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Rodney C. Allison, Major Professor

We have read this thesis
and recommend its acceptance:

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USE OF THE GPS RECIPROCAL HEADING METHOD FOR DETERMINING PITOT-STATIC POSITION ERROR IN HELICOPTER FLIGHT TESTING

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Rucie James Moore
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DEDICATION

This thesis is dedicated to my parents, Jimmy and Rosa Moore, my brothers Darryl and Michael, my sister Connie, and the rest of my family. They have all, throughout my life, given me the love and encouragement that have enabled me to achieve my dreams.

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ABSTRACT

This thesis is an evaluation of using the Global Positioning System (GPS) reciprocal heading method to determine pitot-static position errors in helicopter flight testing. Determination of position error is a fundamental flight test task that must occur early in a test program, as all other results with regard to airspeed rely on the data. The test determines errors of the pitot-static system that cause inaccurate indication of airspeed to the pilot. The measured course, a currently approved method, provides a measure of the helicopter's groundspeed by flying the helicopter over a known distance and converting elapsed time into the speed measurement. An aviation GPS computes a very accurate groundspeed and presents it to the crew quickly and automatically. Using the GPS groundspeed in lieu of flying a measured course is the basis of this thesis. This report compares the two methods in terms of safety, reliability, accuracy of results, and cost. Flight tests were conducted using the GPS method and the measured course to obtain position error data for the OH-58A+ helicopter for comparison. The results of the comparison show the GPS reciprocal heading method to be, accurate, reliable, cost effective, and very safe to perform.

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ABBREVIATIONS AND SYMBOLS

a	Speed of Sound
a_{ssl}	Standard Sea Level Speed of Sound
AC	Advisory Circular
A/C	Aircraft
AGARD	Advisory Group for Aerospace Research and Development
CDI	Course Deviation Indicator
CG	Center of Gravity
CFR	Code of Federal Regulation
D	Distance
DOD	Department of Defense
ECEF	Earth-centered Earth-fixed
FAA	Federal Aviation Administration
fps	Feet per Second
FTM	Flight Test Manual
GPS	Global Positioning System
HDG	Heading
H_{PO}	Pressure Altitude (Observed)
IAW	In Accordance With
KCAS	Knots Calibrated Airspeed
KIAS	Knots Indicated Airspeed
KTAS	Knots True Airspeed
M	Mach Number
OAT	Outside Air Temperature
PPS	Precision Positioning Service
psf	Pounds per Square Foot
P_s	Static Pressure
P_{ssl}	Standard Sea Level Static Pressure
P_t	Total Pressure

q	Dynamic Pressure
$\dot{R}_i$	Range-rate relative to satelite
s_e	Standard Error of Estimate
SHP	Shaft Horsepower
SPS	Standard Positioning Service
THA	Tullahoma Regional Airport
TRK	Track
ΔT	Elapsed Time
USNTPS	United States Navy Test Pilot School
V_C	Calibrated Airspeed
V_E	Equivalent Airspeed
ΔV_{EC}	Compressibility Correction
V_G	Groundspeed
V_H	Maximum Level Flight Speed
V_I	Corrected Indicated Airspeed
ΔV_I	Correction for Instrument Error
V_O	Observed Airspeed
V_{NE}	Velocity Never Exceed
ΔV_{PC}	Position Correction
V_{ref}	Reference Airspeed
V_T	True Airspeed
WGS	World Geodetic System
β	Angle Aircraft Track differs from Heading
δ	Pressure Ratio
γ	Specific Heat Ratio
σ	Density Ratio
θ	Temperature Ratio

CHAPTER 1

INTRODUCTION TO AIRSPEED CALIBRATION

BACKGROUND

The helicopter airspeed indication is a function of the pitot-static system. The airspeed indicator is simply a differential pressure gauge that represents the difference between total and static pressures (P_t - P_s) provided by the pitot-static system. Common design practice is to manufacture the airspeed indication system as to indicate true airspeed (V_T) at standard sea level conditions of 15° C and 29.92 in. Hg. At standard sea level conditions, V_T is the same as calibrated airspeed (V_C). Due to errors in the airspeed indicator and the pitot-static system and varying atmospheric conditions, the airspeed indicator rarely indicates actual V_T. The pitot-static system must therefore be calibrated through application of several processes that establish values for the errors in the airspeed presented to the pilot, which is known as the observed airspeed (V_O). Applying the known values of these errors to V_O gives us the very useful value, V_C. In flight testing, accuracy of all flight test data concerned with the velocity of a helicopter are dependent on the determination of these errors. Errors in the pitot-static system can have an impact on the results of both performance and stability and control flight tests. The pitot-static system must be calibrated as early as possible in a flight test program to determine reliability of the system and determine the values for the associated errors.

Often the goal with respect to airspeed in flight testing is to determine V_T, the actual velocity of the helicopter through the air mass. V_T is most useful in generalizing the performance of the helicopter in non-standard atmospheric conditions. During a flight test, the aircraft pitot-static system or flight test pitot-static boom system provides V_O, which must then be corrected to provide the desired velocity, either V_C or V_T.

VELOCITY CORRECTIONS

The airspeed as read directly from the instrument in the aircraft, as noted previously, rarely represents true airspeed. The reasons that it is in error include; errors of the instrument, lag errors, errors due to the position of the static ports, errors due to the effects of compressibility, and flight at other than standard sea level conditions. The cause and characteristics of each of these errors are given in detail in Chapter 2. Summarizing, the correction of V_O to different, more useful velocities follows:

$$V_O \rightarrow V_I \rightarrow V_C \rightarrow V_E \rightarrow V_T$$

(1) Observed airspeed (V_O), as read directly from the instrument, is corrected for instrument errors and lag errors to produce corrected indicated airspeed (V_I). See equation 3.1.

(2) Calibrated airspeed (V_C) is the result of correcting V_I for errors due to the physical installation of the pressure sensors on the helicopter, which is termed the position error. The value of the correction, change in velocity due to position error, is termed ΔV_{PC} and is determined via flight test.

(3) Equivalent airspeed (V_E) is obtained by correcting V_C for compressibility effects (ΔV_{EC}). See figure 1-1. The effects of compressibility are assumed to be of little factor for helicopter airspeed measurement as their performance envelopes are

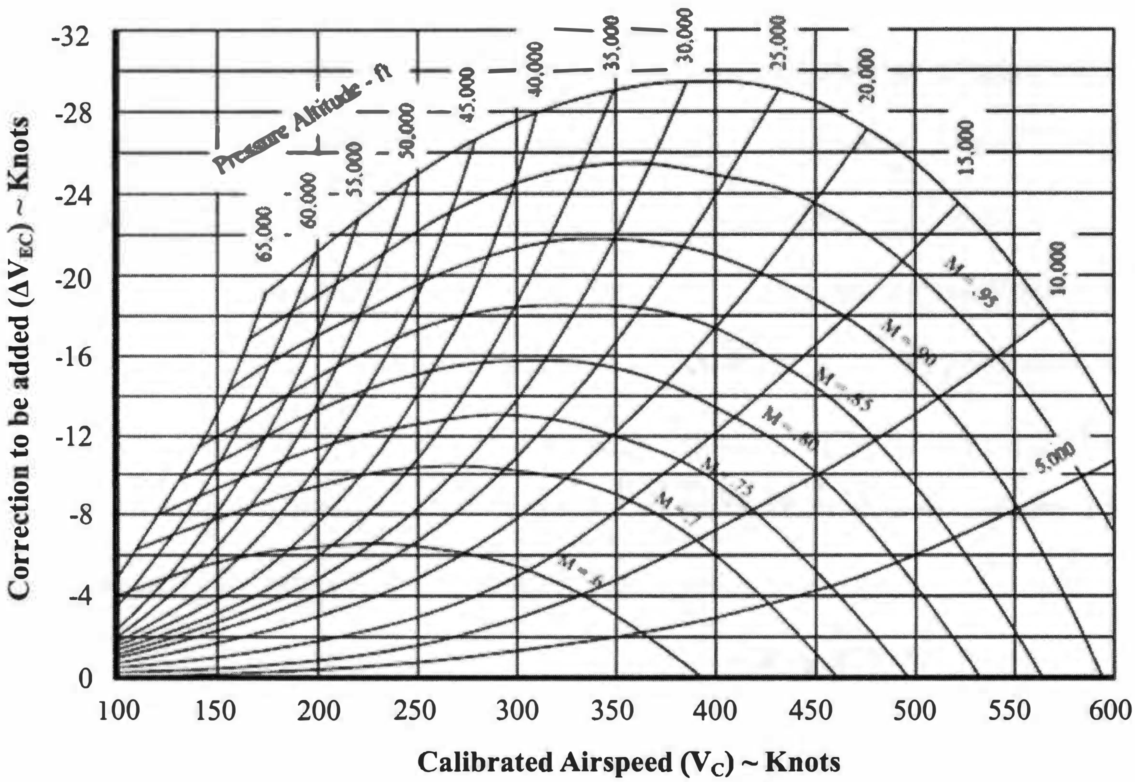

Figure 1-1. Compressibility Correction

Source: U.S. Naval Test Pilot School Flight Test Manual, *Fixed Wing Performance, USNTPS-FTM-No.108,* Maryland: USNTPS, 30 September 1992. [17]

inconsistent with the conditions that would cause compressibility to significantly affect the airspeed indication. Figure 1-1 shows that for, what would be rather extreme conditions for current helicopters, at speeds up to 200 KCAS and pressure altitudes up to 15,000 ft, the correction due to compressibility is less than 2 knots. In helicopter flight testing V_C is assumed to equal V_E.

(4) True airspeed (V_T) is V_E, or in case of helicopters, V_C, corrected for variations in air density associated with other than standard sea level conditions. From a flight test

perspective, the most important of these velocities is V_C. It is important in these terms in that the biggest contributor to its correction, position error, is determined through flight testing. Once V_C is determined, V_T is computed mathematically. See equation 3.4.

V_C is the international standard for airspeed reference. The Advisory Group for Aerospace Research and Development (AGARD), Flight Test Manual [5] states that, "Calibrated airspeed is of interest for the following reasons:

(1) It is measured aboard the airplane by a simple precise instrument amounting to a differential pressure gage (assuming that the correct total and static pressures exist at the pickups). Measurement of any other quantity such as V_T, V_E (equivalent airspeed), or M requires a more complex system.

(2) Calibrated airspeed is equal to true speed at sea level under standard conditions.

(3) It provides a positive measure of take-off and landing speeds regardless of the altitude of the ground or the local barometric pressure (provided the weight is known).

(4) It provides the pilot with a measure of the dynamic pressure, (q), on which, above all, depend the high-speed structural problems."

REGULATORY REQUIREMENTS

The U.S. Code of Federal Regulations, Title 14, pertaining to aviation, (14 CFR), provides general requirements for how to obtain V_C and how accurate the measurement must be. The two documents that are relevant to this discussion of helicopter airspeed indicating system calibration are 14 CFR Part 27, Airworthiness Standards: Normal Category Rotorcraft [4], and FAA Advisory Circular (AC) 27-1B [9].

14 CFR Part 27.1323 Airspeed Indicating System

Part 27.1323 establishes the requirement to calibrate the airspeed indicating system, and further establishes the allowable error. It states:

(a) Each airspeed indicating instrument must be calibrated to indicate true airspeed (at sea level with a standard atmosphere) with a minimum practicable instrument calibration error when the corresponding pitot and static pressures are applied.

(b) The airspeed indicating system must be calibrated in flight at forward speeds of 20 knots and over.

(c) At each forward speed above 80 percent of the climbout speed, the airspeed indicator must indicate true airspeed, at sea level with a standard atmosphere, to within an allowable installation error of not more than the greater of--

(1) ±3 percent of the calibrated airspeed; or

(2) 5 knots.

FAA AC 27.1323 Airspeed Indicating System

AC 27-1B provides information on methods of compliance with 14 CFR Part 27. The AC is based on "precedents set during rotorcraft certification programs spanning over 40 years, and consolidates guidance contained in earlier correspondence among FAA headquarters, foreign authorities, the rotorcraft industry, and certificating regions."

AC 27.1323 specifically addresses the importance of calibrating the airspeed indicating system early in a flight test program. It identifies determination of position error as critical to the accuracy of all other flight test data.

In outlining procedures to determine compliance, the AC states, "there are different methods to determine position error such as trailing bomb, airspeed course, boom system, etc. Each method has its own advantages and disadvantages, but will yield satisfactory results if done correctly." AC 27-1B provides no further description of the methods. The specifics of how to conduct the methods can be found in other flight test references; FAA AC 23-8B, Flight Test Guide for Certification of Part 23 Airplanes [8] and the U.S. Naval Test Pilot School Flight Test Manual, No.-106 [16].

MODERNIZING TEST METHODS

The objective of flight test is to determine safely and accurately needed information without excessive expenditure of time or money. Each of the methods mentioned in the Advisory Circulars for determining position error has advantages and disadvantages relative to this objective. Investigating ways to improve on these methods is important to future flight testing.

Not specifically addressed in AC 27-1B are new methods that use the Global Positioning System (GPS) for determining position error. Several variants of methods using GPS are gaining popularity in fixed-wing flight test, and clearly have application to helicopter flight testing as well. The GPS reciprocal heading method is one such method. AC 23-8B describes the GPS speed track method. Another used at the National Test Pilot School is the GPS Horseshoe method [15].

Comparison of data from a flight test conducted by the UTSI flight research department, shows that the three aforementioned GPS methods all provide similar results. The results are presented in Figure 1-2. The reciprocal heading and horseshoe methods

MODEL OH-58A+ HELICOPTER
S/N 72-21212 N89UT

Configuration:	Doors On	**Rotor Speed:**	100%
Avg. OAT:	6° C	**Avg. GrossWeight:**	2925 lb.
Avg. Hp:	4100 ft	**Avg. CG:**	109.3 in.

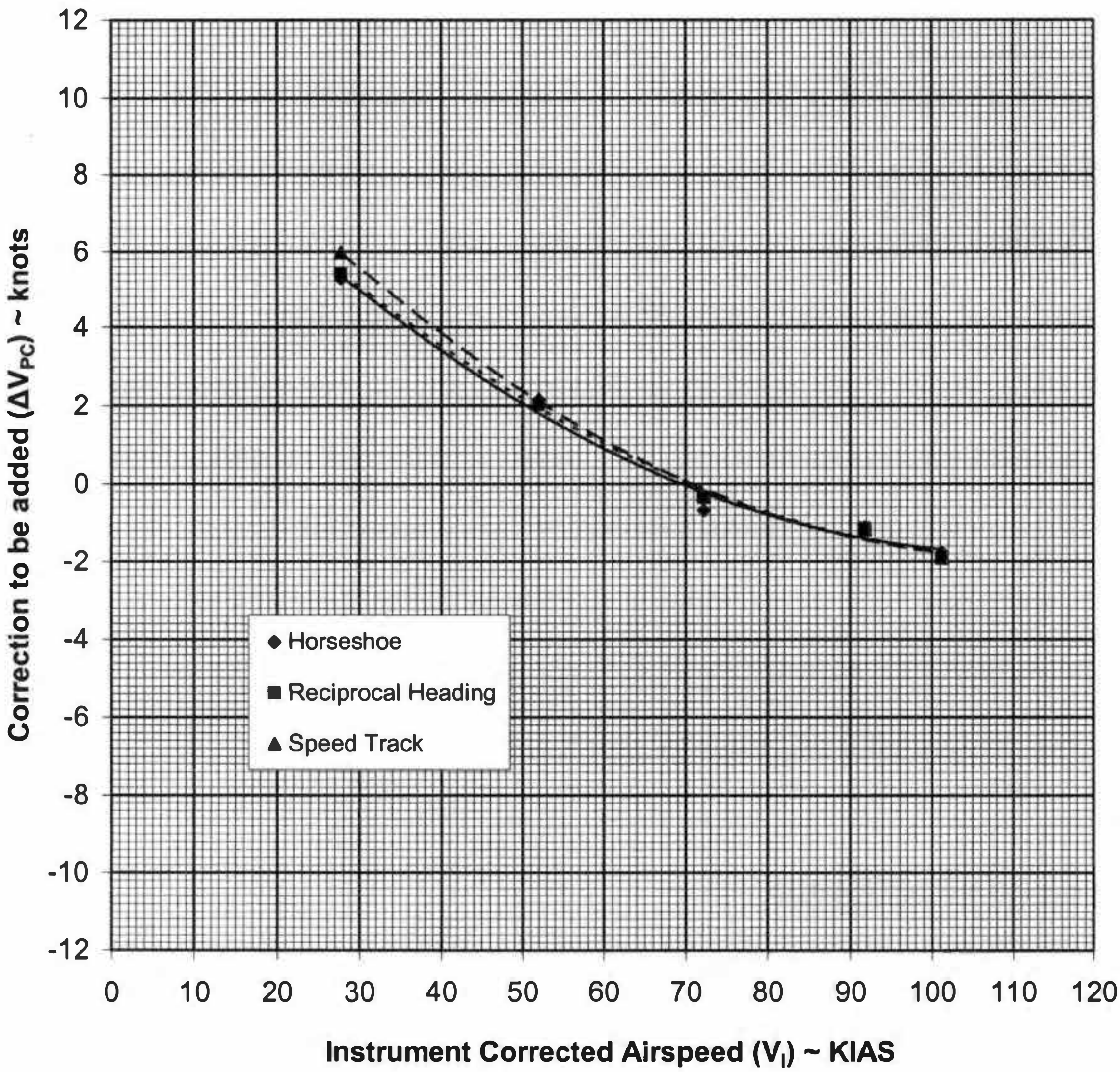

Figure 1-2. Comparison of GPS Methods

provide nearly identical results. The speed track method differs only ½ knot at an extreme low speed condition of less than 30 KIAS, and the difference becomes nearly indiscernible across the remainder of the tested airspeed band. The main differences between the methods are in the data collection and data reduction. In both areas, the reciprocal heading method proves more advantageous. Both the horseshoe and speed track methods require three data points per reference airspeed versus two data points for the reciprocal heading method. The data reduction process of the reciprocal heading method is also significantly shorter and less intensive; it is five steps, while the speed track and horseshoe methods require approximately 24 steps. The additional data points increase the flight time required and the additional steps increase the data reduction time and the potential for error in the calculations, but do not necessarily improve the accuracy of the output data. The only information provided by the increased data reduction steps is wind direction and velocity. The reciprocal heading method provides the same results with less time and effort and ultimately lower cost.

COMPARING METHODS

Dr. Ralph Kimberlin, Head of the Aviation Systems and Flight Research Department at the University of Tennessee Space Institute (UTSI), developed the GPS reciprocal heading method in 1992 and uses it with great success in courses and test programs at the university [13]. This report investigates the use of the GPS reciprocal heading method for determining position errors in helicopter flight testing. The GPS reciprocal heading method is similar to that of the measured course. The technique of the measured course is to determine groundspeed from elapsed time over a known distance and convert that to calibrated airspeed. The GPS method uses the GPS calculated groundspeed in lieu of flying the measured course. The measured course is used as a comparative baseline in this report. The two methods are compared with respect to the accuracy of data each provides, the reliability of that data, and the cost and relative safety of obtaining the data. The objective is to determine if the GPS reciprocal heading method provides comparable results.

CHAPTER 2

PITOT-STATIC AIRSPEED SYSTEM THEORY

AIRSPEED MEASUREMENT

The equation, on which subsonic airspeed measurement is based, is a derivative of Bernoulli's equation for compressible flow.

$$V_T{}^2 = \frac{2a^2}{\gamma - 1}\left[\left(\frac{P_t - P_s}{P_s} + 1\right)^{\frac{(\gamma-1)}{\gamma}} - 1\right] \qquad \text{(eq. 2.1)}$$

where

V_T = True airspeed

a = Speed of sound

P_t = Free stream total pressure

P_s = Free stream static pressure

γ = Specific heat ratio

From equation 2.1, we derive the equation for calibrated airspeed (V_C).

$$V_C = \left[\frac{2a_{ssl}{}^2}{(\gamma - 1)}\left[\left(\frac{P_t - P_s}{P_{ssl}} + 1\right)^{0.2857} - 1\right]\right]^{.5} \qquad \text{(eq. 2.2)}$$

where

V_C = Calibrated airspeed

a_{ssl} = Speed of sound at standard sea level

P_{ssl} = Pressure at standard sea level

Substituting the respective sea level values: Static Pressure (P_{ssl}) 2116 psf, the speed of sound (a_{ssl}) 1117 fps, and the specific heat ratio (γ) 1.4 for air, the equation, with units in feet per second (fps), becomes:

$$V_C = 2497.7\left[\left(\frac{P_t - P_s}{2116} + 1\right)^{0.2857} - 1\right]^{.5} \qquad \text{(eq. 2.3)}$$

In equation 2.3, the only variables remaining are the difference between total pressure and static pressure, P_t - P_s. The pitot-static system is the tool with which we measure this differential pressure in flight. An example of a simple pitot-static airspeed indicating system is presented in figure 2-1. The pitot tube senses total pressure P_t and the static ports provide static pressure P_s at the location of the static port. The difference is shown directly on a gauge calibrated to indicate airspeed. As air pressure and density varies with altitude, the V_O will only be the same as V_T under standard sea level conditions as is reflected in the equation for V_C.

V_O, even under standard sea level conditions, can differ from V_C because the static system does not sense true, free stream, ambient static pressure. Rotor downwash velocity, angle of attack, and sideslip can all contribute to the inconsistent flow field around the static ports and the pitot tube, preventing an accurate measurement of free stream pressure. This error in detection of free stream pressure is known as the position error. If not for variation in the flow field around the helicopter, the differential pressure, presented as airspeed, would be V_C. Determining the value for this position error, to correct the equation for V_C, is the purpose of the airspeed calibration flight test.

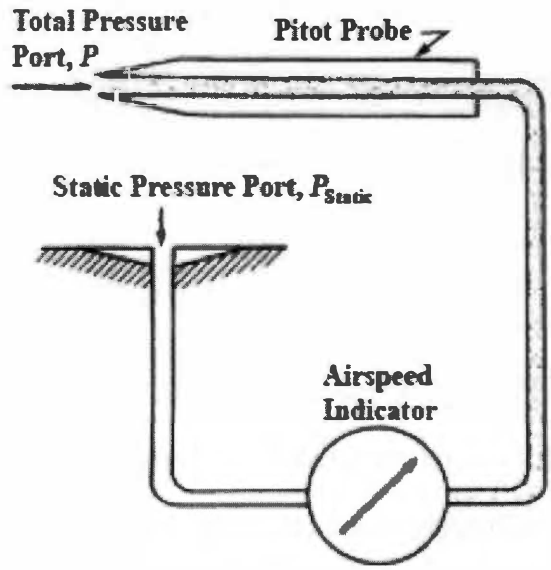

Figure 2-1. Basic Airspeed Indicating System

Source: Hurt, Hugh H. *Aerodynamics for Naval Aviators.* 1960, Rev. 1965. Reprint, Washington: Aviation Supplies & Academics, Inc., 1992. [10]

AIRSPEED SYSTEM ERRORS

Three groups of errors; instrument errors, lag errors, and position errors affect the accuracy of the airspeed indication. Each of these errors is determined in a different manner; laboratory testing, ground testing and flight testing respectively.

Instrument Error

Instrument errors exist due to the mechanical properties of the airspeed indicator itself. Each instrument that is manufactured functions with varying degrees of accuracy due to tolerances in the manufacturing process. Friction, inertia of moving parts, and temperature changes also affect the internal parts of each instrument. Each instrument must be calibrated to a standard source of differential pressure to determine how much correction must be added for a given pressure. The value determined from laboratory calibration is added to an observed velocity (V_O) to give the exact value of corrected indicated velocity (V_I). See figure B-2 for an example of an instrument correction chart.

Lag Error

The affects of lag error are normally associated with accelerating, decelerating, climbing, and descending; conditions when rapidly changing pressures are involved. The speed of pressure propagation, a possible imbalance of volume in the system between the P_t side and the P_s side, and inertia of the air mass in the system can produce a lag between the actual pressure and what is indicated. During level flight calibrations at a steady airspeed, lag errors are not a factor and require no correction.

Position Error

Position error is caused by other than free stream pressures at the pitot-static sensors. In helicopters, pressure-sensing errors occur at both the total and static sensors. The amount of error depends on the location, shape, and orientation of the sensor. Both the pitot tube and static ports are influenced by the rotor downwash and flight path of the helicopter. Depending on the condition of flight of the helicopter (level, climb, descent) the flow field around the helicopter will produce varying amounts of position error. The flow field varies with velocity, sideslip, weight and center of gravity, amount of power applied, rotor speed, and configuration. Position error is determined through flight test methods such as the measured course or GPS reciprocal heading. The term ΔV_{PC} is the correction due to position error. ΔV_{PC} is added to V_I to produce V_C. See equation 3.5.

CHAPTER 3

MEASURED COURSE METHOD

GENERAL

The measured course method is used by both civil and military flight test organizations for fixed-wing as well as helicopter testing. A detailed explanation is available in FAA AC 23-8B [8], Flight Testing of Fixed-wing Aircraft, Kimberlin [14], and USNTPS FTM-106 [16].

To determine the position error of the airspeed system using the measured course method, the helicopter is flown over a course of known length to calculate true airspeed (V_T) from the elapsed time. Calibrated airspeed (V_C) is then calculated from V_T and is compared to the corrected indicated airspeed (V_I) to determine the position correction (ΔV_{PC}). The reliability of the results of this method depends on several factors, the course length, the accuracy of timing the course, the accuracy of the measurement of the course, and the pilot's ability to maintain a constant indicated airspeed for an extended duration. Longer distances reduce the impact of timing error, but increase the potential for inaccuracy in airspeed as it is likely that the airspeed will vary over the lengthened period. The USNTPS FTM-106 [16] recommends the lengths in table 3-1 as minimum lengths to ensure at least 10 seconds of elapsed time for each run to reduce timing errors. Data that must be recorded for each timed leg include: Course length (D), observed airspeed (V_O), observed pressure altitude (H_{PO}), elapsed time (ΔT), aircraft heading (HDG), and observed temperature (OAT).

Table 3-1. Minimum Recommended Measured Course Length

Test Airspeeds (KTAS)	Course Length (ft)
0 - 29	500
30 - 59	1000
60 - 89	1500
90 - 119	2000
120 - 149	2500
150 - 179	3000
180 - 210	3500

Safety

Flying the measured course can require significant attention from the pilot to maintain a constant airspeed for extended durations while flying close to the ground. The pilot must focus on maintaining constant airspeed. The course will likely be an area as flat as possible, often over surfaces where depth perception is poor for maintaining altitude. The lower altitudes also increase risks associated with reaction time to an engine failure or other emergency.

Advantages

The measured course offers some advantages over other methods. It requires no special test equipment such as a static pressure trailing cone. It requires no modification of the test aircraft. The test can be conducted with little external support such as engineers and instrumentation on the ground or a pace aircraft. No special facility or equipment is required as with the space positioning methods based on land-based transmitters pinpointing the location of the aircraft.

Disadvantages

The disadvantages of the measured course are also important to consider. There is potential for large inaccuracies in timing that increase scatter in the data; a 5 percent error is created if a 10-second leg is mistimed by just 0.5 second. It can be costly as it may require several recording flights to reduce scatter in the data. Another is the need for a large area where the aircraft can be flown at a consistent low altitude the full length of the desired leg. The time required to measure and mark the course can be substantial. The entire course must be flown in opposite directions for each reference speed so that effects of wind will cancel. Optimally, the test should be conducted in calm wind or in an area with minimal obstacles near the course. Obstacles can cause the wind to be inconsistent, making it difficult to correct for the effects of the wind during data reduction. Higher wind can be accepted as long as it is constant, but will likely cause turbulence making it more difficult to maintain a constant airspeed.

DATA REDUCTION

The objective of the data reduction is to calculate V_C from test data and compare it with V_I to determine ΔV_{PC}. Test flight data are collected and tabulated for each reference airspeed. The process follows U.S. Naval Test Pilot School FTM-106 [16].

Observed data are first corrected for instrument errors.

$$V_I = V_O + \Delta V_I \qquad \text{(eq. 3.1)}$$

where

V_I = Instrument corrected airspeed

V_O = Indicated airspeed

ΔV_I = Correction for instrument error

ΔT is related to (D) to determine V_G for legs flown in opposing directions.

$$V_G = 0.592\left(\frac{D}{\Delta T}\right) \qquad \text{(eq. 3.2)}$$

where

V_G = Groundspeed (knots)

D = Course length (ft)

ΔT = Elapsed time (sec)

0.592 = Conversion factor (fps to knots)

Averaging the two groundspeeds (V_{G1}, V_{G2}) of each reference speed from opposing headings produces V_T.

$$V_T = \frac{V_{G1} + V_{G2}}{2} \qquad \text{(eq. 3.3)}$$

where

V_T = True airspeed

V_T is then corrected to standard conditions, which produces V_C.

$$V_C = V_T\sqrt{\sigma} \quad \text{(eq. 3.4)}$$

where

V_C = Calibrated airspeed

σ = Density ratio of the test conditions

V_C is adjusted by the value of V_I to determine ΔV_{PC}.

$$\Delta V_{PC} = V_C - V_I \quad \text{(eq. 3.5)}$$

where

ΔV_{PC} = Position correction

Derived data are plotted in a graph as V_I versus V_C, and V_I versus ΔV_{PC}.

CHAPTER 4

GPS RECIPROCAL HEADING METHOD

GPS THEORY

One of the most important factors affecting use of the GPS reciprocal heading method is the accuracy of the groundspeed (velocity) calculation presented in the cockpit. The calculation for groundspeed is a linearized derivative of the position equation solved by the GPS user's receiver unit.

The GPS system solves equations for user position and velocity based on known satellite position. The equations use pseudorange values to compute both position and velocity. The values are called pseudorange because they contain predetermined errors, particularly atmospheric time delays and clock errors. The user's GPS receiver/computer uses initial estimates to iterate and solve the equations and calculates user data in a common position reference system called Earth-centered, Earth-fixed (ECEF), which relates the satellites and user to the same reference point. The receiver then converts the user's ECEF position into World Geodetic System (WGS-84), the international coordinate standard for navigational reference.

Position

The user's receiver receives a transmission from a satellite that contains the satellites position information. The receiver uses timing information contained in the satellite transmission to determine the user's range from the satellite and the

3-dimensional position coordinates for use in the equation. The equation in simplified form, disregarding the error elements that make it pseudo, represents a sphere centered about the respective satellite vehicle [12].

$$R_i = \sqrt{(X_{si} - X_u)^2 + (Y_{si} - Y_u)^2 + (Z_{si} - Z_u)^2} \quad \text{(eq. 4.1)}$$

where

R_i	= Range of the satellite from the user
(X_{si}, Y_{si}, Z_{si})	= Known 3-dimensional coordinates of the satellite vehicle
(X_u, Y_u, Z_u)	= Unknown 3-dimensional coordinates of the user

The equations of at least three satellites are solved, and the intersection of the spheres closest to the earth is the user position.

The U.S. Department of Defense (DOD) ultimately controls the accuracy of the position solution. For security reasons, standard positioning service (SPS), which is available to all users, has some errors intentionally introduced into the satellite transmissions by DOD. Through a concept called selective availability, DOD limits access to precision positioning service (PPS) to authorized military users. PPS has no intentional error values and provides better accuracy. Currently PPS is available to all users but can be restricted if required by a threat to U.S. national security. The advertised accuracy of GPS position is presented in table 4-1.

Table 4-1. GPS Advertised Accuracy

Positioning Service	Vertical Position Accuracy[1] (m)	Horizontal Position Accuracy[1] (m)	Time Accuracy[1] (ns)
PPS	27.7	22	100
SPS	156	100	340

1. Source: Biezad, 1999 [3].

Velocity

The GPS receiver/computer uses Doppler range-rate and the position equation to calculate velocity. User velocity is the first derivative of the position equation. Differentiating the position equation produces the range-rate equation [12].

$$\dot{R}_i = \frac{\overline{X}_k - \overline{X}_u}{R_i} \cdot \left[\overline{V}_k - \overline{V}_u\right]$$

$$\dot{R}_i = \overline{1}_i \cdot \left[\overline{V}_k - \overline{V}_u\right] \qquad \text{(eq. 4.2)}$$

where

$\dot{R}_i$ = Range rate (user velocity)

$\overline{V}_k$ = Known satellite velocity vector

$\overline{V}_u$ = Unknown user velocity vector

$\overline{X}_k$ = Known satellite position vector

$\overline{X}_u$ = Unknown user's position vector

$\overline{1}_i$ = Estimated line-of-site unit vector

The user's receiver linearizes and further iterates, with small perturbations about the estimated position, the range-rate equation to produce the aircrafts velocity with respect to the WGS grid, which is groundspeed (V_G) along the aircraft track. Groundspeed accuracy determined through tests [12] is better than 0.1 m/s with PPS and between 0.3 and 0.9 m/s for SPS.

Differential GPS

Currently implemented Differential GPS uses a land-based receiver-transmitter to mitigate errors from the satellite constellation. The GPS ground station eliminates the pseudorange errors from the satellite messages and transmits them to users in the area of the station; therefore, users receive position messages from the station and the satellites and use the difference to more accurately compute position. Use of Differential GPS reduces errors in position, but does not improve velocity calculations. Further explanation of GPS principles and derivation is available in Kayton and Fried [12].

FLIGHT TEST METHOD

The GPS reciprocal heading method is similar to the measured course in most of the parameters that must be recorded, and the outcome of that data being V_T derived from V_G. The GPS method is very simple to use, and data reduction is similar to that of the measured course. Any aviation GPS that provides track and groundspeed can be used. The GPS need not be integral. A handheld GPS is sufficient, as long as it is fixed in the aircraft during the test flight to ensure consistency in the data.

Data that must be recorded for each run include observed airspeed (V_O), observed pressure altitude (H_{PO}), aircraft heading (HDG), groundspeed (V_G) from the GPS and helicopter track (TRK) from the GPS, and observed temperature (OAT). The helicopter is established in level flight at the desired reference airspeed. In stable flight condition, the parameters are recorded as soon as the GPS references of groundspeed and track are stable. The helicopter may then be accelerated to the next reference speed, or turned to the reciprocal heading to record data for the same reference speed. One technique to expedite data collection is to collect data for several reference speeds on one heading before reversing to capture the same reference speeds on the opposite heading.

Safety

The GPS method can be flown at any altitude; it need not be flown close to the ground, reducing risk associated with reaction times to emergencies, and increased concentration to avoid ground contact. The method requires less focus inside the cockpit than the measured course.

Advantages

The GPS method flight test takes less time than other methods as data is collected much quicker with the pilot only needing to hold the reference airspeed long enough for the GPS groundspeed and track to stabilize. The GPS method is not restricted to a specified course, allowing more flexibility for conducting the test. The GPS method is also less restricted by wind. As long as the wind is constant, it is easily cancelled out of calculations. The benefit over the measured course is that at higher altitudes, the wind is less likely to be turbulent due to ground interference. The GPS method requires minimal data points to obtain satisfactory results.

Disadvantages

If the helicopter is not equipped with an integral GPS, there may be an initial cost, although not substantial, for purchasing and installing a GPS or a handheld unit.

DATA REDUCTION

The data reduction is similar to the measured course. The data for each reference airspeed is tabulated and corrected.

Observed data are first corrected for instrument errors.

$$V_I = V_O + \Delta V_I \qquad \text{(eq. 4.3)}$$

where

V_I = Instrument corrected airspeed

V_O = Observed airspeed

ΔV_I = Change due to instrument error

The desired V_G is that along the heading of the helicopter as opposed to what the GPS delivers, which is along the track of the aircraft.

$$V_G = \cos\beta \cdot V_{G(trk)}) \qquad \text{(eq. 4.4)}$$

where

$V_{G(trk)}$ = Groundspeed along the aircraft track (read from the GPS)

β = Angular difference between observed aircraft heading and track

Averaging the two groundspeeds (V_{G1}, V_{G2}) of each reference speed from opposing headings produces V_T.

$$V_T = \frac{V_{G1} + V_{G2}}{2} \qquad \text{(eq. 4.5)}$$

where

V_T = True airspeed

V_T is then corrected to standard conditions, which produces V_C.

$$V_C = V_T \sqrt{\sigma} \qquad \text{(eq. 4.6)}$$

where

V_C = Calibrated airspeed

σ = Density ratio of the test conditions

V_C is adjusted by the value of V_I to determine ΔV_{PC}.

$$\Delta V_{PC} = V_C - V_I \qquad \text{(eq. 4.7)}$$

where

ΔV_{PC} = Position correction

Derived data are plotted in chart form as V_I versus V_C, and V_I versus ΔV_{PC}.

CHAPTER 5

RESULTS OF FLIGHT TEST

PURPOSE

The purpose of this test was to evaluate the GPS reciprocal heading method for use in determining pitot-static system position error in helicopter flight testing.

CONDUCT OF TEST

Flights were conducted per the flight test plan (appendix A) to determine ΔV_{PC} of the airspeed system of the OH-58A+ helicopter from 20 KIAS to maximum level flight speed (V_H). The data were obtained and reduced using the measured course and the GPS methods per the procedures in Chapter 3 and 4 respectively. The airspeed instrument error was corrected using the calibration provided in figure B-2. The test aircraft's pitot tube is shown in figure 5-1. The static ports are shown in figures 5-2 and 5-3. Test aircraft weight and balance is presented in figure B-1. For more information on test conditions, and a more detailed description of the test aircraft, see appendix A.

The flight test data are used to comparatively evaluate the feasibility, accuracy, and reliability of the GPS reciprocal heading method for determining position error in helicopter flight testing. For the purpose of comparison, the results of the measured course serve as the standard. It is an accepted method of test, and results obtained from a measured course would stand alone in a representative flight test.

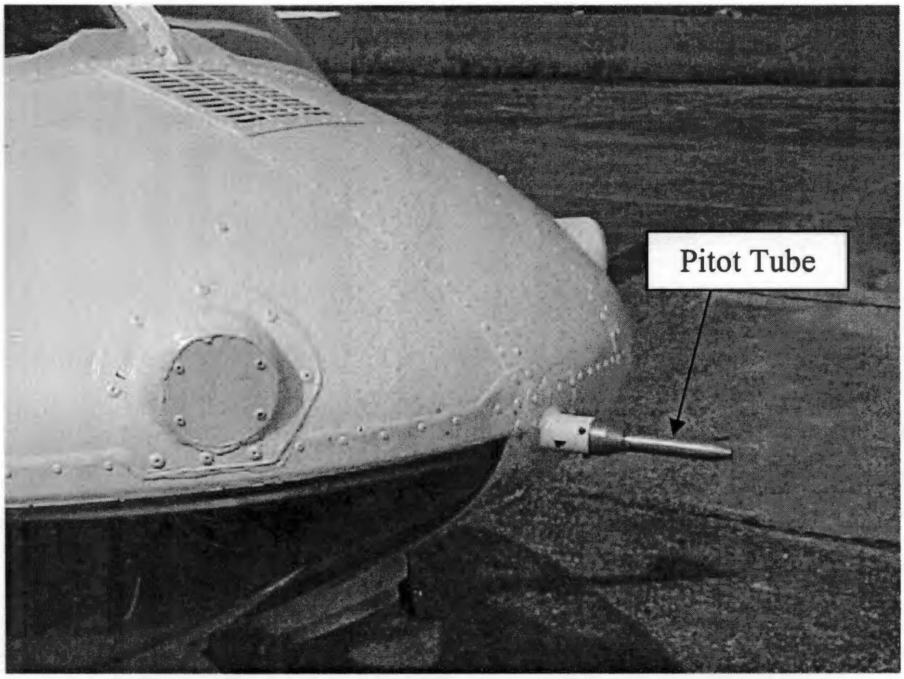

Figure 5-1. OH-58A+ Pitot Tube

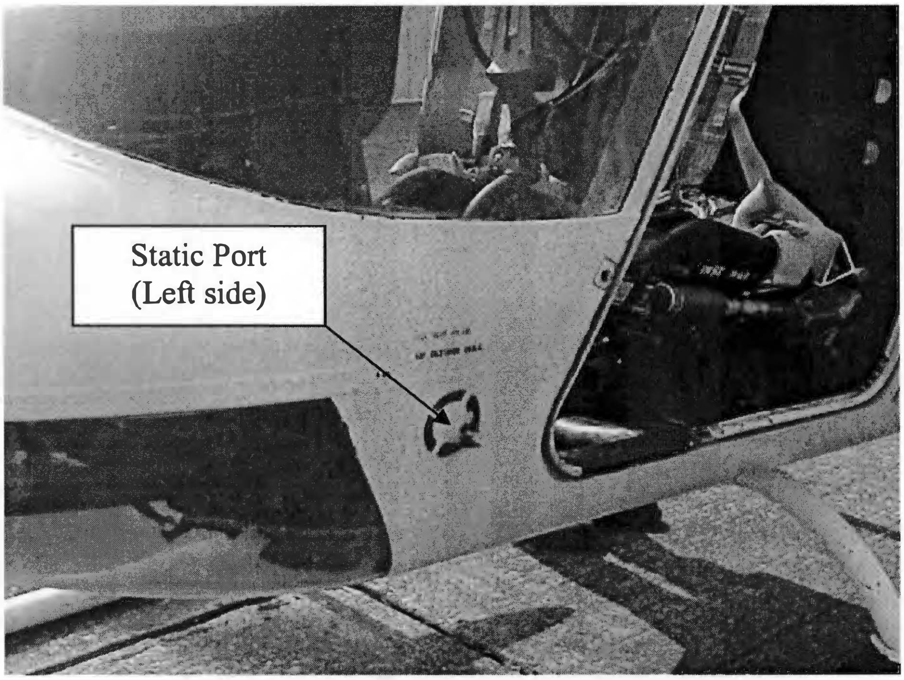

Figure 5-2. OH-58A+ Static Port (Location)

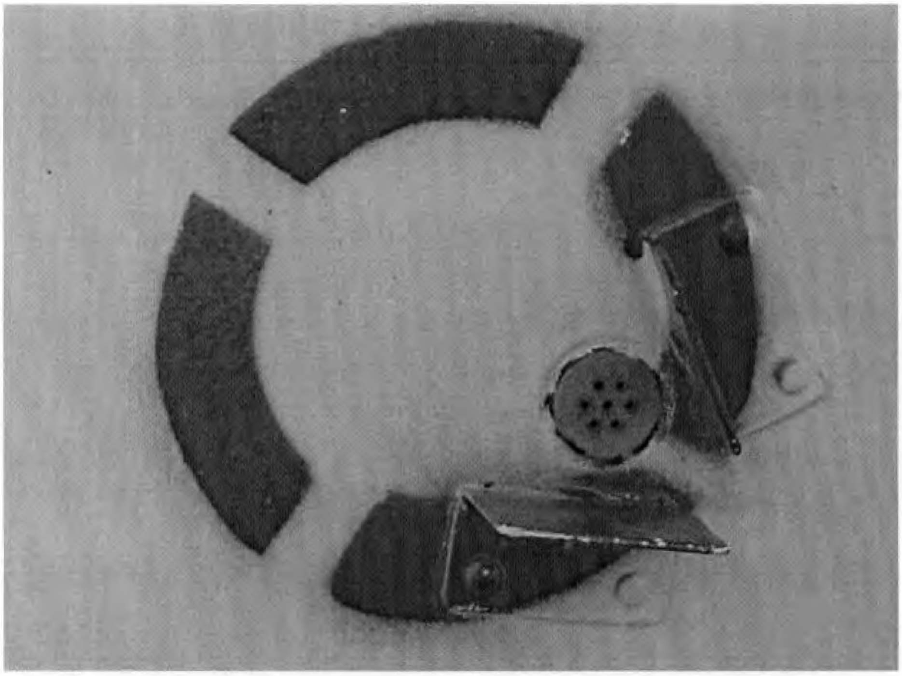

Figure 5-3. OH-58A+ Static Port (Detail)

RESULTS AND EVALUATION

The results of the flight tests are presented in figures 5-4 and 5-5. Figure 5-4 shows the relationship between V_I and V_C. The results of both test methods are presented, referenced to a line of zero error. For this test, the figure shows that both methods produced similar results.

Data presented in figure 5-5, show ΔV_{PC} to be added to a given V_I to obtain V_C. The data show satisfactory Part 27 compliance is obtainable by both GPS and measured course methods. 14 CFR Part 27.1323 requires determination of ΔV_{PC} from 80 percent of the climbout speed and above; and states that the error may not exceed the greater of $\pm$ 3%, or 5 knots. The climbout speed for the OH-58A+ is 60 KIAS. The results of the measured course show at 48 KIAS (80 percent climbout speed) ΔV_{PC} of 3.4 knots, with

MODEL OH-58A+ HELICOPTER
S/N 72-21212 N89UT

Configuration:	Doors Off	**Rotor Speed:**	100%
Avg. OAT:	23° C	**Avg. GrossWeight:**	2800 lb.
Avg. Hp:	1200 ft	**Avg. CG:**	110.7 in.

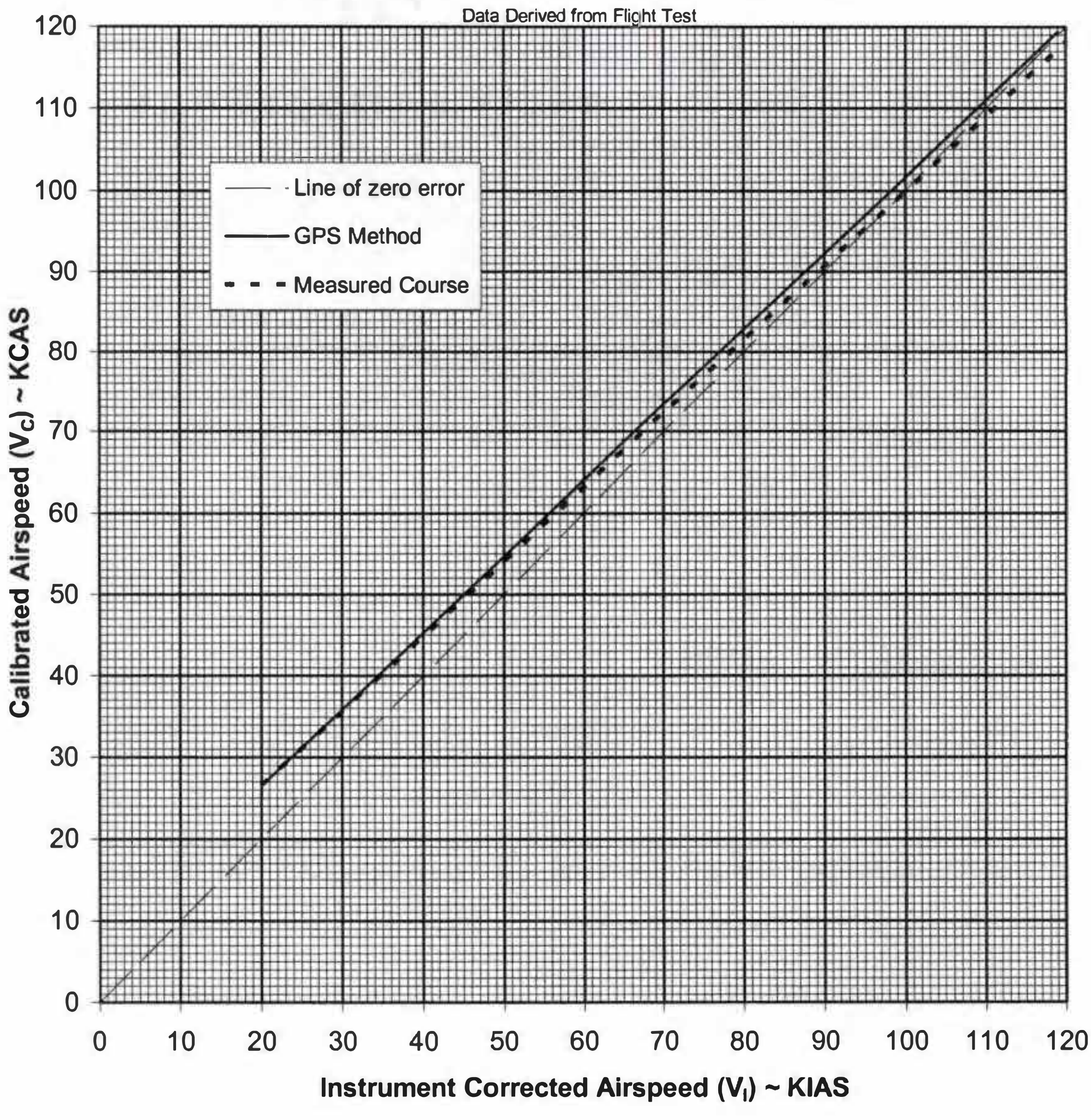

Figure 5-4. Airspeed System Calibration

MODEL OH-58A+ HELICOPTER
S/N 72-21212 N89UT

Configuration:	Doors Off	**Rotor Speed:**	100%
Avg. OAT:	23° C	**Avg. GrossWeight:**	2800 lb.
Avg. Hp:	1200 ft	**Avg. CG:**	110.7 in.

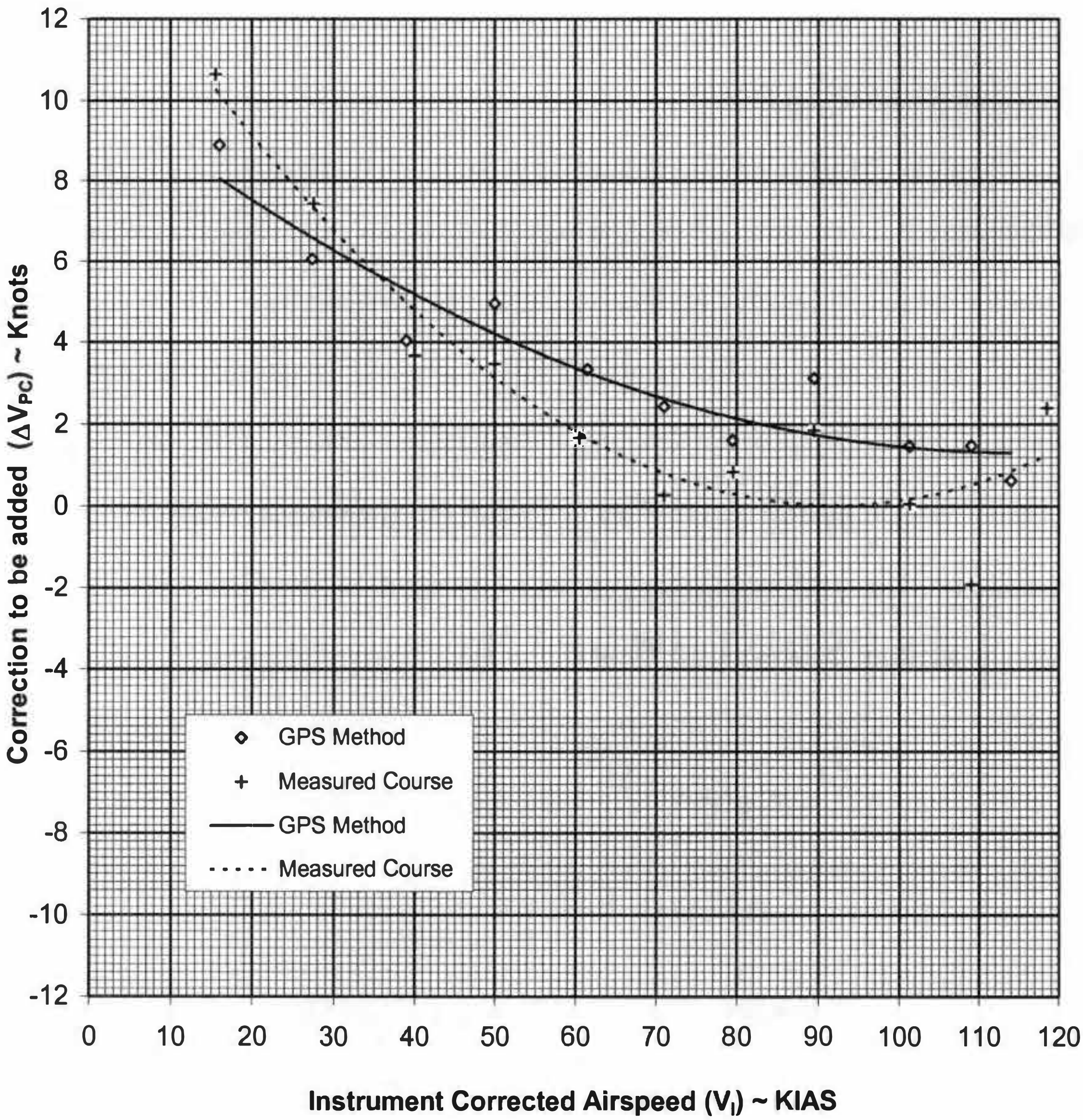

Figure 5-5. Position Correction

the error decreasing to zero at 90 KIAS and then to a value of 1.2 knots at 118 KIAS. The results of the GPS reciprocal heading method show ΔV_{PC} to be 4.4 knots at 48 KIAS decreasing to an error of 1 knot at 115 KIAS.

STATISTICAL COMPARISON

Figure 5-5 includes the flight test data-points of both methods. Regression was used to determine the equation for the line of each set of data. The residuals are used to comment on the confidence that the line accurately represents the data. It is clear visibly that there is less scatter in the data points of the GPS method. To quantify the amount of scatter into terms of confidence, the value for standard error of estimate (s_e) was calculated. The s_e is the standard deviation by which the samples vary from the regression line. The confidence values are shown in table 5-1. The data of the GPS method deviate from the line only 0.786 knots, while the measured course data deviates 1.276 knots. Confidence in the GPS data to determine compliance is very high with one set of data. To increase confidence in the data obtained with the measured course, it would be necessary to obtain more data to reduce the scatter.

Table 5-1. Confidence Values for Test Data

Test Method	Equation of the Line	Standard Error of Estimate (s_e)
GPS	$y = 0.0007x^2 - 0.1591x + 10.425$	0.786
Measured Course	$y = 0.0017x^2 - 0.3219x + 14.856$	1.276

SUPPORTING DATA

In addition to the results of the flight tests, other elements of the evaluation of the GPS reciprocal heading method include comparison of preparation activities and time required to complete the tests.

The GPS method required no special preparation. The measured course however required approximately two additional man-hours for establishing the course. The required lengths for the desired reference airspeeds were determined, and a 2-man crew measured and marked appropriate points for start and finish with paint that would be visible from the aircraft.

The tests were flown in two separate flights with refueling occurring between the flights to provide similar conditions of weight and center of gravity (CG) for each method. The measured course required approximately 43 minutes to obtain one set of data. The GPS reciprocal heading method required only 35 minutes to complete.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

General

Within the scope of the tests performed, the GPS reciprocal heading method is satisfactory for determining pitot-static system position error in helicopter flight testing. The method is accurate, cost effective, safe, reliable, and can be performed quickly with little preparation and few external resources. Comparing the test results provided by the GPS reciprocal heading method to the measured course method clearly show benefits of using the GPS method.

Safety

The key safety advantages of the GPS method over the measured course are in the quick manner in which data are obtained, and that the GPS need not be flown at restrictive low altitudes. The GPS method requires only a few seconds of stability at the reference airspeed, so the pilot need not focus attention inside the cockpit attempting to maintain a constant airspeed for entire lengths of measured course. Flying at a higher altitude requires less attention to obstacle avoidance, and provides more reaction time for emergencies, as well as avoiding operations in the caution-avoid areas of the test aircraft.

Accuracy and Reliability

Because the GPS method provided less scatter in the collected data, the regression line computed to represent the data is more reliable. Statistically the results are of higher confidence. There is less opportunity to introduce error in data collection with the GPS method. The greatest potential contributor to error in the measured course, timing error, is eliminated by the GPS reciprocal heading method. The length of time the helicopter must be flown on steady condition is less; the groundspeed reading is an immediate solution, instead of at best an average speed over the distance represented by the measured course.

Cost

The reduction in cost for a test program can be found in the reduced time required to conduct the test, both in terms of man-hours and flight time. The GPS method can provide adequate results with fewer flights than the measured course. Since data can be collected with less concern for wind conditions, fewer delays will be encountered. The GPS method can be conducted concurrently with other tests, providing more flexibility to the test program. The only additional cost could be the acquisition of a GPS if one were not already installed in the aircraft or otherwise available.

Time

There is no separate preparation time for the GPS method. The measured course, depending on the suitability of area chosen for the course, can require significant time to accurately measure the course and adequately mark the start and finish points of each leg so that they are visible from the aircraft during flight. During the conduct of the flight, the GPS data may also be obtained faster, as the time on each point is minimal. The measured course requires more time to fly the necessary minimum distances for each reference speed, and could require multiple runs to have sufficient data to accurately compute the regression line.

RECOMMENDATIONS

- Both civil and military flight test organizations should consider using the GPS reciprocal heading method to determine pitot-static position error in helicopters.
- The FAA should consider revising AC 27-1B to include the GPS reciprocal heading method as an approved method for determining position error in helicopter flight testing.
- Further testing to should be conducted to investigate expanding the use of the GPS reciprocal heading method for use in determining position error in climbing and during autorotation.

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LIST OF REFERENCES

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APPENDICES

APPENDIX A: TEST PLAN

TEST PLAN

PURPOSE OF TEST

The purpose of this test is to evaluate the GPS reciprocal heading method for use in determining pitot-static system position error in helicopter flight testing.

DESCRIPTION OF TEST AIRCRAFT

The OH-58A+ is a single engine, single main rotor helicopter built by Bell Helicopter Textron (figure A-1). It is a four-place light helicopter with a maximum gross weight of 3200 lbs. The aircraft is equipped with an Allison T63-A-720 gas turbine engine rated at 420 shaft horsepower (SHP), uninstalled. The main transmission is limited to an input of 317 SHP. The maximum speed of the aircraft (V_{NE}) is 120 KIAS. The main rotor assembly is two bladed, semi-rigid, mounted on an under-slung feathering axis hub. The tail rotor design is single hub 2 blades. The aircraft has a single internal fuel cell with a capacity of 71.5 gals, 70.3 gals usable. The pitot-static system includes a single, nose-mounted, heated pitot tube and two static ports, symmetrically located (left and right), mounted forward of the front crew member doors (figures 5-1, 5-2, 5-3). The aircraft has a Bendix/King KLN 89B GPS installed. It is a standard installation that consists of a panel mounted unit that contains the GPS sensor, the navigation computer, a gas plasma discharge display, and all controls to operate the system (figure A-2). The system has analog outputs to drive a Course Deviation Indicator (CDI). The test aircraft, S/N 72-21212, is representative of production aircraft. A more detailed description of the aircraft is available in the aircraft Operator's Manual, TM-55-1520-235-10 [6].

Figure A-1. The Bell Helicopter OH-58A+

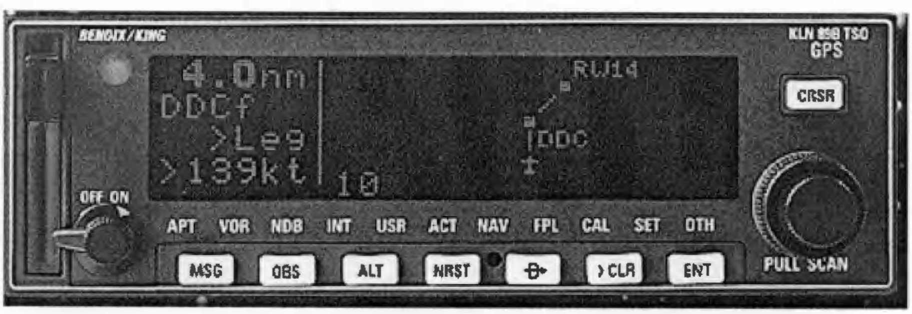

Figure A-2. The KLN-89B Control Head

SCOPE OF TEST

The test flights will be conducted in the local flying area of the Tullahoma Regional Airport (THA), Tullahoma, Tennessee under VMC conditions. Minimum weather required is defined as 3000 ft ceiling and 1-mile visibility, wind speed less than 10 knots. Two flights, approximately 45 minutes each, will be used to collect test data. Test conditions IAW table A-1, Test and Test Conditions. The aircraft will be refueled between flights to ensure similar conditions of weight and CG for both tests. The aircraft will be operated within limitations established in the aircraft Operator's Manual TM-55-1520-235-10 [6].

METHOD OF TEST

The measured course method will be conducted IAW USNTPS FTM-106 [16] and FAA AC 27-1B [9]. The course is marked on a section of closed runway at THA. Painted marks on the runway, indicate the start and stop points for three distances; the increasing lengths to accommodate higher reference airspeeds. The distances are defined in table A-2. Data reduction and presentation will be IAW USNTPS FTM- 106 [16] using Microsoft Excel and Microsoft Word.

The GPS reciprocal heading method is a modified version of methods currently approved for airplane flight testing. The aircraft is flown on a specified magnetic heading, and altitude (H_{PO}), at the reference test airspeed (V_O) long enough for the GPS groundspeed (V_G) and track to stabilize. Track and groundspeed are recorded from the GPS, as well as H_{PO}, V_O, T_O, and magnetic heading (HDG) from the aircraft integral instruments. The aircraft is then flown on the reciprocal heading at the same test airspeed and data collection is repeated. The procedure is repeated over the desired range of reference airspeeds. Data reduction is similar to the measured course, substituting GPS V_G for computations obtained from the measured course.

Table A-1. Test and Test Conditions

Task	Altitude[1] (ft)	Airspeed (KIAS)	Method	Remarks[2]
Determine Position Error	20 – 50 AGL	20 – 120	Measured Course	10 knot increments
Determine Position Error	1500 H_P	20 – 120	GPS Reciprocal Heading	10 knot increments

1. Altitude for measured course 20 ft AGL for reference speeds 20 – 30 KIAS, 50 ft AGL for reference speeds greater than 30 knots to remain outside avoid area.
2. N_R 100%; 3 crewmembers; FWD doors removed; weight and balance and CG IAW Operator's Manual.[6]

Table A-2. Measured Course Lengths

Airspeed (KIAS)	Course Length (ft)
20 - 30	640
40 – 80	1647
90 - 120	2500

RISK MANAGEMENT

The level of risk associated with the tests varies between the two methods. The measured course method is the riskier of the two. In the measured course, the pilot must fly the aircraft close to the ground to accurately determine the start and stop of the course while dedicating significant attention inside the aircraft attempting to maintain a constant airspeed for the length of the course. The GPS reciprocal heading method can be flown at a higher altitude, requiring less attention to obstacle avoidance and concentration required to obtain data is required only for a brief moment as the GPS stabilized V_G and track.

Considerations specific to this flight test require evaluation and the crew must be briefed on all restrictions or limitations prior to the flight.

- The Pre-flight briefing shall include a review of:
  - Test Plan/Procedures
  - Aircraft Procedures
  - Weather Conditions
- There is no special aircrew training required prior to conduct of the test.
- The aircraft discrepancy book will be reviewed prior to the test flights.
- All normal downing discrepancies are applicable. Normal maintenance preflight and post flight checks will be performed by maintenance personnel. A preflight walk around of the aircraft will be performed by the flight crew.
- All normal maintenance and ground handling procedures are applicable.
- Potential emergencies and emergency procedures are addressed in the OH-58A+ Operator's Manual [6].

- The aircrew will be responsible for traffic avoidance and monitoring of aircraft's position.
- Altitude, attitude, engine, and rotor limitations will be monitored by the aircrew with all maneuvers terminating prior to exceeding Test Plan limitations.
- The aircrew will record data using kneeboard data card. Note taking responsibilities will be briefed prior to flight.
- There is no requirement for external notification, such as Notice to Airman, FAA coordination etc.
- No special procedures required and no external test equipment will be installed.
- No external loads will be used.
- No chase aircraft is needed.

APPENDIX B: TEST DAY DATA

Table B-1. Measured Course Test Data

Test Aircraft: OH-58A+ Helicopter					ID: N89UT		Purpose: Airspeed Calibration (Measured Course)					
Crew:	Moore		Allison		T/O	FUEL	LDG	T/O	TIME	LDG		
			Hill		400	(lb)	305	0746		0822	Date: 27 July 2004	
V_{ref} (kt)	HDG (deg)	V_I[1] (kt)	H_{po} (ft)	OAT (C)	ΔT (sec)	D (ft)	δ	θ	$\sqrt{\sigma}$	V_G[2] (kt)	V_C[1] (kt)	ΔV_{PC}[1] (kt)
20	137	15.5	710	22	13.5	640	0.975	1.024	0.976	28.1	27.4	11.9
30	137	28	720	22	10	640	0.975	1.024	0.975	37.9	36.9	8.9
40	137	40.5	730	22	21.5	1647	0.974	1.024	0.975	45.3	44.2	3.7
50	137	50	770	22	17.5	1647	0.973	1.024	0.975	55.7	54.3	4.3
60	137	60	790	23	15	1647	0.972	1.028	0.973	65.0	63.2	3.2
70	137	71	790	23	13.2	1647	0.972	1.028	0.973	73.8	71.8	0.8
80	137	79.5	790	23	11.7	1647	0.972	1.028	0.973	83.3	81.0	1.5
90	137	89.5	800	23	15.6	2500	0.972	1.028	0.972	94.8	92.2	2.7
100	137	100.5	800	23	14.2	2500	0.972	1.028	0.972	104.2	101.3	0.8
110	135	109	800	23	13.9	2500	0.972	1.028	0.972	106.4	103.5	-5.5
V_H	136	118	800	23	12	2500	0.972	1.028	0.972	123.3	119.9	1.9
20	317	15.5	740	23	14.8	640	0.974	1.028	0.974	25.6	24.9	9.4
30	317	27	720	23	11.2	640	0.975	1.028	0.974	33.8	32.9	5.9
40	317	39.5	725	23	22	1647	0.975	1.028	0.974	44.3	43.1	3.6
50	321	50	780	23	18	1647	0.973	1.028	0.973	54.1	52.7	2.7
60	319	61	800	23	15.5	1647	0.972	1.028	0.972	62.9	61.1	0.1
70	320	71	790	23	13.4	1647	0.972	1.028	0.973	72.7	70.7	-0.3
80	320	79.5	790	23	11.9	1647	0.972	1.028	0.973	81.9	79.7	0.2
90	320	89.5	790	23	15.9	2500	0.972	1.028	0.973	93.0	90.5	1.0
100	320	102	800	23	14.2	2500	0.972	1.028	0.972	104.2	101.3	-0.7
110	320	109	800	23	13	2500	0.972	1.028	0.972	113.8	110.7	1.7
V_H	320	119	800	23	11.8	2500	0.972	1.028	0.972	125.4	121.9	2.9

1. Data in these columns are the values that are averaged to produce the final value for presentation purposes.
2. V_G of opposing headings averaged considers wind, and becomes V_T.

Table B-2. GPS Test data

Test Aircraft: OH-58A+ Helicopter					ID: N89UT		Purpose: Airspeed Calibration (GPS Method)						
Crew:	Moore		Allison		T/O	FUEL	LDG	T/O	TIME	LDG			
			Hill		400	(lb)	325	0827		0858	Date: 27 July 2004		
V_{ref} (kt)	HDG (deg)	V_I[1] (kt)	H_{po} (ft)	OAT (C)	$V_{G(trk)}$ (kt)	TRK (deg)	δ	θ	$\sqrt{\sigma}$	V_G[2] (kt)	V_C[1] (kt)	ΔV_{PC}[1] (kt)	β[3] (deg)
20	140	15.5	1500	22.5	23	142	0.948	1.026	0.961	23.0	22.1	6.6	2
30	140	28	1560	22.5	32	135	0.946	1.026	0.960	31.9	30.6	2.6	-5
40	140	39.5	1520	22.5	41	139	0.947	1.026	0.961	41.0	39.4	-0.1	-1
50	140	50	1480	22.5	56	141	0.949	1.026	0.962	56.0	53.8	3.8	1
60	140	62	1470	22.5	63	140	0.949	1.026	0.962	63.0	60.6	-1.4	0
70	140	71	1470	22.5	72	141	0.949	1.026	0.962	72.0	69.2	-1.8	1
80	140	79.4	1490	23	80	140	0.948	1.028	0.961	80.0	76.8	-2.6	0
90	140	89.5	1500	22.5	91	143	0.948	1.026	0.961	90.9	87.3	-2.2	3
100	140	100.5	1500	22.5	102	143	0.948	1.026	0.961	101.9	97.9	-2.6	3
110	140	109	1490	22.5	111	141	0.948	1.026	0.961	111.0	106.7	-2.3	1
V_H	140	114.5	1500	23.5	117	142	0.948	1.029	0.960	116.9	112.2	-2.3	2
20	320	16.5	1490	22	29	313	0.948	1.024	0.962	28.8	27.7	11.2	-7
30	320	26.7	1500	22	38	312	0.948	1.024	0.962	37.6	36.2	9.5	-8
40	320	38.5	1500	22	49	312	0.948	1.024	0.962	48.5	46.7	8.2	-8
50	320	50	1520	22	59	311	0.947	1.024	0.962	58.3	56.0	6.0	-9
60	320	61	1510	22	72	316	0.948	1.024	0.962	71.8	69.1	8.1	-4
70	320	71	1500	22	81	315	0.948	1.024	0.962	80.7	77.6	6.6	-5
80	320	79.5	1500	23	89	316	0.948	1.028	0.960	88.8	85.3	5.8	-4
90	320	89.5	1520	23	102	319	0.947	1.028	0.960	102.0	97.9	8.4	-1
100	320	102	1510	23	112	319	0.948	1.028	0.960	112.0	107.5	5.5	-1
110	320	109	1500	23	119	321	0.948	1.028	0.960	119.0	114.3	5.3	1
V_H	320	113.5	1500	23.5	122	319	0.948	1.029	0.960	122.0	117.0	3.5	-1

1. Data in these columns are the values that are averaged to produce the final value for presentation purposes.
2. V_G of opposing headings averaged considers wind, and becomes V_T.
3. β is the angle between the heading and the GPS track.

AIRCRAFT: N89UT **DATE: 27-Jul-04**

Max Gross Weight (lb)	Max Fuel (gal)
3200	71 @ 6.8 lbs/gal

	Weight	Arm	Moment
A/C Empty	1909	117.8	224946.8
Fuel Rem - lb	400	116.3	46514.7
Forward Crew	375	65.0	24375.0
Aft Passengers	339	104.0	35256.0
Cargo	0	96.0	0.0
Take-off	3023	109.5	331092.5
Fuel Rem ~ lb	305	115.5	35236.4
Landing	2928	109.2	319814.2

Fuel Convert: Gal to lb

71	483

Crew

Moore	Allison
	Hill

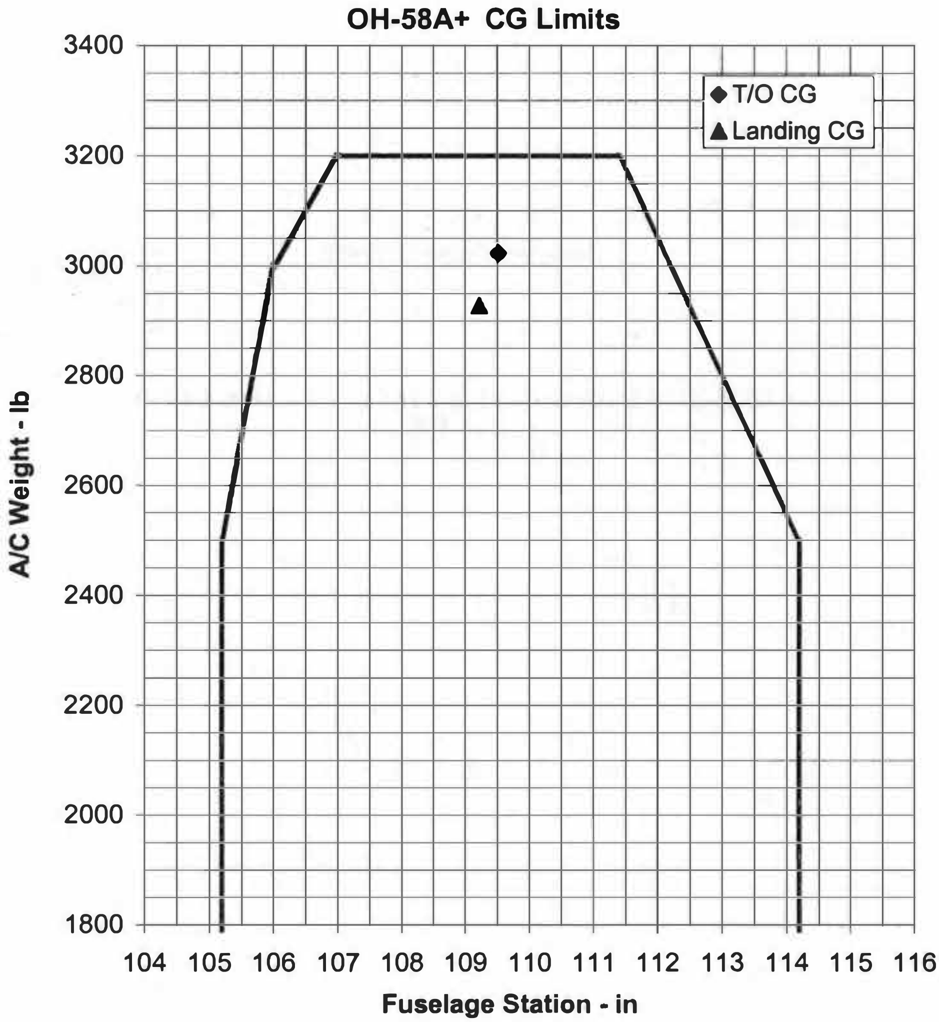

Figure B-1. Test Aircraft Weight and Balance Data

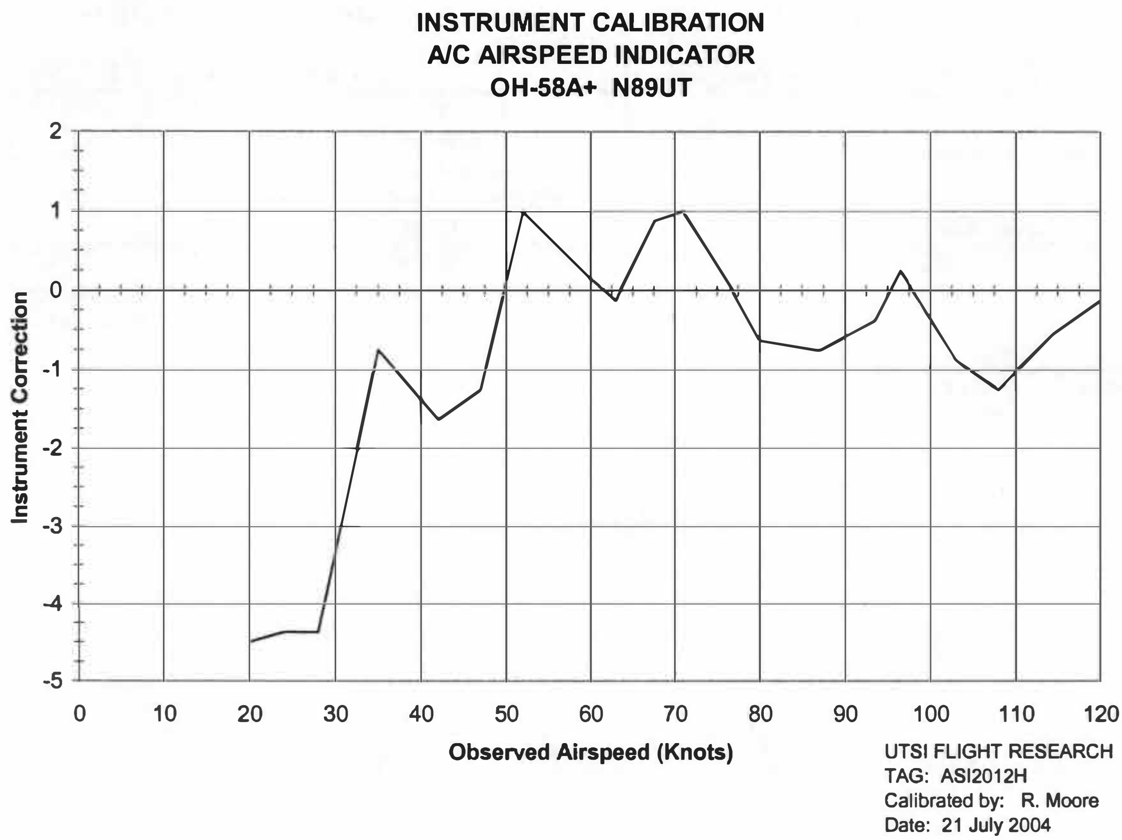

Figure B-2. Airspeed Instrument Correction Chart

VITA

Rucie J. Moore was born to Jimmy and Rosa Moore, February 1967 in Sulphur, Louisiana. He developed a love for helicopters at the age of four and pursued his dream of becoming a helicopter pilot from that point on. He graduated from Vinton High School, Vinton, Louisiana and obtained his private pilots license in 1985. He joined the Army and entered the Warrant Officer Flight Training Program, in November 1986. He graduated from flight training in February 1987, and has flown scout and attack helicopters, and is an attack helicopter instructor pilot. In addition to fighting in Operation Desert Storm, he has served with the Army in the United States and in Europe, and served a tour as an instructor pilot with the Royal Netherlands Air Force. During his military service, he has continued pursuing higher education, graduating in 1998, magna cum laude with a Bachelor of Science in Professional Aeronautics from Embry Riddle Aeronautical University. Upon graduating from the University of Tennessee Space Institute, Rucie will attend the United States Naval Test Pilot School.