR cos PA + YR COS PA sin RA
R = YR cos PA cos RA - PR sin RA
WHERE RR=ROLL RATE, RA=ROLL ANGLE, YR=YAW RATE
YA=YAW ANGLE, PR=PITCH RATE, PA=PITCH ANGLE

Figure 8.- Comparison between calculated components of angular velocity and actual components.

Two capacitors, 0.1 and 0.01 microfarad, were installed in front of the 3B10 signal conditioning blocks. The 0.1 microfarad capacitor filtered the fundamental frequency while the 0.01 microfarad capacitor filtered the harmonics. Estimated capacitance was calculated using Faraday's Laws. Then trial and error led to final capacitors. A shielded cable was used leading into and out of the four hundred hertz invertor. The noise was reduced noticeably by steps taken as shown in Figure 8.



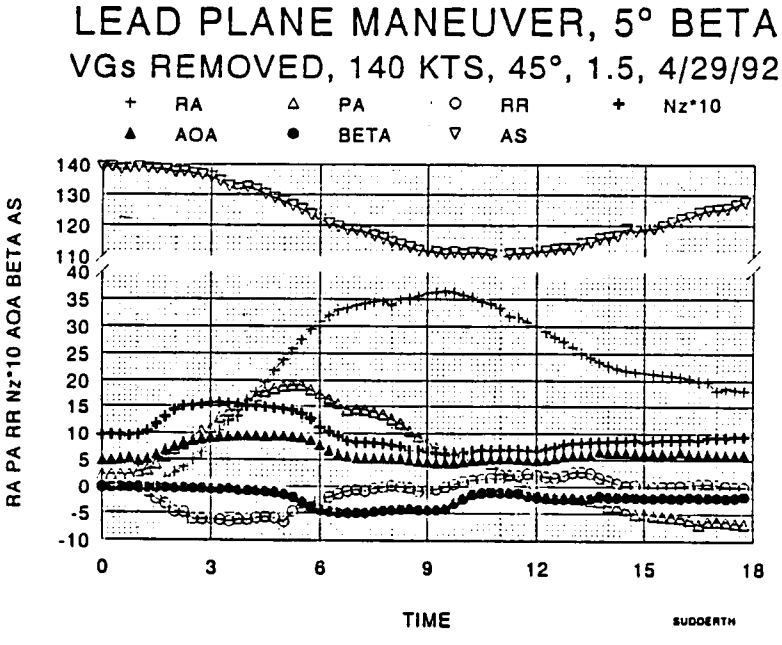


Figure 9.-Above, Data prior to noise reduction.

Below, Data after noise reduction.

Chapter VII

Systems Operation and Results

The system was operated by the flight test engineer. Ten minutes prior to data collection the engineer supplied power to the instruments via a remote switch, allowing the gyroscopes to stabilize. Following the stabilization of the gyroscopes, the engineer activated the computer. Upon receiving power the auto execute file booted the Labtech program and data collection began. The data were sampled at a rate of four hertz for 20 minutes. Maneuvers being investigated during the 20 minutes were tagged using a data marker controlled by the engineer.

The memory on the Dell System 220 failed two flights prior to the end of the test. The memory failure occurred in a three year old computer that had been involved in numerous flight test programs. The computer was replaced by a Dell System 325 and the system was on line in one hour. The failure caused one flight to be delayed during the test.

While preparing to do an airspeed calibration on the ship's airspeed indicator a significant leak in the ship's pitot static system was discovered. The leak was found in the static systems interface to the autopilot.

The ship's airspeed indicator demonstrated an error between negative five and ten knots. The error was large enough to cause concern for the pilot's safety during the Lead Plane Maneuver.

Chapter VIII

Conclusions

A data collection system was implemented to collect data in order to evaluate the Lead Plane Maneuver performed by the Baron 58P for the U. S. Forest Service. The ease in which the data were collected and the speed at which the data could be reviewed allowed for quick flights and short turn around times. The data collection was successful allowing the actual number of flight hours to be approximately seven hours less than originally proposed. The system functioned effectively and provided timely data to accomplish the objectives of the flight test program. The low cost of the system was a contributing factor in being awarded the contract.

Chapter IX

Recommendations

The objectives of the flight test performed by the University of Tennessee Space Institute for the U.S. Forest Service were to determine the safety of the Lead Plane Maneuver. As a result of the instrumentation, the following recommendations were made. The first recommendation was to check the U.S. Forest Services Lead Planes for pitot static leaks. The second recommendation was to calibrate all of the Lead Planes airspeed indicators. Complete results, conclusions and recommendations from the flight test can be found reference 4.

LIST OF REFERENCES

LIST OF REFERENCES

1. National Transportation Safety Board. "Safety Recommendations #A-81-49 through 53". Washington, D.C., May 7, 1981.

2. V/G systems letter to Director of Air Operations U.S.D.A. Forest Service/Aviation. September 4, 1991.

3. "In-Flight Operations Handbook". U.S. Forest Service Document, 1991

4. Sedor, Joseph M. "A Flight Test Evaluation of the Beechcraft 58P Lead Plane Mission Profile for the U.S. Forest Service." Thesis, The University of Tennessee Space Institute, August, 1992.

5. Beechcraft Pressurized Baron 58P Pilot's Operating Handbook and FAA Approved Airplane Flight Manual. Wichita, Kansas: Commercial Publications, 1990.

6. Supplemental Type Certificate Number SA4016NM. U.S. Department of Transportation-Federal Aviation Administration, 1987.

7. Paludan, Ted. Measurement Science 1. The University of Tennessee Space Institute. Tullahoma, TN.

8. The 3B Series Signal Conditioning I/O Subsystem Users Manual. Norwood, Ma: Analog Devices Inc., 1986.

9. Labtech Notebook Users Manual. Wilmington, MA., 1991.

10. Craychee, Daniele,and White. Slidewrite Plus Users Manual. Sunnyvale CA: Ventura Publishers, 1990.

11. McCormick, Barnes. Aerodynamics, Aeronautics, and Flight Mechanics. New York: John Wiley and Sons, 1979.

APPENDICES

APPENDIX A

WIRING DIAGRAM

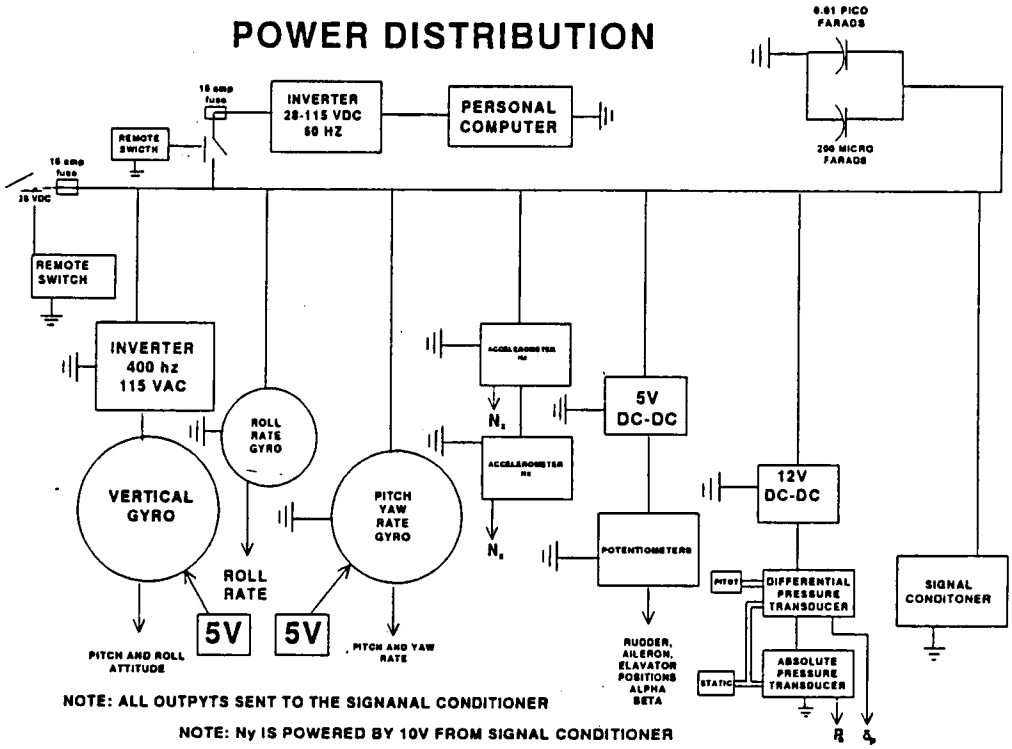


Figure A.1- Power Distribution

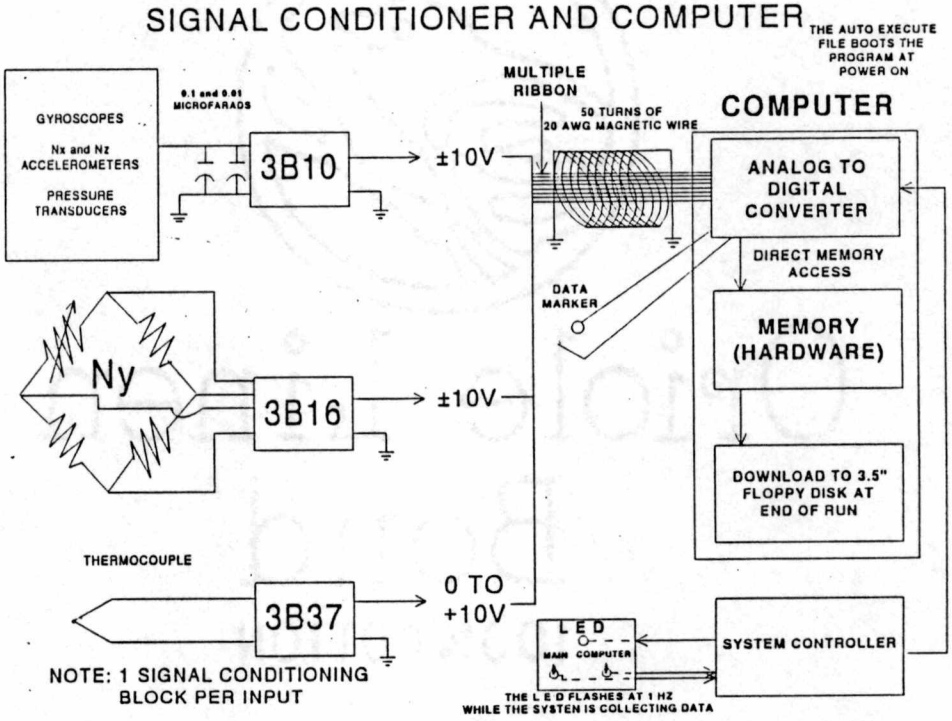
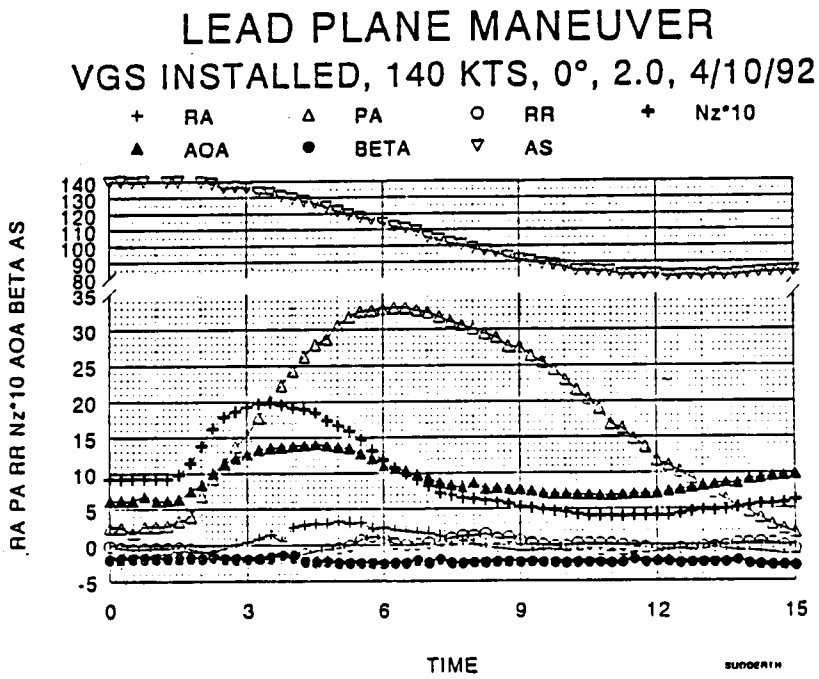


Figure A.2- Signal Conditioner and Computer

APPENDIX B

SAMPLE DATA



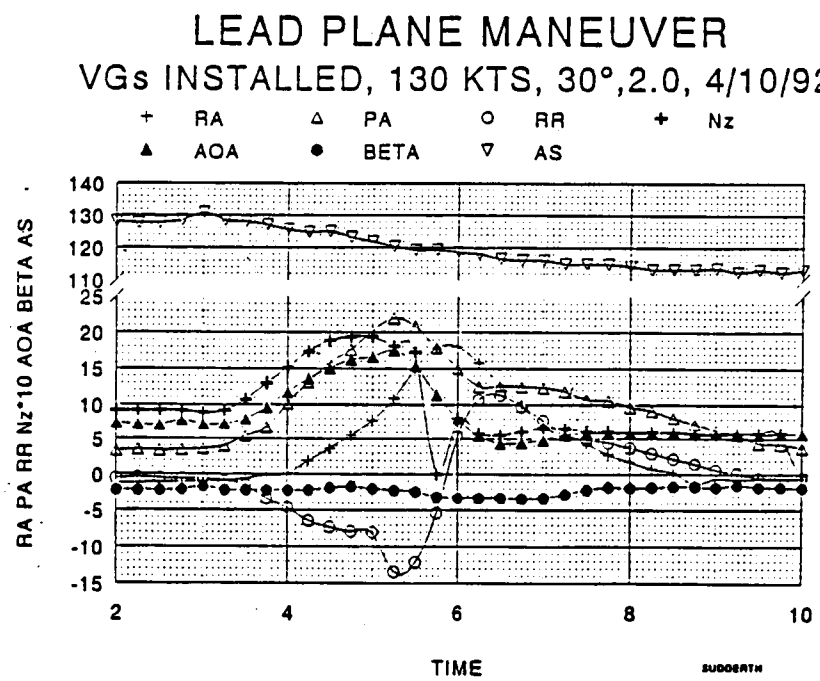
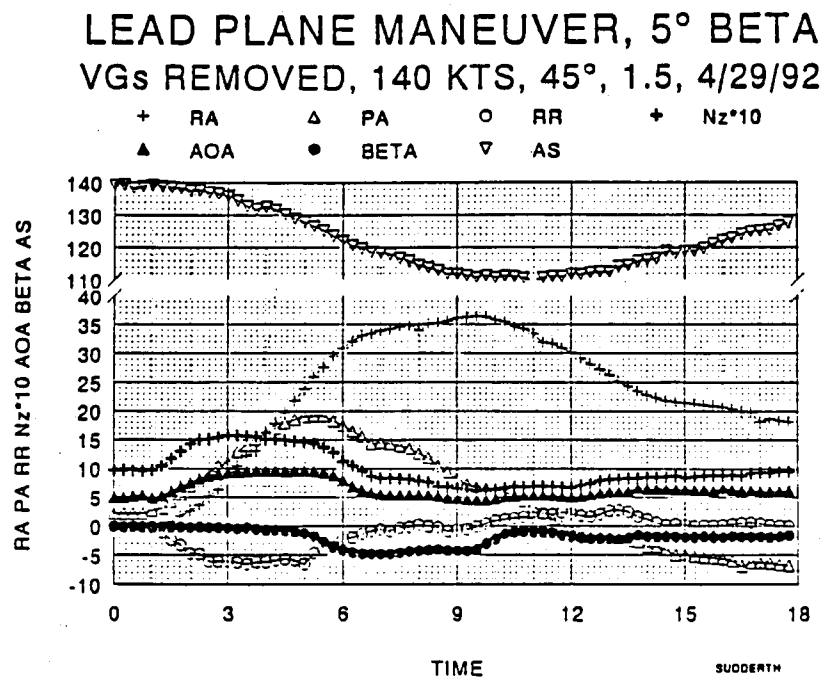


Figure B.1- Lead Plane Maneuver VGs installed



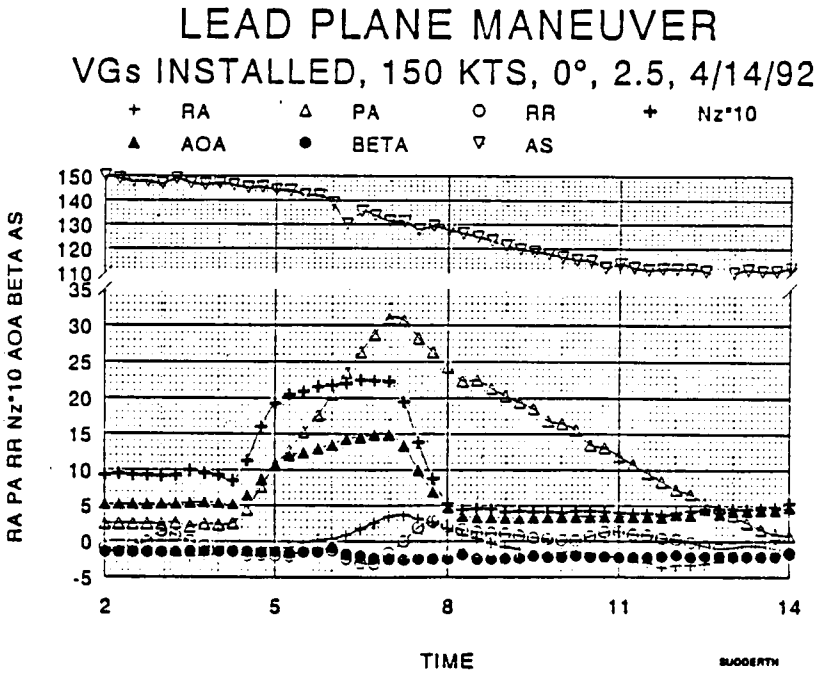
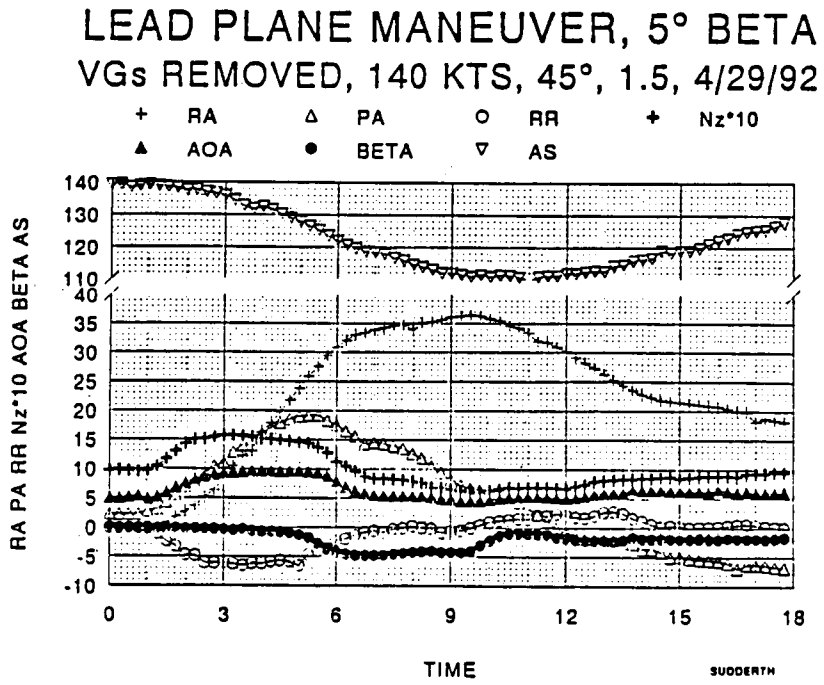


Figure B.2- Lead Plane Maneuver; Above-VGs removed

Below-VGs installed



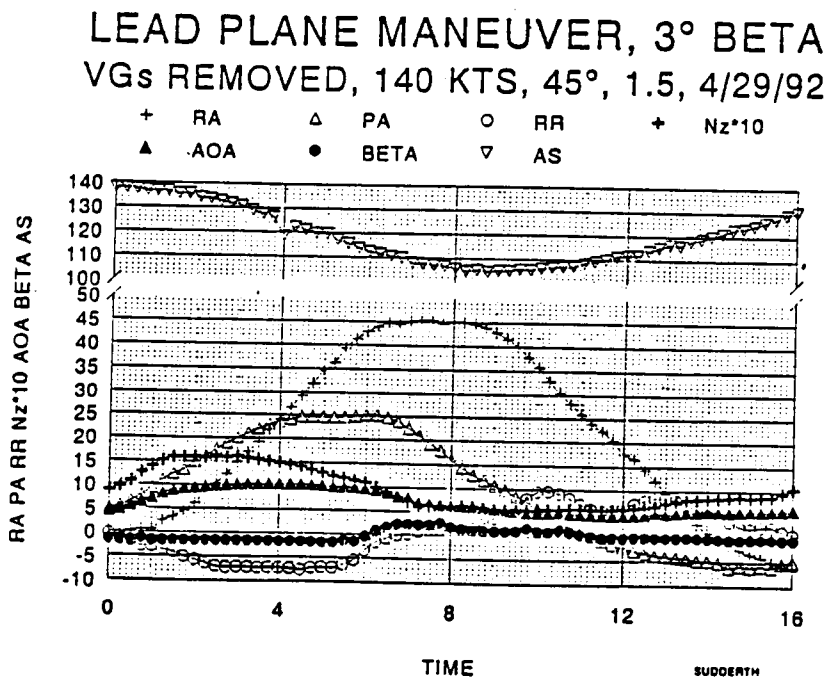


Figure B.3- Lead Plane Maneuver VGs removed

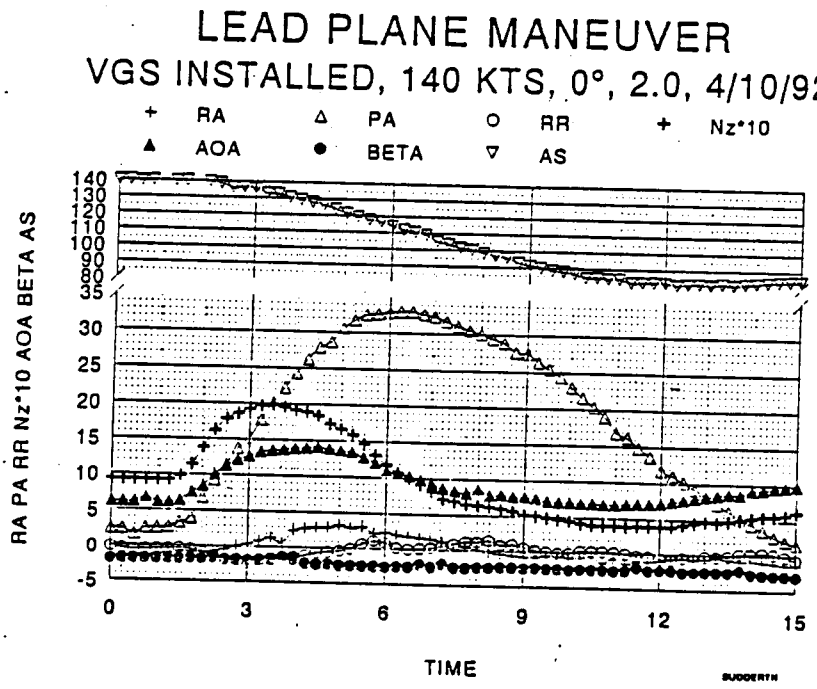


Figure B.4- Lead Plane Maneuver VGs removed

APPENDIX C

CALIBRATION CURVES

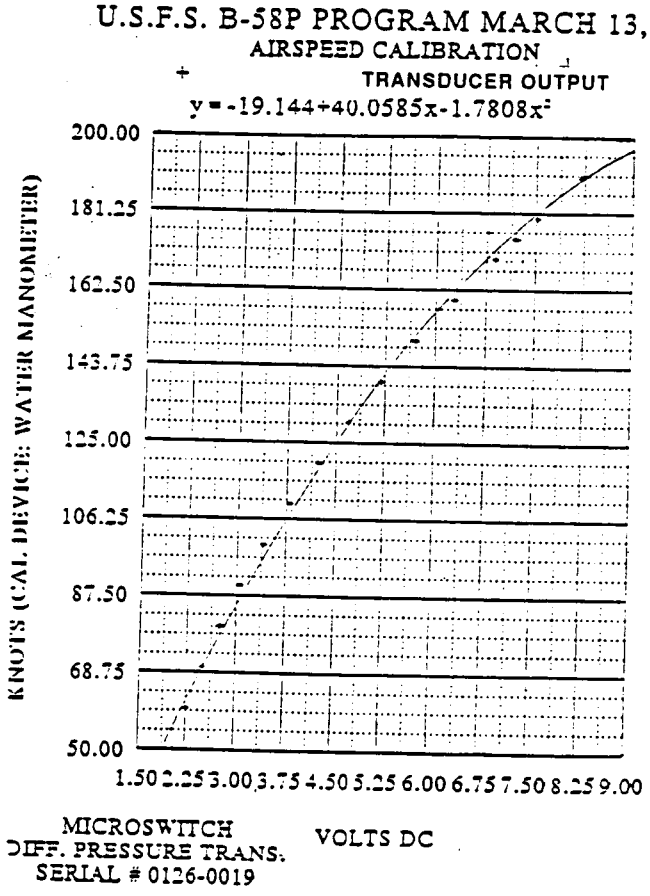


Figure C.1- Differential Pressure Transducer Calibration

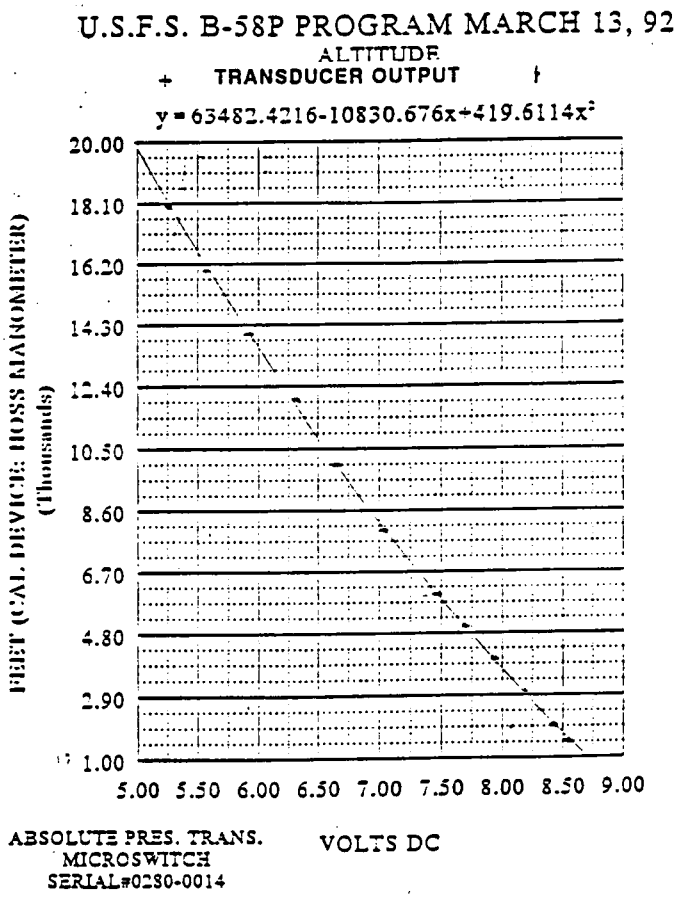


Figure C.2- Absolute Pressure Transducer Calibration

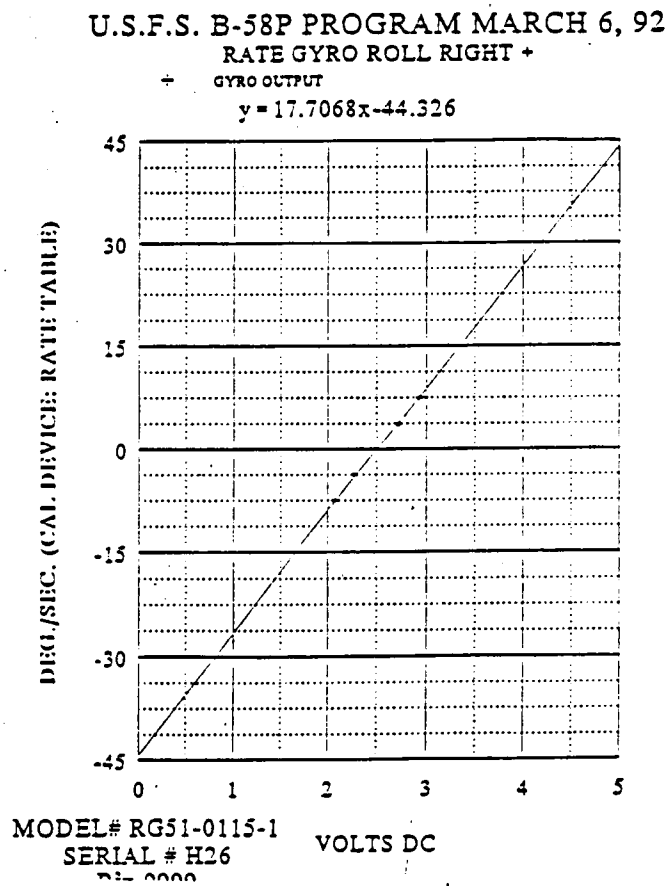


Figure C.3- Roll Rate Calibration

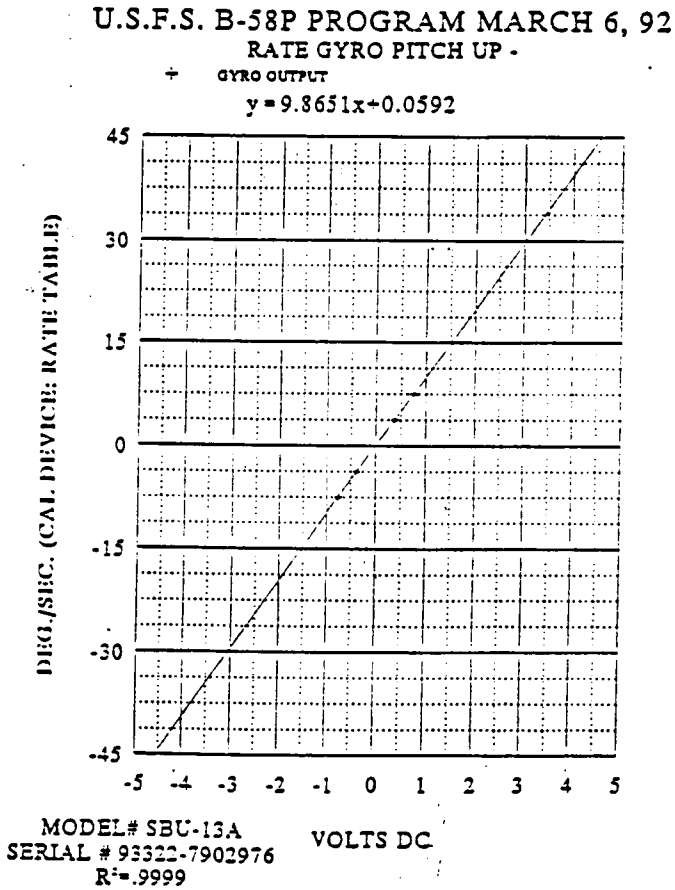


Figure C.4- Pitch Rate Calibration

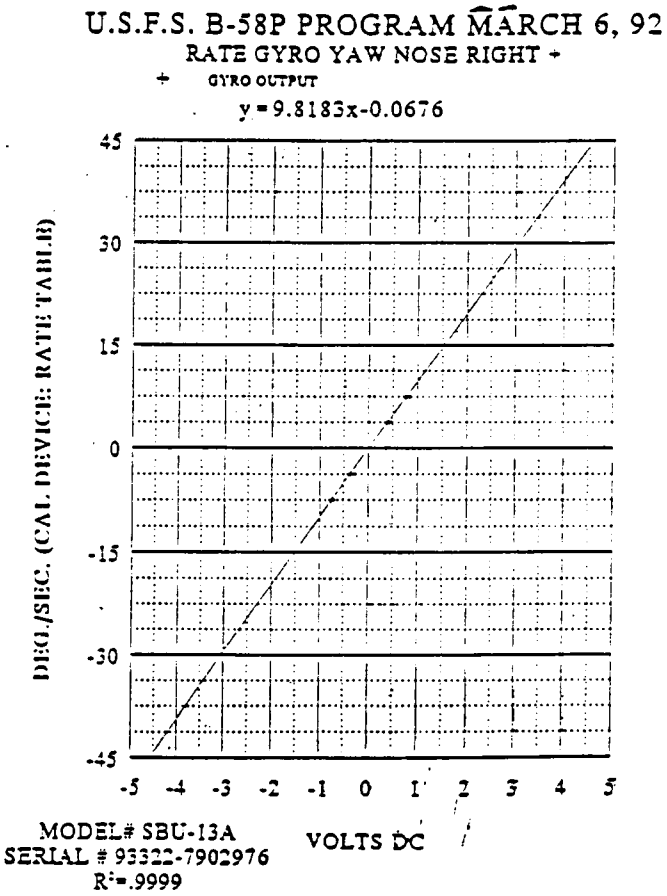


Figure C.5- Yaw Rate Calibration

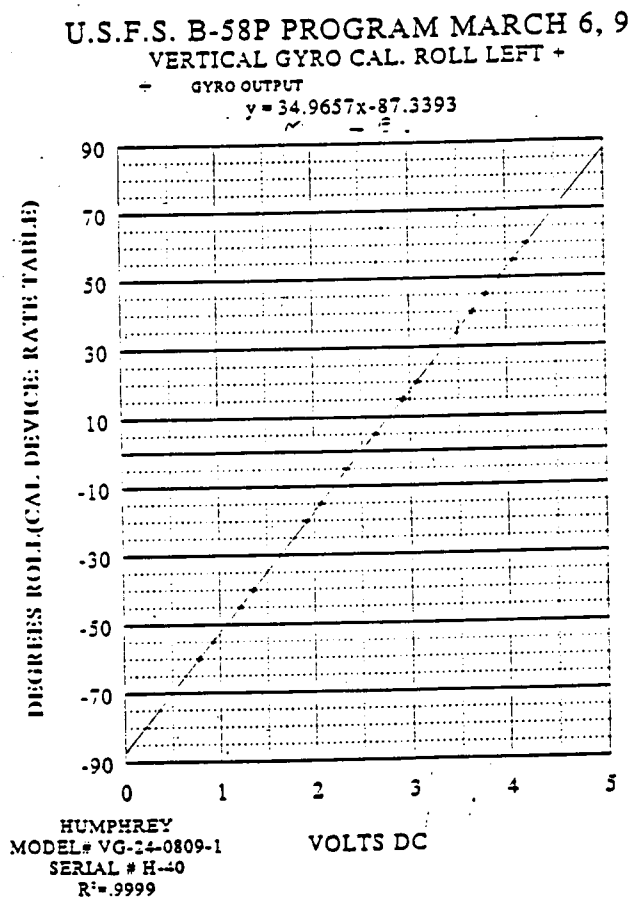


Figure C.6- Roll Angle Calibration

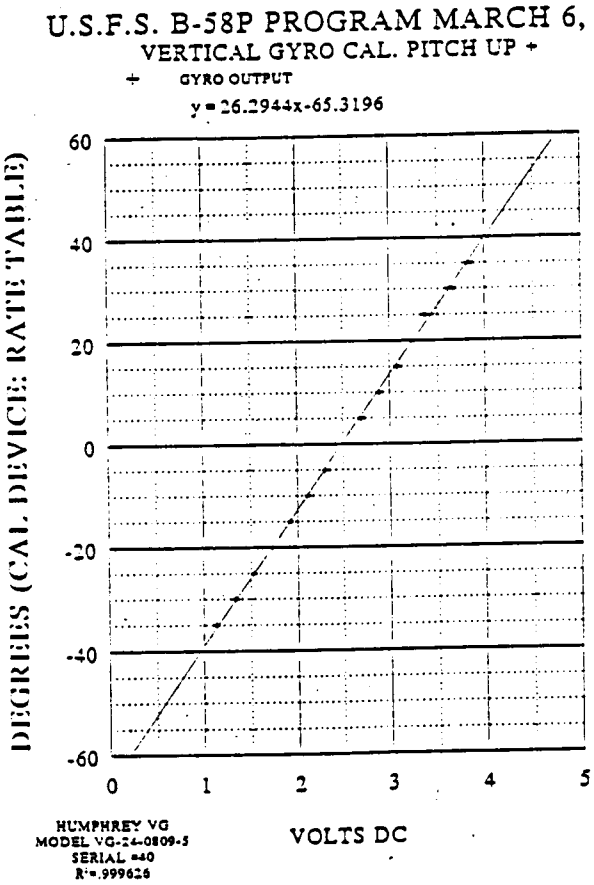


Figure C.7- Pitch Angle Calibration

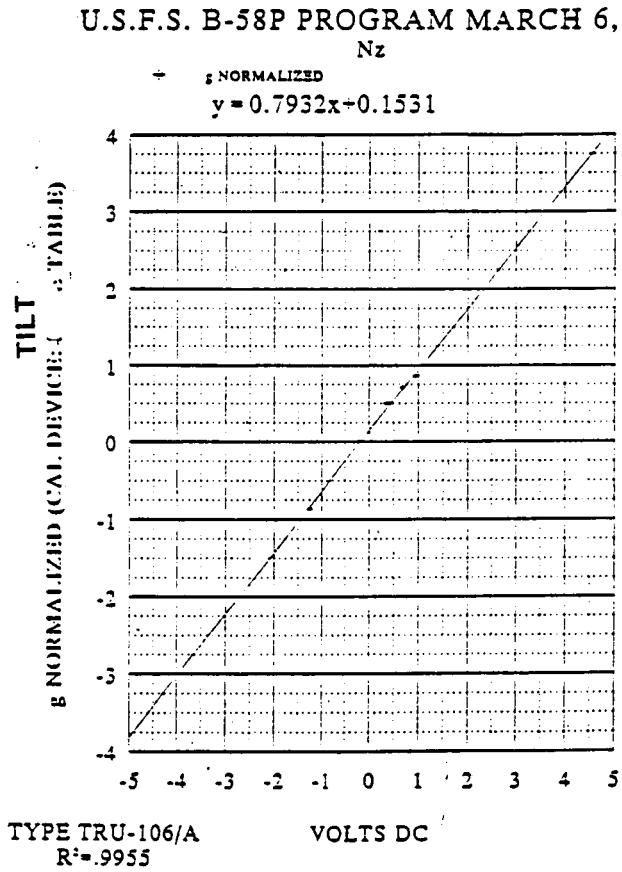


Figure C.8- N_z Calibration

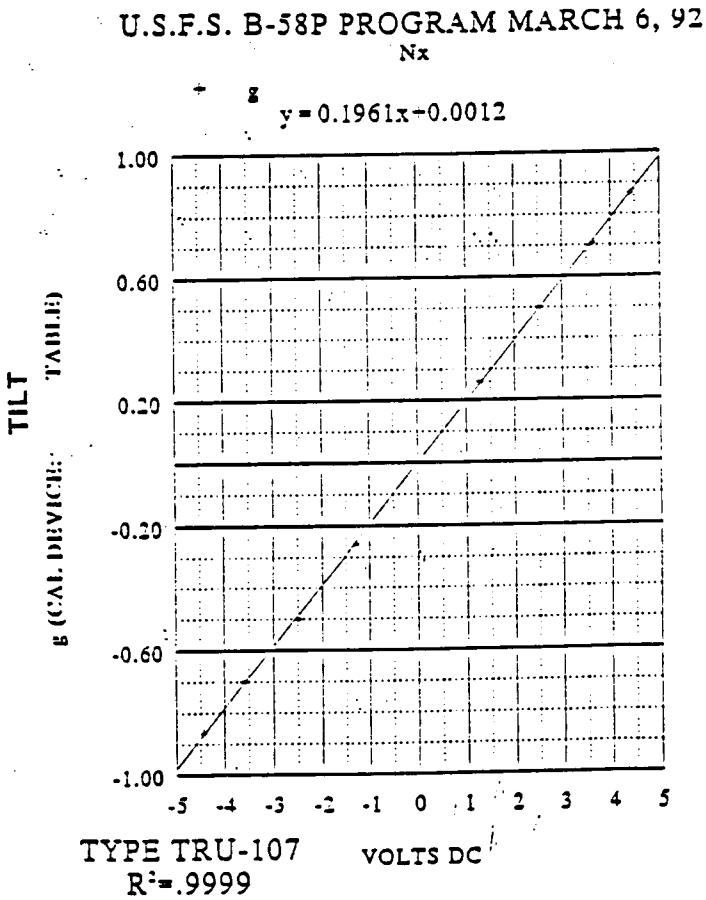


Figure C.9- N_z Calibration

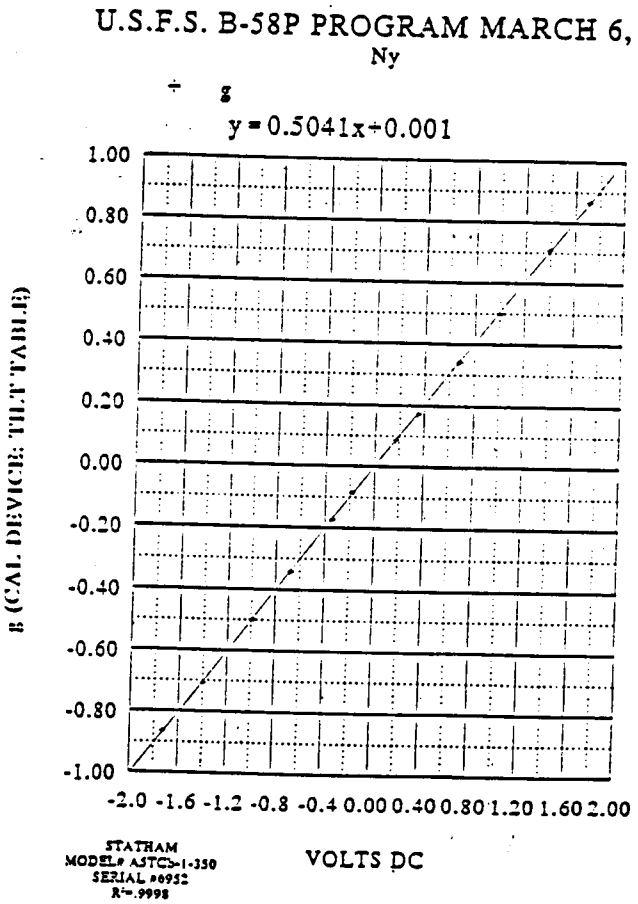


Figure C.10– N_y Calibration

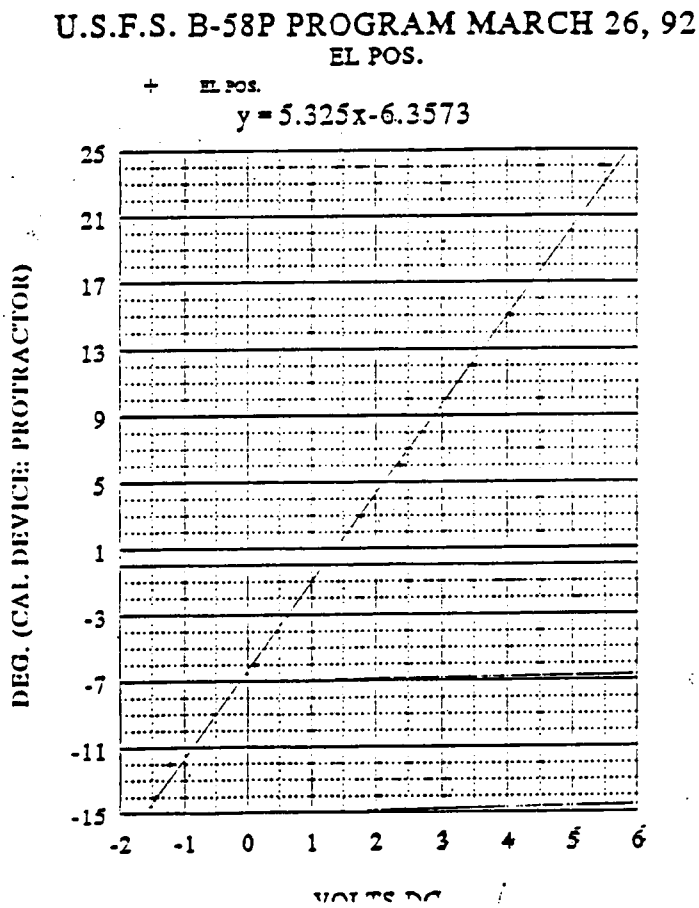


Figure C.11- Elevator Position Calibration

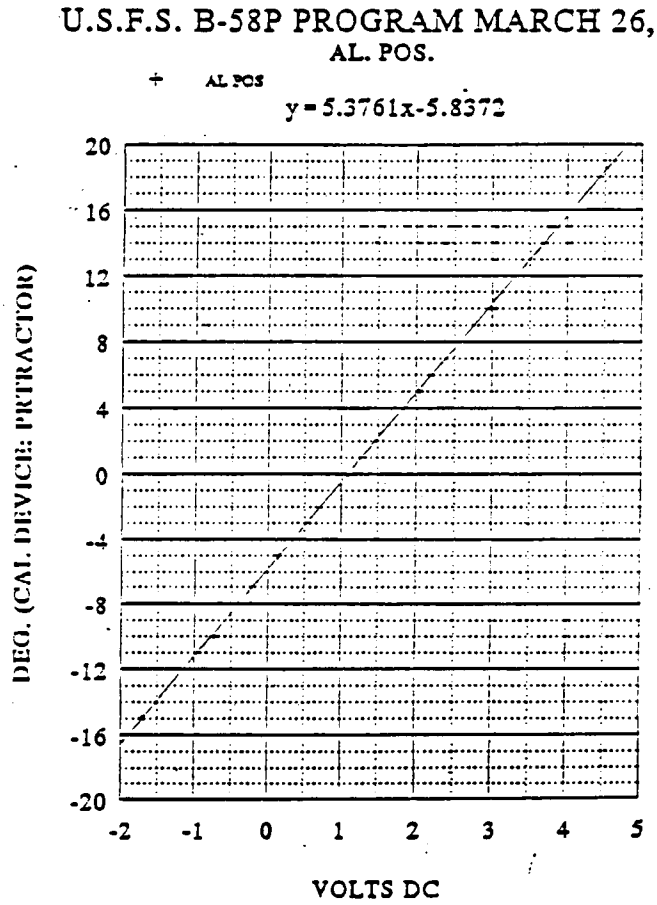


Figure C.12- Aileron Position Calibration

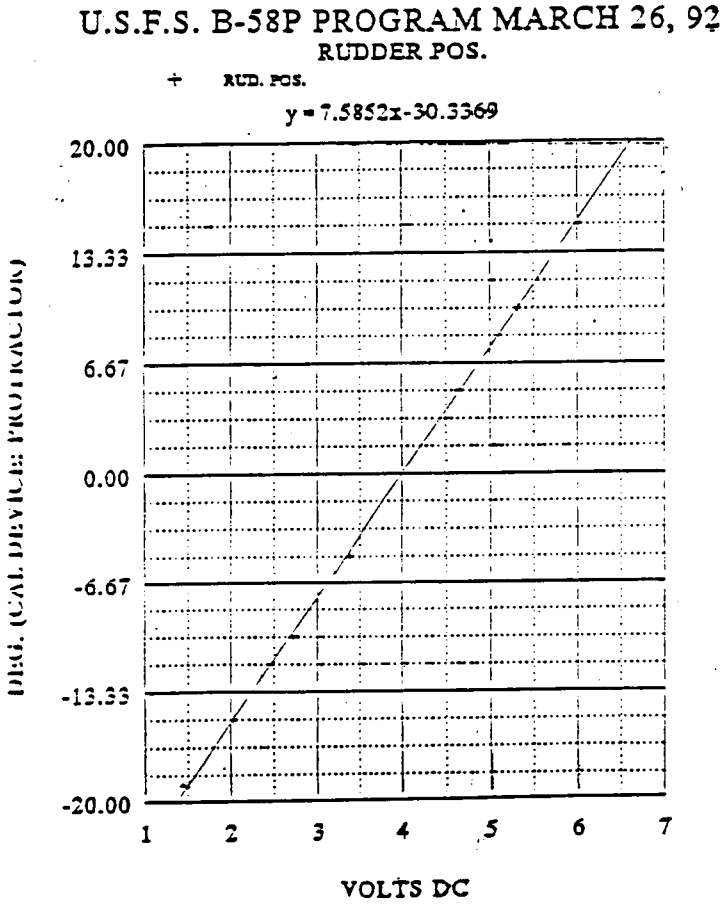


Figure C.13- Rudder Position Calibration

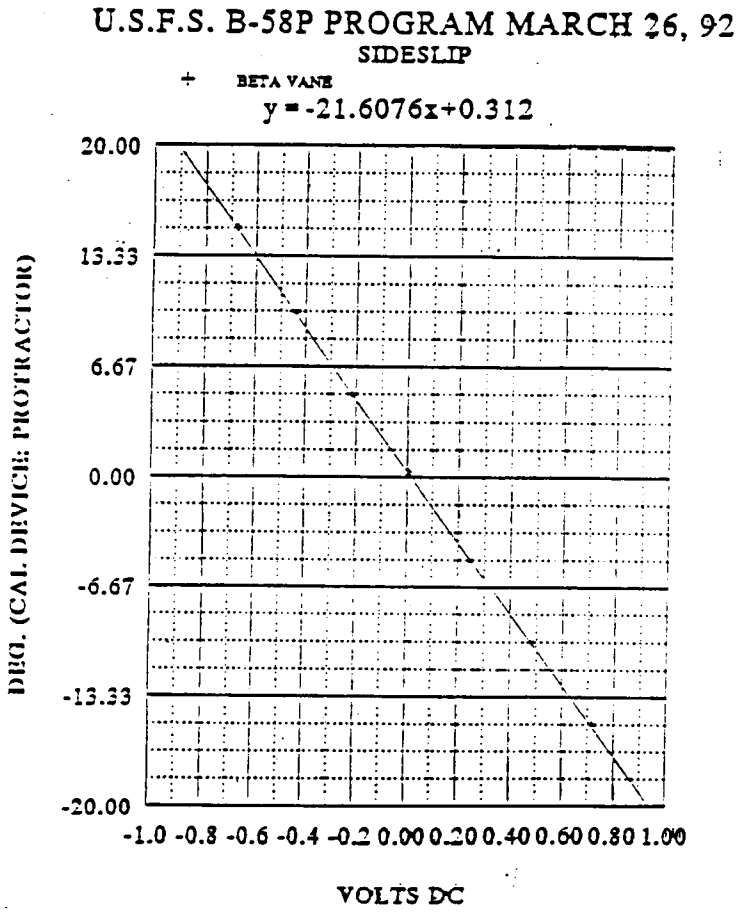


Figure C.14- Beta Calibration

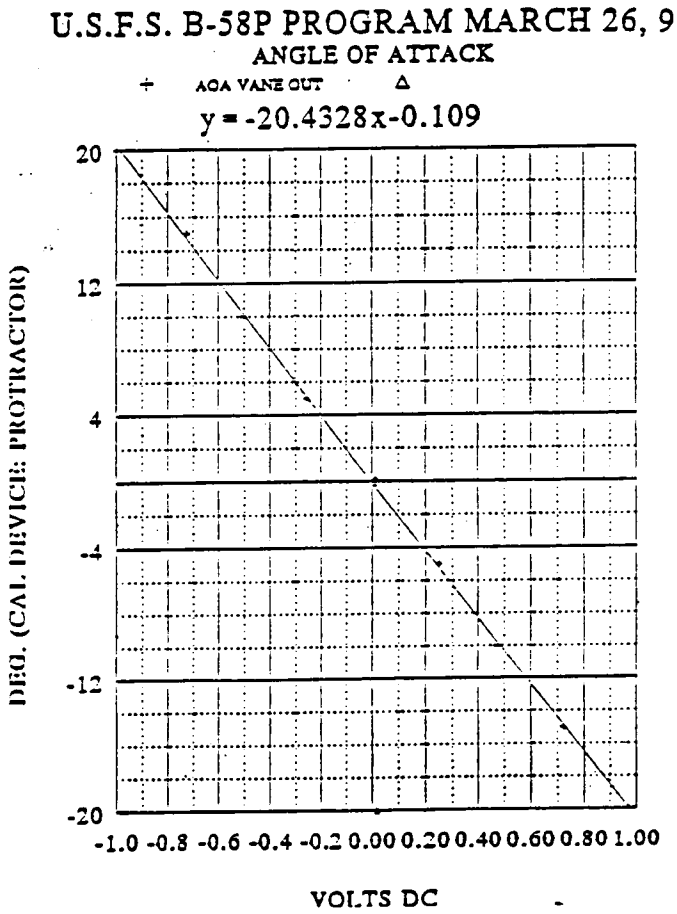


Figure C.15- Alpha Calibration

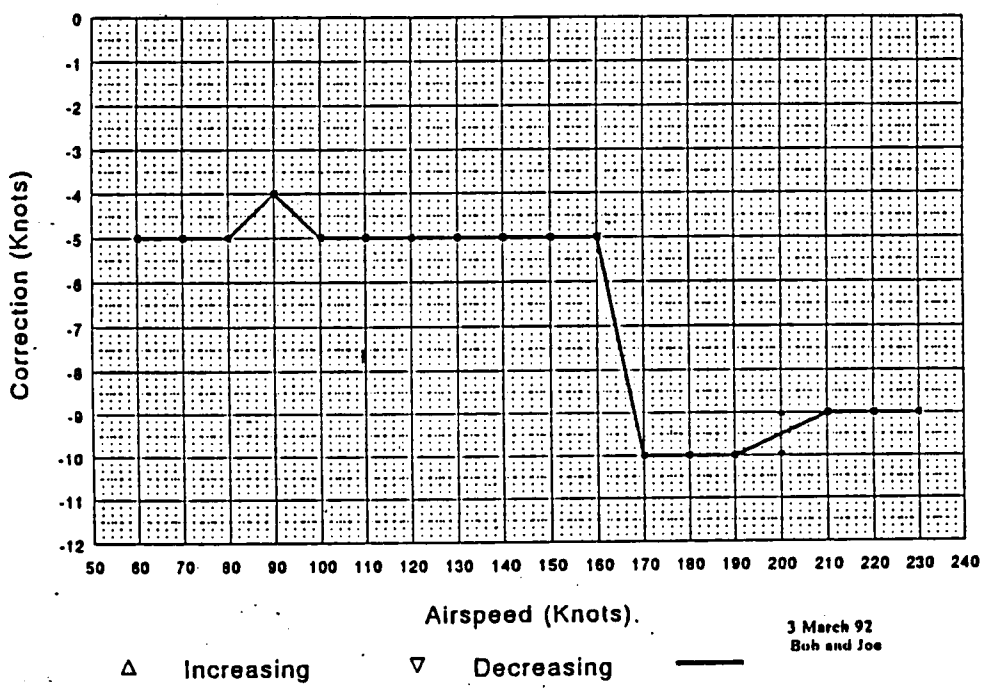


Figure C.16- Ship's Airspeed Instrument Correction Curve

VITA

Joseph Benson Sudderth was born in Johnson City, Tennessee, on July 28, 1965. He graduated from Hendersonville High School on June 3, 1983, where he was an all state soccer player and a member of the 1983 state championship team. He received a soccer scholarship to Tusculum College where he played one year before transferring. He received two degrees from Middle Tennessee State University, his first in August of 1988, and his second in May of 1992. He entered the University of Tennessee Space Institute in June of 1989 working toward a Master of Science in Aviation System. He recently accepted a job with Perception/Aquaterra Inc. of Easley, South Carolina.