To the Graduate Council:

I am submitting herewith a thesis written by Scott William Sowles entitled, "An Evaluation of Climb Performance Data Reduction Methods." 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

Ralph D. Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Frank G. Collins

Fred Stellar

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

An Evaluation of Climb Performance Data Reduction Methods

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Scott W. Sowles

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DEDICATION

This thesis is dedicated to

my family, friends, and loved ones,

whose love and support

provided me with the courage and strength

to accomplish all my goals.

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ABSTRACT

Climb performance of aircraft is an extremely important aspect to the aviation community. Flight test engineers evaluate climb performance using many different data reduction techniques. This thesis presents a climb performance flight test of two single-engine aircraft and an evaluation of three different climb performance data reduction techniques used for single-engine general aviation aircraft. A total of two different techniques are used to determine climb performance of aircraft. The two techniques used for climb performance are steady climb and level acceleration. The thesis incorporates the steady climb method on a Cessna 150M Commuter and a Piper Saratoga PA32-301. The three different data reduction techniques used in the flight tests are PIW (standardized power) versus CIW (standardized rate of climb) method, density altitude method, and equivalent altitude method.

In order to evaluate the three different data reduction techniques, a total of two flight tests were conducted. The first flight test incorporated a steady climb technique on a Piper Saratoga (N11UT), and the second flight test incorporated a steady climb technique on a Cessna 150 Commuter (N66525). The flight tests were performed at Tullahoma airport located in Tullahoma, Tennessee, during daylight hours and in visual meteorological conditions on two different test days.

All three methods are accurate when compared to one another in close to standard temperature conditions. The major differences between the methods are the aircraft efficiency and propeller efficiency estimations used in the equivalent altitude

and density altitude data reduction methods. Aircraft efficiency is estimated in the equivalent altitude method and does not change the results significantly when the estimated value is increased or decreased. Aircraft efficiency and propeller efficiency values are estimated in the density altitude method. The results for the aircraft tested change in a range of eighty feet when the estimated values are increased and decreased. Results show that an exact value of aircraft and propeller efficiency needs to be calculated in order to determine the accuracy of the density altitude method.

The results also show inaccurate results for the density altitude climb performance data reduction method when a non standard temperature lapse rate or temperature inversion is encountered. The PIW versus CIW method shows a minimum change from the temperature inversion and the standard lapse rate encounters. Other results include the fact that the PIW versus CIW and the equivalent altitude methods are easy to use and simple to follow. The density altitude method is difficult to use and hard to follow.

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LIST OF ABBREVIATIONS

A	Continental Engine Series (O-200A)
AC	Advisory Circular
b	Aircraft Wing Span
BHP	Engine Brake Horsepower
CIW	Standardized Rate of Climb
D	Aircraft Drag
Di	Induced Drag
e	Aircraft Efficiency Factor
F	Aircraft Thrust
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FHP	Aircraft Thrust Horsepower
GPH	Gallons per Hour
Hc	Calibrated Altitude
Hd	Density Altitude
He	Equivalent Altitude
Hg	Mercury
Hp	Pressure Altitude
Hpi	Instrument Corrected Altitude
Hpo	Observed Altitude

LIST OF ABBREVIAIONS (continued)

IO	Fuel Injected
K1G5	Lycoming Engine Series (TIO-540-K1G5)
L	Aircraft Lift
M	Cessna Series (Cessna 150M)
N	North American Aircraft Registration (N22UT)
NACA	National Advisory Commission of Aeronautics
O	Horizontally Opposed
OAT	Outside Air Temperature
LBS	Pounds
MP	Manifold Pressure
MPH	Miles per Hour
NIW	Standardized Engine Revolutions per Minute
PA	Piper Series (PA32-301)
PIW	Standardized Engine Horsepower
R	Retractable Landing Gear
R/C	Rate of Climb
RPM	Engine Revolutions per Minute
SP	Piper Series (SP PA32-301)
T	Temperature
T	Turbo Charged

LIST OF ABBREVIATIONS (continued)

T(cat)	Carburetor Temperature
TAS	True Airspeed
THP	Thrust Horsepower
TIO	Turbo Charged, Fuel Injected
Ts	Standard Temperature
UTSI	University of Tennessee Space Institute
Vc	Calibrated Airspeed
Vi	Instrument Corrected Airspeed
Vio	Observed Airspeed
VIW	Standardized Airspeed
Vs1	Stall Speed
W	Aircraft Weight
Wc	Aircraft Weight to be corrected to
Ws	Standard Aircraft Weight
Wt	Aircraft Test Weight
δ	Delta, Ratio of Ambient Pressure to Sea Level Value
ηp	Propeller Efficiency
γ	Gamma, Climb Angle
σ	Sigma, Ratio of Air Mass Density to Sea Level Value
θ	Theta, Ratio of Ambient Temperature to Sea Level Value

Chapter 1

Introduction

Objective

The objective of this thesis is to evaluate three different climb performance data reduction methods using two general aviation aircraft. The two aircraft incorporated in this thesis are the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525. Climb performance flight tests were performed in Tullahoma, Tennessee at the Tullahoma airport using both aircraft to evaluate the data reduction methods. The three climb performance data reduction techniques evaluated in this thesis are the PIW (standardized power) versus CIW (standardized rate of climb), equivalent altitude method, and density altitude method. All three data reduction methods are approved by the Federal Aviation Administration (FAA). The FAA publishes only the density altitude method in the Advisory Circular 23-8A, a flight test guide for certification for FAR Part 23 aircraft.

Since all three climb performance data reduction methods are acceptable to the FAA, this thesis evaluates the methods against each other to determine the best method. Comparisons of each method as applied to both aircraft are evaluated in the thesis.

Background

The Federal Aviation Administration (FAA) Regulation requires a certain value of climb performance of each aircraft certified under Federal Air Regulation (FAR) 23.65. Therefore climb performance is a basic requirement of performance flight testing. The two possible techniques for determining climb performance are the Steady Climb technique and Level Acceleration technique. The Steady Climb technique is used for low speed aircraft on all FAA climb performance flight tests while the Level Acceleration technique is used primarily for high speed military aircraft. The technique discussed in this thesis is the Steady Climb technique (Kimberlin, 1998).

Theory

The two separate approaches used in climb performance theory are the Vector Approach and the Energy Approach. In the Vector Approach, three assumptions to simplify the analysis are: 1) the angle of attack is small (less than fifteen degrees), 2) the thrust line acts along direction of flight, and 3) the airplane is both climbing and accelerating in the direction of flight (Kimberlin, 1998). In level unaccelerated flight the aircraft experiences forces of weight, lift, drag, and thrust. Lift and weight are equal and the thrust balances the drag. If an increment of thrust is applied to the aircraft, acceleration of the aircraft will occur and if an increment of thrust is removed from the aircraft the excess drag will cause the aircraft to decelerate. If the thrust is applied and the airspeed of the aircraft is held at a constant, the nose of the aircraft must be pulled up in order to maintain the constant airspeed and create a climbing attitude. The excess thrust created in this case is used to maintain the attitude of the aircraft (Hamlin, 1946).

The forces acting on the aircraft in level flight and in a climb attitude are shown in Figure 1.0.

Illustrated in Figure 1.0 the climb angle of the aircraft is represented by gamma γ. If the climb angle is known then gamma γ multiplied by the flight path velocity of the aircraft gives the vertical velocity or rate of climb (Hamlin, 1946). Figure 1.0 shows that:

(1.0) $L = W \cos \gamma$

(1.1) $F = D + W \sin \gamma$

Newton's second law of motion states that the acceleration of a body is directly proportional to the applied force and inversely proportional to the mass of the body (Kroes & Wild, 1990). Applying Newton's second law results in:

(1.2) $F - D - W \sin \gamma = Ma = (W/g)\,(dV/dt)$

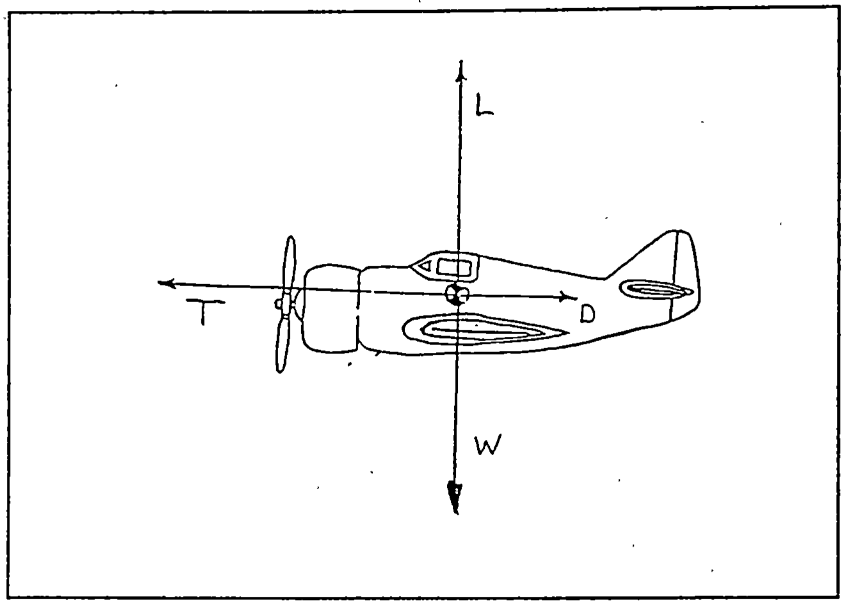
true airspeed is multiplied through, and weight is divided through equation (1.3) then:

(1.3) $V\,(F\text{-}D) / W = V \sin \gamma + (V/g)(dV/dt)$ (Kimberlin, 1998).

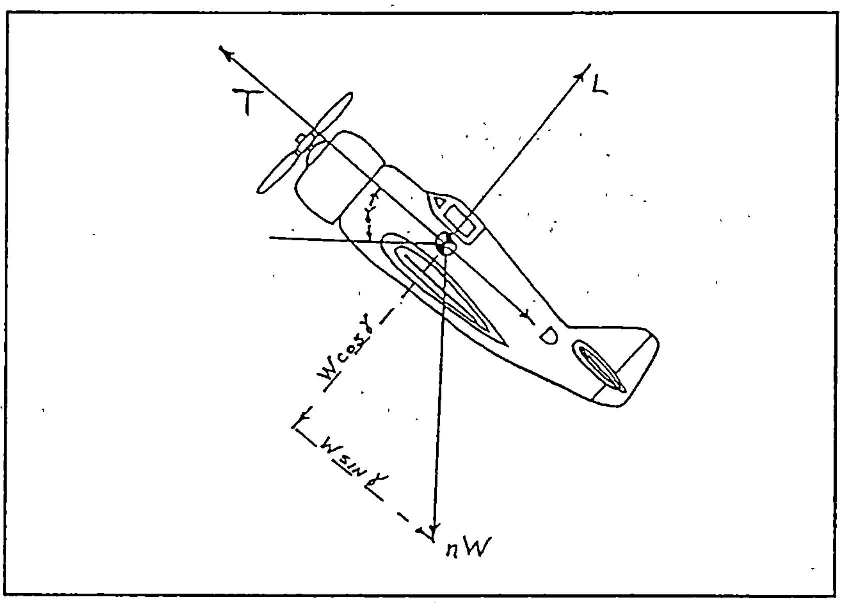
Figure 1.1 displays a climb vector diagram of an aircraft in a climb attitude which is described by the equation:

(1.4) $\textit{Rate of Climb} = dH/dt = V\,(\textit{true airspeed}) \sin \gamma$

If weight is multiplied through equation (1.4) then the $V\,(F\text{-}D)$ term can be expressed as the total horsepower minus the drag thrust horsepower known as the thrust horsepower required. The quantity developed through this method is the excess horsepower. Excess horsepower is that additional power available over that which is necessary to



Level Flight



Climb

Figure 1.0.

Climb and Level Flight Forces on Aircraft (Kimberlin, 1998).

overcome drag and is called thrust horsepower in excess which the pilot has available to maneuver or climb (Kimberlin, 1998).

(1.5) *FHP in excess = W (dH/dt) + (W/g) (dV/dt) V (true airspeed)*

Equation (1.5) displays thrust horsepower in excess defined by rate of climb term and acceleration term. In a steady state climb at a constant true airspeed, the acceleration term becomes zero therefore:

(1.6) *FHP in excess = W (dH/dt)* (Kimberlin, 1998),

The acceleration term becomes zero in a steady climb at a constant true airspeed but true airspeed varies with altitude therefore the change in airspeed and the change in altitude must be accounted for *(dV/dh)* so:

(1.7) $dV/dt = (dV/dH)\ dH/dt$

Now substitute *dV/dt* into equation (1.4):

(1.8) $V\ (F\text{-}D)\ /\ W = dH/dt + V/g\ (dV/dH)\ dH/dt$

By factoring and solving for rate of climb *(dH/dt)*:

(1.9) *Rate of Climb* $= dH/dt = [(F\text{-}D/W)\ V]\ /\ [1 + V/g\ (dV/dH)]$

The term *V/g (dV/dH)* is an acceleration factor and is dimensionless (Kimberlin, 1998). Maximum rate of climb is plotted versus each test altitude. This plots allows one to determine the maximum rate of climb at sea level, the service ceiling, and the absolute ceiling of the aircraft (Kimberlin, 1998).

The Energy Approach is another method of determining the rate of climb of an aircraft. The total energy *(Etotal)* of an aircraft is the sum of the potential energy and the kinetic energy it possesses (USNTPS, 1973).

(2.0) $Etotal = mgH + \frac{1}{2}\, mV^2$

$m = (aircraft\ mass)$

By dividing aircraft weight through equation (2.0) specific energy *(he)* in feet may be obtained:

(2.1) $h_e = H + V^2/2g$

Therefore if equation (2.1) is differentiated with respect to time:

(2.2) $dh_e/dt = dH/dt + (V/g)\ (dV/dt)$

If equation (2.2) is multiplied by weight then:

(2.3) $FHP\ in\ excess = W\ (dH/dt) + (W/g)\ (dV/dt)\ V\ (true\ airspeed)$

which is the same as equation (1.5) (USNTPS, 1973).

Data Reduction Methods

The three data reduction methods evaluated in this thesis are the density altitude method, the equivalent altitude method, and the PIW (standardized power) versus CIW (standardized rate of climb) method. The three methods are used for propeller driven aircraft and were used in the climb performance evaluation of a Piper Saratoga PA32-301 and a Cessna 150M. The equivalent altitude method is used primarily for fixed pitch propellers while the density altitude method and the PIW versus CIW method are used for both fixed pitch and constant speed propellers (Kimberlin, 1998). The three data reduction methods are found in Appendix A Figures A.1, A.2, and A.3.

Flight Test Program

The flight test program of this project consisted of three flights. One climb performance flight was performed in the Piper Saratoga PA32-301, N22UT. The other two flights (airspeed position error and climb performance) were accomplished in the Cessna 150M, N66525. The thesis describes the project in a flight test report manner. Aircraft descriptions, instrumentation, fight test procedures, data reduction methods and procedures, results, discussions, conclusions and recommendations are presented in this thesis.

Chapter 2

Test Aircraft Descriptions

History

The Cessna 150M Commuter and the Piper Saratoga PA32-301 used for this evaluation are common aircraft in the general aviation fleet. Cessna Aircraft Company, which was founded by Clyde V. Cessna in 1911, is known for manufacturing trainer aircraft to regional jets. In September of 1957, the Cessna model 150 flew for the first time and received FAA Type Approval on July 10, 1958 (Taylor, 1977). In 1973, the Cessna model 150 was available in standard, trainer, and commuter (Taylor, 1973). Now the Cessna 150 model is available in Commuter, Commuter II, and Aerobat (Taylor, 1977).

Piper Aircraft Corporation, which was founded by William T. Piper in 1930, is known for manufacturing trainer aircraft to single engine turbo propeller aircraft. Piper started production of the Piper Saratoga on December 17, 1979 which was to replace the former six-seater aircraft known as the Cherokee Six and the Piper Lance (Taylor, 1982). The Piper Saratoga is offered in four different arrangements. The Saratoga PA32-301 which is a basic version with a fixed landing gear and a normally aspirated engine. The Turbo Saratoga PA32-301T which is the same as the PA32-301 but contains an Avco Lycoming TIO-540-S1AD turbo-charged engine (Taylor, 1982). The other two versions are the Saratoga SP PA32R-301 and the Turbo Saratoga SP PA32R-

301T. The difference between the Saratoga SP and the regular Saratoga is the landing gear. The Saratoga SP has a retractable landing gear for the basic version of the Saratoga PA32-301 and the Turbo Saratoga PA32-301T (Taylor, 1982). Figures 2.0 and 2.1 show the test aircraft incorporated in the thesis.

Cessna 150M Commuter, N66525 Test Aircraft

The 1975 Cessna 150M Commuter, serial number 15076100, registration number N66525, is a two seat cabin monoplane type that is owned and operated by the University of Tennessee Space Institute Aero Club (see Figure 2.0) and was used for this evaluation. The Cessna 150 is a high wing type with the NACA 2412 airfoil section. The dihedral angle of the wings is one degree while the incidence angle at the root of the wing is one degree and at the tip is zero degree. The Cessna 150M Commuter's wings are of all metal structure with conical-camber, glass fiber wing tips. The Cessna 150 has all metal ailerons and Fowler flaps which are electrically actuated (Taylor, 1982).

The fuselage of the Cessna 150 is all metal semi-monocoque structure, while the tail section of the Cessna is a cantilever all metal structure with sweptback vertical surface that incorporates the rudder and a horizontal surface which incorporates the elevator (Taylor, 1977). The rudder contains a ground adjustable trim tab while the elevator contains a pilot adjustable trim tab.

The landing gear of the Cessna 150 is a non-retractable tricycle type. The main struts of the landing gear contain a one-piece machined conically tapered spring steel tube. The nose wheel of the Cessna 150M Commuter is steerable and on an oleo-

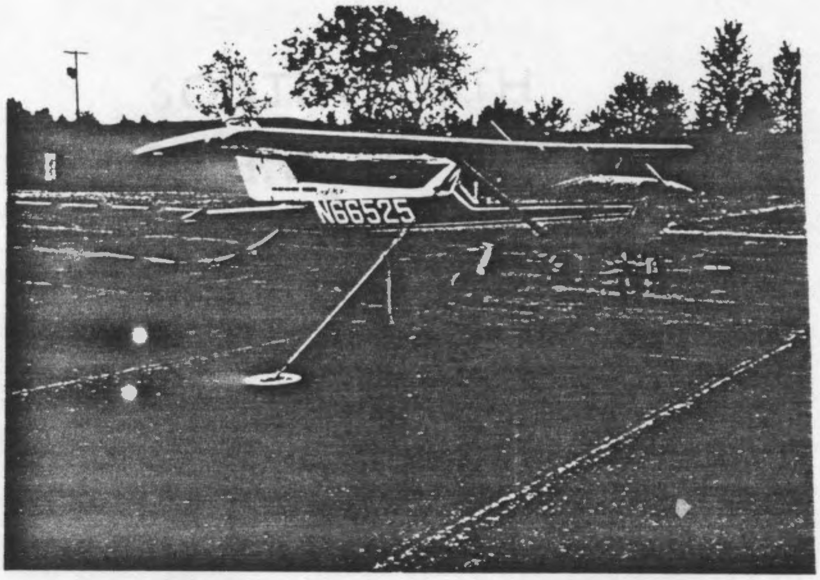


Figure 2.0 Cessna 150M, N66525

Figure 2.1 Piper Saratoga, N22UT

pneumatic shock absorber strut (Taylor, 1977). Wheel fairings are standard on the Cessna 150 Commuters but for maintenance reasons the wheel fairings on N66525 are removed and were not used in the flight test.

The Cessna 150M Commuter is powered by a Continental O-200-A, serial number 252116-A-48, four cylinder, horizontally opposed, air cooled engine. The Continental engine drives a two bladed fixed pitch all metal McCauley propeller. The Continental O-200-A is rated at 100 maximum horsepower at 2700 revolutions per minute. The Cessna 150 has two all metal fuel tanks located in the wings which hold a total of 22.5 useable gallons of fuel (Taylor, 1977).

The Cessna 150M Commuter N66525 is configured for a pilot and one passenger. The Cessna is used primarily for training and visual meteorological conditions cross-country. The aircraft systems include a hydraulic system for brakes and an electrical system including a twelve volt, sixty ampere alternator and a twelve volt battery (Taylor, 1977). The gross weight of the Cessna 150 is 1600 pounds and the basic empty weight is 1122 pounds with the wheel fairings removed. The wing span of the Cessna 150M Commuter is 33.2 feet (Cessna, 1975).

Piper Saratoga PA32-301, N22UT Test Aircraft

The 1981 Piper Saratoga PA32-301, serial number 32-8106067, registration number N22UT, is a six seat cabin monoplane that is owned and operated by the University of Tennessee Space Institute Aviation Systems Flight Research Department (see Figure 2.1). The Saratoga is the second aircraft used in this evaluation. The Saratoga is a low wing type aircraft with the wings being a light alloy single spar structure with glass fiber wing tips (Taylor, 1982). The semi-tapered design of the wing employs a laminar flow NACA 65(2)-415 airfoil section (Piper, 1984). The Saratoga's ailerons are plain of light alloy construction while the flaps are light alloy construction with ribbed skins (Taylor, 1982).

The fuselage of the Piper Saratoga is a conventional semi-monocoque structure of light alloy with a fiber glass engine cowling. The tail section of the Piper Saratoga is a cantilever structure of light alloy except for the glass fiber tips on the vertical fin, rudder, and stabilator (Taylor, 1982). The stabilator and the rudder section of the aircraft contain ribbed metal skins. The stabilator contains a leading geared tab along with a pilot actuated trim tab.

The landing gear of the Piper Saratoga is a non-retractable tricycle type. The wheels of the landing gear are on oleo-pneumatic struts while the nose wheel is steerable (Taylor, 1982). Wheel fairings are an option on the Piper Saratoga, but the main wheel fairings were not installed on N22UT during the flight test.

The Piper Saratoga PA32-301 is powered by a Lycoming IO-540-K1G5, serial number L-21175-48A, six cylinder, direct drive, horizontally opposed, air cooled, and fuel injected engine. The Lycoming engine drives a two bladed constant speed all metal Hartzell propeller. The Lycoming IO-540-K1G5 is rated at 300 maximum horsepower at 2700 revolutions per minute. The Piper Saratoga has two bladder type fuel tanks located in each wing that have the combined capacity of 102 gallons of fuel useable (Taylor, 1982).

The Piper Saratoga PA32-301 N22UT is configured for a pilot and five passengers. The Saratoga is used primarily for classroom studies and local cross-country business flights in visual meteorological and instrument meteorological conditions. The gross weight of the Piper Saratoga is 3600 pounds and the basic empty weight is 2161.79 pounds (Piper, 1984). The basic empty weight of the Saratoga during the flight test incorporated in this thesis is 2160.54 pounds due to the removal of the main wheel fairings. The wing area of the Saratoga is 178.3 square feet and the wing span is 36.2 feet (Kimberlin, 1998).

Chapter 3

Instrumentation and Calibrations

General

Aircraft pitot-static systems refer to the airspeed and altimeter system. The three sources of error associated with the pitot-static system of an aircraft are position, lag, and instrument. Position error is defined as the airspeed error caused by the failure of the static and total pressure ports to sense the actual free stream pressures. The two pressure ports used to measure airspeed and altitude are the pitot tube (airspeed) and the static port (airspeed and altitude). If the pitot tube is within approximately twenty degrees of the free air stream flow direction then there is minimum error associated with it. Therefore the static port location is the significant source of the position error. The position error of an aircraft can be determined by a number of flight test techniques (Kimberlin).

Lag error is another source of error in the pitot-static system of an aircraft. Lag error is defined as the error associated with the length and diameter of the pitot and static lines. When one line is larger in diameter or length than the other line, it creates a source of error in the pitot-static system (Kimberlin, 1998).

The instrument is the last source of error in the pitot-static system of an aircraft. All mechanical instruments contain error due to the friction, gearing histerisis, or the way the instrument was assembled. Instruments used in flight testing must be calibrated in order to collect accurate data during a flight test. Calibrations must be made in both the increasing values and the decreasing values (Kimberlin, 1998). The calibrations of the instruments involved in the flight test reported herein were performed by the University of Tennessee Space Institute Flight Research personnel.

Instrumentation

The data required for climb performance flight testing is as follows: time, pressure altitude, free air temperature, engine revolutions per minute (RPM), engine manifold pressure, and fuel burn (Kimberlin, 1998). In order to collect data for the climb performance flight test of an aircraft a calibrated airspeed indicator, a calibrated altimeter, a calibrated temperature gauge, a calibrated RPM gauge, and a calibrated manifold pressure gauge must be incorporated in the aircraft to be tested. The Cessna 150M Commuter, N66525, is equipped with all the requirements except for an engine manifold pressure gauge and a stopwatch for time and fuel burn measurements. For this flight test, a calibrated engine manifold pressure gauge, serial number I-03477, was used by attaching a line to the primer inlet of the Cessna 150M Commuter's engine to record accurate data. A stopwatch was used for time measurements and a wristwatch for time to measure fuel burn. All Cessna 150M Commuter, N66525, instrument calibrations are presented in Appendix B (Figures B.1 through B.3).

The Piper Saratoga PA32-301, N22UT, is equipped with all the required instruments for climb performance flight testing. The Saratoga contains a standard arrangement of instruments with a temperature gauge used by the pilot along with a copilot's side calibrated airspeed indicator, calibrated altimeter, and a fuel consumed indicator. The Saratoga was equipped with a calibrated airspeed indicator, calibrated altimeter, calibrated engine RPM gauge, and a calibrated engine manifold pressure gauge. The rear aft facing panel instruments and the cockpit temperature gauge were used in collecting the data for the climb performance flight test of the Piper Saratoga PA32-301, N22UT. All Piper Saratoga PA32-301, N22UT, instrument calibrations are found in Appendix B (Figures B.4 through B.8).

Pitot-Static Calibrations

To create reliable altimeter data, the pressure lines attached to the altimeter and airspeed indicator must be pressure tested for leaks and the instruments must be calibrated. Calibrations of the altimeters and the leak checks of the pressure lines of the Cessna 150M Commuter, N66525, and the Piper Saratoga PA32-301, N22UT, were performed by University of Tennessee Space Institute Flight Research personnel.

To create reliable airspeed data, instrument calibrations were conducted, pressure lines of the pitot-static system were leak evaluated, and position error flight tests should be performed. Although the flight tests of the Cessna 150M Commuter and the Piper Saratoga PA32-301 used the best rate of climb airspeed at sea level, position error calculations were determined. The flight test technique used to determine the airspeed position correction of the Cessna 150M Commuter and the Piper Saratoga PA32-301 was the speed course method.

The speed course method is performed with the aircraft flying over a known measured course on the ground. The aircraft must fly at a low altitude so that an accurate measure of ground speed can be obtained. In order to minimize wind errors the ground course is flown in both directions and the ground speeds are averaged. The position error is found by comparing the true flight speed to the average ground speed (Kimberlin, 1998).

The speed course used for the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, is located on Arnold Air Force Base. The measured course is 2.35 nautical miles and runs parallel with the Arnold Engineering Development Center road. Airspeed position error data, for the Piper Saratoga PA32-301, N22UT, was completed by Dr. Ralph Kimberlin in January 1984 (see Appendix C, Figure C.1). Airspeed position error data, for the Cessna 150M Commuter, N66525, was completed by Carvil Chalk and Scott Sowles in March 1999 (see Appendix C, Figure C.2 through C.3).

Chapter 4

Flight Test Methods and Procedures

General

In order to analyze climb performance data, a certain test method should be incorporated in the flight test to fulfill all of the data reduction sequence requirements. The Federal Aviation Administration (FAA) requires under FAR 23.65 paragraph b for an aircraft less than 6,000 pounds to a have a steady rate of climb at sea level of at least 300 feet per minute or 11.5 times the stall speed (Vs1) of the aircraft whichever is greater (FAA, 1999). The FAA issues a flight test guide for certification of FAR (Federal Air Regulations) Part 23 aircraft as an Advisory Circular (AC 23-8A). The last revision made to AC 23-8A was August 30, 1993.

A common method used in flight testing is the sawtooth climb method. The sawtooth climb method is a series of climbs conducted at different airspeeds and altitudes. The sawtooth climbs are performed with the aircraft in a prescribed configuration which is usually the standard takeoff configuration (meaning flaps up) (FAA, 1993). The climbs are made at constant predetermined airspeeds and in opposite directions at each altitude to be tested. The climbs are timed to a minimum of three minutes and a maximum of five minutes. In order to minimize wind effects and to cancel wind gradient acceleration effects on the rate of climb, the climbs are conducted crosswind (Kimberlin, 1998).

Plots of pressure altitude versus time can be made from the sawtooth climb method. From these plots, an average curve can be determined from the opposite direction climbs. The slope of this curve is the rate of climb. The rate of climb can be determined for each airspeed and altitude. From that data, rates of climb versus airspeed can be plotted. From these plots, best rate of climb and best angle of climb can be determined for an aircraft (Kimberlin, 1998). The best rate of climb at sea level airspeed for the Cessna 150M Commuter, N66525, is 78 miles per hour and the Piper Saratoga PA32-301, N22UT, is 92 knots.

The flight test conducted in this thesis used the predetermined best rate of climb airspeeds at sea level of each aircraft and incorporated check climbs. Check climbs are sawtooth climbs performed using the best rate of climb airspeed of an aircraft. The check climbs are conducted crosswind and in opposite directions at several different altitudes. Plots of pressure altitude versus time are made and the rate of climb is determined for each altitude tested. A data reduction method may be evaluated after the rate of climb information is determined for the aircraft at the altitude tested (Kimberlin, 1998).

Technique

The sawtooth climb technique should be followed when conducting a check climb flight test. The series of climbs should be initiated at a predetermined altitude and the altimeter should be set on 29.92 inches Hg in order to read pressure altitude. Time is recorded for fuel burn measurements and for timing the climb. The airspeed is held constant and the aircraft should be climbed at climb airspeed for three minutes. The climbs are conducted at ninety degrees from the wind to cancel the effects of the wind on the data to be collected. The altimeter is observed to assure a positive rate of climb. All data should be recorded every thirty seconds or less. The data to be recorded are altitude, airspeed, temperature, engine RPM, engine manifold pressure, and fuel burn. Since rates of climb in the range of zero tend to be unreliable, the aircraft should perform at least one hundred feet per minute climbs to assure positive data. This technique is recommended by the Federal Aviation Administration in Advisory Circular AC23-8A (FAA, 1993).

The air quality during the flight test should be smooth and with no turbulence so that the data will be accurate. Turbulence and temperature inversions tend to make the data less accurate and unreliable so one should avoid these conditions when possible (FAA, 1993). Climbs should be performed at sunrise or late in the evening when the best atmospheric conditions are usually encountered. Midday climb results tend to be unsatisfactory because of the erratic weather encountered during this time of the day (Hamlin, 1946).

Method

The method used for the determination of climb performance of the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, incorporated two primary steps. The first step was to conduct three minute climbs in opposite directions, about the same altitude, climbing at sea level best rate of climb airspeeds with flaps retracted and maximum continuous power. By receiving a standard weather briefing and getting the winds aloft at altitudes of 3,000 and 6,000 feet, all climbs were conducted perpendicular to the wind and in visual meteorological conditions in smooth air. Data were recorded every thirty seconds in the three minute timed climbs. The second step was to conduct the climbs at least 3,000 feet apart.

The Piper Saratoga PA32-301 was tested at altitudes of 3,500 feet pressure altitude and 7,000 feet pressure altitude at an airspeed of 92 knots indicated. The first and second climbs were conducted at 3,490 feet pressure altitude with headings of 270 and 090 degrees. The aircraft weight at the start of the first climb was 3,105 pounds and at the end 3,097 pounds. The Saratoga climbed a total of 2,350 feet pressure altitude in the first climb. The aircraft weight at the start of the second climb was 3,084 pounds and at the end 3,075 pounds. The Saratoga climbed a total of 2,240 feet pressure altitude in the second climb. The third and fourth climbs of the Piper Saratoga were conducted at 6,760 feet pressure altitude with the headings of 090 and 270 degrees. The aircraft weight at the start of the third climb was 3,072 pounds and at the end was 3,064 pounds. The Saratoga climbed a total of 1,910 feet pressure altitude in the third climb. The aircraft weight at the start of the fourth climb was 3,058 pounds and at the end 3,050 pounds. The Saratoga climbed a total of 2,110 feet pressure altitude. Table 4.0 depicts all the climb performance data calibrated for the Piper Saratoga PA32-301, N22UT. From Table 4.0, plots of pressure altitude versus time can be developed and rate of climb can be determined (see Appendix E, Figure E.1 and E.2).

The observed rate of climb is determined by finding the equation of the average line from the pressure altitude versus time plot and taking the slope. The derivative is the slope of the line and now one can determine the rate of climb over a certain amount of time. Sixty seconds was used in determining the rate of climb of the Piper Saratoga

Table 4.0. Piper Saratoga PA32-301 N22UT Climb Performance Data.

Start Time	9:40am						
	Time	Altitude	OAT	RPM	M.P.	Fuel Burn	Aircraft Test
3500 feet	(seconds)	(feet)	(degrees Celsius)		(in. Hg.)	(gallons)	Weight (lbs.)
270 heading	0	3490	-2.2	2700	25.8	1.8	3104.74
	30	4010	-3.3	2700	25.6	2	3103.54
	60	4500	-5	2700	25.2	2.2	3102.34
	90	4960	-5.6	2700	24.79	2.4	3101.14
	120	5320	-6.7	2700	24.38	2.6	3099.94
	150	5610	-3.3	2700	23.97	2.8	3098.74
	180	5840	-1.1	2700	23.66	3.1	3096.94
3500 feet							
090 heading	0	3490	-2.2	2700	26.2	5.3	3083.74
	30	4040	-3.3	2700	25.8	5.5	3082.54
	60	4470	-4.4	2700	25.3	5.8	3080.74
	90	4930	-5.6	2700	24.89	6	3079.54
	120	5260	-6.1	2700	24.48	6.2	3078.34
	150	5530	-1.1	2700	24.07	6.4	3077.14
	180	5730	0	2700	23.76	6.7	3075.34
7000 feet							
090 heading	0	6760	0.6	2700	23.06	7.3	3071.74
	30	7000	0	2700	22.76	7.5	3070.54
	60	7440	-0.6	2700	22.45	7.7	3069.34
	90	7750	-0.6	2700	22.25	7.9	3068.14
	120	8100	-0.6	2700	21.95	8.1	3066.94
	150	8380	-0.6	2700	21.74	8.4	3065.14
	180	8670	-1.1	2700	21.54	8.6	3063.94
7000 feet							
270 heading	0	6760	0	2700	22.96	9.6	3057.94
	30	7010	-0.6	2700	22.66	9.8	3056.74
	60	7430	-0.6	2700	22.45	10	3055.54
	90	7810	-0.6	2700	22.15	10.2	3054.34
	120	8240	-0.6	2700	21.95	10.4	3053.14
	150	8540	-0.6	2700	21.64	10.7	3051.34
	180	8870	-1.1	2700	21.44	10.9	3050.14

PA32-301, N22UT. The observed rate of climb for the altitude of 3,500 feet pressure altitude was 900 feet per minute and for 7,000 feet pressure altitude 704 feet per minute.

The Cessna 150M Commuter was tested at altitudes of 2,000 feet pressure altitude and 4,000 feet pressure altitude to avoid the presence of temperature inversions at an indicated airspeed of 78 miles per hour. The first and second climbs of the Cessna 150M Commuter were conducted at 2,140 feet pressure altitude with headings of 300 and 120 degrees. The aircraft weight at the start of the first climb was 1,538 pounds and at the end 1,536 pounds. The Cessna 150M Commuter climbed a total of 1,203 feet pressure altitude in the first climb. The aircraft weight at the start of the second climb was 1,535 pounds and at the end 1,533 pounds. The Commuter climbed a total of 1,355 feet pressure altitude in the second climb. The third and fourth climbs of the Cessna 150M Commuter were conducted at 4,150 feet pressure altitude with headings of 300 and 120 degrees. The aircraft weight at the start of the third climb was 1,533 pounds and at the end 1,532 pounds. The Cessna climbed a total of 955 feet pressure altitude in the third climb. The aircraft weight at the start of the fourth climb was 1,530 pounds and at the end 1,529 pounds. The Cessna climbed a total of 1,005 feet pressure altitude in the fourth climb. Table 4.1 depicts all the climb performance data calibrated for the Cessna 150M Commuter, N66525. From Table 4.1, plots of pressure altitude versus time can be developed and rate of climb can be determined (see Appendix E, Figures E.3 and E.4). The time increment, used to determine the rate of climb for the Cessna 150M Commuter, N66525, was sixty seconds. The observed rate of climb for 2,000 feet pressure altitude was 427 feet per minute and for 4,000 feet pressure altitude was 334 feet per minute.

Table 4.1. Cessna 150M Commuter N66525 Climb Performance Data.

Start Time	10:30 AM							
3000 feet	Time (sec)	Altitude (feet)	OAT °Celsius	RPM	M.P. (in. Hg.)	Time of Flight (AM)	Fuel Burn (4.3 gph)	Aircraft Test Weight
300 heading	0	2140	10	2400	26.3	10:38	0.57333	1537.56002
	30	2340	10	2400	26.1	10:39	0.64500003	1537.13
	60	2540	10	2400	26	10:39	0.645	1537.13
	90	2790	10	2400	25.8	10:40	0.7166667	1536.7
	120	2910	8	2400	25.6	10:40	0.7166667	1536.7
	150	3121	6	2400	25.5	10:41	0.7883334	1536.27
	180	3343	7	2400	25.3	10:41	0.7883334	1536.27
3000 feet								
120 heading	0	2140	6	2400	26.2	10:44	1.00334	1534.97996
	30	2340	6	2400	26.2	10:45	1.075	1534.55
	60	2590	6	2400	26	10:45	1.075	1534.55
	90	2790	5	2400	25.6	10:46	1.146667	1534.119998
	120	3080	5	2400	25.5	10:46	1.146667	1534.119998
	150	3242	5	2400	25.3	10:47	1.2183334	1533.69
	180	3495	5	2400	25.1	10:48	1.29	1533.26
6000 feet	0	4150	10	2400	24.48	10:49	1.361667	1532.829998
050 heading	30	4359	10	2400	24.38	10:49	1.361667	1532.829998
	60	4547	10	2400	24.17	10:50	1.4333334	1532.4
	90	4667	10	2400	24.07	10:51	1.50500007	1531.97
	120	4806	10	2400	23.97	10:51	1.50500007	1531.97
	150	4945	10	2400	23.87	10:52	1.57666674	1531.54
	180	5105	10	2400	23.77	10:52	1.57666674	1531.54
6000 feet								
230 heading	0	4150	10	2450	24.48	10:55	1.79166675	1530.25
	30	4299	10	2450	24.28	10:56	1.86333342	1529.819999
	60	4468	10	2450	24.17	10:56	1.86333342	1529.819999
	90	4647	10	2450	24.07	10:57	1.93500009	1529.389999
	120	4836	10	2450	23.97	10:57	1.93500009	1529.389999
	150	4985	10	2450	23.87	10:58	2.00666676	1528.959999
	180	5155	10	2450	23.67	10:58	2.00666676	1528.959999

Scope of Test

The climb performance flight test for the Piper Saratoga PA32-301, N22UT, was performed in daylight visual, meteorological conditions in the area of the Tullahoma, Tennessee airport at the time of 9:30 am Central Standard Time on November 6, 1998. The total time of the flight test was approximately forty-five minutes. The fuel load at take off was 300 pounds while the aircraft weight was 3,116 pounds with a mid center of gravity location of 91.7 inches aft the datum (see Appendix D, Figure D.1). The total fuel burn of the test portion of the flight was 10.9 gallons. The aircraft weight decreased 65.4 pounds with a minimal change in the center of gravity location from 91.7 inches aft the datum to 91.11 inches aft the datum. The main gear wheel fairings were removed during this flight test which decreased the basic empty weight of the aircraft by 1.25 pounds (see Appendix D, Figure D.2). The test pilot of the climb performance flight was Dr. Ralph Kimberlin and the test observers were Carvil Chalk (co-pilot seat), Mike Meely (rear front facing seat), and Scott Sowles (rear front facing seat). Normal climb operating procedures were followed during the flight test of the Piper Saratoga PA32-301, N22UT.

The climb performance flight test for the Cessna 150M Commuter, N66525, was performed in daylight visual, meteorological conditions in the area of the Tullahoma, Tennessee airport at the time of 10:30 am Central Standard Time on March 19, 1999. The total time of the climb performance flight test was approximately forty minutes. The fuel load at take off was 114 pounds while the aircraft weight was 1,541 pounds with a mid center of gravity location of 35.35 inches aft the datum (see Appendix D, Figure D.3). The total fuel burn of the test data collection of the flight was 2.01 gallons. The aircraft weight decreased by 12 pounds with a minimal change in the center of gravity location from 35.35 inches aft the datum to 35.43 inches aft the datum. The wheel fairings were removed during the flight test but no corrections to the aircraft's empty weight were needed due to the aircraft being weighed without the fairings. The test pilot of the climb performance flight of the Cessna 150M Commuter, N66525, was Carvil Chalk and the test observer was Scott Sowles (co-pilot seat). Normal climb operating procedures were followed during the flight test of the Cessna 150M Commuter, N66525.

Chapter 5

Climb Performance Data Reduction

Methods & Procedures

General

Currently several data reduction methods are used in determining climb performance of aircraft. All the data reduction methods involve several assumptions and approximations. Assumptions and approximations are necessary since the aircraft is in a dynamic state which means no equilibrium conditions are actually maintained in the climb (Hamlin, 1946).

The three data reduction methods evaluated in this thesis are 1) PIW (standardized power) versus CIW (standardized rate of climb), 2) density altitude, and 3) equivalent altitude methods. All three of these methods are acceptable to the Federal Aviation Administration. Advisory Circular 23-8A published by the FAA only describes the density altitude method. The two methods that are simple and easy to execute and understand are the PIW versus CIW method and the equivalent altitude method. The density altitude method is more complex in calculations and estimations and is difficult to understand. The density altitude method and the PIW versus CIW method can be used for both constant speed propellers and fixed pitch propellers while the equivalent altitude method is used for constant speed propellers only (Kimberlin, 1998).

For all three data reduction methods compared, the first four steps are the same. Pressure altitude readings are corrected for instrument error and plotted versus time for both directions of flight. Data for each direction of flight are averaged. The value for the observed rate of climb for a specified altitude is determined from the slope of the altitude versus time plot. The third step is to calculate the aircraft test weight for the climb. The fourth step is to repeat the first three steps for each test altitude (Kimberlin, 1998).

PIW (standardized power) versus CIW (standardized rate of climb) Method

Table 5.0 depicts the PIW versus CIW data reduction technique. The Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, are not equipped with carburetor temperature probes, therefore ambient temperature was substituted for the value of carburetor temperature. The standard temperature at the calibrated altitude is found in altitude charts or by equation 5.0.

(5.0) $Ts = T\, sea\ level * (1 - .00000687535\ Hc)$

Hc – calibrated altitude

The engine horsepower at altitude is read off the engine chart provided by the manufacturer of the engine. Appendix F, Figures F.1 and F.2, contain the engine charts for the Piper Saratoga PA32-301, N22UT and the Cessna 150M Commuter, N66525. Horsepower temperature corrected is determined by multiplying the engine horsepower at altitude, read off the engine manufacturer's chart, and the square root of the ratio of the absolute values of standard temperature divided by the outside air temperature.

Table 5.0.

PIW versus CIW Data Reduction Method.

No.	Quantity	Reference	Units	Information
1	Vo	Flight Data	Knots	
2	Vi	Instrument Calibration	Knots	
3	Vc	Position Calibration	Knots	
4	hpo	Flight Data	Feet	
5	hpi	Instrument Calibration	Feet	
6	OATo/OATi	Flight Data	°Celsius	
7	ta	(6) in °Celsius	°Celsius	
8	Ta	273.16 + (7)	°Kelvin	
9	CATi/CATi	Flight Data	°Celsius	Not recorded
10	t cat	(9) in °Celsius	°Celsius	Not recorded
11	No	Flight Data	Revolutions per Minute (RPM)	
12	Ni	Instrument Calibration	Revolutions per Minute (RPM)	
13	MP obs	Flight Data	Inches Mercury (in. Hg.)	
14	MP ind	Instrument Calibration	Inches Mercury (in. Hg.)	
15	Dry/Wet Psy	Flight Data	N/D	Not recorded
16	Δ MP	Psyc. Chart	Inches Mercury (in. Hg.)	Not recorded
17	MP eff	(14)-(16)	Inches Mercury (in. Hg.)	Not recorded
18	Ts at hpi	Altitude Charts	°Kelvin	
19	Tcat	273.16 + (10)	°Kelvin	Not recorded
20	Ts/Tcat	(18)/(19)	N/D	
21	(Ts/Tcat)^.5	(20)^.5	N/D	
22	HP alt.	Engine Chart	Horsepower	
23	HP temp. cor.	(22)*(21)	Horsepower	
24	δ at hpi	Altitude Charts	N/D	
25	θ	(8)/288.16	N/D	
26	σ = δ/θ	(24)/(25)	N/D	
27	(σ)^.5	(26)^.5	N/D	
28	Wt	Flight Data	Pounds (lbs.)	
29	Ws	Aircraft Manual	Pounds (lbs.)	
30	Wt/Ws	(28)/(29)	N/D	
31	(Wt/Ws)^.5	(30)^.5	N/D	
32	(Wt/Ws)^1.5	(30)^1.5	N/D	
33	PIW	(23)*(27)/(32)	Horsepower	
34	VIW	(3)/(31)	Knots	
35	NIW	(12)*(27)/ (31)	Revolutions per Minute (RPM)	
36	R/C	Flight Data	Feet per Minute (FPM)	
37	R/C temp. cor.	(36)*(8)/(18)	Feet per Minute (FPM)	
38	CIW	(37)*(27)/(31)	Feet per Minute (FPM)	

The PIW versus CIW data reduction sequence involves temperature, pressure, and density ratios. Delta (δ) refers to the ratio of ambient pressure to sea level pressure and is found in standard altitude tables (McCormick, 1995). Theta (θ) is the observed outside air temperature in degrees Kelvin divided by the standard sea level temperature in degrees Kelvin. Theta (θ) is referred to as the ratio of ambient temperature to sea level temperature (McCormick, 1995). Sigma (σ) is the ratio of delta (δ) divided by theta (θ). Sigma is referred to as the ratio of ambient air density to sea level density (McCormick, 1995).

In the PIW versus CIW data reduction sequence, numbers thirty-three through thirty-nine are concerned with standardized values of horsepower, speed, engine revolutions per minute, and rate of climb. Equation 5.1 shows how to obtain the value of PIW (standardized power).

(5.1) $PIW = BHP\ temperature\ corrected * \sqrt{\sigma} / (Wt/Ws)^{1.5}$

VIW is standardized speed in knots and is not an important factor in this flight test because the airspeed does not change significantly. NIW is standardized engine revolutions per minute and is not an important factor in this flight test because of the low altitudes used and the RPM will not change. Tapeline rate of climb or rate of climb temperature corrected is determined by Equation 5.2.

(5.2) $R/C\ temperature\ corrected = (R/C)\ observed * (Ta/Ts)$

CIW is standardized rate of climb in feet per minute. Equation 5.3 shows how to obtain the CIW value.

(5.3) $CIW = (R/C)\ temp.cor. * \sqrt{\sigma} / \sqrt{(Wt/Ws)}$

The final step of the PIW versus CIW data reduction method before continuing to the expansion calculations of altitude and rate of climb is to develop a plot of PIW versus CIW (Kimberlin, 1998).

The climb performance data may be expanded to values of altitude and rate of climb by using the plot of PIW versus CIW and the expansion calculation data reduction sequence found in Table 5.1. The square root of the air density ratio is a standard value and altitude tables are used to determine the value. A plot of engine manifold pressure versus pressure altitude is developed using flight data and is used for recording the manifold pressure in the expansion calculation sequence. Appendix G, Figures G.1 and G.2, contain the plots of engine manifold pressure versus pressure altitude for the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525.

Equation 5.4 shows how to obtain the PIW value in the expansion calculation.

(5.4) $PIW = BHP\ temperature\ corrected * \sqrt{\sigma}\ at\ (39) / (W/Ws)^{1.5}$

CIW is determined by the PIW versus CIW plot. Appendix H, Figures H.1 and H.2, contain the PIW (standardized power) versus CIW (standardized rate of climb) plots for the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525. Equation 5.5 shows how to obtain the value of rate of climb for a standard day in feet per minute units.

(5.5) $R/C\ standard\ day = CIW * \sqrt{(W/Ws)} / \sqrt{\sigma}\ at\ (39)$

The final step in the PIW versus CIW data reduction method is to develop a plot of altitude versus rate of climb. Maximum rate of climb at sea level, service ceiling, and maximum ceiling can be determined from the plot of altitude versus rate of climb. The

Table 5.1.

PIW versus CIW Data Reduction Expansion Calculation – Standard Day Only.

No.	Quantity	Reference	Units
39	Altitude	Arbitrary	Feet
40	(σ)^.5	Altitude Tables at (39)	N/D
41	MP at (39)	MP vs. hpi plot	Inches Mercury (in. Hg.)
42	W	Arbitrary	Pounds (lbs.)
43	W/Ws	(41)/(42)	N/D
44	(W/Ws)^.5	(43)^.5	N/D
45	(W/Ws)^1.5	(43)^1.5	N/D
46	BHP std. Day	Engine Chart	Horsepower
47	PIW	(46)*(40)/(45)	Horsepower
48	CIW	PIW vs. CIW plot	Feet per Minute (FPM)
49	R/C	(48)*(44)/(40)	Feet per Minute (FPM)

service ceiling of an aircraft is where the rate of climb equals one hundred feet per minute. The maximum ceiling of an aircraft is where the rate of climb equals zero (Kimberlin, 1998). Appendix I, Figures I.1 and I.2, contain the altitude versus rate of climb plots for the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, determined by the PIW versus CIW data reduction method. The key assumptions in the PIW versus CIW method are that propeller efficiency remains constant because a nearly constant airspeed is held in the climb and that the lift coefficient and the drag coefficient are assumed constant in deriving the reduction equations. These are reasonable assumptions providing weight changes remain small.

Equivalent Altitude Method

Table 5.2 depicts the equivalent altitude method of data reduction. The square root of the air density ratio, delta (δ), and theta (θ) are determined in the manner described in the PIW versus CIW section. Equivalent altitude is calculated in the equivalent altitude method and is determined by using a plot of equivalent altitude, pressure altitude, and temperature. The plot and formula used to determine equivalent altitude are found in Appendix J, Figure J.1. Equivalent altitude is not used in the PIW versus CIW method or the density altitude method. The equivalent altitude is determined by Equation 5.6 and is used in the altitude versus rate of climb plot while the PIW versus CIW method used pressure altitude in the plot.

(5.6) $He = Hp + 0.36(Hd - Hp)$

Hp – pressure altitude

Hd – density altitude

Table 5.2.

Equivalent Altitude Data Reduction Method.

No	Symbol	Reference	Units
1	Vio	Flight Data	MPH
2	Vc	Ins. & Pos. Calibration	MPH
3	Hp	Flight Data	Feet
4	OAT	Flight Data	°F
5	$\sqrt{\sigma}$	$\sqrt{\delta/\theta}$	N/D
6	He	Equivalent Altitude Chart	Feet
7	T	(4) + 460	°F
8	Ts	Std. Temp. at (3)	°F
9	T/Ts	(7) / (8)	N/D
10	dh/dt (R/C observed)	Flight Data	FPM
11	Ct	(9) * (10)	FPM
12	Wt	Flight Data	Pounds
13	Wt/Ws	(12) / Ws	N/D
14	Ct (Wt/Ws)	(11) * (13)	FPM
15	(Wt/Ws)^2	(13)^2	N/D
16	1-(Wt/Ws)^2	1 - (15)	N/D
17	K / Vc $\sqrt{\sigma}$	K / (2) * (5)	N/D
18	Induced Drag Correction	(16) * (17)	FPM
19	R/C at Std. Alt. & Weight (Ws)	(14) - (18)	FPM

Standard absolute temperature is found in the altitude tables or by using Equation 5.0. The temperature ratio is found by dividing the absolute air temperature by the standard absolute air temperature.

The observed rate of climb is found from the plots of pressure altitude versus time. The "tapeline" rate of climb or temperature corrected rate of climb at the aircraft test weight is calculated by multiplying the temperature ratio by the observed rate of climb. The rate of climb weight corrected is determined by multiplying the tapeline rate of climb by the weight ratio.

The aircraft efficiency factor value is calculated by the Equation 5.7.

(5.7) $K / Vc * \sqrt{\sigma}$

The value of K is determined by Equation 5.8.

(5.8) $K = 10{,}940\ Ws / eb^2$

e = *airplane factor / Oswald's efficiency factor*

b = *wing span*

Ws = *standard weight*

The value of *e* is estimated to be 0.8 if a more exact value cannot be obtained (FAA, 1993). The approximation of *e* could be a cause of inaccurate climb performance data. The induced drag correction is calculated by Equation 5.9.

(5.9) $Di = [1-(Wt/Ws)^2] * K / Vc \sqrt{\sigma}$

Equation 5.10 shows how to obtain the rate of climb at standard altitude and weight value.

(5.10) $R/C\ std.\ Day = R/C\ at\ test\ weight * (Wt/Ws) - [1-(Wt/Ws)^2 * K / Vc \sqrt{\sigma}]$

A plot of equivalent altitude versus rate of climb is then developed (FAA, 1971). Maximum rate of climb at sea level, service ceiling, and maximum ceiling of an aircraft can be determined by the plot of equivalent altitude versus rate of climb. Appendix K, Figures K.1, depicts the plot of equivalent altitude versus rate of climb for the Cessna 150M Commuter, N66525 determined by the equivalent altitude method of data reduction. One key assumption the equivalent altitude method makes is the aircraft efficiency factor being estimated at 0.8. The FAA allows an estimation of 0.8 to be used as the aircraft efficiency factor when in fact the aircraft efficiency is known to change in value.

Density Altitude Method

Table 5.3 depicts the density altitude data reduction technique. The atmospheric density ratio (σ) is recorded in the density altitude data reduction method and is determined using delta (δ) divided by theta (θ). The density altitude is calculated by Equation 5.11.

(5.11) $Hd = 145539\,[1 - \sqrt{\sigma}^{0.4699}]$

Density altitude is not recorded in the PIW versus CIW method or the equivalent altitude method. Density altitude is incorporated in the altitude versus rate of climb plot while equivalent altitude is used in the equivalent altitude method and pressure altitude is used in the PIW versus CIW method. The true airspeed of the aircraft is calculated in the density altitude method and is not recorded in the PIW versus CIW or equivalent altitude methods. True airspeed is determined by Equation 5.12.

Table 5.3.

Density Altitude Data Reduction Method.

No.	Symbol	Rerference	Units
1	Hp	Instrument Calibration	Feet
2	OAT	Flight Data	°F
3	σ	δ/θ	N/D
4	Hd	Hd = 145539[1-(√σ)^.4699	Feet
5	Ts at Hp	°F + 460	°F
6	IAS	Flight Data	knots
7	CAS	Inst. And Pos. Calibration	knots
8	TAS	(7) / √(3)	knots
9	R/C observed	Flight Data	FPM
10	T/Ts	[(2) + 460] / (5)	N/D
11	Actual R/C	(9) * (10)	FPM
12	Wt	Flight Data	Pounds
13	Δ R/C Δ W	(11) * [1- (12) / Wc]	FPM
14	q πe b^2	(7)^2 πe b^2 / 295	N/D
15	Δ Di	[Wc^2 - (12)^2] / (14)	N/D
16	Δ R/C Δ Di	[101.27 * (15) * (8)] / Ws	FPM
17	Calibrated RPM	Flight Data	RPM
18	Calibrated MP	Flight Data	Inches Mercury
19	Inlet Air Temperature	Flight Data	°F
20	BHP temp. cor. At Hp	BHP engine chart * temp. ratio, at HP	Horsepower
21	BHP temp. cor. At Hd	BHP engine chart * temp. ratio, at HD	Horsepower
22	ηp (propeller efficiency)	Propeller manufacturer , or estimated (.83)	N/D
23	Δ THP	(22) * [(21)-(20)]	N/D
24	Δ R/C Δ p	[(23) * 33,000] / Wc	FPM
25	R/C std.	(11) - (13) - (16) + (24)	FPM

(5.12) $TAS = Vc / \sqrt{\sigma}$

The temperature ratio for the density altitude method is determined by Equation 5.13.

(5.13) $T/Ts = [OAT\ (°F) + 460] / Ts$

The "tapeline" rate of climb is determined by the observed rate of climb multiplied by the temperature ratio. The rate of climb at the aircraft test weight (ΔR/C ΔWt) is determined by Equation 5.14.

(5.14) $\Delta R/C\ \Delta Wt = [R/C\ observed * T/Ts] * [1-(Wt/Wc)]$

Wc = aircraft standard weight or aircraft weight to be corrected to

The aircraft efficiency value is determined using Equation 5.15.

(5.15) $[Vc^2 * \pi e * b^2] / 295$

e = Oswald's efficiency factor

b = wing span

The value of 0.8 is to be used if Oswald's efficiency factor cannot be obtained (FAA, 1993). The induced drag correction (Δ Di) is determined by using Equation 5.16.

(5.16) $\Delta Di = [Wc^2 - Wt^2] / [(Vc^2 * \pi e * b^2) / 295]$

The rate of climb induced drag corrected is determined using Equation 5.17.

(5.17) $\Delta R/C\Delta Di = (101.27 * \Delta Di * TAS) / Ws$

The Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, are not equipped with engine inlet air temperature probes. The inlet air temperature used in this thesis in the density altitude method is the observed outside air temperature. Test day horsepower corrected for temperature is determined by multiplying the horsepower read off the engine manufacturer's chart and the square root of the temperature ratio. Horsepower corrected for temperature at density altitude is determined the exact way test day horsepower corrected for temperature at calibrated pressure altitude is calculated.

The propeller efficiency is determined from the propeller manufacturer or may be estimated as 0.83 (FAA, 1993). The thrust horsepower correction factor (ΔTHP) uses the estimated propeller efficiency factor and is determined by using Equation 5.18.

(5.18) $\Delta THP = \eta p * (BHP\ temp.\ cor.\ At\ Hd - BHP\ temp.\ cor.\ At\ Hp)$

Rate of climb pressure corrected (ΔR/C Δp) is determined by the Equation 5.19.

(5.19) $\Delta R/C\ \Delta p = (\Delta THP * 33{,}000) / Wc$

The rate of climb standard day is determined by using Equation 5.20.

(5.20) $R/C\ std.\ Day = (R/C\ obs. * T/TS) - (\Delta R/C\ \Delta Wt) - (\Delta R/C\ \Delta Di) + (\Delta R/C\ \Delta p)$

The final step of the density altitude data reduction sequence is to develop a plot of density altitude versus standard day rate of climb (FAA, 1993). Maximum rate of climb at sea level, service ceiling, and maximum ceiling of an aircraft can be determined from this plot of density altitude versus rate of climb. Appendix L, Figure L.1, contains the plot of density altitude versus rate of climb for the Piper Saratoga PA32-301, N22UT, determined by the density altitude method. The density altitude method incorporates estimations for both the aircraft efficiency factor and propeller efficiency factor values. The FAA allows the use of 0.8 for the aircraft efficiency factor and 0.83 for the propeller efficiency factor.

Chapter 6

Results and Discussion

General

The purpose of the flight test was to provide data for use in comparing various climb performance data reduction methodologies. The climb performance results of the Piper Saratoga PA32-301, N22UT, were determined by PIW versus CIW data reduction method and the density altitude data reduction method. The climb performance results of the Cessna 150M Commuter, N66525, were determined using the PIW versus CIW data reduction method, equivalent altitude data reduction method, and the density altitude data reduction method. The density altitude method was then compared to the PIW versus CIW method for both aircraft. The equivalent altitude method was then compared to the PIW versus CIW method for the Cessna 150M Commuter, N66525. The results of each data reduction sequence varied in data, assumptions, and calculations.

PIW versus CIW Data Analysis

The PIW versus CIW data reduction method is outlined in Dr. Ralph Kimberlin's *Performance Lecture Notes*, Hamlin's *Flight Testing*, and *Advisory Group For Aeronautical Research And Development Flight Test Manual, Volume I Performance*. The PIW versus CIW data reduction method results are found in

Appendix I Figure I.1 for the Piper Saratoga PA32-301, N22UT, and in Figure I.2 for the Cessna 150M Commuter, N66525. The PIW versus CIW data reduction sequence for the Piper Saratoga PA32-301, N22UT, is found in Appendix M, Figures M.1 through M.5. Figure M.1 shows the results of the PIW calculated values in the data reduction sequence as 331 standardized horsepower for 3,490 feet and 277 standardized horsepower for 6,760 feet. The values of PIW were calculated using Equation 6.0.

(6.0) $PIW = BHP\ temperature\ corrected * \sqrt{\sigma} / (Wt/Ws)^{1.5}$

The CIW values of the data reduction sequence are 906 standardized feet per minute for 3,490 feet and 687 standardized feet per minute for 6,760 feet. The CIW values were calculated using the Equation 6.1.

(6.1) $CIW = (R/C\ temperature\ corrected) * \sqrt{\sigma} / \sqrt{Wt/Ws}$

The plot of PIW versus CIW for the Piper Saratoga PA32-301, N22UT, was constructed using these values (see Appendix H, Figure H.1).

The expansion calculation for the PIW versus CIW method was determined after the PIW and CIW values were calculated for 3,600 pounds, 3,200 pounds, 3,000 pounds, and 2,800 pounds aircraft weight. The expansion calculations for the Piper Saratoga PA32-301, N22UT, are found in Figures M.2 through M.5. A total of fifteen data points were constructed in the PIW versus CIW data reduction method by using the expansion calculation sequence. Altitudes ranging from sea level to 14,000 feet were used in the data reduction sequence. The CIW values were determined from the plot of PIW versus CIW and the rate of climb values were determined using Equation 6.2 for each altitude in the data reduction sequence.

(6.2) $Rate\ of\ Climb = [CIW * (\sqrt{W/Ws})] / \sqrt{\sigma}$

The values of rate of climb were plotted against the altitudes entered in the data reduction sequence and a plot of altitude versus rate of climb was developed. Figure I.1 depicts the altitude versus rate of climb plot of the Piper Saratoga PA32-301, N22UT for aircraft weights of 3,600 pounds, 3,200 pounds, 3,000 pounds, and 2,800 pounds. Maximum rate of climb at sea level, service ceiling, and maximum ceiling are determined from the plot of altitude versus rate of climb. Figure I.1 shows the maximum rate of climb at sea level to be 800 feet per minute using the PIW versus CIW data reduction method at 3,600 pounds. The maximum rate of climb at sea level at 3,200 pounds is 980 feet per minute. The maximum rate of climb at sea level at 3,000 pounds is 1,085 feet per minute and at 2,800 pounds is 1,210 feet per minute. The service ceiling and maximum ceiling are depicted for each weight on Figure I.1.

The PIW versus CIW data reduction sequence for the Cessna 150M Commuter, N66525, is found in Appendix M, Figures M.6 through M.8. Figure M.6 depicts the results of the PIW values in the data reduction sequence as 85 standardized horsepower for 2,140 feet and 75 standardized horsepower for 4,150 feet. The PIW values were calculated using Equation 6.0. The CIW values of the data reduction sequence are 422 feet per minute for 2,140 feet and 322 feet per minute for 4,150 feet. The CIW values were calculated using Equation 6.1. The plot of PIW versus CIW was developed using these values for the Cessna 150M Commuter, N66525 (see Appendix H, Figure H.2). The expansion calculations for the Cessna 150M Commuter, N66525, are found in Figures M.7 and M.8. A total of twelve data points were constructed in the PIW versus CIW data reduction method by using the expansion calculation sequence. Altitudes ranging from sea level to 11,000 feet were used in the data reduction sequence. The

CIW values were determined from the plot of PIW versus CIW for the Cessna 150M, N66525. The rate of climb values, determined in the same manner as for the Piper Saratoga by using Equation 6.2, are depicted in Figures M.7 and M.8.

A plot of altitude versus rate of climb was developed using the data reduction sequence of expansion calculation. Figure I.2 depicts the altitude versus rate of climb plot of the Cessna 150M Commuter, N66525, for aircraft weights of 1,600 pounds and 1,500 pounds. The maximum rate of climb at sea level, service ceiling, and maximum ceiling of the Cessna 150M Commuter, N66525, are determined using Figure I.2. The maximum rate of climb at sea level is 460 feet per minute at 1,600 pounds and 540 feet per minute at 1,500 pounds using the PIW versus CIW data reduction method. The service ceiling and maximum ceiling are determined using Figure I.2 for both aircraft weights. The results of the PIW versus CIW method for both the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525, were determined by extrapolating a line through the data points and forecasting the line to the desired values.

Equivalent Altitude Data Analysis

The equivalent altitude data reduction method is used only for fixed pitch propeller aircraft, therefore, only the Cessna 150M Commuter, N66525, incorporated this data reduction method. The equivalent altitude data reduction method is outlined in the *Engineering Flight Test Training Guide For Small Airplanes*. The FAA developed this document and used it until FAA Order 8110.8 was published. The equivalent altitude data reduction method results are found in Appendix K Figure K.1 for the

Cessna 150M Commuter, N66525 at 1,600 pounds and 1,500 pounds. The equivalent altitude in the data reduction sequence was determined by using Equation 6.3.

(6.3) $He = Hp + 0.36\,(Hd - Hp)$

In Equation 6.3, *He* represents equivalent altitude while *Hp* represents pressure altitude and *Hd* represents density altitude. Density altitude is determined by using Equation 6.4.

(6.4) $Hd = 145539\,[1 - (\sqrt{\sigma})^{0.4699}]$

The square root of sigma, which is required for Equation 6.4, was calculated by Equation 6.5.

(6.5) *Square root of sigma* $(\sqrt{\sigma}) = \sqrt{\delta/\theta}$

The value of delta (δ) is the ratio of ambient pressure to sea level value and is determined from altitude charts. The value of theta (θ) is the ratio of ambient temperature to sea level value and is determined from Equation 6.6.

(6.6) $Theta = Ta / 288.16$

The value of *Ta* is calculated by Equation 6.7.

(6.7) $Ta = Ti + 273.16$

Ti = *indicated temperature*

The rate of climb values for the equivalent altitude method were determined using Equation 6.8.

(6.8) $R/C \text{ at std. Day} = [(R/C \text{ at } Wt)*(Wt/Ws)] - [1-(Wt/Ws)^2 * (K/Vc* \sqrt{\sigma})]$

The equivalent altitude data reduction method sequence for the Cessna 150M Commuter, N66525, is found in Appendix N, Figure N.1 and N.2. Figure N.1 and N.2

depict the equivalent altitude values in the data reduction sequence as 2,108 feet for 2,140 feet pressure altitude and 4,290 feet for 4,150 feet pressure altitude. The equivalent altitude values for the Cessna 150M Commuter, N66525, were determined using Equations 6.3 and 6.4 by calculating the density altitude first. The rate of climb values for the equivalent altitude method were determined using Equation 6.8 for the Cessna 150M Commuter, N66525. The rate of climb values developed by the equivalent altitude data reduction method at 1,600 pounds were 389 feet per minute at 2,110 feet equivalent altitude and 300 feet per minute at 4,290 feet equivalent altitude using Figure N.1. The rate of climb values developed by the equivalent altitude data reduction method at 1,500 pounds were 450 feet per minute at 2,110 feet equivalent altitude and 356 feet per minute at 4,290 feet equivalent altitude using Figure N.2. A plot of equivalent altitude versus rate of climb was constructed for the Cessna 150M Commuter, N66525, using the values of equivalent altitude and rate of climb determined by the data reduction sequence for 1,600 pounds and 1,500 pounds. Figure K.1 shows the plot of equivalent altitude versus rate of climb for the Cessna 150M Commuter, N66525, at aircraft weights of 1,600 pounds and 1,500 pounds.

Maximum rate of climb at sea level, service ceiling, and maximum ceiling of the Cessna 150M Commuter, N66525, can be determined from the plot of equivalent altitude versus rate of climb. The rate of climb at sea level is 460 feet per minute at 1,600 pounds and 540 feet per minute at 1,500 pounds using Figure K.1. The service ceiling and maximum ceiling are determined using Figure K.1 for both aircraft weights. A total of two data points for each aircraft weight were constructed in the plots of equivalent altitude versus rate of climb for the Cessna 150M Commuter, N66525. The lines used to determine the rate of climb, service ceiling, and maximum ceiling values were extrapolated from the two data points to the desired values.

Density Altitude Data Analysis

The density altitude data reduction method was used for both aircraft. The density altitude method is outlined in Advisory Circular 23-8A and is used for both constant speed propeller and fixed pitch propellers. The density altitude results for the Piper Saratoga PA32-301, N22UT, are found in Appendix L Figure L.1. The density altitude data reduction sequence for the Piper Saratoga PA32-301, N22UT, is found in Appendix O, Figures O.1 through O.4. The density altitude values in the data reduction sequence were calculated using Equations 6.4 through 6.7. The rate of climb calculated in the density altitude data reduction method was determined by Equation 6.9.

(6.9) $R/C\ standard = Actual\ R/C - \Delta R/C\ \Delta w - \Delta R/C\ \Delta Di + \Delta R/C\ \Delta p$

Figures O.1 through O.4 depict the results of density altitude as 2,240 feet for 3,490 feet pressure altitude and 6,650 feet for 6,760 feet pressure altitude. Figure O.1 shows the rate of climb values at 3,600 pounds as 607 feet per minute at 2,240 feet density altitude and 482 feet per minute at 6,650 feet density altitude. Figure O.2 shows the rate of climb values at 3,200 pounds as 770 feet per minute at 2,240 feet density altitude and 637 feet per minute at 6,650 feet density altitude. Figure O.3 shows the rate of climb values at 3,000 pounds as 864 feet per minute at 2,240 feet density altitude and 725 feet per minute at 6,650 feet density altitude. Figure O.4 shows the rate of climb values at 2,800 pounds as 968 feet per minute at 2,240 feet density altitude and 823 feet per minute at 6,650 feet density altitude. A plot of density altitude versus rate of climb was developed using the values calculated by the density altitude data reduction sequence. Figure L.1 depicts the plot of density altitude versus rate of climb for all aircraft corrected weights.

Maximum rate of climb at sea level, maximum ceiling, and service ceiling are determined using the plot of density altitude versus rate of climb. Figure L.1 depicts the maximum rate of climb at sea level as 670 feet per minute at 3,600 pounds, 840 feet per minute at 3,200 pounds, 935 feet per minute at 3,000 pounds, and 1,045 feet per minute at 2,800 pounds. The service ceiling and maximum ceiling are determined using Figure L.1.

The density altitude results for the Cessna 150M Commuter, N66525, are found in Appendix L Figure L.2. The density altitude data reduction sequence for the Cessna 150M Commuter, N66525, is found in Appendix O, Figure O.5 through O.6. The density altitude values were determined using Equations 6.4 through 6.7 and the rate of climb values were determined using Equation 6.9.

Figures O.5 and O.6 depict the values of density altitude as 2,050 feet at 2,140 feet pressure altitude and 4,530 feet at 4,150 feet pressure altitude. Figure O.5 depicts the rate of climb values at 1,600 pounds as 371 feet per minute at 2,050 feet density altitude and 291 feet per minute at 4,530 feet density altitude. Figure O.6 depicts the rate of climb values at 1,500 pounds as 431 feet per minute at 2,050 feet density altitude and 347 feet per minute at 4,530 feet density altitude. A plot of density altitude versus rate of climb was developed using the determined values of density altitude and rate of climb for the Cessna 150M Commuter, N66525, at the aircraft weights of 1,600 pounds and 1,500 pounds and is found in Figure L.2.

Maximum rate of climb at sea level, maximum ceiling, and service ceiling are determined for the Cessna 150M Commuter, N66525, using the plot of density altitude versus rate of climb. The maximum rate of climb at sea level values using Figure L.2 were determined as 438 feet per minute at 1,600 pounds and 500 feet per minute at 1,500 pounds. The service ceiling and maximum ceiling are determined using Figure L.2. A total of two data points were constructed in the plots of density altitude versus rate of climb for both aircraft. The lines used to determine the rate of climb, maximum ceiling, and service ceiling values were extrapolated from the two data points to the desired values.

Equivalent Altitude/PIW versus CIW Comparison

The Cessna 150M Commuter, N66525, equivalent altitude results were compared to the PIW versus CIW results of the aircraft. Figure 6.0 shows the results of both methods compared to each other for an aircraft weight of 1,600 pounds. The values for the maximum rate of climb at sea level were within fifteen feet (five percent of each other). The values for the service ceiling and the maximum ceiling of the aircraft were within two hundred feet (one percent of each other). Figure 6.1 shows the results of the methods being compared for the Cessna 150M Commuter, N66525 for an aircraft weight of 1,500 pounds. The results were within five feet (one percent) of each other for the maximum rate of climb at sea level and within seven hundred feet (four percent of each other) for the maximum ceiling and the service ceiling.

The results of the two methods being compared to each other show that each method is accurate for climb performance data reduction. The major differences

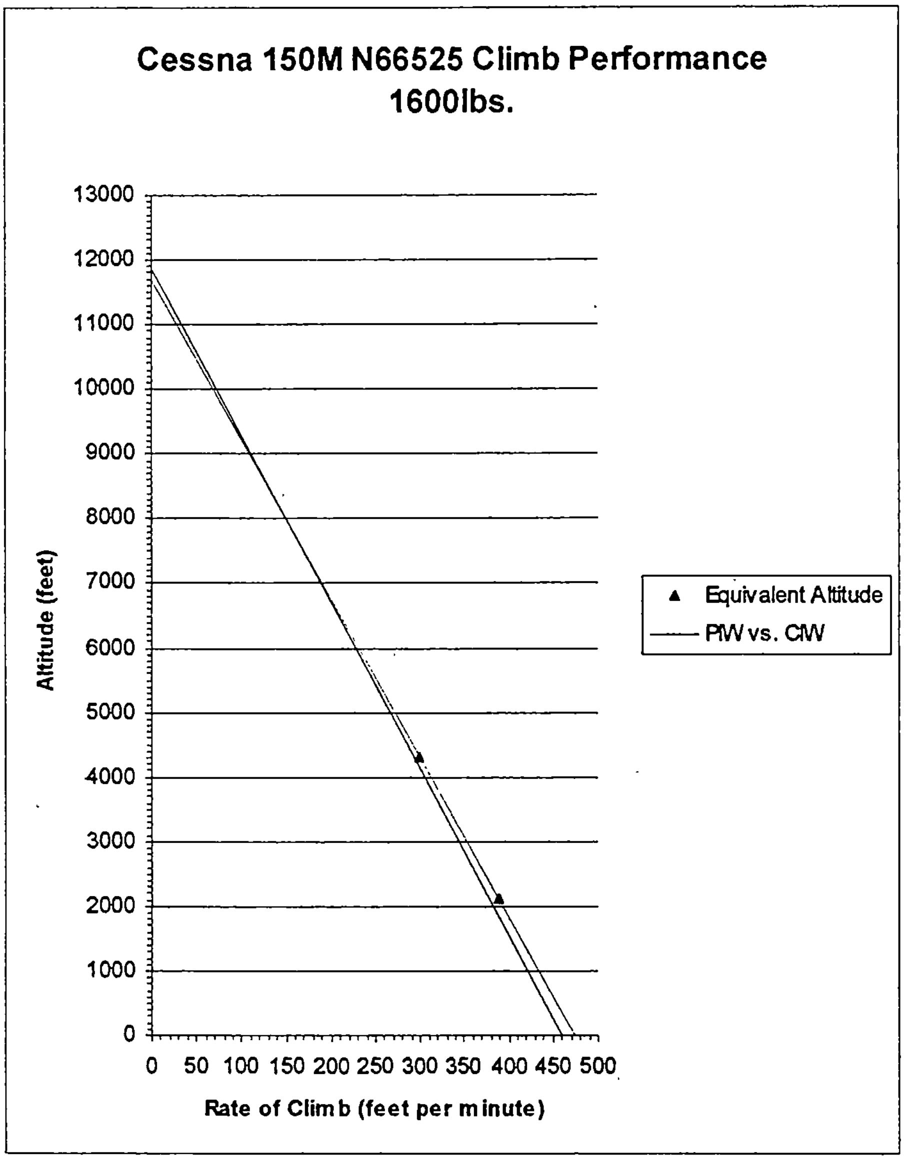


Figure 6.0. Cessna 150M N66525

Climb Performance 1,600 pounds (PIW versus CIW/Equivalent Altitude).

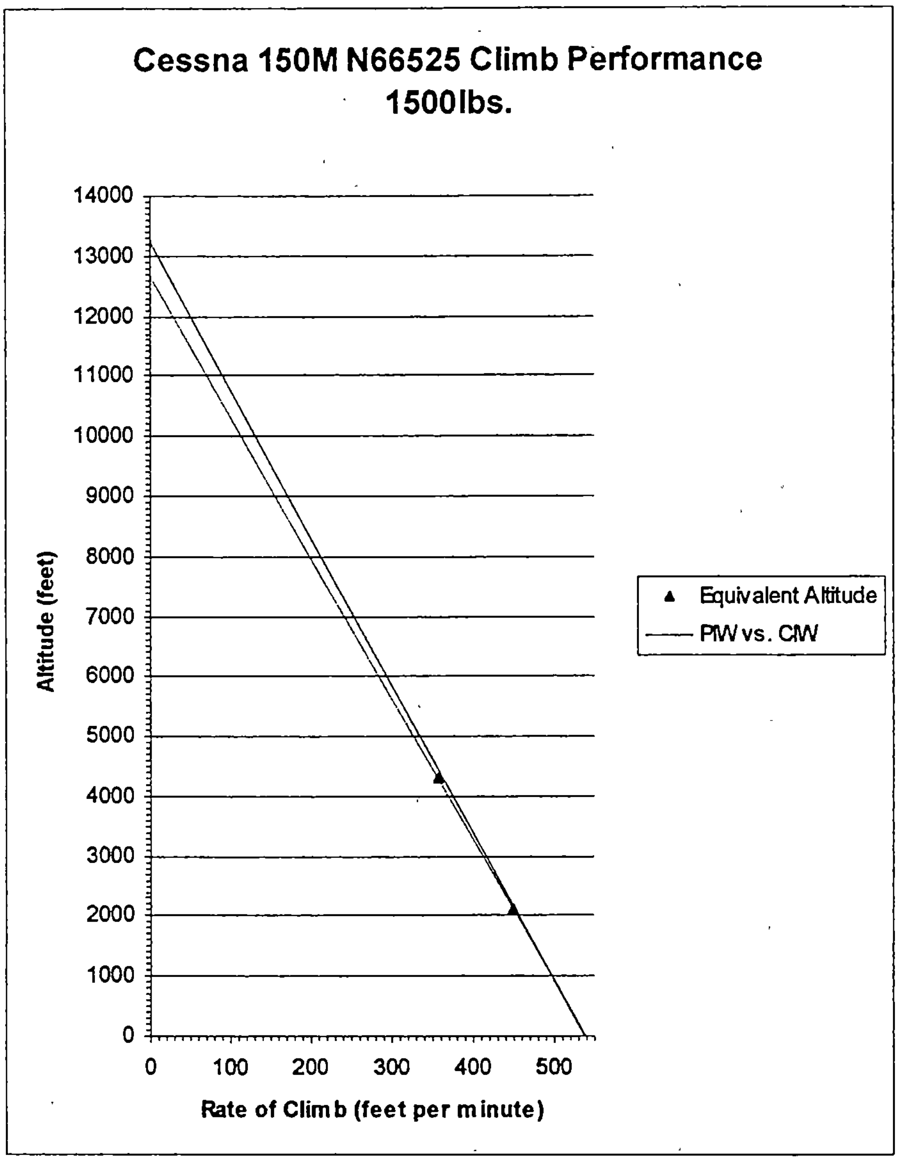


Figure 6.1. Cessna 150M N66525

Climb Performance 1,500 pounds (PIW versus CIW/Equivalent Altitude).

between the methods are the approximations of aircraft efficiency. The equivalent altitude method incorporates the value of K in the method. The value K assumes aircraft efficiency to be a value of 0.8. Figure 6.2 shows the results of aircraft efficiency at values of 0.7 through 0.9. The results of the plots conclude that the maximum rate of climb at sea level changes less than ten feet, which shows that a typical value of aircraft efficiency does not play a major factor in the rate of climb results.

Other differences in the methods include the use of density altitude and equivalent altitude for the equivalent altitude method while the PIW versus CIW only incorporates pressure altitude. The equivalent altitude method does not incorporate the engine horsepower, which makes the method easy to use if no engine horsepower charts are available. The equivalent altitude method is used primarily for fixed pitch propellers since no engine horsepower calculations and no propeller efficiency estimations are required. Both methods are easy to use and simple to follow. The equivalent altitude climb performance data reduction method is not published in Advisory Circular 23-8A.

Density Altitude/PIW versus CIW Comparison

The Cessna 150M Commuter, N66525, density altitude results were compared to the PIW versus CIW results for the aircraft. Figure 6.3 shows the results of each method for an aircraft weight of 1,600 pounds. The results of each method were within twenty-five feet (five percent of each other) for the maximum rate of climb. The results for the maximum ceiling and service ceiling exceeded one thousand five hundred feet

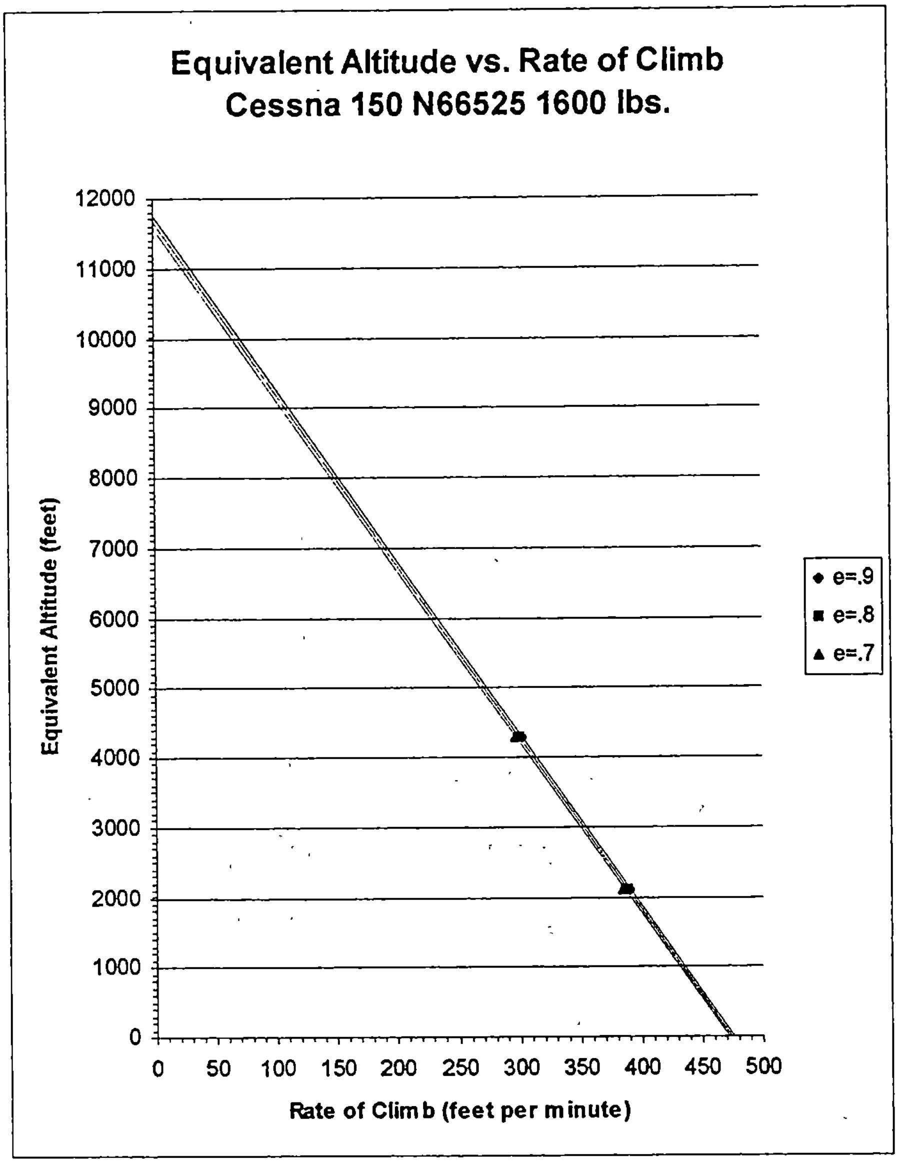


Figure 6.2. Cessna 150M N66525

Aircraft Efficiency Factor Comparisons.

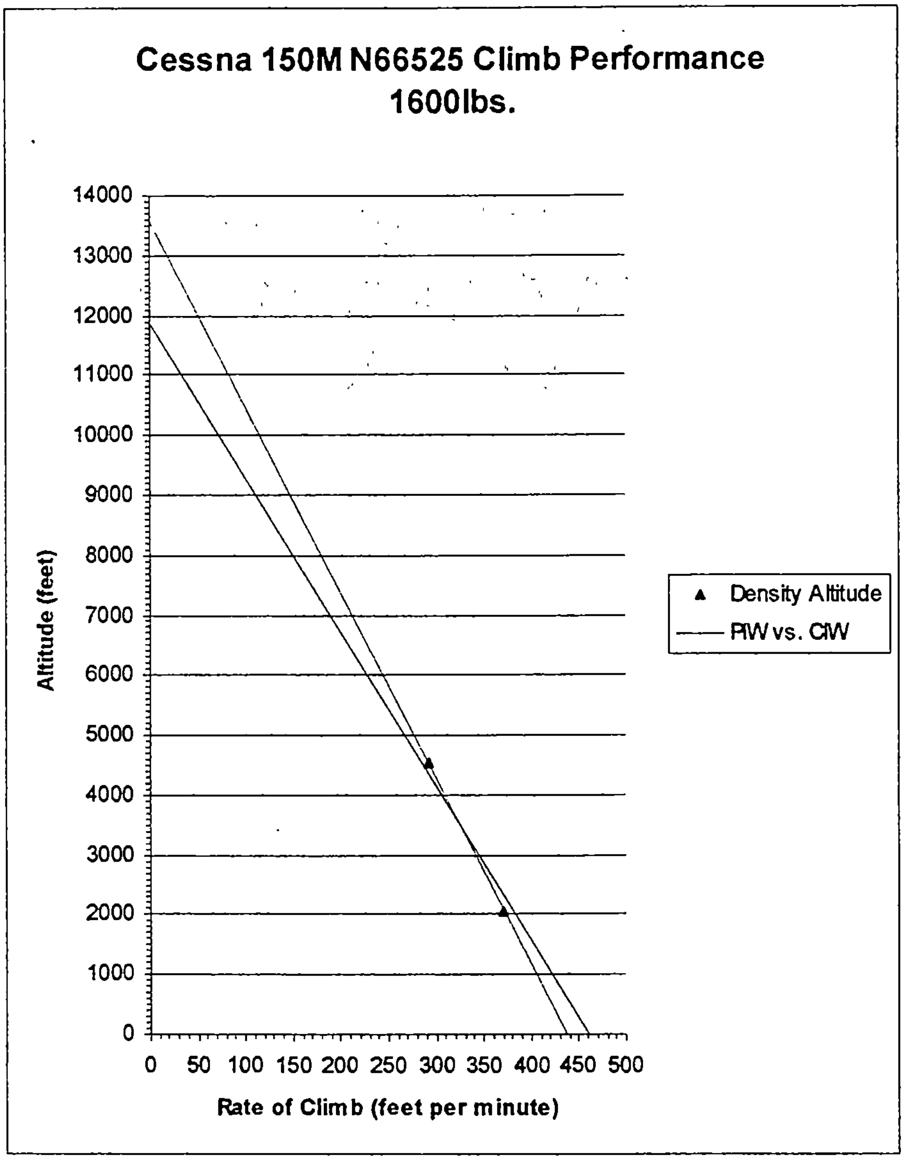


Figure 6.3. Cessna 150M N66525

Climb Performance 1,600 pounds (PIW versus CIW/Density Altitude).

(thirteen percent of each other). Figure 6.4 shows the results of the both methods for an aircraft weight of 1,500 pounds. The maximum rate of climb results for each method are within forty feet (seven percent of each other). The maximum ceiling and service ceiling for each data reduction method exceeded one thousand six hundred feet (eleven percent of each other).

The Piper Saratoga PA32-301, N22UT, density altitude results were compared to the PIW versus CIW results of the aircraft. Figure 6.5 shows the results of each method for an aircraft weight of 3,600 pounds, Figure 6.6 for 3,200 pounds, Figure 6.7 for 3,000 pounds, and Figure 6.8 for 2,800 pounds. The results for each aircraft weight for both data reduction methods are within one hundred and sixty feet (sixteen percent of each other) for the maximum rate of climb at sea level and exceeded ten thousand feet (twenty nine percent of each other) for the maximum ceiling and service ceiling.

The results of the two methods being compared to each other show significant differences in rate of climb at sea level and for service ceiling and maximum ceiling. The major differences between the methods in the reduction sequence are the approximations of aircraft efficiency factor and propeller efficiency factor values. The density altitude method incorporates the aircraft efficiency factor assumption and the propeller efficiency factor assumption. The FAA allows an assumption of 0.8 for the aircraft efficiency factor and 0.83 for the propeller efficiency factor. Figure 6.9 shows the results of aircraft efficiency values of 0.6 through 0.9 and propeller efficiency values of 0.6 through 0.9 for the Piper Saratoga PA32-301, N22UT. The results show a range of thirty feet between the different values for maximum rate of climb at sea level. Figure 6.10 shows the results of maintaining a constant propeller efficiency of 0.83 and

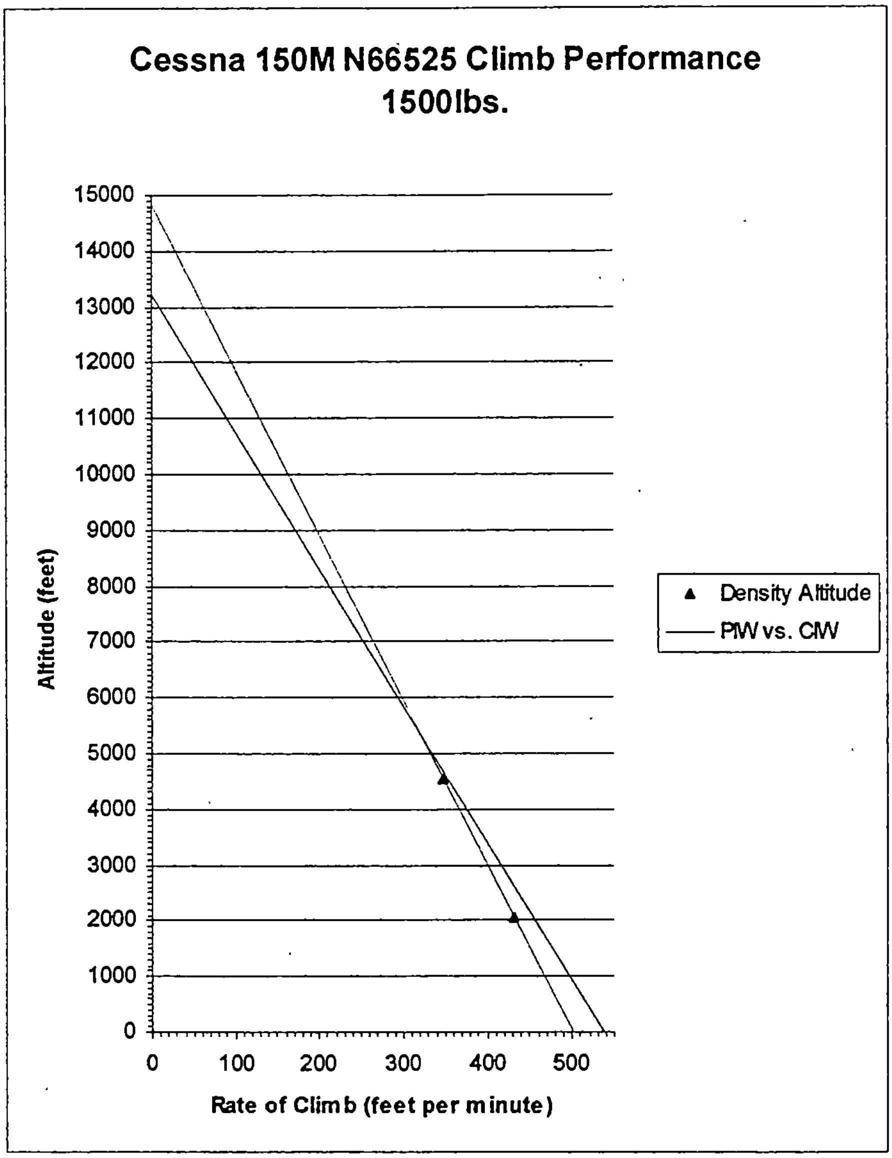


Figure 6.4. Cessna 150M N66525

Climb Performance 1,500 pounds (PIW versus CIW/Density Altitude).

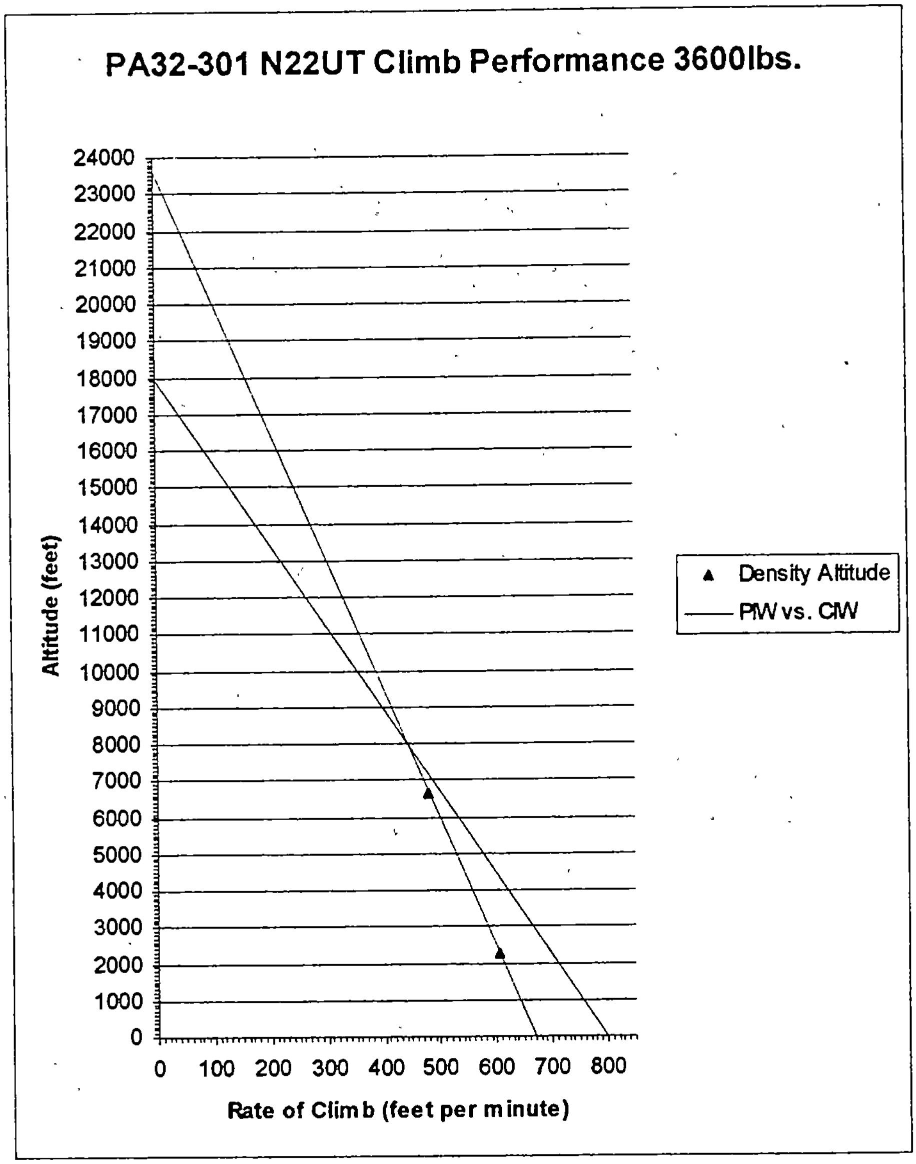


Figure 6.5. Piper Saratoga N22UT

Climb Performance 3,600 pounds (PIW versus CIW/Density Altitude).

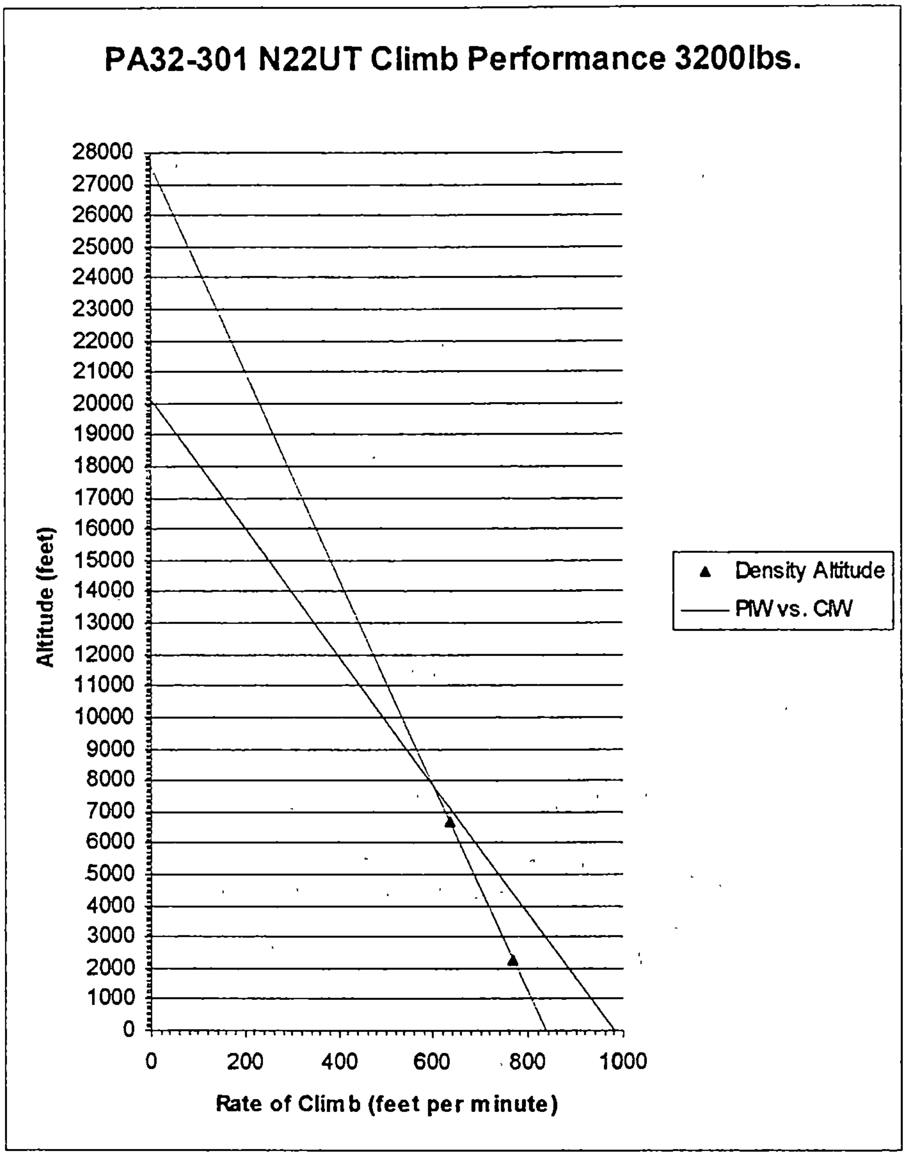


Figure 6.6. Piper Saratoga N22UT

Climb Performance 3,200 pounds (PIW versus CIW/Density Altitude).

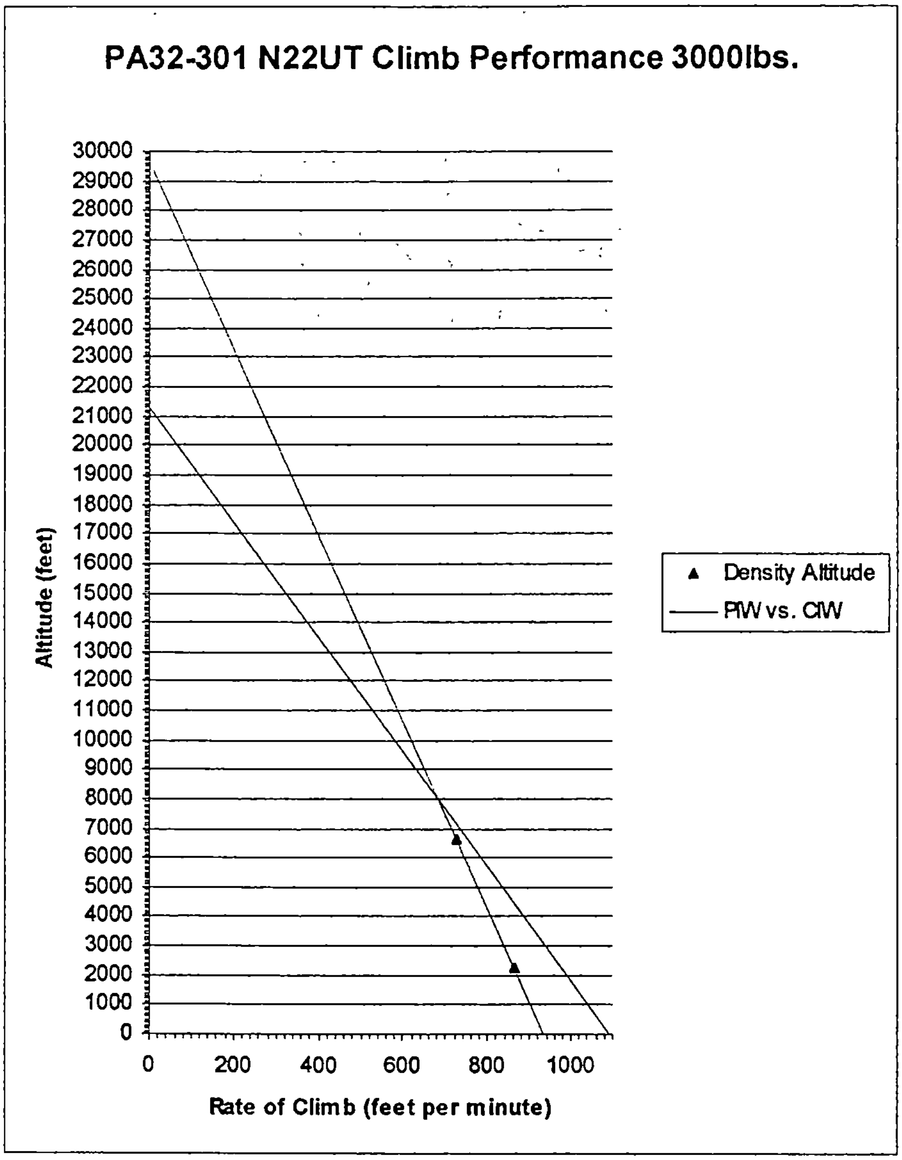


Figure 6.7. Piper Saratoga N22UT

Climb Performance 3,000 pounds (PIW versus CIW/Density Altitude).

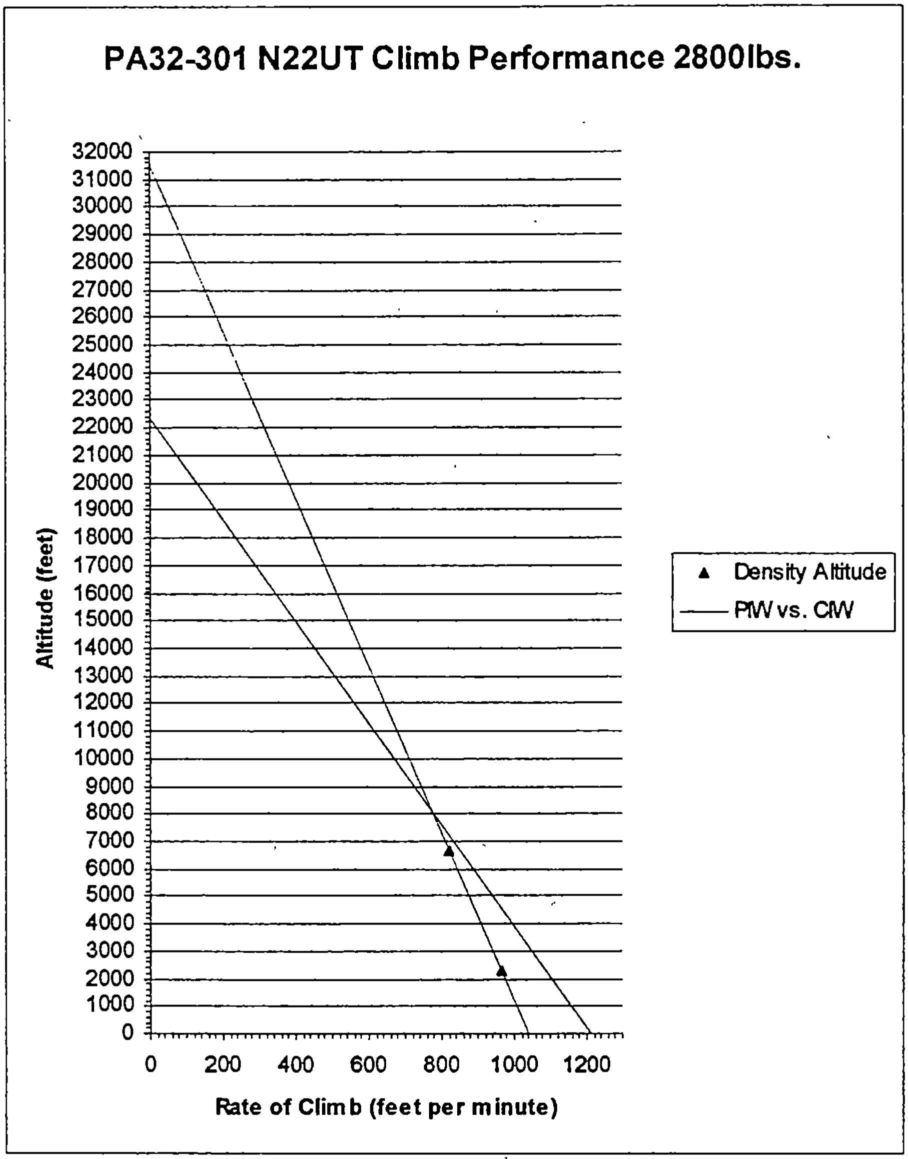


Figure 6.8. Piper Saratoga N22UT

Climb Performance 2,800 pounds (PIW versus CIW/Density Altitude).

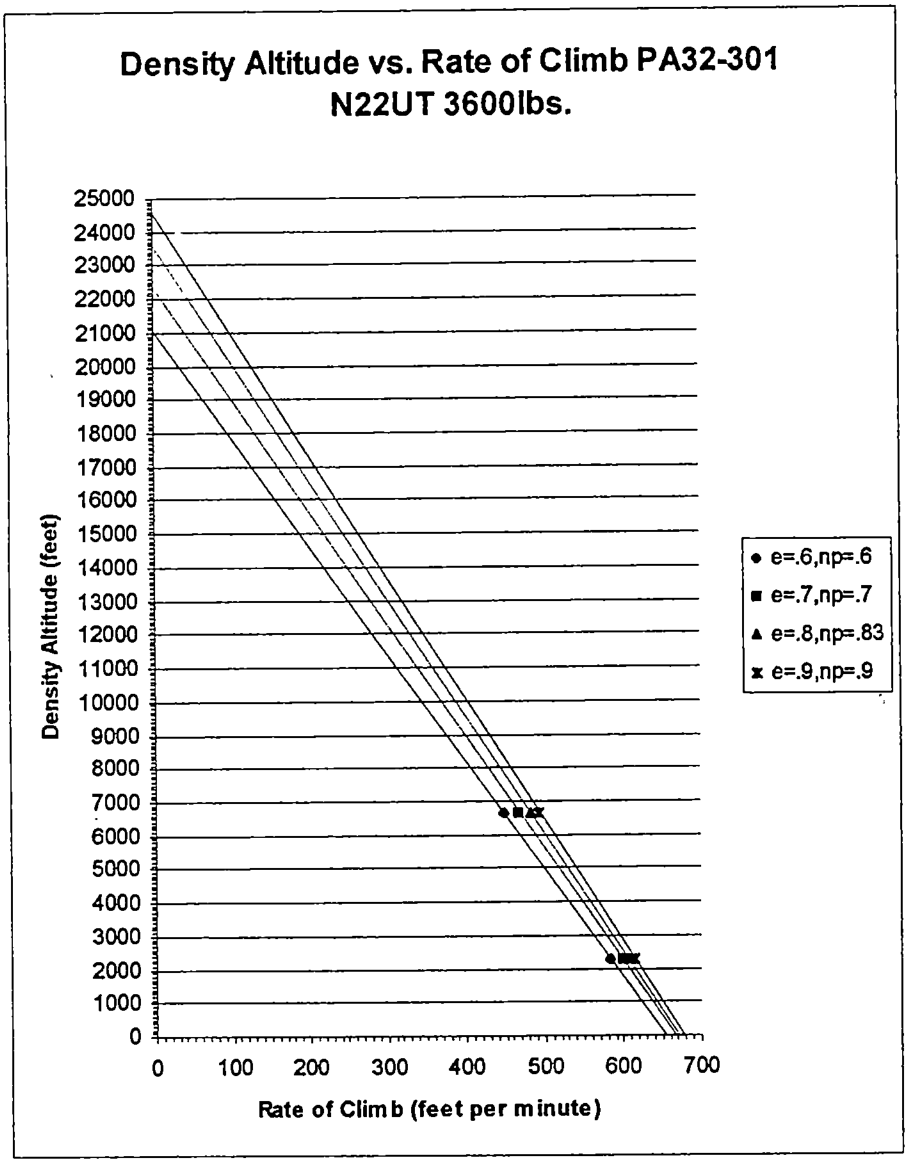


Figure 6.9. Piper Saratoga N22UT

Aircraft and Propeller Efficiency Factor Comparisons.

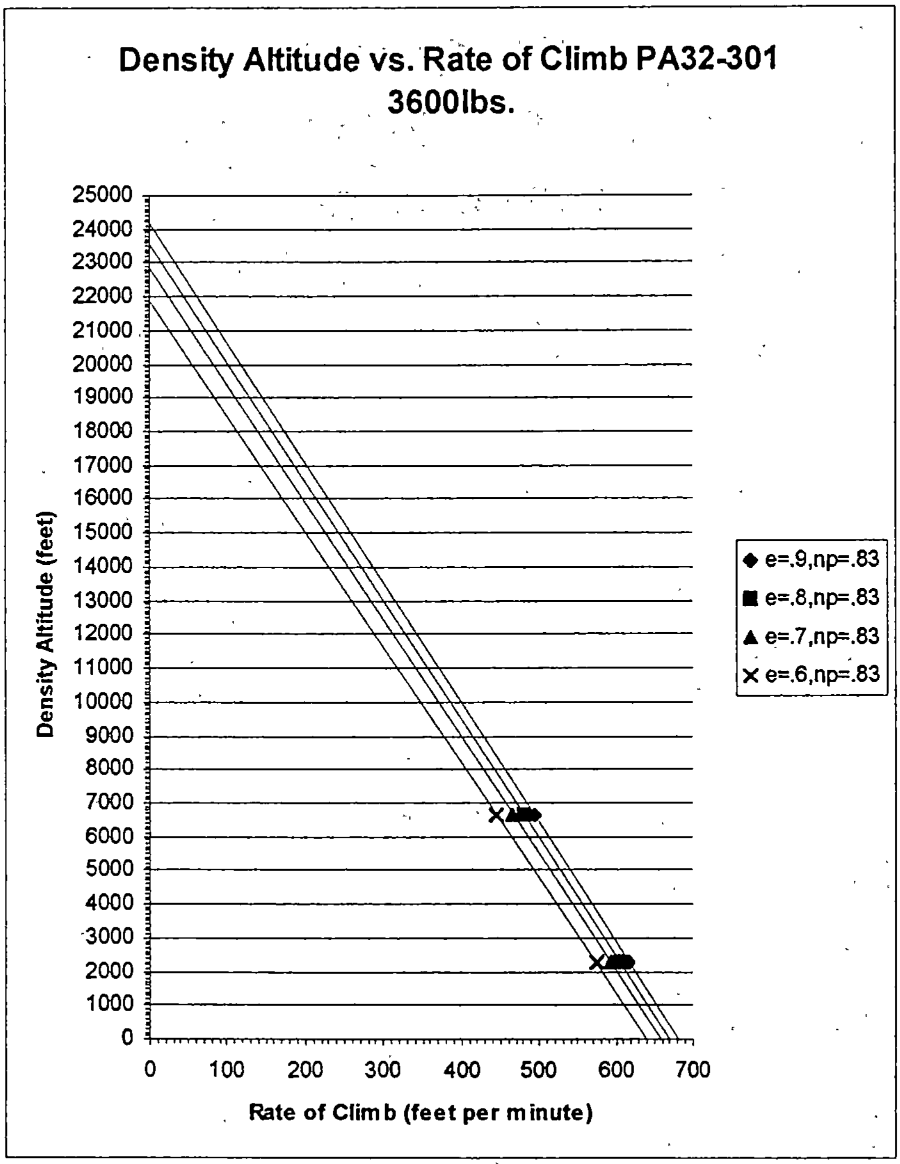


Figure 6.10. Piper Saratoga N22UT

Aircraft Efficiency Factor Comparisons.

varying the aircraft efficiency factor from 0.6 to 0.9. Figure 6.11 shows the results of maintaining the aircraft efficiency factor at 0.8 and varying the propeller efficiency factor value from 0.6 to 0.9. The results of these plots show that aircraft efficiency and propeller efficiency values play a factor in the final results of the climb performance evaluation. The aircraft efficiency factor is a more important parameter in the data reduction method due to the results in Figure 6.10. A range of forty feet is observed in the rate of climb value when propeller efficiency is held constant and the aircraft efficiency is varied from 0.6 to 0.9 which are potential values for the span efficiency.

Figures 6.12 through 6.14 show the aircraft efficiency factor and propeller efficiency factor comparisons for the Cessna 150M Commuter, N66525. Figure 6.12 shows the values of aircraft efficiency and propeller efficiency varying together in values ranging from 0.6 to 0.9. The results show no major changes in rate of climb values but do show a range of five hundred feet for aircraft ceiling values. Figure 6.13 shows the propeller efficiency factor held constant and the aircraft efficiency factor varying from 0.6 to 0.9. The results show a range of fifteen feet of difference for the rate of climb values. Figure 6.14 shows the aircraft efficiency factor held constant and the propeller efficiency factor varying from 0.6 to 0.9 and the results show only a fifteen feet difference for the rate of climb values. These changes are insignificant.

Other differences in the methods include the use of density altitude for the density altitude method while the PIW versus CIW incorporates only pressure altitude. The density altitude method incorporates engine horsepower at density altitude. The density altitude method is used for both fixed pitch and constant speed propellers and is the only method currently published in the Advisory Circular 23-8A. The sequence

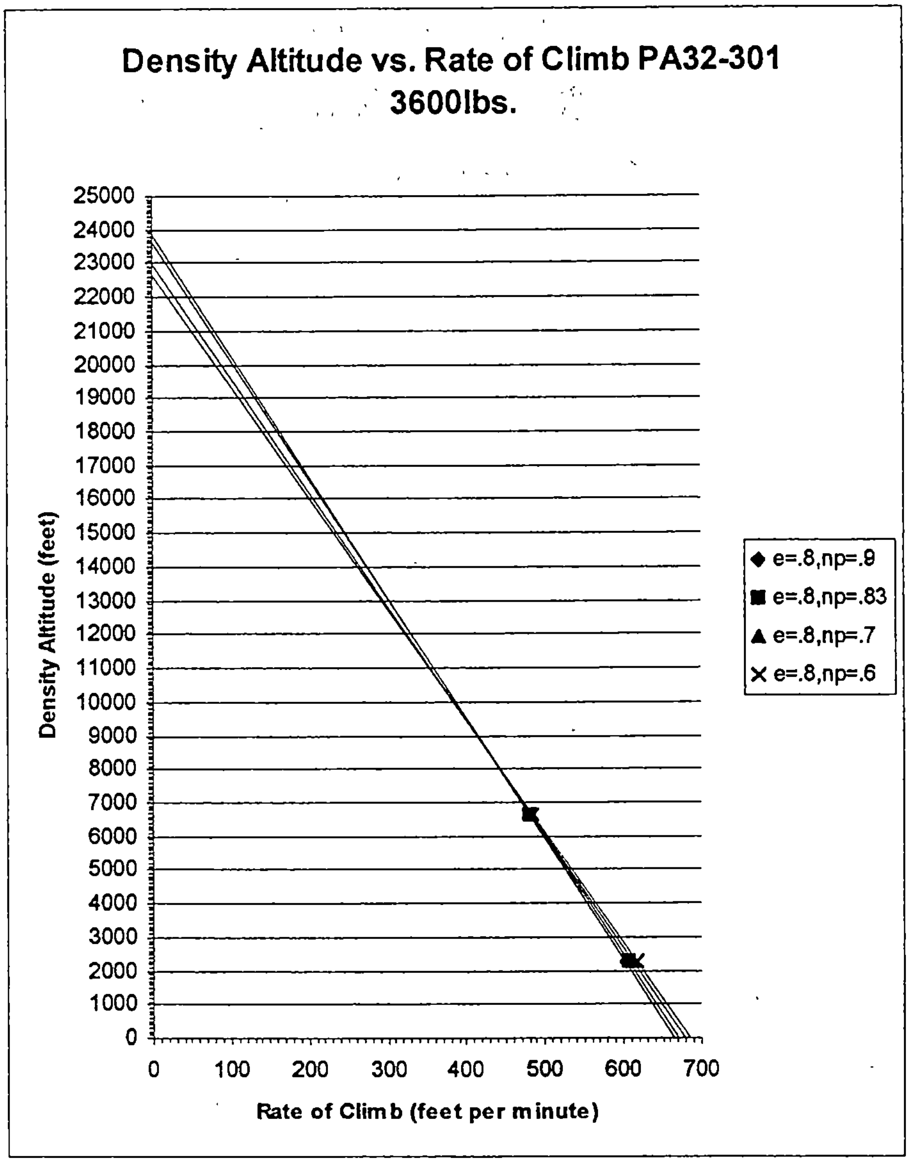


Figure 6.11. Piper Saratoga N22UT

Propeller Efficiency Factor Comparisons.

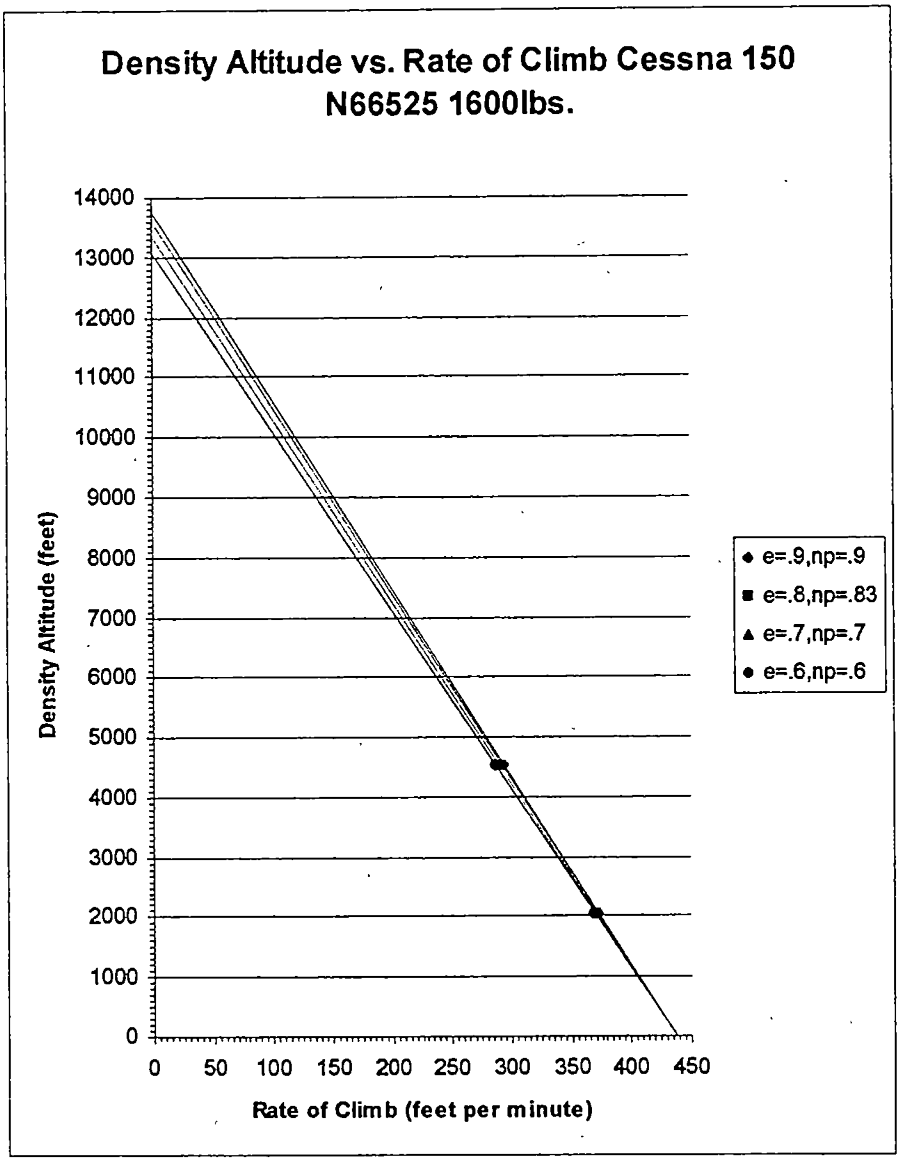


Figure 6.12. Cessna 150 N66525

Aircraft Efficiency and Propeller Efficiency Factor Comparisons.

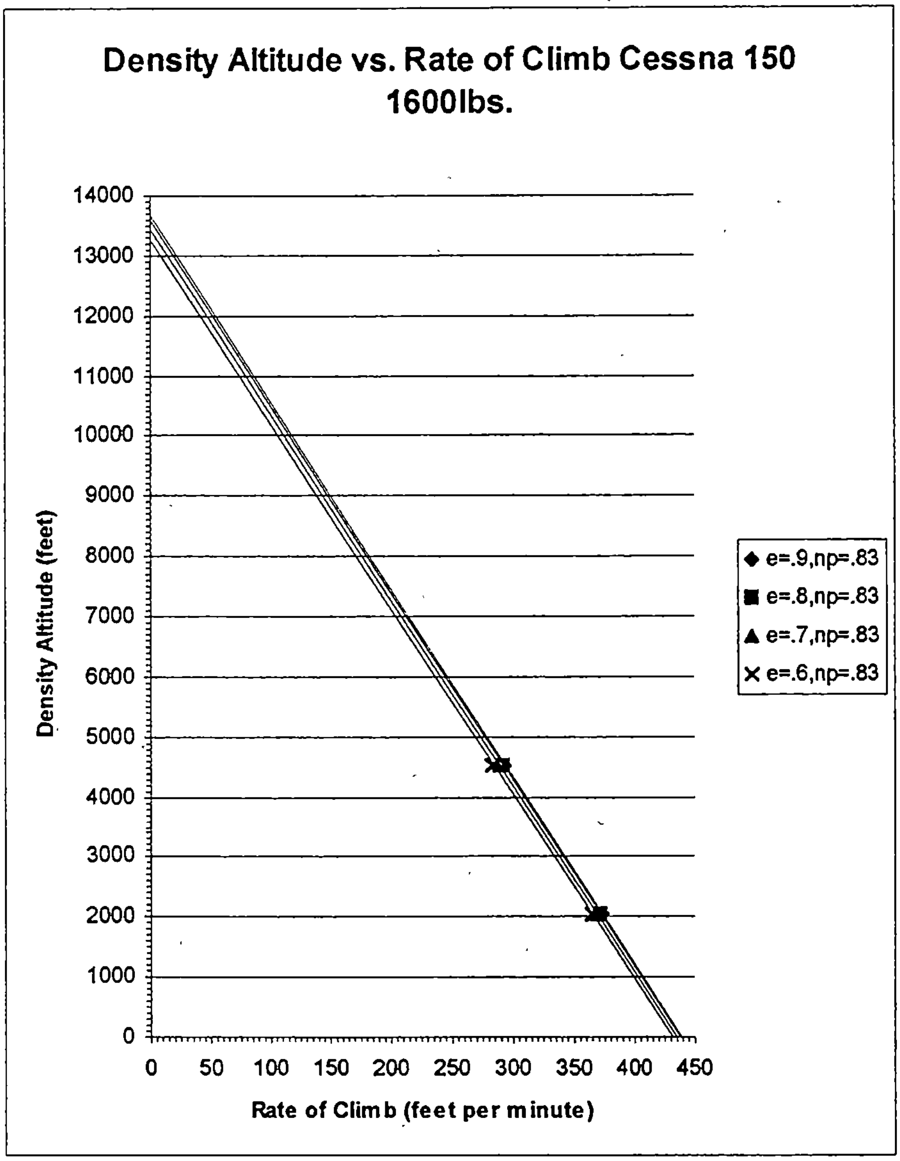


Figure 6.13. Cessna 150 N66525

Aircraft Efficiency Factor Comparisons.

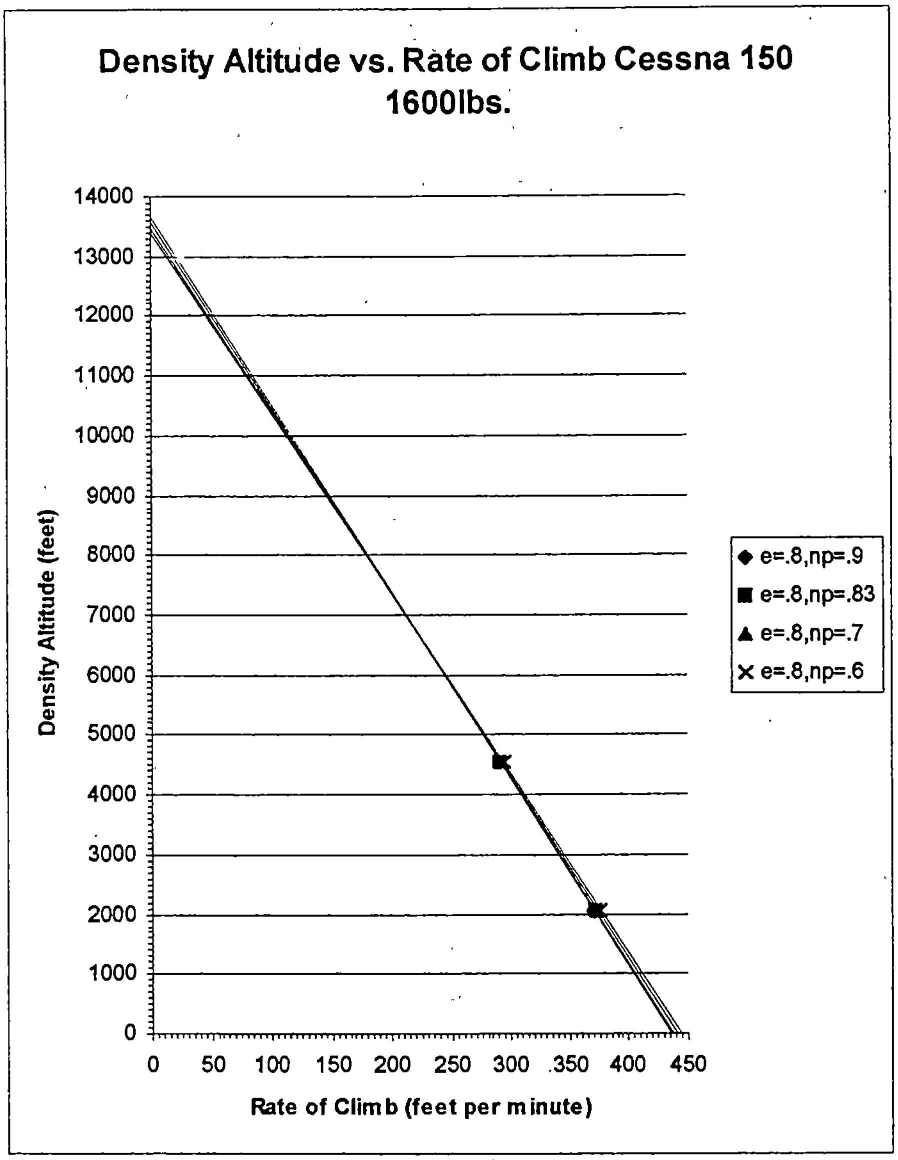


Figure 6.14. Cessna 150 N66525

Propeller Efficiency Factor Comparisons.

outlined in AC23-8A is difficult to understand and follow because of a misprint and estimations, as compared to either the PIW versus CIW method or the equivalent altitude method.

The results of Figures 6.5 through 6.8 show inaccurate values of sea level rate of climb and aircraft ceilings for the density altitude method. Figures 6.15 through 6.18 show the results of PIW versus CIW and density altitude for aircraft weights of 2,800 pounds, 3,000 pounds, 3,200 pounds, and 3,600 pounds with the test day temperatures adjusted to reflect a standard lapse rate. The reason for including Figures 6.15 through 6.18 with adjusted temperature values is because of the large differences in results of the density altitude method for the Piper Saratoga, N22UT. The original flight data shows a large temperature inversion encountered during the flight test of the Piper Saratoga PA32-301, N22UT. The temperature inversion encountered during the flight test results in inaccurate ceilings and rate of climb calculations. Figures 6.15 through 6.18 show the results of both methods using the standard temperature lapse rate of two degrees per one thousand feet of altitude. The temperature value entered for 3,490 feet pressure altitude is 8.6 degrees Celsius. The 8.6 °C is a more standard temperature at that altitude that –2.2 °C. The temperature value of 0.6 °C for 6,760 feet pressure altitude is close to a standard temperature value and was used in Figures 6.15 through 6.18. The Figures show a larger change in the results of the density altitude method than in the PIW versus CIW method. This indicates that the PIW versus CIW method is more robust, in the fact that the method can be used without large errors even in a temperature inversion situation. The density altitude method on the other hand appears very sensitive to temperature inversions.

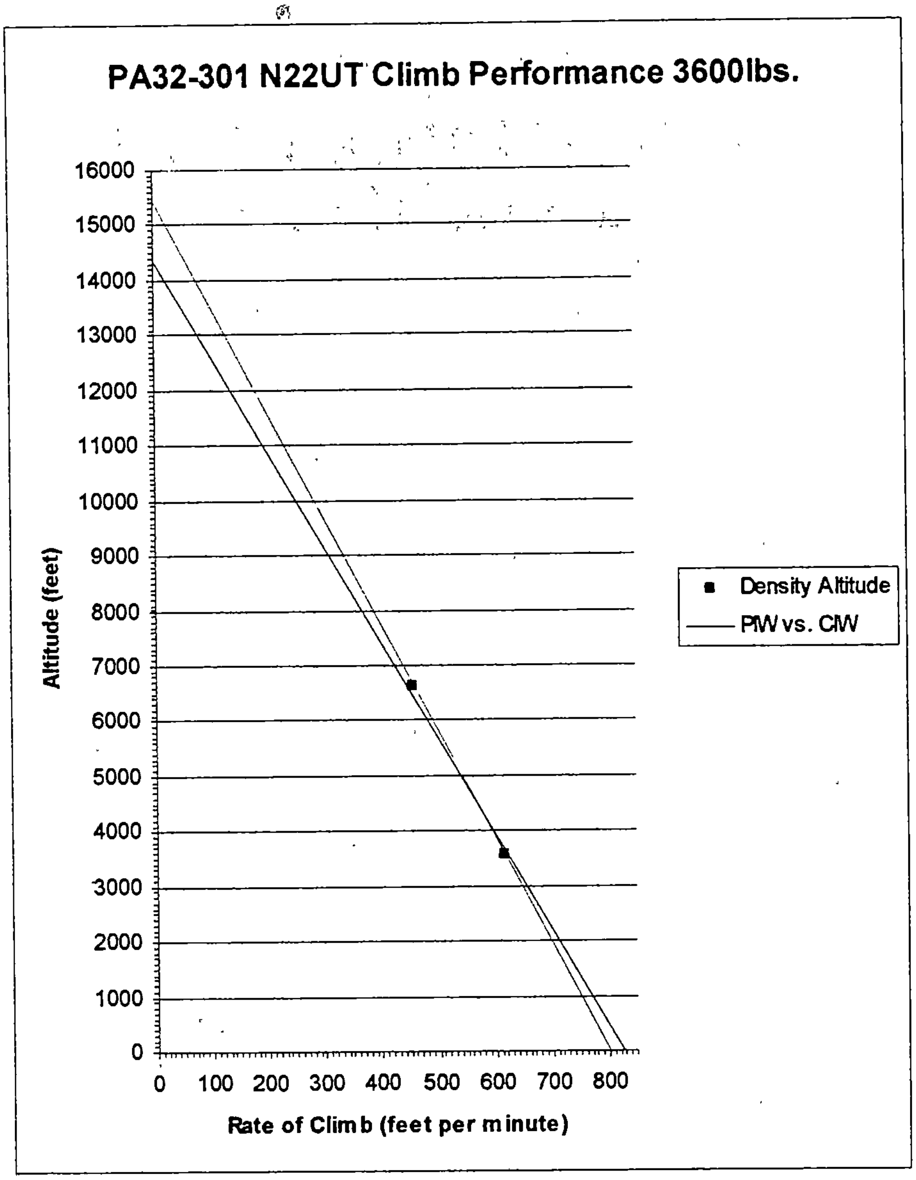


Figure 6.15. Piper Saratoga N22UT

Temperature Correction Data 3,600 pounds.

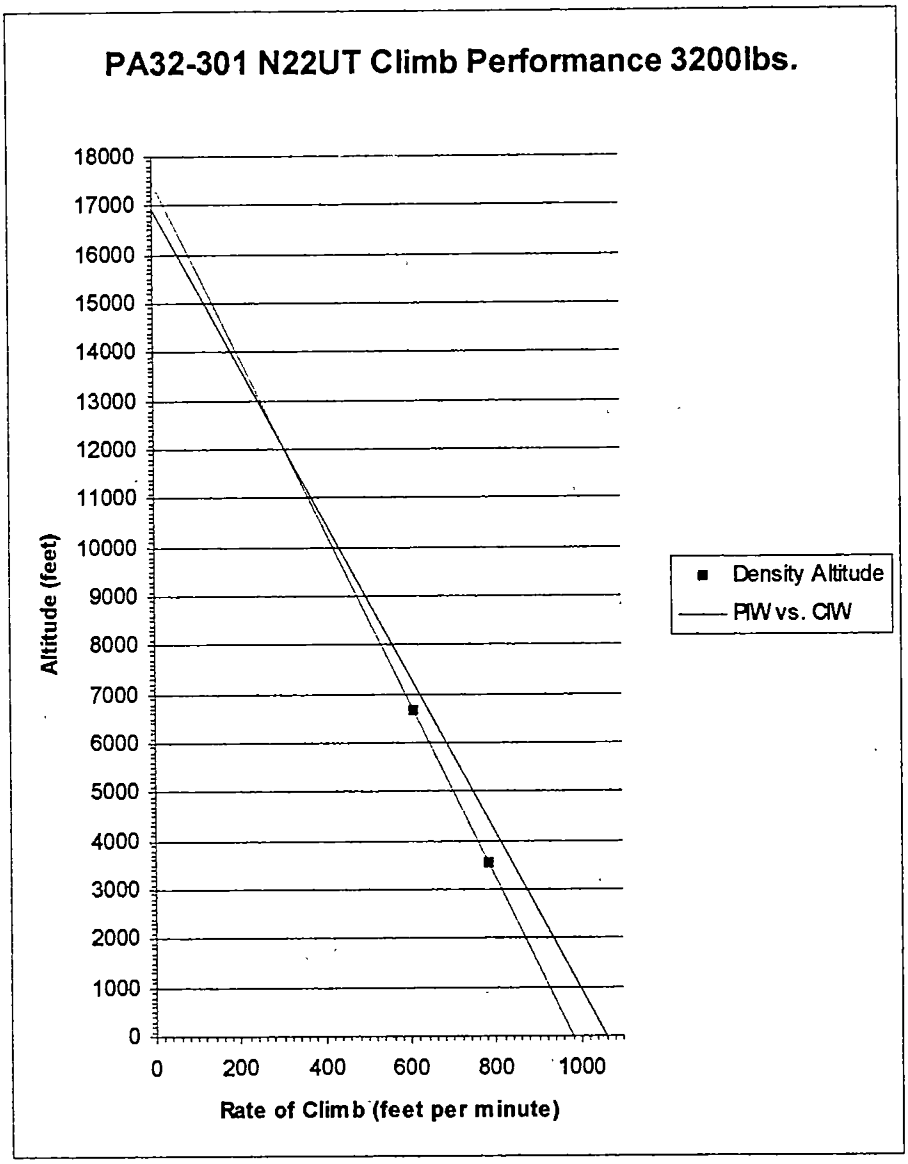


Figure 6.16. Piper Saratoga N22UT

Temperature Correction Data 3,200 pounds.

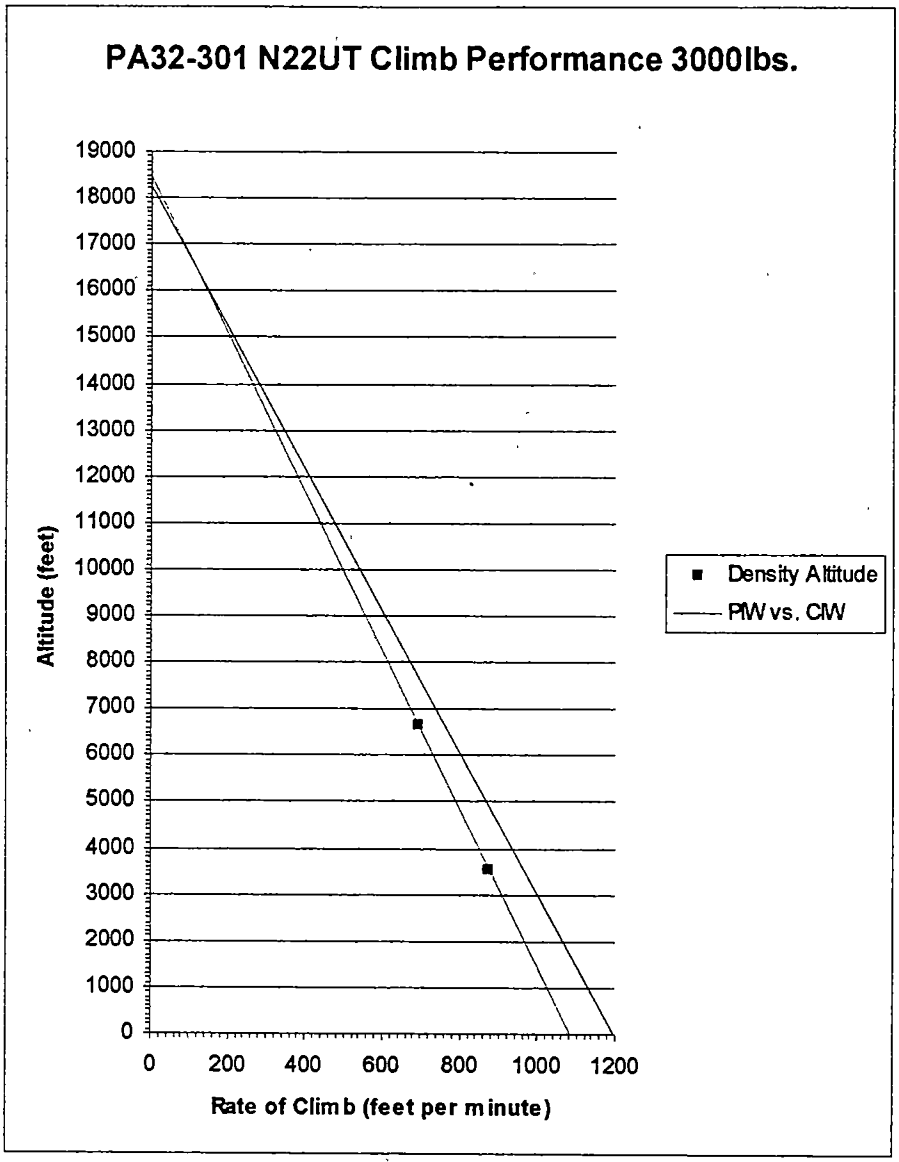


Figure 6.17. Piper Saratoga N22UT

Temperature Correction Data 3,000 pounds.

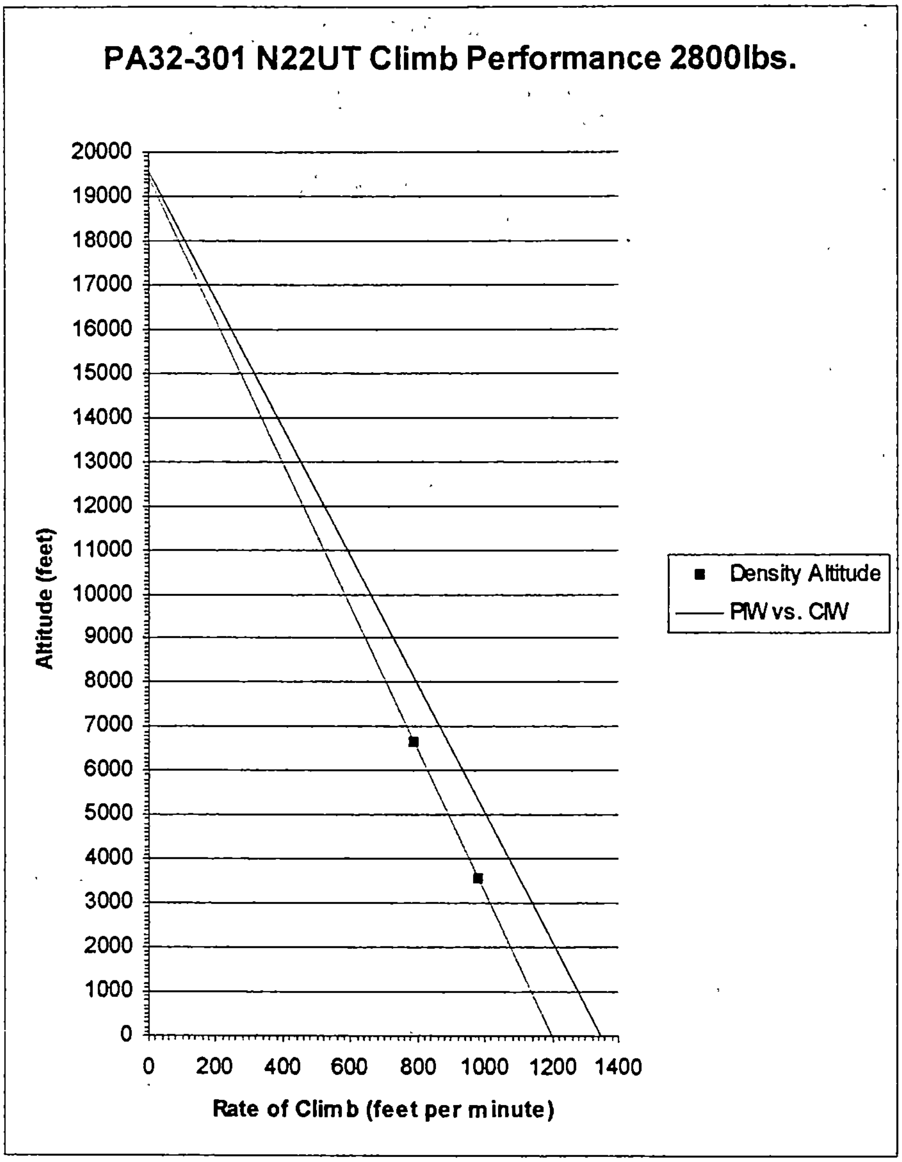


Figure 6.18. Piper Saratoga N22UT

Temperature Correction Data 2,800 pounds.

Chapter 7

Conclusions and Recommendations

General

The PIW versus CIW method was compared to the other two data reduction methods incorporating the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525. A total of nineteen comparisons are incorporated in the thesis. The equivalent altitude method was compared to the PIW versus CIW method for the Cessna 150M Commuter, N66525. The density altitude method was compared to the PIW versus CIW method for the Piper Saratoga PA32-301, N22UT, and the Cessna 150M Commuter, N66525. A density altitude/PIW versus CIW comparison was made for the flight test conditions of both aircraft and then another comparison made by adjusting the test temperature to a more standard lapse rate for the Piper Saratoga, N22UT. Aircraft efficiency and propeller efficiency values were compared to develop an understanding of how the values affect the final results.

Conclusion

The PIW versus CIW climb performance data reduction method is a robust easy to use method which provides the ability to reduce data for increasing and decreasing aircraft weights, and the calculation of engine horsepower without the use of propeller efficiency and aircraft efficiency estimations. The equivalent altitude method gives comparable results to the PIW versus CIW method for fixed pitch propeller driven aircraft. The equivalent altitude method compares well with other methods for increasing aircraft weights and for decreasing aircraft weights past the aircraft test day weight. The aircraft efficiency factor (K) is used in the equivalent altitude method to determine the induced drag correction. The estimated aircraft efficiency factor changes the maximum rate of climb value by minimal amounts. The estimated aircraft efficiency factor does not increase or decrease the final results enough to affect overall climb performance of an aircraft. The equivalent altitude method is only used for fixed pitch propellers since there are no engine horsepower calculations and no propeller efficiency estimations. The equivalent altitude climb performance data reduction method is easy to understand and simple to execute.

The density altitude method is more sensitive to non-standard weather conditions than the PIW versus CIW method. The flight test for the Cessna 150M Commuter, N66525, was performed in an atmosphere without a significant temperature inversion. The temperature was the same at both test altitudes for the flight test of the Cessna 150M Commuter. The results of the density altitude and PIW versus CIW methods compared favorably. A temperature inversion was encountered during the Piper Saratoga, N22UT, flight test. A temperature of –2.2 degrees Celsius was encountered at 3,490 feet pressure altitude and a temperature of 0.6 degrees Celsius at 6,760 feet pressure altitude. The low temperature encountered at 3,490 feet led to a much lower value for density altitude. This low value for density altitude resulted in the large differences between the results of the density altitude and the PIW versus CIW methods. When a near standard temperature value of 8.6 degrees Celsius was substituted for the test temperature in the density altitude method, a closer agreement of climb performance was obtained. This confirmed that the density altitude method is sensitive to temperature inversions.

The results show that the PIW (standardized power) versus CIW (standardized rate of climb) is a better method under conditions of a non-standard temperature lapse rates. The small changes that occurred to the PIW versus CIW method when a temperature value of 8.6 degrees Celsius was used for the 3,490 feet pressure altitude show the lack of sensitivity of the method to nonstandard temperature lapse rates.

Aircraft efficiency factor and propeller efficiency factor estimations are calculated in the density altitude data reduction method. The climb performance of the aircraft increases with an increase in propeller and aircraft efficiency. The aircraft efficiency and propeller efficiency values change the final results as much as fifty feet for the maximum rate of climb at sea level value. The density altitude method is difficult to understand and follow because of the calculations and estimations to be made in the data reduction sequence. The density altitude method is published in Advisory Circular 23-8A (Revision 1) and is known to have at least one misprint. The misprint is the value of Ws when it should read the value of Wc (weight to be corrected to).

Recommendations

The sensitivity of the density altitude method to propeller efficiency estimations, aircraft efficiency estimations, and temperature inversions substantiates the need for an alternate climb performance method in the Federal Aviation Administration Advisory

Circular 23-8A. Based on results due to insensitivity to temperature inversions, reduced use of estimated values, and ease of use, the standard climb performance data reduction method should be PIW (standardized power) versus CIW (standardized rate of climb). Based on the limited results calculated by the thesis, equivalent altitude seems to provide excellent data reduction methodology for fixed pitch aircraft and does not rely on aircraft efficiency factor estimations.

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BIBLIOGRAPHY

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APPENDICES

Appendix A: Climb Performance Data Reduction Methods

Appendix B: Instrument Calibrations

Appendix C: Airspeed Position Error Calibrations

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Appendix F: Engine Horsepower Charts

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APPENDIX A

Climb Performance Data Reduction Methods

No.	Quantity	Reference	Units	Information
1	Vo	Flight Data	Knots	
2	Vi	Instrument Calibration	Knots	
3	Vc	Position Calibration	Knots	
4	hpo	Flight Data	Feet	
5	hpi	Instrument Calibration	Feet	
6	OATo/OATi	Flight Data	°Celsius	
7	ta	(6) in °Celsius	°Celsius	
8	Ta	273.16 + (7)	°Kelvin	
9	CATi/CATi	Flight Data	°Celsius	Not recorded
10	t cat	(9) in °Celsius	°Celsius	Not recorded
11	No	Flight Data	Revolutions per Minute (RPM)	
12	Ni	Instrument Calibration	Revolutions per Minute (RPM)	
13	MP obs	Flight Data	Inches Mercury (in. Hg.)	
14	MP ind	Instrument Calibration	Inches Mercury (in. Hg.)	
15	Dry/Wet Psy	Flight Data	N/D	Not recorded
16	Δ MP	Psyc. Chart	Inches Mercury (in. Hg.)	Not recorded
17	MP eff	(14)-(16)	Inches Mercury (in. Hg.)	Not recorded
18	Ts at hpi	Altitude Charts	°Kelvin	
19	Tcat	273.16 + (10)	°Kelvin	Not recorded
20	Ts/Tcat	(18)/(19)	N/D	
21	(Ts/Tcat)^.5	(20)^.5	N/D	
22	HP alt.	Engine Chart	Horsepower	
23	HP temp. cor.	(22)*(21)	Horsepower	
24	δ at hpi	Altitude Charts	N/D	
25	θ	(8)/288.16	N/D	
26	σ = δ/θ	(24)/(25)	N/D	
27	(σ)^.5	(26)^.5	N/D	
28	Wt	Flight Data	Pounds (lbs.)	
29	Ws	Aircraft Manual	Pounds (lbs.)	
30	Wt/Ws	(28)/(29)	N/D	
31	(Wt/Ws)^.5	(30)^.5	N/D	
32	(Wt/Ws)^1.5	(30)^1.5	N/D	
33	PIW	(23)*(27)/(32)	Horsepower	
34	VIW	(3)/(31)	Knots	
35	NIW	(12)*(27)/ (31)	Revolutions per Minute (RPM)	
36	R/C	Flight Data	Feet per Minute (FPM)	
37	R/C temp. cor.	(36)*(8)/(18)	Feet per Minute (FPM)	
38	CIW	(37)*(27)/(31)	Feet per Minute (FPM)	

Figure A.1. PIW versus CIW Data Reduction Method.

No.	Quantity	Reference	Units
39	Altitude	Arbitrary	Feet
40	(σ)^.5	Altitude Tables at (39)	N/D
41	MP at (39)	MP vs. hpi plot	Inches Mercury (in. Hg.)
42	W	Arbitrary	Pounds (lbs.)
43	W/Ws	(41)/(42)	N/D
44	(W/Ws)^.5	(43)^.5	N/D
45	(W/Ws)^1.5	(43)^1.5	N/D
46	BHP std. Day	Engine Chart	Horsepower
47	PIW	(46)*(40)/(45)	Horsepower
48	CIW	PIW vs. CIW plot	Feet per Minute (FPM)
49	R/C	(48)*(44)/(40)	Feet per Minute (FPM)

Figure A.2. PIW versus CIW Data Reduction Expansion Calculation – Standard Day.

No	Symbol	Reference	Units
1	Vio	Flight Data	MPH
2	Vc	Ins. & Pos. Calibration	MPH
3	Hp	Flight Data	Feet
4	OAT	Flight Data	°F
5	$\sqrt{\sigma}$	$\sqrt{\delta/\theta}$	N/D
6	He	Equivalent Altitude Chart	Feet
7	T	(4) + 460	°F
8	Ts	Std. Temp. at (3)	°F
9	T/Ts	(7) / (8)	N/D
10	dh/dt (R/C observed)	Flight Data	Feet per Minute
11	Ct	(9) * (10)	Feet per Minute
12	Wt	Flight Data	Pounds
13	Wt/Ws	(12) / Ws	N/D
14	Ct (Wt/Ws)	(11) * (13)	Feet per Minute
15	(Wt/Ws)^2	(13)^2	N/D
16	1-(Wt/Ws)^2	1 - (15)	N/D
17	K / Vc $\sqrt{\sigma}$	K / (2) * (5)	N/D
18	Induced Drag Correction	(16) * (17)	Feet per Minute
19	R/C at Std. Alt. & Weight (Ws)	(14) - (18)	Feet per Minute

Figure A.3. Equivalent Altitude Data Reduction Method.

No.	Symbol	Rerference	Units
1	Hp	Instrument Calibration	Feet
2	OAT	Flight Data	°F
3	σ	δ/θ	N/D
4	Hd	Hd = 145539[1-(√σ)^.4699	Feet
5	Ts at Hp	°F + 460	°F
6	IAS	Flight Data	knots
7	CAS	Inst. And Pos. Calibration	knots
8	TAS	(7) / √(3)	knots
9	R/C observed	Flight Data	Feet per Minute
10	T/Ts	[(2) + 460] / (5)	N/D
11	Actual R/C	(9) * (10)	Feet per Minute
12	Wt	Flight Data	Pounds
13	Δ R/C Δ W	(11) * [1- (12) / Wc]	Feet per Minute
14	q πe b^2	(7)^2 πe b^2 / 295	N/D
15	Δ Di	[Wc^2 - (12)^2] / (14)	N/D
16	Δ R/C Δ Di	[101.27 * (15) * (8)] / Ws	Feet per Minute
17	Calibrated RPM	Flight Data	Revolutions per Minute
18	Calibrated MP	Flight Data	Inches Mercury
19	Inlet Air Temperature	Flight Data	°F
20	BHP temp. cor. At Hp	BHP engine chart * temp. ratio, at HP	Horsepower
21	BHP temp. cor. At Hd	BHP engine chart * temp. ratio, at HD	Horsepower
22	ηp (propeller efficiency)	Propeller manufacturer , or estimated (.83)	N/D
23	Δ THP	(22) * [(21)-(20)]	N/D
24	Δ R/C Δ p	[(23) * 33,000] / Wc	Feet per Minute
25	R/C std.	(11) - (13) - (16) + (24)	Feet per Minute

Figure A.4. Density Altitude Data Reduction Method.

APPENDIX B

Instrument Calibrations

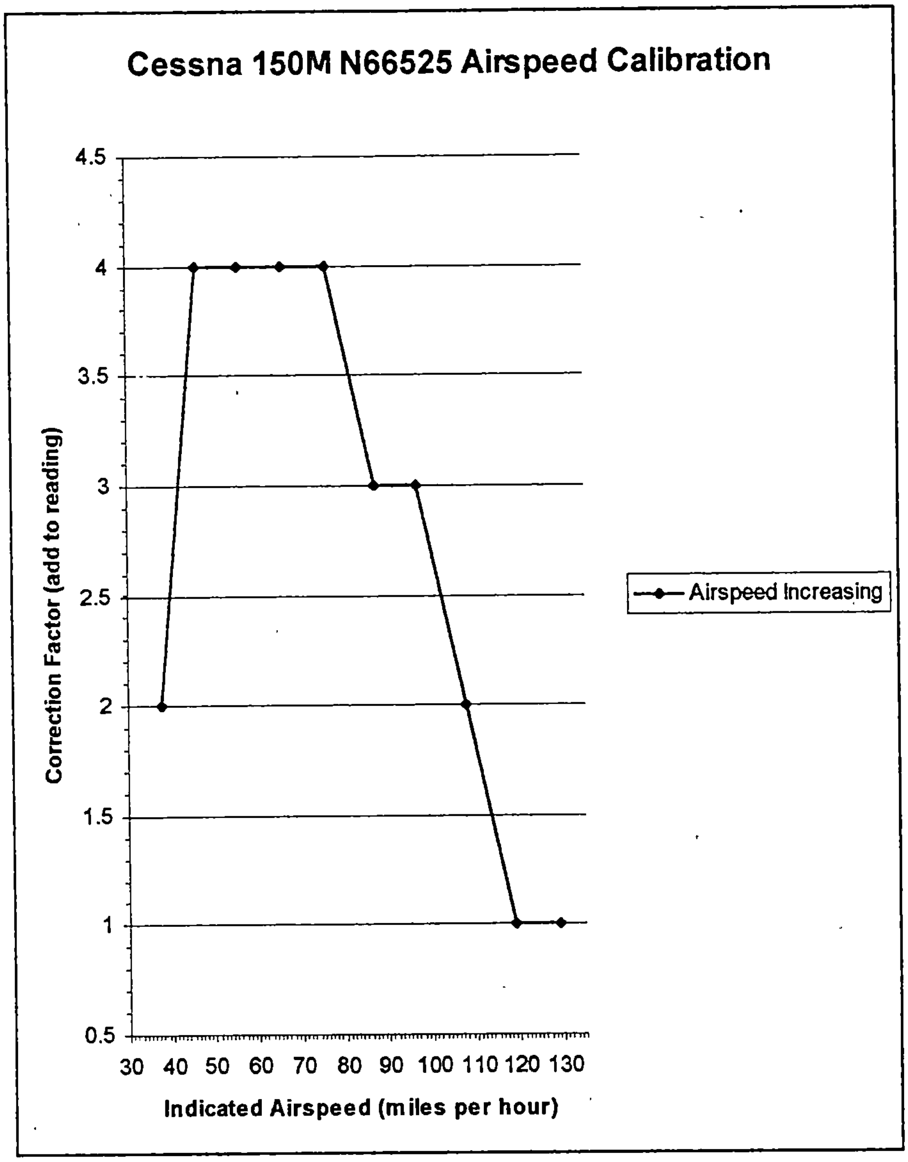

Figure B.1. Cessna 150M N66525 Airspeed Calibration.

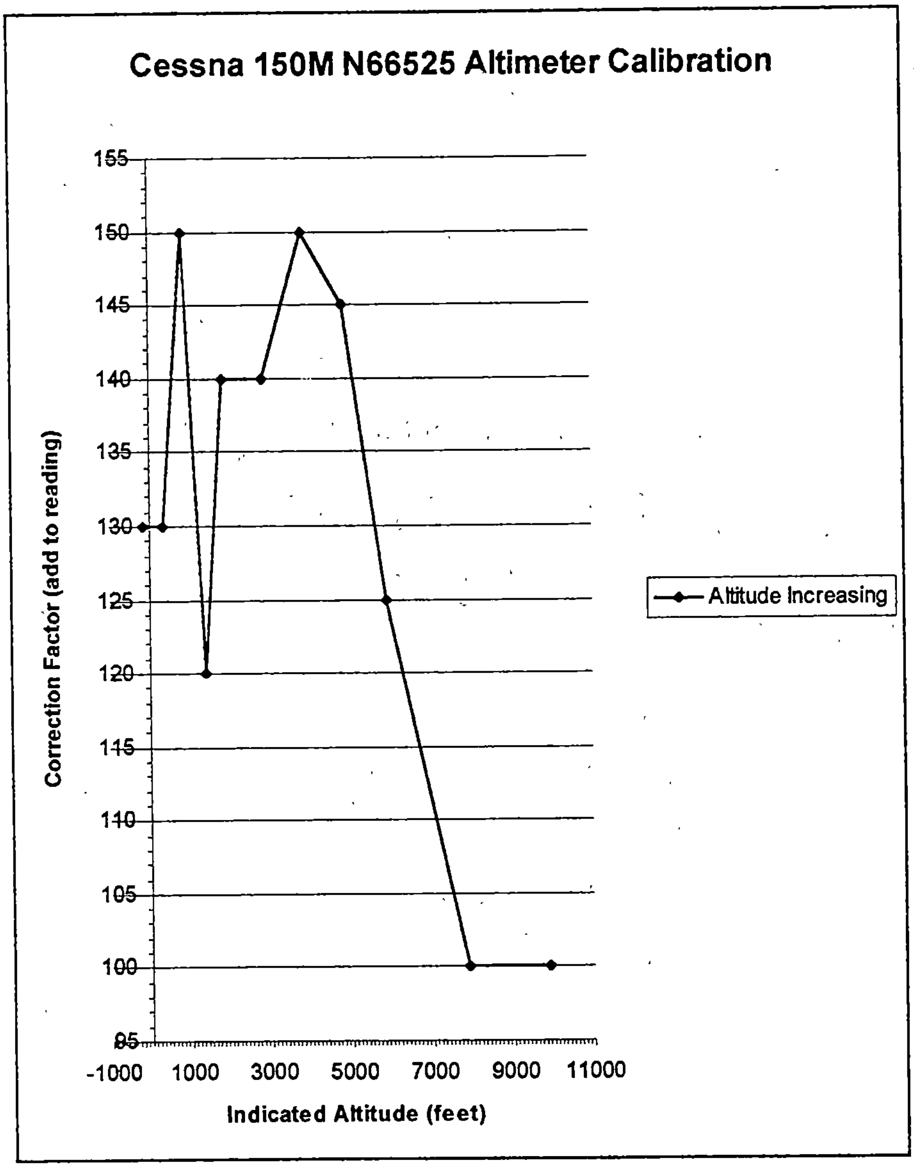

Figure B.2. Cessna 150M N66525 Altimeter Calibration.

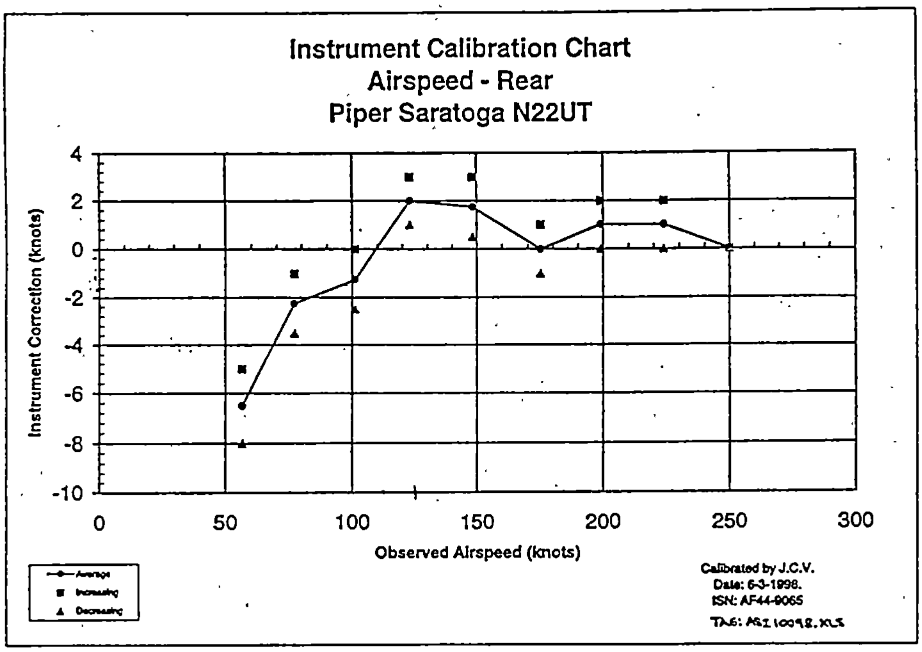

Figure B.3. Piper Saratoga N22UT Airspeed Calibration.

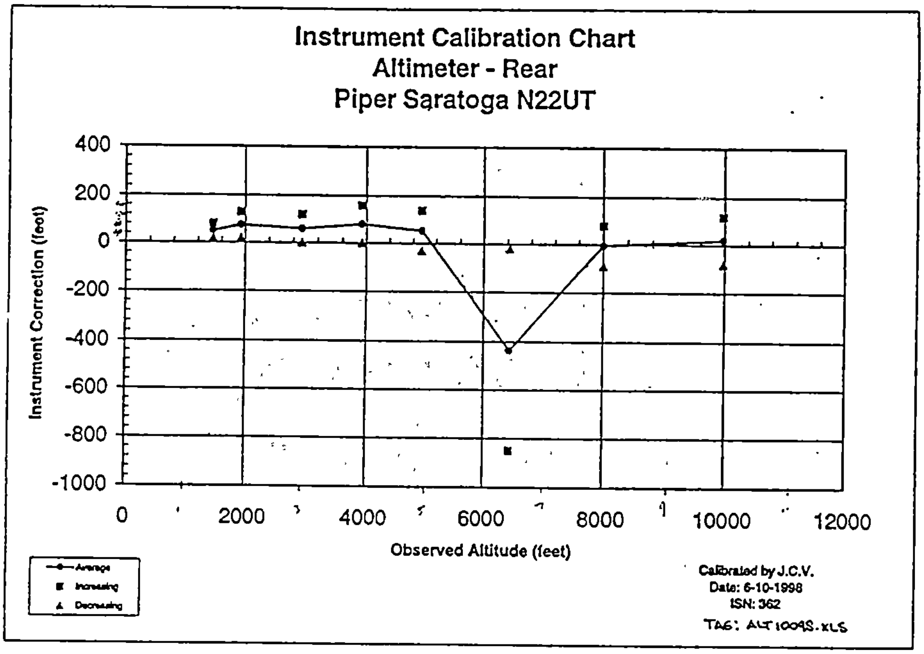

Figure B.4. Piper Saratoga N22UT Altimeter Calibration.

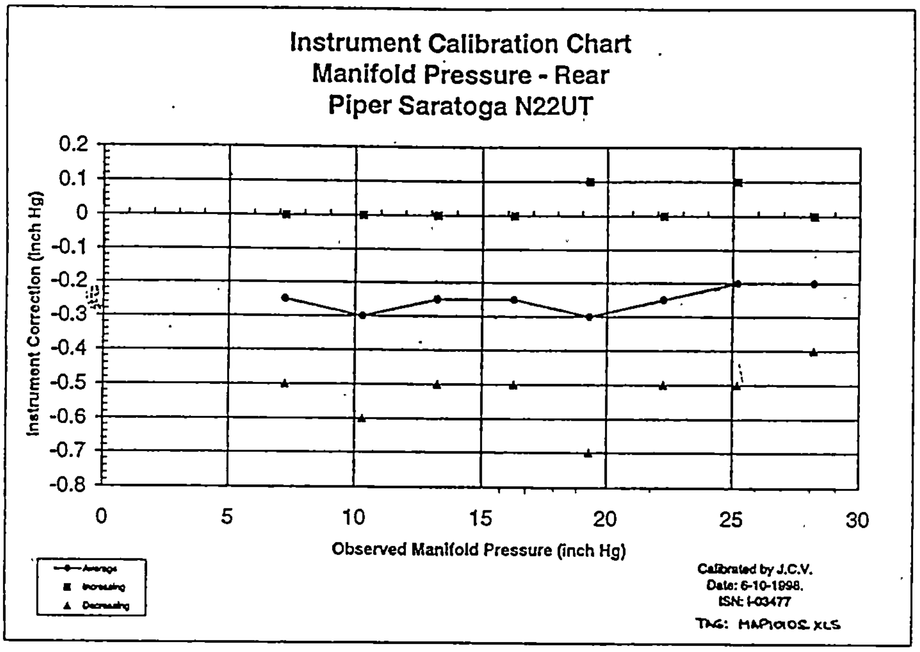

Figure B.5.

Piper Saratoga N22UT and Cessna 150M N66525 Manifold Pressure Calibration.

APPENDIX C

Airspeed Position Error Calibrations

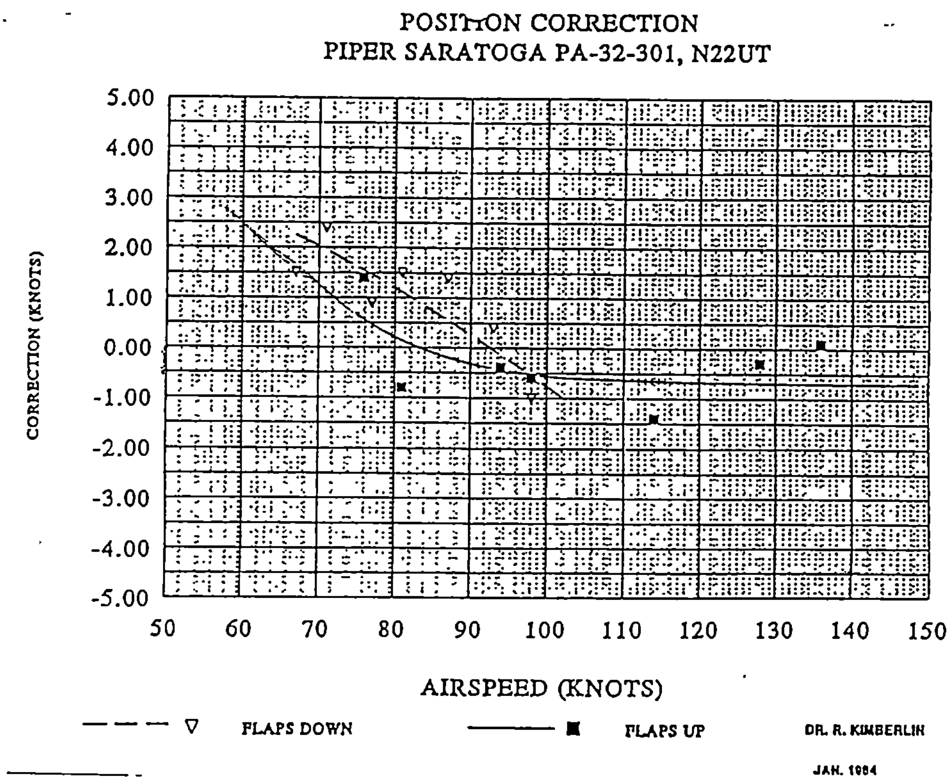

Figure C.1. Piper Saratoga N22UT Airspeed Position Error Calibrations.

Cessna 150 Airspeed Calibration Speed Course 2.35 Nautical Miles	N66525							3/2/99
	70 MPH		80 MPH		90 MPH		100 MPH	
	1	2	1	2	1	2	1	2
Elapsed Time	2.78	1.8	2.58	1.65	2.28	1.5	2.02	1.45
Rpm	2100	2000	2050	2100	2100	2250	2300	2350
Pressure Altitude (ft.)	1650	1675	1525	1550	1600	1525	1550	1500
Hpo (calibrated) ft.	1777	1802	1645	1672	1725	1645	1672	1620
OAT (C)	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
IAS (knots)	62.6	61.7	69.5	72.13	77.3	79.1	86.9	87.8
IAS (calibrated) knots	66	65.2	72.65	75.1	79.95	81.69	89.25	90.03
delta ai (altitude tables)	0.9376	0.9366	0.9419	0.9409	0.9392	0.9419	0.9409	0.9428
theta ai	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941	0.9941
sigma ai	0.9432	0.9423	0.9475	0.9465	0.9448	0.9475	0.9465	0.9484
square root sigma	0.9712	0.9707	0.9734	0.9729	0.972	0.9734	0.9729	0.9739
ground speed (knots)	50.72	78.3	54.7	85.5	61.8	94	69.8	97.24
gs square root sigma	49.3	76.01	53.24	83.2	60.1	91.5	67.91	94.7
gs sq. rt. Sigma avg.	62.66	62.66	68.22	68.22	75.8	75.8	81.31	81.31
Vi average (knots)	65.6	65.6	73.88	73.88	80.82	80.82	89.64	89.64
delta Vpc	-2.94	-2.94	-5.66	-5.66	-5.02	-5.02	-8.33	-8.33
Vc (knots)	63.06	62.26	66.99	69.44	74.93	76.67	80.92	81.7
V (knots)	64.93	64.14	68.8	71.4	77.1	78.8	83.2	83.89
ground speed (knots)	50.72	78.3	54.7	85.5	61.8	94	69.8	97.24
wind	14.21	-14.16	14.1	-14.1	15.3	-15.2	13.4	-13.35

Figure C.2. Cessna 150M N66525 Airspeed Position Error Values.

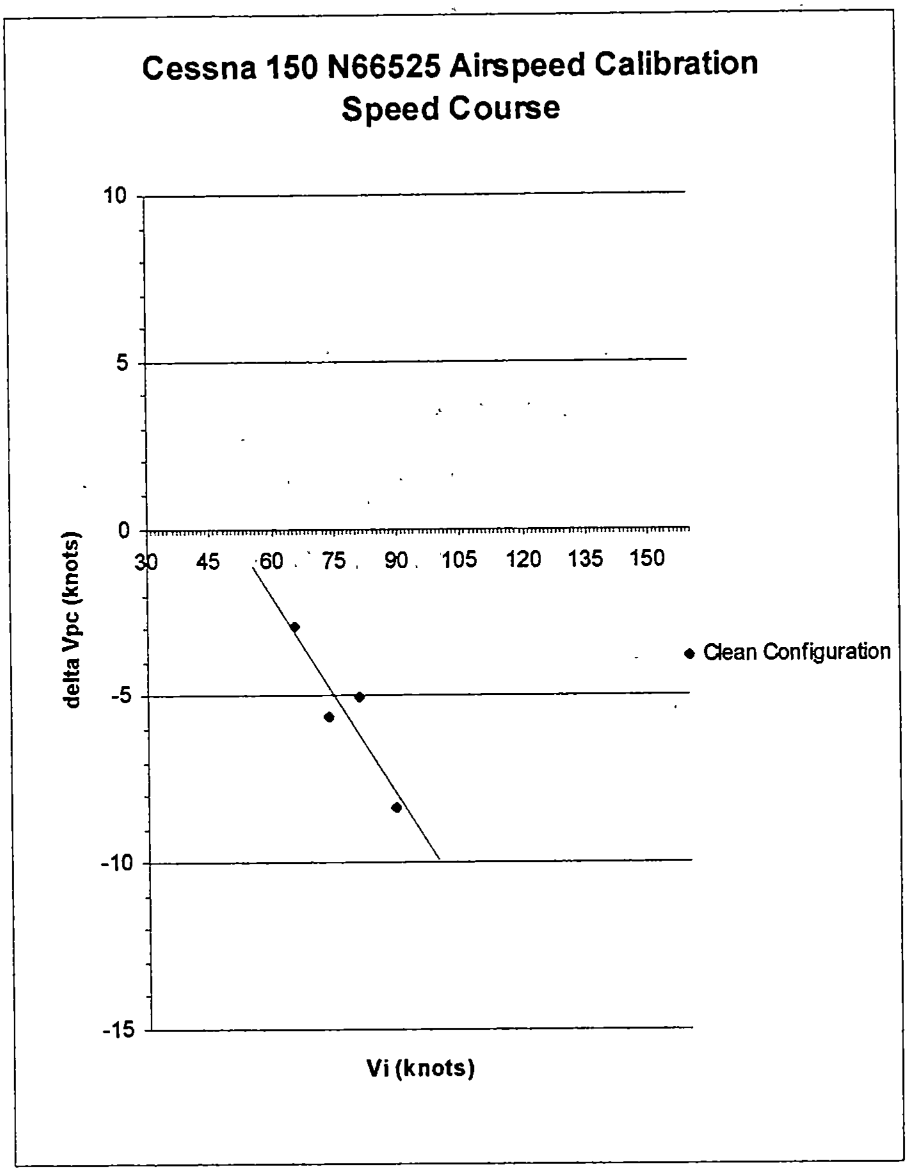

Figure C.3. Cessna 150M N66525 Airspeed Position Error Calibrations.

APPENDIX D

Aircraft Weight and Balance

Station	Weight (lbs.)	Arm (in.)	Moment (in.-lbs.)
Basic Empty Weight	2160.54	81.82	176766.46
Pilot & Front Passenger	310	85.5	26505
Center Seat Passengers (2)			
Forward Facing	0	118.1	0
Aft Facing	0	119.1	0
Rear Seat Passengers (2)	345	157.6	54372
Jump Seat Passengers (2)	0	118.1	0
Fuel (102 Gallon Maximum)			
Left	150	94	14100
Right	150	94	14100
Fore Baggage (100 lb limit)	0	42	0
Aft Baggage (100 lb limit)	0	178.7	0
TOTALS	3115.54		285843.46
Center of Gravity Location (inches aft datum)	91.7 inches		
Center of Gravity Location (% mean aerdynamic chord)	21.4 % MAC		

Figure D.1. Piper Saratoga N22UT Flight Test Weight and Balance.

Station	Weight (lbs.)	Moment (in. lbs.)/1000
Basic Empty Weight	1122	37.77
Fuel	114	4.8
Front Seats	305	11.9
Baggage Area 1 (120 lbs. maximum)	0	0
Baggage Area 2 (40 lbs. maximum)	0	0
TOTALS	1541	54.47
Center of Gravity Location (inches aft datum)	35.35 inches	

Figure D.2. Cessna 150M N66525 Flight Test Weight and Balance.

APPENDIX E

Pressure Altitude versus Time Graphs

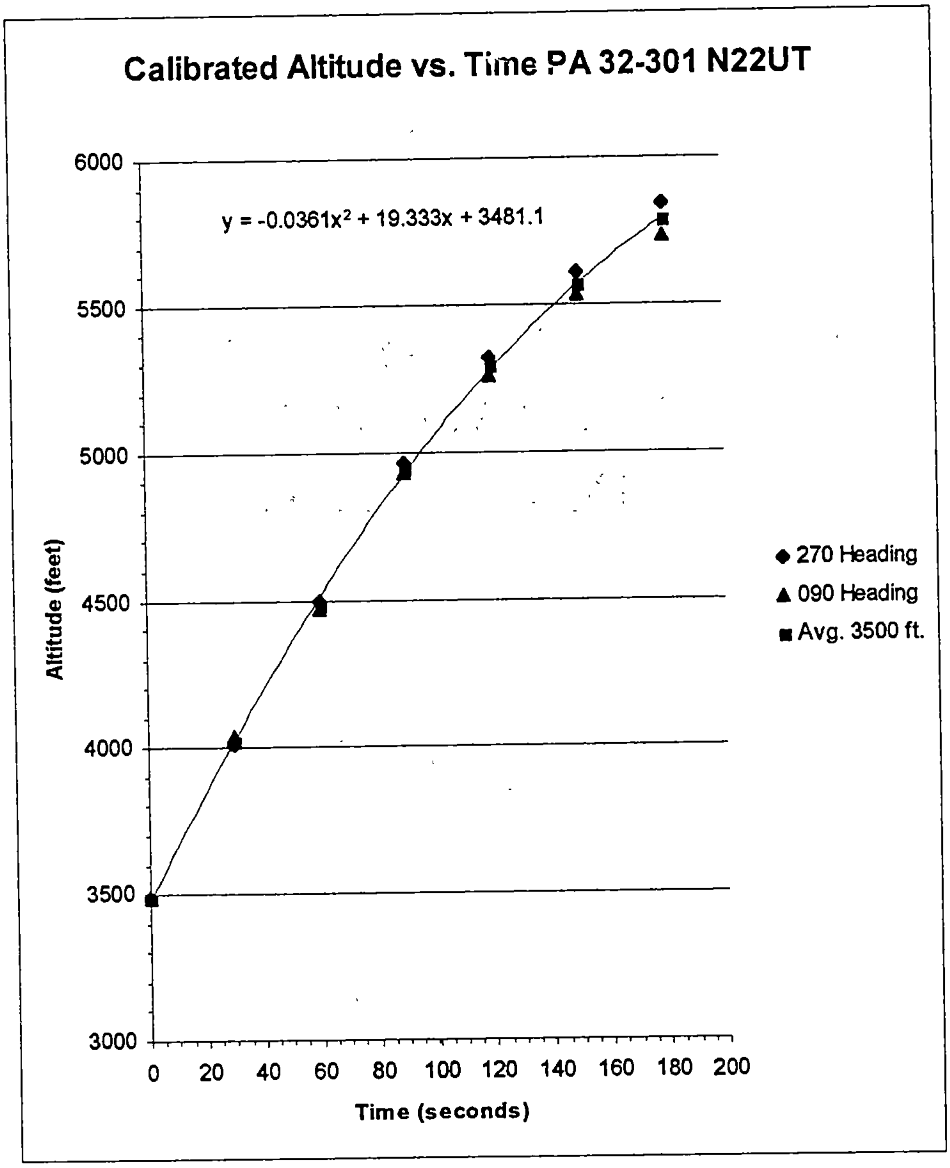

Figure E.1. Piper Saratoga N22UT Calibrated Altitude versus Time Graph 3,500 feet.

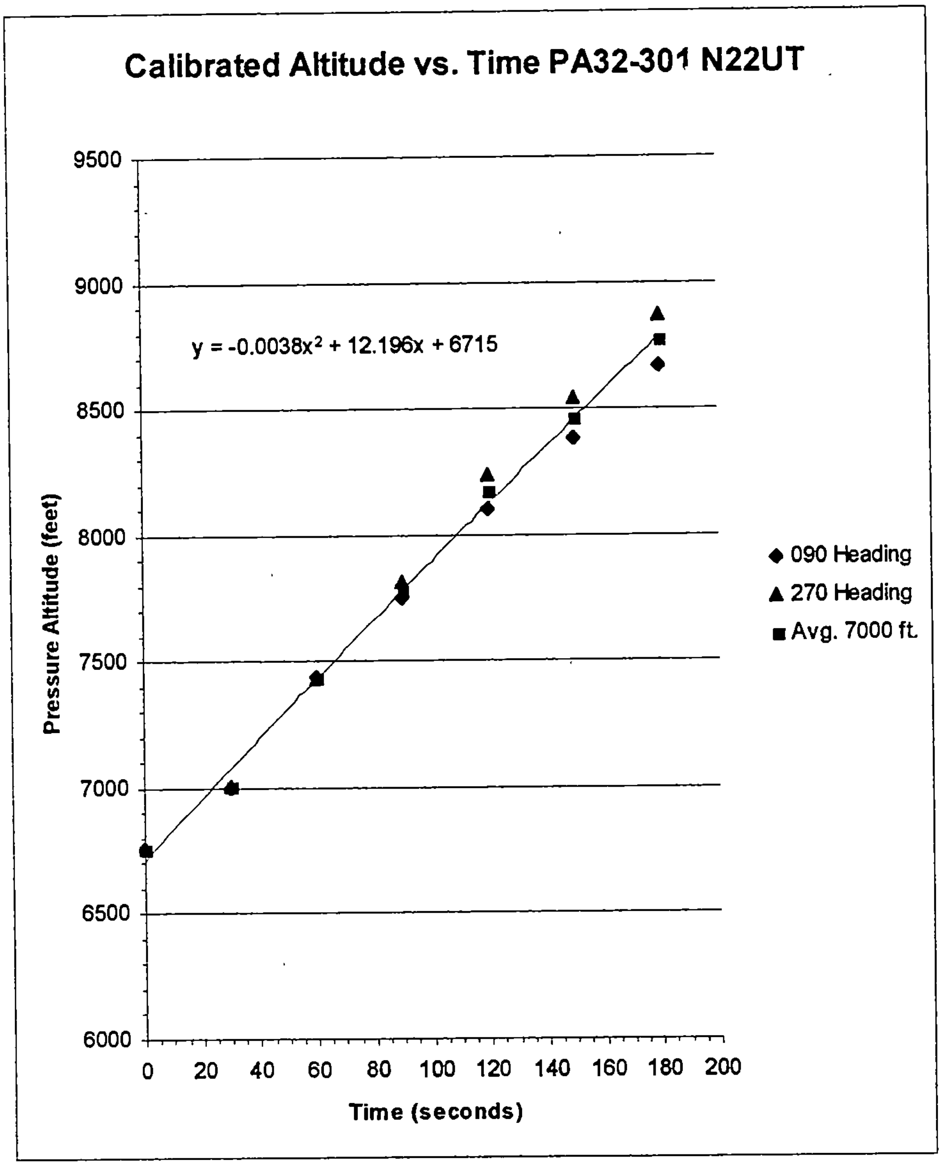

Figure E.2. Piper Saratoga N22UT Calibrated Altitude versus Time Graph 7,000 feet.

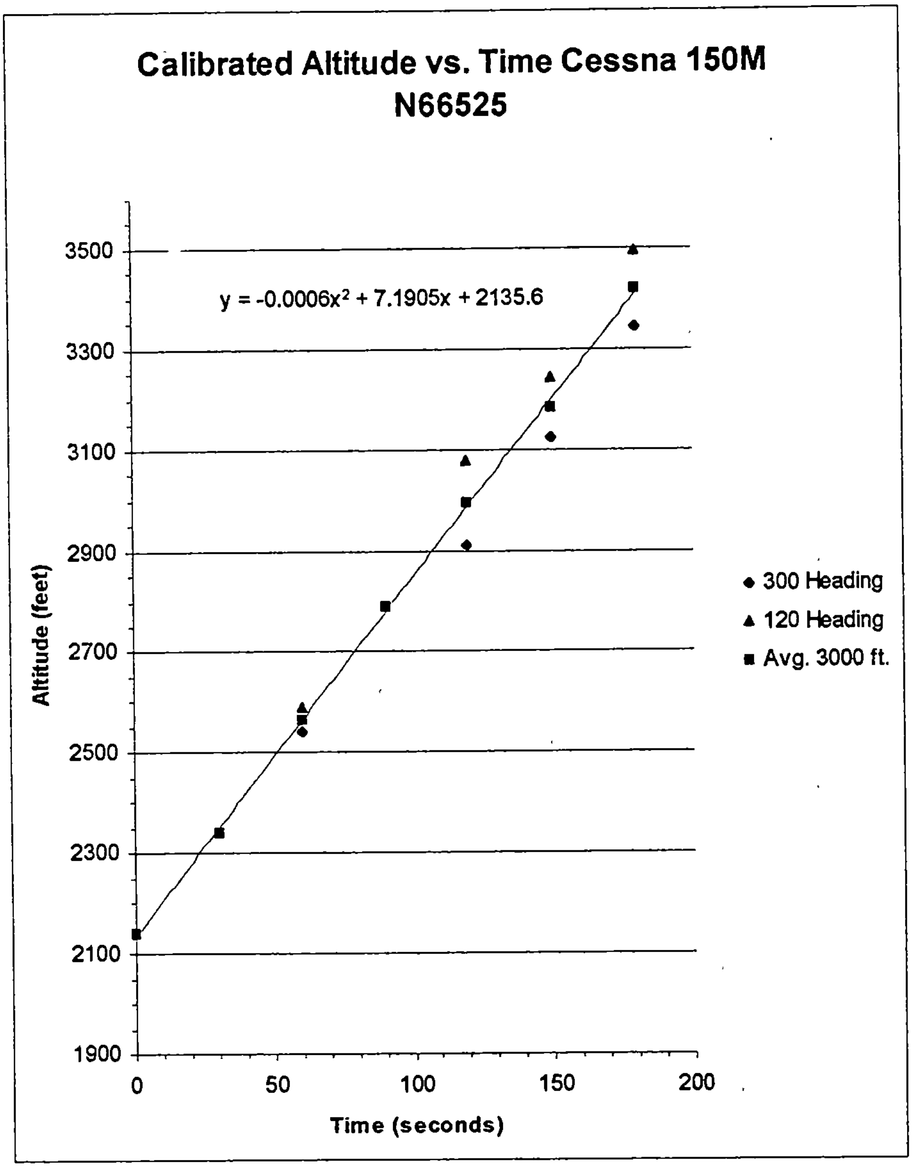

Figure E.3. Cessna 150M N66525 Calibrated Altitude versus Time 3,000 feet.

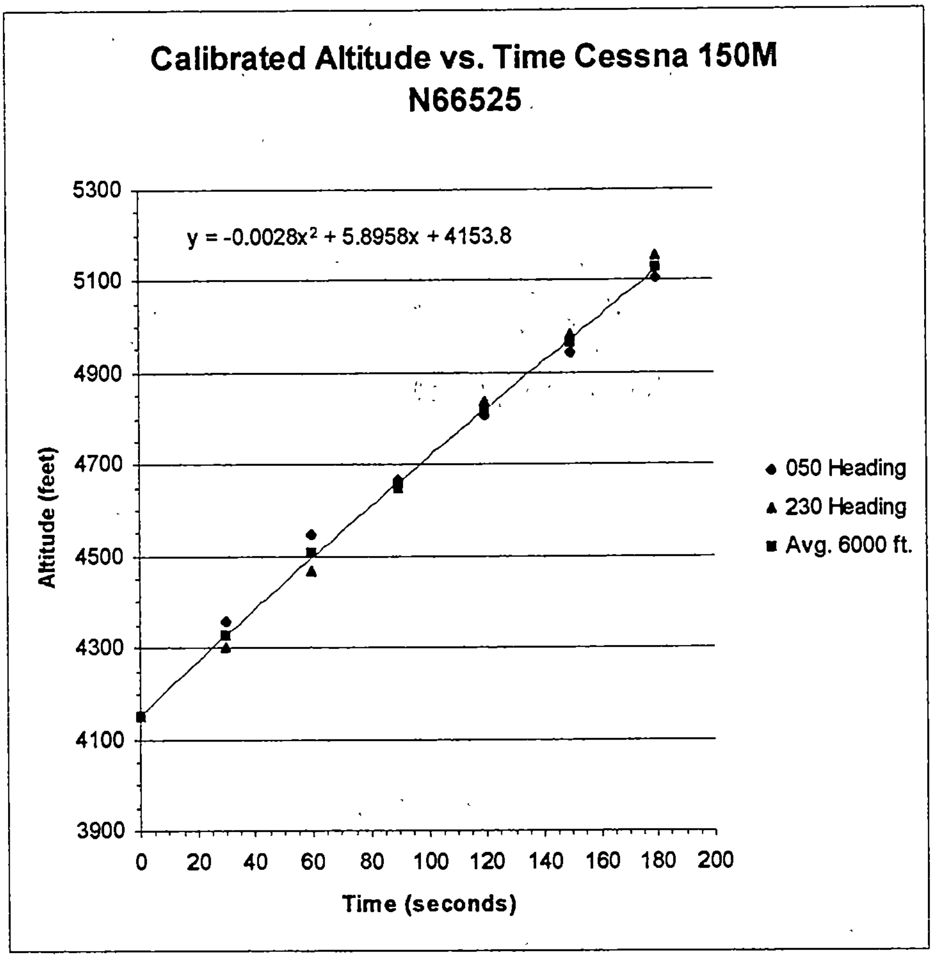

Figure E.4. Cessna 150M N66525 Calibrated Altitude versus Time 6,000 feet.

APPENDIX F

Engine Horsepower Charts

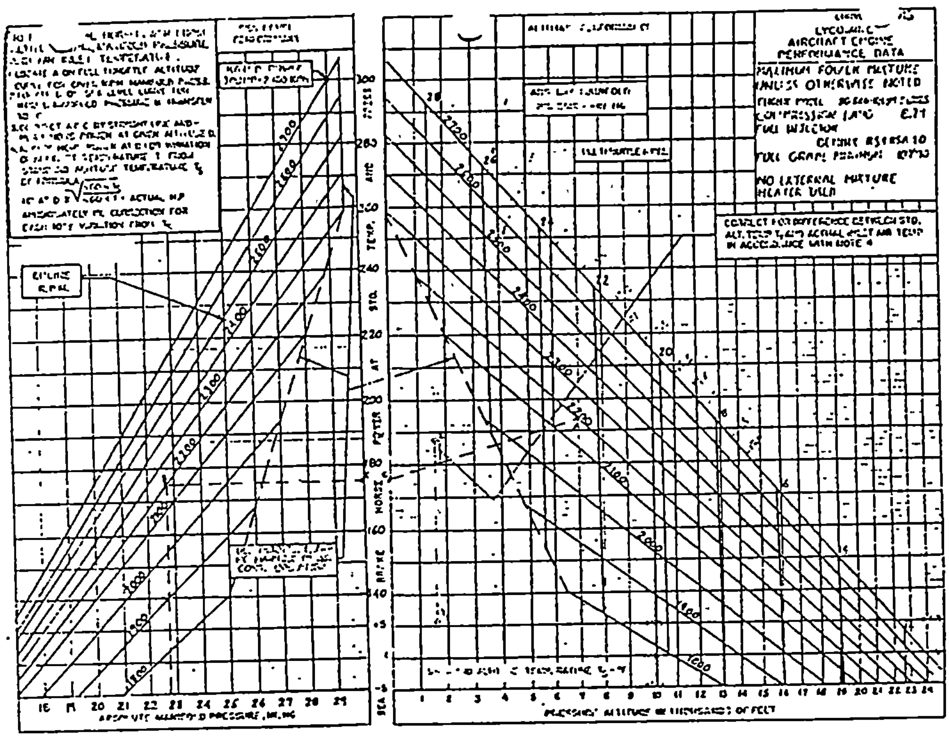

Figure F.1. Piper Saratoga Engine Horsepower Chart Lycoming IO-540-K1G5.

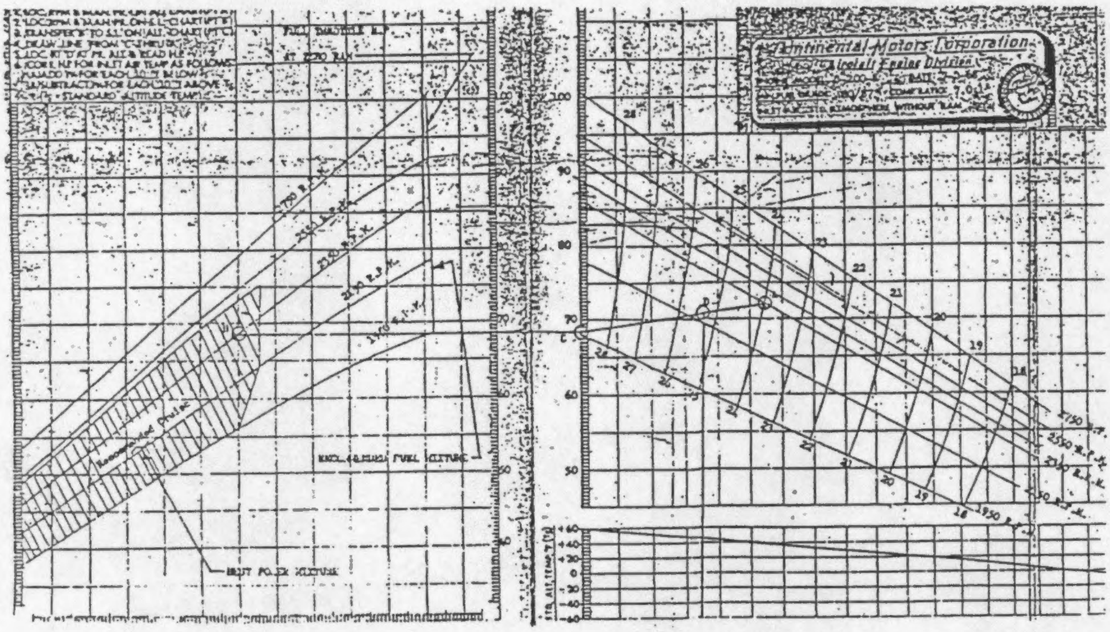

Figure F.2. Cessna 150M N66525 Engine Horsepower Chart Continental O-200-A.

APPENDIX G

Manifold Pressure Graphs

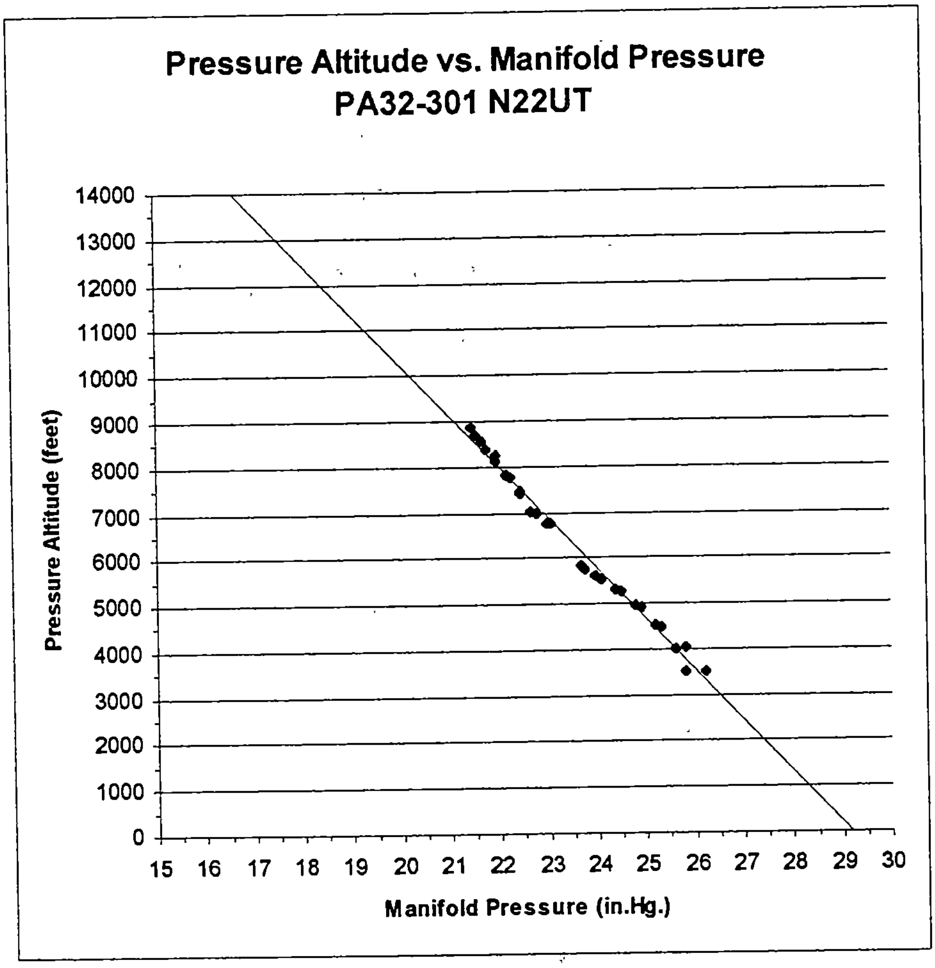

Figure G.1. Piper Saratoga N22UT Manifold Pressure Chart.

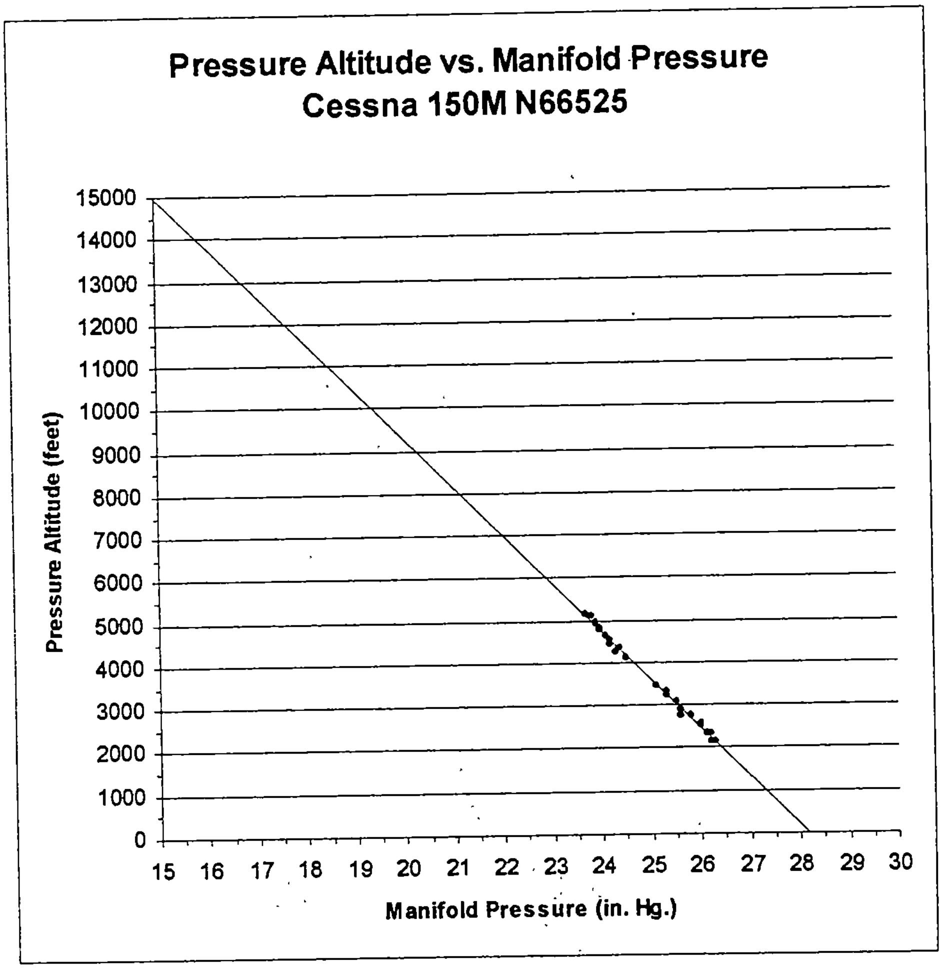

Figure G.2. Cessna 150M N66525 Manifold Pressure Chart.

APPENDIX H

PIW versus CIW Graphs

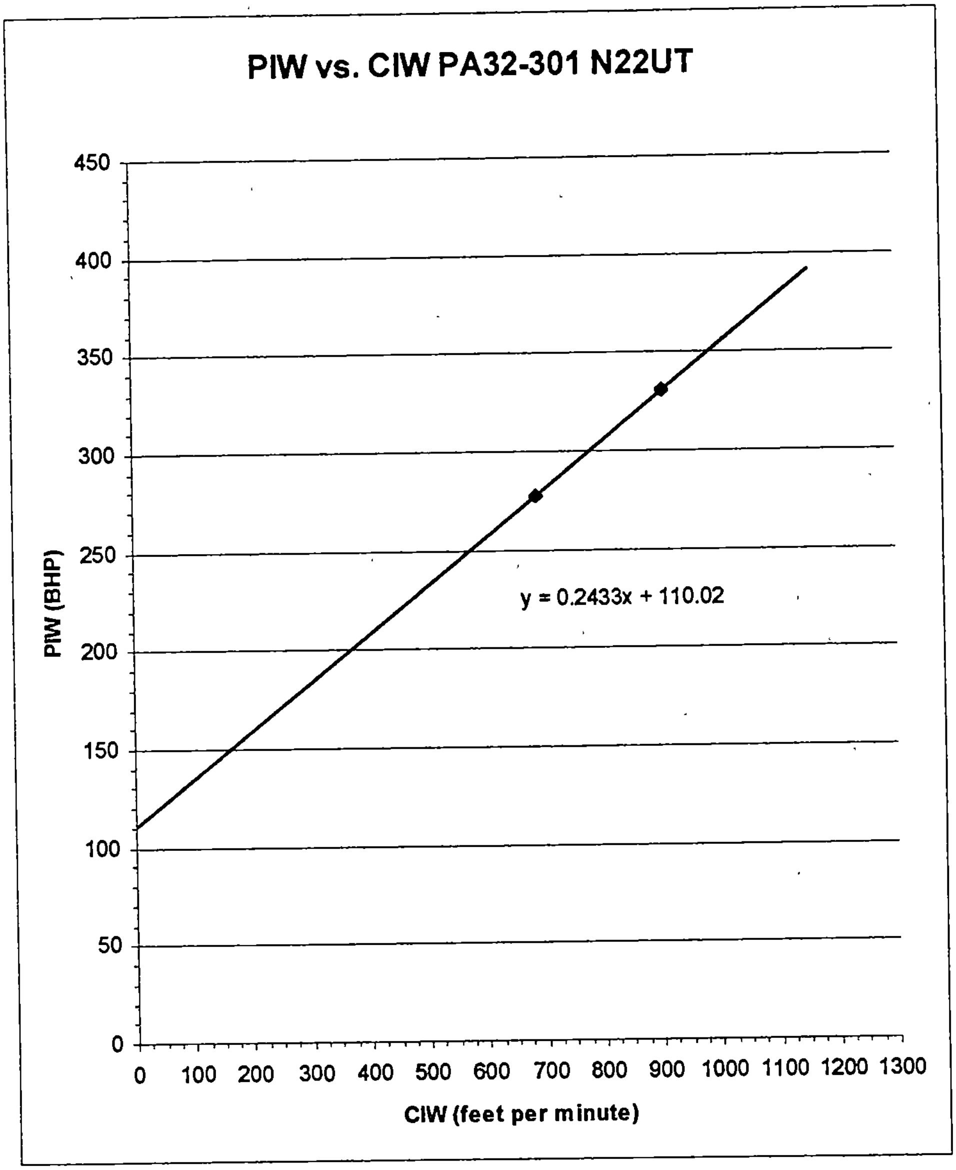

Figure H.1. Piper Saratoga N22UT PIW versus CIW Graph.

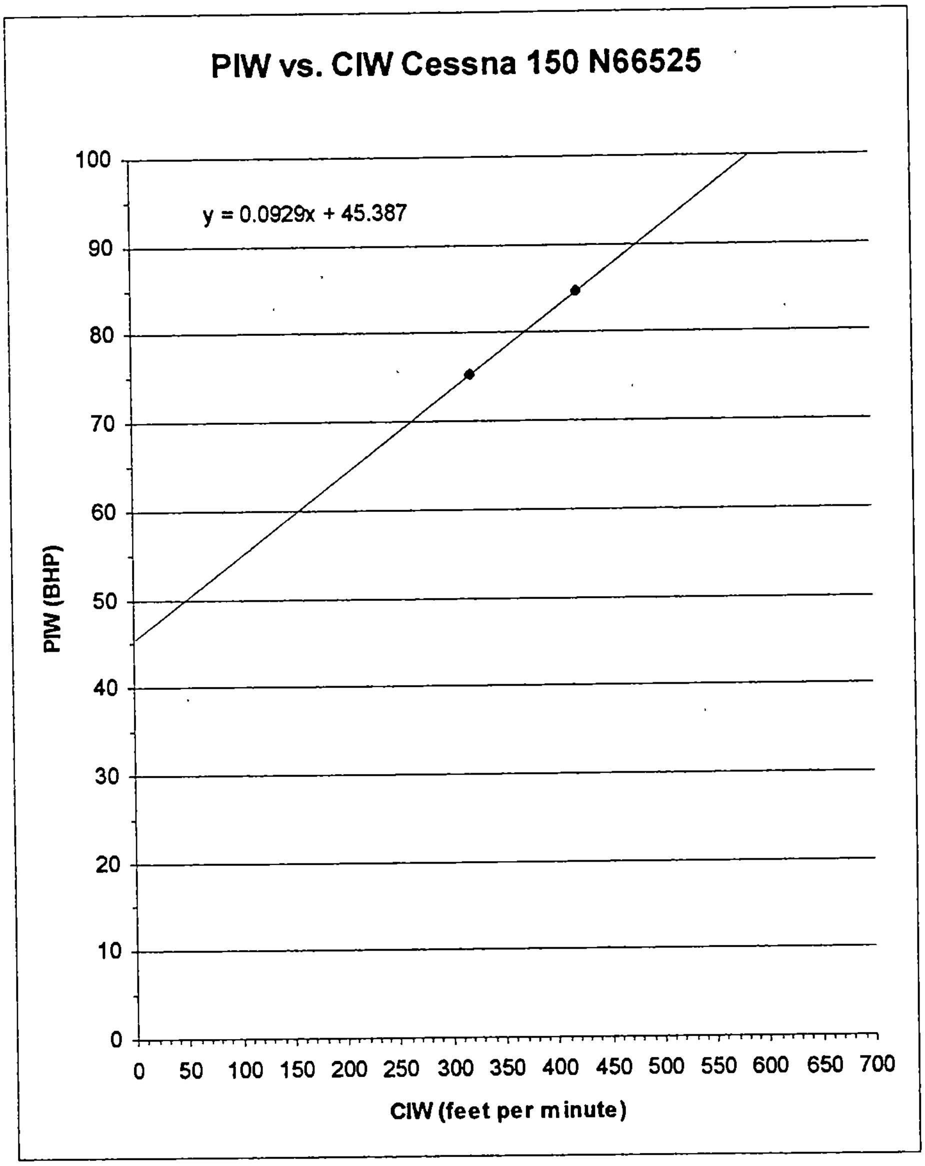

Figure H.2. Cessna 150M PIW versus CIW Graph.

APPENDIX I

Pressure Altitude versus Rate of Climb Graphs

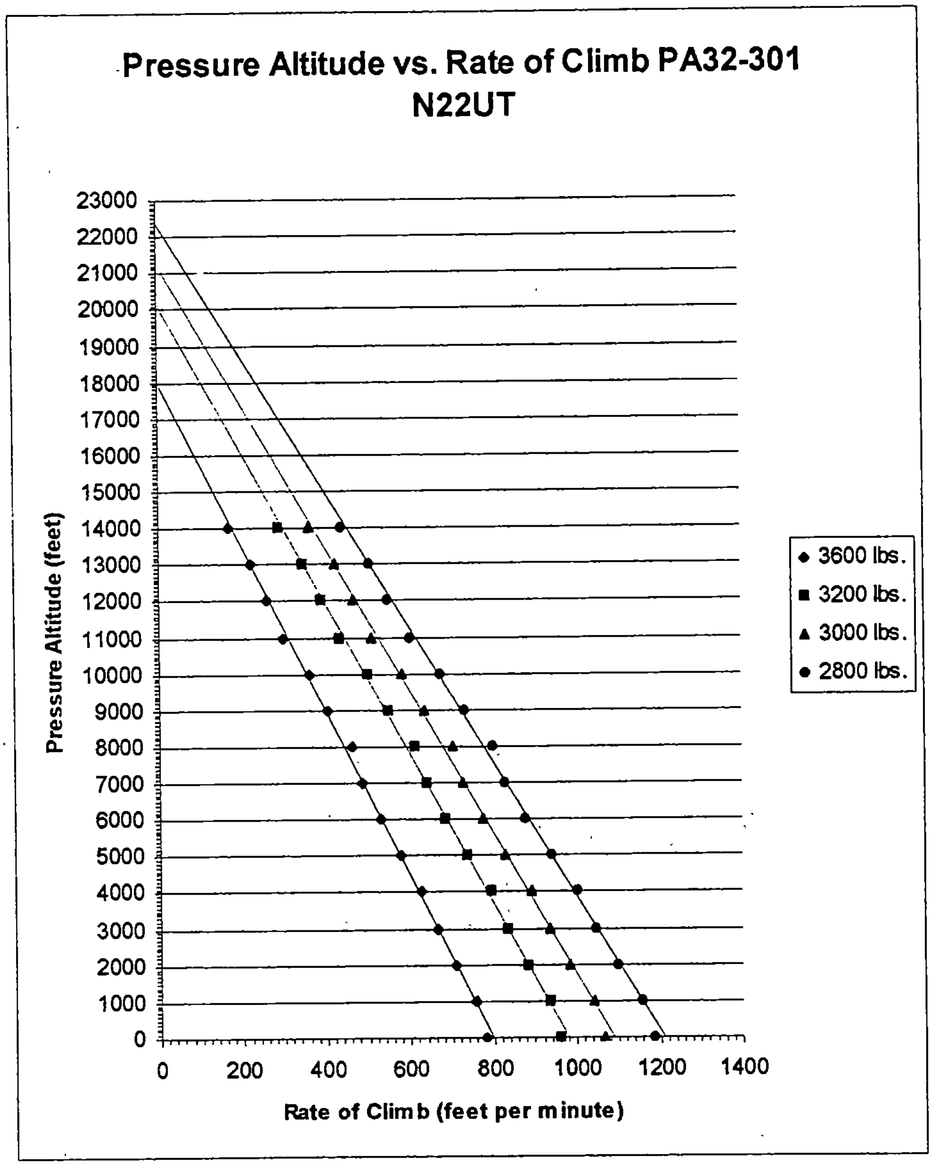

Figure I.1. Piper Saratoga N22UT Pressure Altitude versus Rate of Climb Graph.

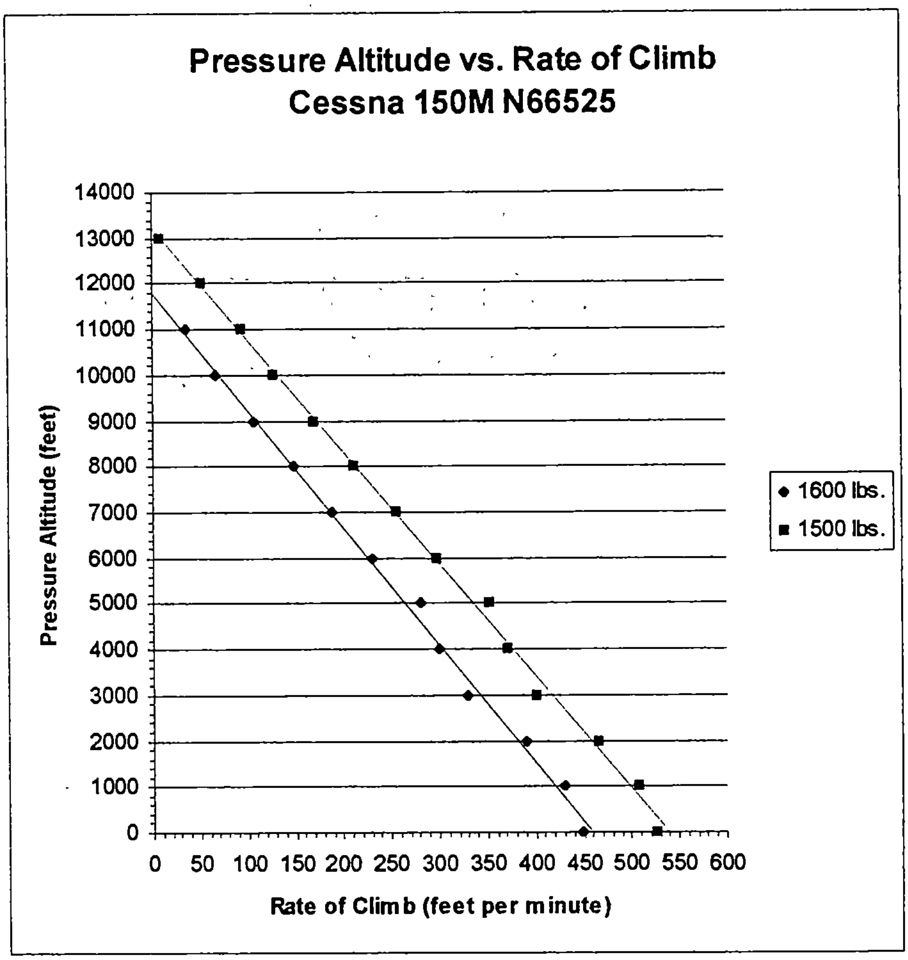

Figure I.2. Cessna 150M N66525 Pressure Altitude versus Rate of Climb Graph.

APPENDIX J

Equivalent Altitude Formula and Chart

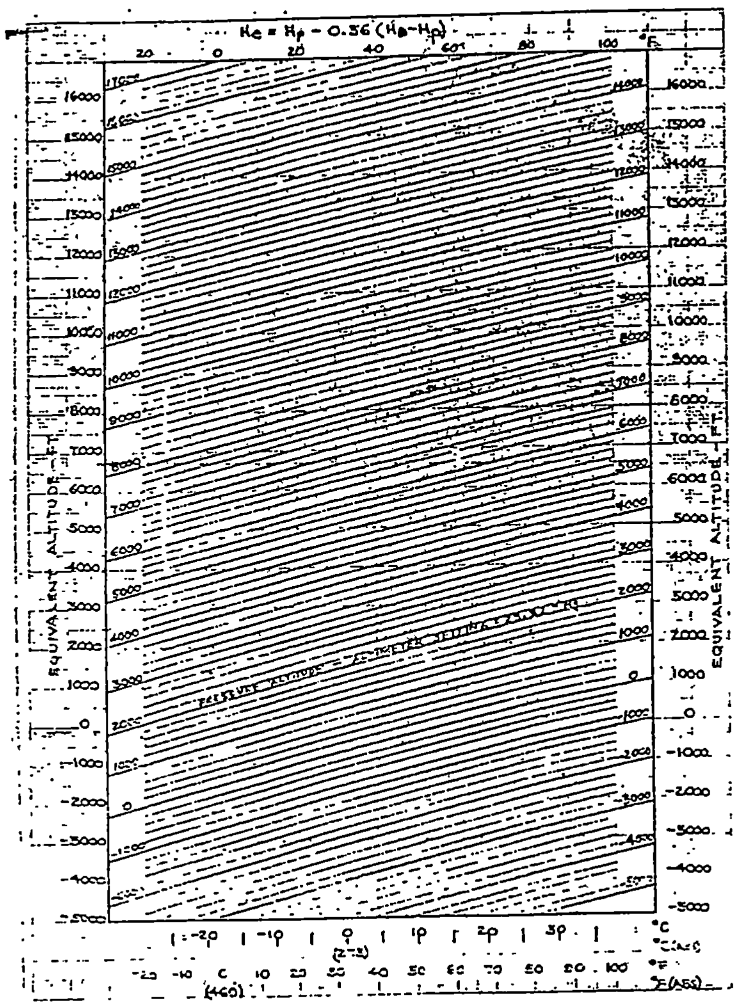

Figure J.1. Equivalent Altitude Formula and Chart.

APPENDIX K

Equivalent Altitude versus Rate of Climb Graph

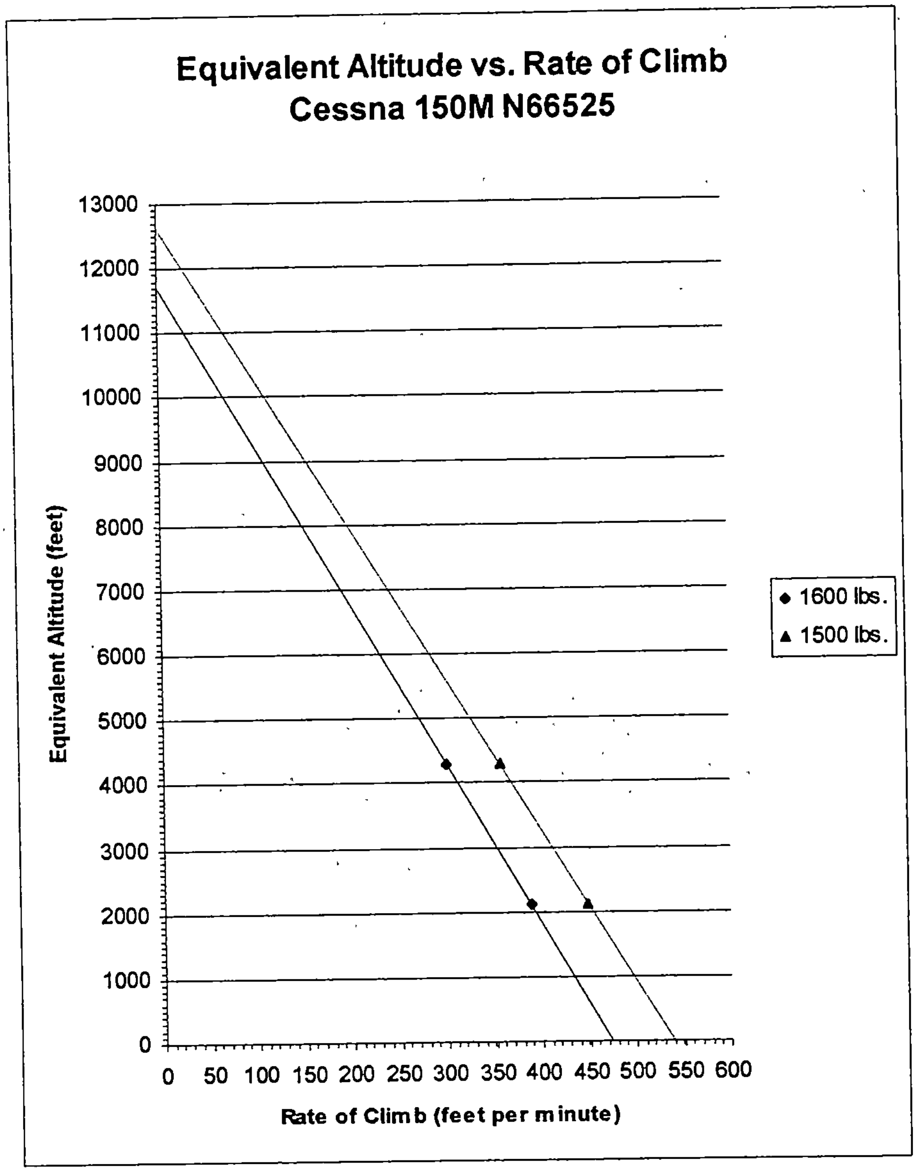

Figure K.1. Cessna 150M N66525 Equivalent Altitude versus Rate of Climb Graph.

APPENDIX L

Density Altitude versus Rate of Climb Graph

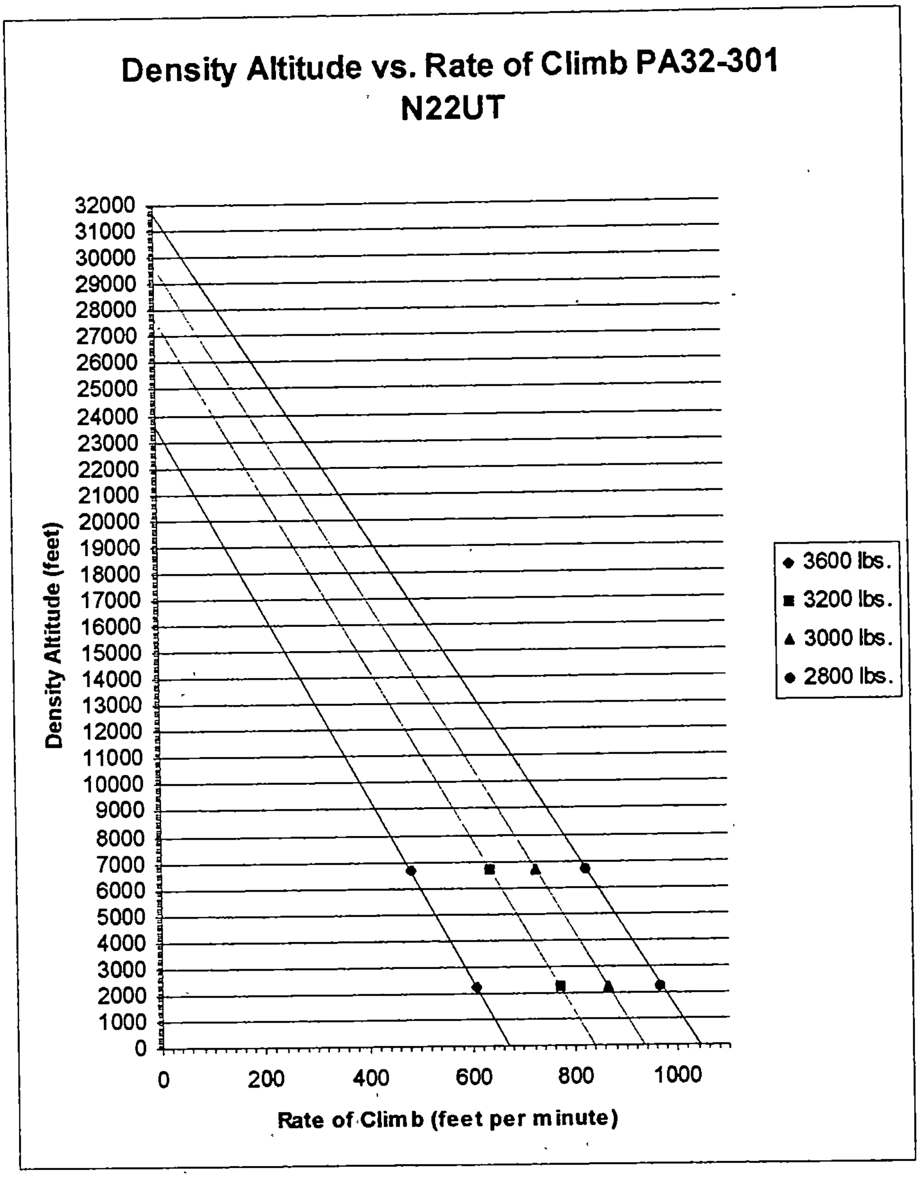

Figure L.1. Piper Saratoga N22UT

Density Altitude versus Rate of Climb Graph.

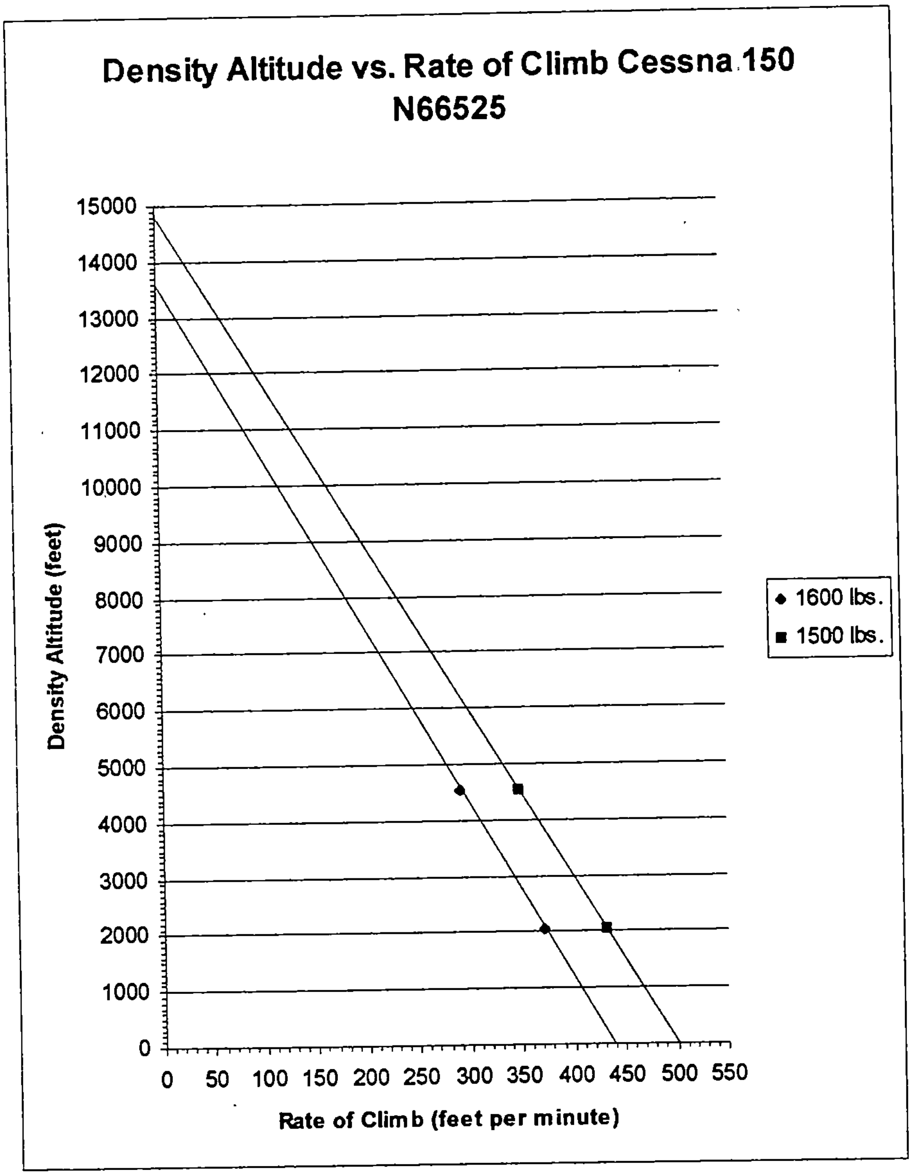

Figure L.2. Cessna 150M N66525

Density Altitude versus Rate of Climb Graph.

APPENDIX M

PIW versus CIW Data Reduction Results

No	Quantity	Reference	Units	1	2
1	Vo	Fl. Data	Knots	92.6	92.4
2	Vi	Inst. Cal.	Knots	92.2	91.2
3	Vc	Pos. Cal.	Knots	91	89.8
4	hpo	Fl. Data	Feet	3400	6890
5	hpi	Inst. Cal.	Feet	3490	6760
6	OATo/OATi	Flt & Cal.	C	-2.2	0.6
7	ta	(6) in C	C	-2.2	0.6
8	Ta	273.16 + (7)	K	270.96	273.76
11	No	Fl. Data	RPM	2700	2700
12	Ni	Inst. Cal.	RPM	2700	2700
13	Mpo	Fl. Data	In.Hg.	26.4	23.3
14	Mpi	Inst. Cal.	In.Hg.	26.2	23.06
18	Ts @ hpi	Chart	K	281.25	274.767
20	Ts/Tcat	(18)/(19)	N/D	1.03797	1.003678
21	Ts/Tcat^.5	(20)^.5	N/D	1.018808	1.0018373
22	HP alt.	Eng. Chart	HP	276	242
23	HP temp. cor.	(22)*(21)	HP	270.9048221	241.5561888
24	delta @ hpi	Chart	N/D	0.88012	0.77779
25	theta	(8)/288.16	N/D	0.940310938	0.950027762
26	sigma	(24)/(25)	N/D	0.935988261	0.81870239
27	sigma^.5	(26)^.5	N/D	0.96746473	0.9048215
28	Wt	Fl. Data	Lbs.	3083.74	3071.74
29	Ws	Arbitrary	Lbs.	3600	3600
30	Wt/Ws	(28)/(29)	N/D	0.8565944	0.8532611
31	Wt/Ws^.5	(30)^.5	N/D	0.9255236	0.92372127
32	Wt/Ws^1.5	(30)^1.5	N/D	0.79279799	0.7881753
33	PIW	(23)*(27)/(32)	HP	330.5897137	277.3053572
34	VIW	(3)/(31)	Knots	98.3227224	97.2154728
35	NIW	(12)*(27)/(31)	RPM	2822.353499	2644.756735
36	R/C	Fl. Data	FPM	900.06	704.4
37	R/C temp. cor.	(36)*(8)/(18)	FPM	867.1298048	701.818428
38	CIW	(37)*(27)/(31)	FPM	906.4247551	687.4588941

Figure M.1. Piper Saratoga N22UT PIW versus CIW Data Reduction Results.

No.	Quantity	Reference	Units						
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000	5000
	sigma	Chart @ (39)	N/D	1	0.971	0.9427	0.9151	0.888	0.8616
40	sigma^.5	Chart @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424	0.9283
41	MP @ 39	MP vs. hpi	In.Hg.	29.2	28.3	27.4	26.5	25.7	24.7
42	W	Arbitrary	Lbs.	3600	3600	3600	3600	3600	3600
43	W/Ws	(41)/(42)	N/D	1	1	1	1	1	1
44	W/Ws^.5	(43)^.5	N/D	1	1	1	1	1	1
45	W/Ws^1.5	(43)^1.5	N/D	1	1	1	1	1	1
46	BHP std. Day	Eng. Chart	HP	300	296	286	277	270	259
47	PIW	(46)*(40)/(45)	HP	300	291.678	277.71	264.98	254.448	240.43
48	CIW	Piw vs.Ciw	FPM	780.8467	746.644	689.21	636.9	593.621	536.004
49	R/C	(48)*(44)/(40)	FPM	780.8467	757.706	709.8	665.8	629.903	577.404
39	Altitude	Arbitrary	Feet	6000	7000	8000	9000	10000	11000
	sigma	Chart @ (39)	N/D	0.8358	0.8106	0.786	0.7619	0.7384	0.7155
40	sigma^.5	Chart @ (39)	N/D	0.9143	0.9004	0.8866	0.8729	0.8593	0.84587
41	MP @ 39	MP vs. hpi	In.Hg.	23.7	22.8	22.2	21.1	20.3	19.3
42	W	Arbitrary	Lbs.	3600	3600	3600	3600	3600	3600
43	W/Ws	(41)/(42)	N/D	1	1	1	1	1	1
44	W/Ws^.5	(43)^.5	N/D	1	1	1	1	1	1
45	W/Ws^1.5	(43)^1.5	N/D	1	1	1	1	1	1
46	BHP std. Day	Eng. Chart	HP	249	241	237	225	216	203
47	PIW	(46)*(40)/(45)	HP	227.6607	216.996	210.12	196.4	185.609	171.712
48	CIW	Piw vs.Ciw	FPM	483.5212	439.689	411.44	355.05	310.681	253.562
49	R/C	(48)*(44)/(40)	FPM	528.843	488.327	464.07	406.74	361.552	299.765
39	Altitude	Arbitrary	Feet	12000	13000	14000			
	sigma	Chart @ (39)	N/D	0.6932	0.6721	0.65			
40	sigma^.5	Chart @ (39)	N/D	0.832586	0.81982	0.8062			
41	MP @ 39	MP vs. hpi	In.Hg.	18.6	17.7	16.7			
42	W	Arbitrary	Lbs.	3600	3600	3600			
43	W/Ws	(41)/(42)	N/D	1	1	1			
44	W/Ws^.5	(43)^.5	N/D	1	1	1			
45	W/Ws^1.5	(43)^1.5	N/D	1	1	1			
46	BHP std. Day	Eng. Chart	HP	195	188	177			
47	PIW	(46)*(40)/(45)	HP	162.3543	154.126	142.7			
48	CIW	Piw vs.Ciw	FPM	215.1018	181.281	134.33			
49	R/C	(48)*(44)/(40)	FPM	258.3539	221.123	166.61			

Figure M.2. Piper Saratoga N22UT

PIW versus CIW Expansion Calculation – Standard Day 3,600 pounds.

No.	Quantity	Reference	Units						
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000	5000
	sigma	Chart @ (39)	N/D	1	0.971	0.9427	0.9151	0.888	0.8616
40	sigma^.5	Chart @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424	0.9283
41	MP @ 39	MP vs. hpi	In.Hg.	29.2	28.3	27.4	26.5	25.7	24.7
42	W	Arbitrary	Lbs.	3200	3200	3200	3200	3200	3200
43	W/Ws	(41)/(42)	N/D	0.88889	0.888889	0.8888889	0.88889	0.88889	0.8888889
44	W/Ws^.5	(43)^.5	N/D	0.94281	0.942809	0.942809	0.94281	0.94281	0.942809
45	W/Ws^1.5	(43)^1.5	N/D	0.8381	0.8381	0.8381	0.8381	0.8381	0.8381
46	BHP std. Day	Eng. Chart	HP	300	296	286	277	270	259
47	PIW	(46)*(40)/(45)	HP	357.953	348.0234	331.35187	316.165	303.601	286.87472
48	CIW	Piw vs.Ciw	FPM	1019.04	978.2301	909.70763	847.289	795.647	726.89978
49	R/C	(48)*(44)/(40)	FPM	960.76	935.9491	883.29617	835.074	795.993	738.261
39	Altitude	Arbitrary	Feet	6000	7000	8000	9000	10000	11000
	sigma	Chart @ (39)	N/D	0.8358	0.8106	0.786	0.7619	0.7384	0.7155
40	sigma^.5	Chart @ (39)	N/D	0.9143	0.9004	0.8866	0.8729	0.8593	0.84587
41	MP @ 39	MP vs. hpi	In.Hg.	23.7	22.8	22.2	21.1	20.3	19.3
42	W	Arbitrary	Lbs.	3200	3200	3200	3200	3200	3200
43	W/Ws	(41)/(42)	N/D	0.88889	0.888889	0.8888889	0.88889	0.88889	0.8888889
44	W/Ws^.5	(43)^.5	N/D	0.94281	0.942809	0.942809	0.94281	0.94281	0.942809
45	W/Ws^1.5	(43)^1.5	N/D	0.8381	0.8381	0.8381	0.8381	0.8381	0.8381
46	BHP std. Day	Eng. Cnart	HP	249	241	237	225	216	203
47	PIW	(46)*(40)/(45)	HP	271.639	258.9147	250.71495	234.343	221.464	204.88201
48	CIW	Piw vs.Ciw	FPM	664.279	611.9798	578.27764	510.985	458.051	389.89727
49	R/C	(48)*(44)/(40)	FPM	684.992	640.8042	614.93953	551.908	502.566	434.58058
39	Altitude	Arbitrary	Feet	12000	13000	14000			
	sigma	Chart @ (39)	N/D	0.6932	0.6721	0.65			
40	sigma^.5	Chart @ (39)	N/D	0.83259	0.819817	0.8062257			
41	MP @ 39	MP vs. hpi	In.Hg.	18.6	17.7	16.7			
42	W	Arbitrary	Lbs.	3200	3200	3200			
43	W/Ws	(41)/(42)	N/D	0.88889	0.888889	0.8888889			
44	W/Ws^.5	(43)^.5	N/D	0.94281	0.942809	0.942809			
45	W/Ws^1.5	(43)^1.5	N/D	0.8381	0.8381	0.8381			
46	BHP std. Day	Eng. Chart	HP	195	188	177			
47	PIW	(46)*(40)/(45)	HP	193.717	183.8988	170.2684			
48	CIW	Piw vs.Ciw	FPM	344.008	303.6532	247.6301			
49	R/C	(48)*(44)/(40)	FPM	389.55	349.2084	289.58131			

Figure M.3. Piper Saratoga N22UT

PIW versus CIW Expansion Calculation – Standard Day 3,200 pounds.

No.	Quantity	Reference	Units						
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000	5000
	sigma	Chart @ (39)	N/D	1	0.971	0.9427	0.9151	0.888	0.8616
40	sigma^.5	Chart @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424	0.9283
41	MP @ 39	MP vs. hpi	In.Hg.	29.2	28.3	27.4	26.5	25.7	24.7
42	W	Arbitrary	Lbs.	3000	3000	3000	3000	3000	3000
43	W/Ws	(41)/(42)	N/D	0.833333	0.833333	0.83333	0.83333	0.833333	0.83333
44	W/Ws^.5	(43)^.5	N/D	0.912871	0.912871	0.91287	0.91287	0.912871	0.91287
45	W/Ws^1.5	(43)^1.5	N/D	0.760725	0.760725	0.76073	0.76073	0.760725	0.76073
46	BHP std. Day	Eng. Chart	HP	300	296	286	277	270	259
47	PIW	(46)*(40)/(45)	HP	394.3605	383.4215	365.054	348.323	334.4808	316.053
48	CIW	Piw vs.Ciw	FPM	1168.683	1123.722	1048.23	979.462	922.568	846.828
49	R/C	(48)*(44)/(40)	FPM	1066.856	1041.011	985.477	934.688	893.6601	832.753
39	Altitude	Arbitrary	Feet	6000	7000	8000	9000	10000	11000
	sigma	Chart @ (39)	N/D	0.8358	0.8106	0.786	0.7619	0.7384	0.7155
40	sigma^.5	Chart @ (39)	N/D	0.9143	0.9004	0.8866	0.8729	0.8593	0.84587
41	MP @ 39	MP vs. hpi	In.Hg.	23.7	22.8	22.2	21.1	20.3	19.3
42	W	Arbitrary	Lbs.	3000	3000	3000	3000	3000	3000
43	W/Ws	(41)/(42)	N/D	0.833333	0.833333	0.83333	0.83333	0.833333	0.83333
44	W/Ws^.5	(43)^.5	N/D	0.912871	0.912871	0.91287	0.91287	0.912871	0.91287
45	W/Ws^1.5	(43)^1.5	N/D	0.760725	0.760725	0.76073	0.76073	0.760725	0.76073
46	BHP std. Day	Eng. Chart	HP	249	241	237	225	216	203
47	PIW	(46)*(40)/(45)	HP	299.2679	285.2494	276.216	258.178	243.9893	225.721
48	CIW	Piw vs.Ciw	FPM	777.8378	720.2193	683.089	608.952	550.634	475.548
49	R/C	(48)*(44)/(40)	FPM	776.6219	730.1945	703.33	636.836	584.9618	513.216
39	Altitude	Arbitrary	Feet	12000	13000	14000			
	sigma	Chart @ (39)	N/D	0.6932	0.6721	0.65			
40	sigma^.5	Chart @ (39)	N/D	0.832586	0.819817	0.80623			
41	MP @ 39	MP vs. hpi	In.Hg.	18.6	17.7	16.7			
42	W	Arbitrary	Lbs.	3000	3000	3000			
43	W/Ws	(41)/(42)	N/D	0.833333	0.833333	0.83333			
44	W/Ws^.5	(43)^.5	N/D	0.912871	0.912871	0.91287			
45	W/Ws^1.5	(43)^1.5	N/D	0.760725	0.760725	0.76073			
46	BHP std. Day	Eng. Chart	HP	195	188	177			
47	PIW	(46)*(40)/(45)	HP	213.4204	202.6035	187.587			
48	CIW	Piw vs.Ciw	FPM	424.9912	380.5322	318.811			
49	R/C	(48)*(44)/(40)	FPM	465.9723	423.7247	360.982			

Figure M.4. Piper Saratoga N22UT

PIW versus CIW Expansion Calculation – Standard Day 3,000 pounds.

No.	Quantity	Reference	Units						
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000	5000
	sigma	Chart @ (39)	N/D	1	0.971	0.9427	0.9151	0.888	0.8616
40	sigma^.5	Chart @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424	0.9283
41	MP @ 39	MP vs. hpi	In.Hg.	29.2	28.3	27.4	26.5	25.7	24.7
42	W	Arbitrary	Lbs.	2800	2800	2800	2800	2800	2800
43	W/Ws	(41)/(42)	N/D	0.77778	0.7778	0.7778	0.77778	0.777778	0.77778
44	W/Ws^.5	(43)^.5	N/D	0.88192	0.8819	0.8819	0.88192	0.881917	0.88192
45	W/Ws^1.5	(43)^1.5	N/D	0.68594	0.6859	0.6859	0.68594	0.685936	0.68594
46	BHP std. Day	Eng. Chart	HP	300	296	286	277	270	259
47	PIW	(46)*(40)/(45)	HP	437.359	425.23	404.86	386.302	370.9503	350.514
48	CIW	Piw vs.Ciw	FPM	1345.41	1295.5	1211.8	1135.56	1072.463	988.465
49	R/C	(48)*(44)/(40)	FPM	1186.54	1159.5	1100.6	1046.91	1003.633	939.076
39	Altitude	Arbitrary	Feet	6000	7000	8000	9000	10000	11000
	sigma	Chart @ (39)	N/D	0.8358	0.8106	0.786	0.7619	0.7384	0.7155
40	sigma^.5	Chart @ (39)	N/D	0.9143	0.9004	0.8866	0.8729	0.8593	0.84587
41	MP @ 39	MP vs. hpi	In.Hg.	23.7	22.8	22.2	21.1	20.3	19.3
42	W	Arbitrary	Lbs.	2800	2800	2800	2800	2800	2800
43	W/Ws	(41)/(42)	N/D	0.77778	0.7778	0.7778	0.77778	0.777778	0.77778
44	W/Ws^.5	(43)^.5	N/D	0.88192	0.8819	0.8819	0.88192	0.881917	0.88192
45	W/Ws^1.5	(43)^1.5	N/D	0.68594	0.6859	0.6859	0.68594	0.685936	0.68594
46	BHP std. Day	Eng. Chart	HP	249	241	237	225	216	203
47	PIW	(46)*(40)/(45)	HP	331.898	316.35	306.33	286.328	270.5922	250.332
48	CIW	Piw vs.Ciw	FPM	911.953	848.05	806.87	724.652	659.9761	576.704
49	R/C	(48)*(44)/(40)	FPM	879.653	830.64	802.61	732.138	677.3469	601.28
39	Altitude	Arbitrary	Feet	12000	13000	14000			
	sigma	Chart @ (39)	N/D	0.6932	0.6721	0.65			
40	sigma^.5	Chart @ (39)	N/D	0.83259	0.8198	0.8062			
41	MP @ 39	MP vs. hpi	In.Hg.	18.6	17.7	16.7			
42	W	Arbitrary	Lbs.	2800	2800	2800			
43	W/Ws	(41)/(42)	N/D	0.77778	0.7778	0.7778			
44	W/Ws^.5	(43)^.5	N/D	0.88192	0.8819	0.8819			
45	W/Ws^1.5	(43)^1.5	N/D	0.68594	0.6859	0.6859			
46	BHP std. Day	Eng. Chart	HP	195	188	177			
47	PIW	(46)*(40)/(45)	HP	236.69	224.69	208.04			
48	CIW	Piw vs.Ciw	FPM	520.634	471.33	402.88			
49	R/C	(48)*(44)/(40)	FPM	551.482	507.03	440.7			

Figure M.5. Piper Saratoga N22UT

PIW versus CIW Expansion Calculation – Standard Day 2,800 pounds.

No.	Quantity	Reference	Units	1	2
1	Vo	Flight Data	mph	78	78
2	Vi	Inst. Cal.	mph	81.8	81.8
3	Vc	Pos. Cal.	mph	75.3	75.3
	Vc		knots	65.44	65.44
4	hpo	Flight Data	feet	2000	4000
5	hpi	Inst. Cal.	feet	2140	4150
6	OATo/OATi	Flight Data	°Celsius	10	10
7	ta	(6) in °Celsius	°Celsius	10	10
8	Ta	273.16 + (7)	°Kelvin	283.16	283.16
11	No	Flight Data	RPM	2400	2400
12	Ni	Flight Data	RPM	2400	2400
13	Mpo	Flight Data	In.Hg.	26.5	24.7
14	Mpi	Inst. Cal.	In.Hg.	26.3	24.48
18	Ts @ hpi	Afftc H'd book	°Kelvin	283.92	279.94
20	Ts/Tcat (opt)	(18) / (19)	N/D	1.002684	0.98863
21	(Ts/Tcat)^.5	(20)^.5	N/D	1.001341101	0.994298748
22	HP alt	Eng. Chart	HP	82	76
23	HP temp cor.	(22)*(21)	HP	82.10997026	75.56670484
24	δ @ hpi	Afftc H'd book	N/D	0.92504	0.8588
25	θ	(8) / 288.16	N/D	0.982648529	0.982648529
26	σ = δ/θ (opt)	(24) / (25)	N/D	0.941374228	0.873964571
27	(σ)^.5	(26)^.5	N/D	0.970244417	0.934860723
28	Wt	Flight Data	lbs.	1537.56	1532.83
29	Ws	Arbitrary	lbs.	1600	1600
30	Wt/Ws	(28) / (29)	N/D	0.960975	0.95801875
31	(Wt/Ws)^.5	(30)^.5	N/D	0.980293323	0.978784323
32	(Wt/Ws)^1.5	(30)^1.5	N/D	0.942037377	0.937693733
33	PIW	(23)*(27) / (32)	HP	84.56855554	75.33839868
34	VIW	(3) / (31)	knots	66.75552963	66.85844725
35	NIW	(12)*(27) / (31)	RPM	2375.397796	2292.298399
36	R/C	Flight Data	FPM	427.11	333.588
37	R/C temp. cor.	(36)*(8) /(18)	FPM	425.9667075	337.4250842
38	CIW	(37)*(27) / (31)	FPM	421.6001576	322.2829084

Figure M.6. Cessna 150M N66525 PIW versus CIW Data Reduction Results.

No.	Quantity	Reference	Units					
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000
	σ	AFFTC	N/D	1	0.971	0.9427	0.9151	0.888
40	(σ)^.5	AFFTC @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424
41	MP @ (39)	MP vs. hpi	In. Hg.	28.1	27.3	26.4	25.5	24.6
42	W	Arbitrary	lbs.	1600	1600	1600	1600	1600
43	W/Ws	(41)/(42)	N/D	1	1	1	1	1
44	(W/Ws)^.5	(43)^.5	N/D	1	1	1	1	1
45	(W/Ws)^1.5	(43)^1.5	N/D	1	1	1	1	1
46	BHP std day	Eng. Chart	HP	87	86	83	78	76
47	PIW	(46)*(40)/(45)	HP	87	84.7444	80.593	74.6148	71.6224
48	CIW	PIW vs. CIW	FPM	447.9333	423.653	378.967	314.616	282.4047
49	R/C	(48)*(44)/(40)	FPM	447.9333	429.93	390.285	328.89	299.6655
39	Altitude	Arbitrary	Feet	5000	6000	7000	8000	9000
	σ	AFFTC	N/D	0.8616	0.8358	0.8106	0.786	0.7619
40	(σ)^.5	AFFTC @ (39)	N/D	0.9283	0.9143	0.9004	0.8866	0.8729
41	MP @ (39)	MP vs. hpi	In. Hg.	23.8	22.9	22	21.2	20.3
42	W	Arbitrary	lbs.	1600	1600	1600	1600	1600
43	W/Ws	(41)/(42)	N/D	1	1	1	1	1
44	(W/Ws)^.5	(43)^.5	N/D	1	1	1	1	1
45	(W/Ws)^1.5	(43)^1.5	N/D	1	1	1	1	1
46	BHP std day	Eng. Chart	HP	75	71	68	65	62
47	PIW	(46)*(40)/(45)	HP	69.6225	64.9153	61.2272	57.629	54.1198
48	CIW	PIW vs. CIW	FPM	260.8773	210.208	170.508	131.776	94.00215
49	R/C	(48)*(44)/(40)	FPM	281.0269	229.911	189.369	148.631	107.6895
39	Altitude	Arbitrary	Feet	10000	11000	12000	13000	14000
	σ	AFFTC	N/D	0.7384	0.7155	0.6932	0.6721	0.65
40	(σ)^.5	AFFTC @ (39)	N/D	0.8593	0.84587	0.83259	0.81982	0.806226
41	MP @ (39)	MP vs. hpi	In. Hg.	19.5	18.6	17.7	16.8	16
42	W	Arbitrary	lbs.	1600	1600	1600	1600	1600
43	W/Ws	(41)/(42)	N/D	1	1	1	1	1
44	(W/Ws)^.5	(43)^.5	N/D	1	1	1	1	1
45	(W/Ws)^1.5	(43)^1.5	N/D	1	1	1	1	1
46	BHP std day	Eng. Chart	HP	59	57	54	51	48
47	PIW	(46)*(40)/(45)	HP	50.6987	48.2146	44.9596	41.8107	38.69885
48	CIW	PIW vs. CIW	FPM	57.17653	30.4369	-4.60017	-38.497	-71.993
49	R/C	(48)*(44)/(40)	FPM	66.5385	35.983	-5.52516	-46.958	-89.2963

Figure M.7. Cessna 150M N66525

PIW versus CIW Expansion Calculation – Standard Day 1,600 pounds.

No.	Quantity	Reference	Units					
39	Altitude	Arbitrary	Feet	0	1000	2000	3000	4000
	σ	AFFTC	N/D	1	0.971	0.9427	0.9151	0.888
40	(σ)^.5	AFFTC @ (39)	N/D	1	0.9854	0.971	0.9566	0.9424
41	MP @ (39)	MP vs. hpi	In. Hg.	28.1	27.3	26.4	25.5	24.6
42	W	Arbitrary	lbs.	1500	1500	1500	1500	1500
43	W/Ws	(41)/(42)	N/D	0.9375	0.9375	0.9375	0.9375	0.9375
44	(W/Ws)^.5	(43)^.5	N/D	0.9682458	0.96825	0.968246	0.96825	0.968246
45	(W/Ws)^1.5	(43)^1.5	N/D	0.9077305	0.90773	0.907731	0.90773	0.907731
46	BHP std day	Eng. Chart	HP	87	86	83	78	76
47	PIW	(46)*(40)/(45)	HP	95.843425	93.3585	88.78516	82.1993	78.90271
48	CIW	PIW vs. CIW	FPM	543.12621	516.378	467.1492	396.257	360.7719
49	R/C	(48)*(44)/(40)	FPM	525.87967	507.389	465.8242	401.081	370.6663
39	Altitude	Arbitrary	Feet	5000	6000	7000	8000	9000
	σ	AFFTC	N/D	0.8616	0.8358	0.8106	0.786	0.7619
40	(σ)^.5	AFFTC @ (39)	N/D	0.9283	0.9143	0.9004	0.8866	0.8729
41	MP @ (39)	MP vs. hpi	In. Hg.	23.8	22.9	22	21.2	20.3
42	W	Arbitrary	lbs.	1500	1500	1500	1500	1500
43	W/Ws	(41)/(42)	N/D	0.9375	0.9375	0.9375	0.9375	0.9375
44	(W/Ws)^.5	(43)^.5	N/D	0.9682458	0.96825	0.968246	0.96825	0.968246
45	(W/Ws)^1.5	(43)^1.5	N/D	0.9077305	0.90773	0.907731	0.90773	0.907731
46	BHP std day	Eng. Chart	HP	75	71	68	65	62
47	PIW	(46)*(40)/(45)	HP	76.699527	71.5138	67.45086	63.4869	59.621
48	CIW	PIW vs. CIW	FPM	337.05626	281.236	237.5011	194.832	153.2185
49	R/C	(48)*(44)/(40)	FPM	351.56018	297.83	255.397	212.774	169.9544
39	Altitude	Arbitrary	Feet	10000	11000	12000	13000	14000
	σ	AFFTC	N/D	0.7384	0.7155	0.6932	0.6721	0.65
40	(σ)^.5	AFFTC @ (39)	N/D	0.8593	0.84587	0.832586	0.81982	0.806226
41	MP @ (39)	MP vs. hpi	In. Hg.	19.5	18.6	17.7	16.8	16
42	W	Arbitrary	lbs.	1500	1500	1500	1500	1500
43	W/Ws	(41)/(42)	N/D	0.9375	0.9375	0.9375	0.9375	0.9375
44	(W/Ws)^.5	(43)^.5	N/D	0.9682458	0.96825	0.968246	0.96825	0.968246
45	(W/Ws)^1.5	(43)^1.5	N/D	0.9077305	0.90773	0.907731	0.90773	0.907731
46	BHP std day	Eng. Chart	HP	59	57	54	51	48
47	PIW	(46)*(40)/(45)	HP	55.85215	53.1155	49.52973	46.0607	42.63253
48	CIW	PIW vs. CIW	FPM	112.64962	83.192	44.5934	7.25147	-29.6498
49	R/C	(48)*(44)/(40)	FPM	126.93183	95.2277	51.85936	8.56435	-35.6083

Figure M.8. Cessna 150M N66525

PIW versus CIW Expansion Calculation – Standard Day 1,500 pounds.

APPENDIX N

Equivalent Altitude Data Reduction Results

No.	Symbol	Item	Units	1	2
1	Vi	Ind. Airspeed	MPH	78	78
2	Vc	Cal. Airspeed	MPH	75.3	75.3
3	Hp	Pressure Alt.	Feet	2140	4150
4	OAT	Free Air Temp	°F	50	50
5	σ^.5	(ρ/ρo)^.5 @ (3) & (4)		0.9702444	0.9348607
6	He	Equivalent Alt.	Feet	2108.0486	4288.3732
7	T	OAT Abs. = (4) + 460	°F	510	510
8	Ts	std. Abs. Temp. @ (3)	°F	511.41	504.24
9	T/Ts	Temp. ratio (7)/(8)		0.9972429	1.0114231
10	dh/dt	Obs. Rate of Change of Press. Alt.	FPM	427.11	333.588
11	Ct	R/C @ Test Weight, Wt= (9)*(10)	FPM	425.93242	337.39862
12	Wt	Aircraft Test Weight	Lbs.	1537.56	1532.83
13	Wt/Ws	Weight Ratio (12)/Ws		0.960975	0.9580188
14		Ct Wt/Ws = (11)*(13)	FPM	409.31041	323.2342
15	(Wt/Ws)^2	(13)^2		0.923473	0.9177999
16		1-(Wt/Ws)^2 = 1 - (15)		0.076527	0.0822001
17		K/Vc*σ^.5 = K/(2)*(5)		271.70337	281.98711
18		Induced drag corr. = (16)*(17)	FPM	20.792657	23.179361
19	Cc	R/C @ Std. Alt. (6) & Weight (Ws) = (14)-(18)	FPM	388.51775	300.05484

Figure N.1. Cessna 150M N66525

Equivalent Altitude Data Reduction Results 1,600 pounds.

No.	Symbol	Item	Units	1	2
1	Vi	Ind. Airspeed	MPH	78	78
2	Vc	Cal. Airspeed	MPH	75.3	75.3
3	Hp	Pressure Alt.	Feet	2140	4150
4	OAT	Free Air Temp	°F	50	50
5	σ^.5	(ρ/ρo)^.5 @ (3) & (4)		0.9702444	0.9348607
6	He	Equivalent Alt.	Feet	2108.0486	4288.3732
7	T	OAT Abs. = (4) + 460	°F	510	510
8	Ts	std. Abs. Temp. @ (3)	°F	511.41	504.24
9	T/Ts	Temp. ratio (7)/(8)		0.9972429	1.0114231
10	dh/dt	Obs. Rate of Change of Press. Alt.	FPM	427.11	333.588
11	Ct	R/C @ Test Weight, Wt= (9)*(10)	FPM	425.93242	337.39862
12	Wt	Aircraft Test Weight	Lbs.	1537.56	1532.83
13	Wt/Ws	Weight Ratio (12)/Ws		1.02504	1.0218867
14		Ct Wt/Ws = (11)*(13)	FPM	436.59777	344.78315
15	(Wt/Ws)^2	(13)^2		1.050707	1.0442524
16		1-(Wt/Ws)^2 = 1 - (15)		-0.050707	-0.0442524
17		K/Vc*σ^.5 = K/(2)*(5)		254.72191	264.36291
18		Induced drag corr. = (16)*(17)	FPM	-12.916184	-11.698683
19	Cc	R/C @ Std. Alt. (6) & Weight (Ws) = (14)-(18)	FPM	449.51395	356.48183

Figure N.2. Cessna 150M N66525

Equivalent Altitude Data Reduction Results 1,500 pounds.

APPENDIX O

Density Altitude Data Reduction Results

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	3490	6760
2	Outside Air Temp.		°F	28	33
3	Atmospheric Density Ratio		σ	0.935988261	0.819618153
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2244.548201	6645.335598
5	Std. Temp. at Hp (Ts)	°F + 460	°F	506.59	494.94
6	Indicated Airspeed		knots	92.6	92.4
7	Calibrated Airspeed		knots	91	89.8
8	True Airspeed	(7)/(3)^.5	knots	94.06025996	99.19060247
9	Observed Rate of Climb		ft./min.	900.06	704.4
10	T/Ts	(2)+460/(5)		0.963303658	0.996080333
11	Actual R/C	(9) * (10)		867.0310902	701.6389865
12	Test Weight		lbs.	3083.74	3071.74
13	Δ R/C Δw	(11)[1-(12)/Wc]		124.3371	102.95773
14	q π e b^2	(7)^2*πe b^2/295		92405.44117	89984.44316
15	Δ Di	Wc^2-(12)^2/(14)		37.34138995	39.16691873
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		98.80409931	109.2869345
17	Calibrated RPM		RPM	2700	2700
18	Calibrated MP		in. Hg.	26.2	23.06
19	Inlet Air Temp.		°F	28	33
20	BHP cor. for Temp. at Hp		HP	267.63	235.8759
21	BHPc cor. for Temp. at Hd		HP	262.7877	234.9012
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-4.019109	-0.809001
24	Δ R/C Δ p	(23)*33,000/Wc		-36.8418325	-7.4158425
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	607.0480584	481.9784795

Figure O.1. Piper Saratoga N22UT

Density Altitude Data Reduction Results 3,600 pounds.

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	3490	6760
2	Outside Air Temp.		°F	28	33
3	Atmospheric Density Ratio		σ	0.935988261	0.819618153
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2244.548201	6645.335598
5	Std. Temp. at Hp (Ts)	°F + 460	°F	506.59	494.94
6	Indicated Airspeed		knots	92.6	92.4
7	Calibrated Airspeed		knots	91	89.8
8	True Airspeed	(7)/(3)^.5	knots	94.06025996	99.19060247
9	Observed Rate of Climb		ft./min.	900.06	704.4
10	T/Ts	(2)+460/(5)		0.963303658	0.996080333
11	Actual R/C	(9) * (10)		867.0310902	701.6389865
12	Test Weight		lbs.	3083.74	3071.74
13	Δ R/C Δw	(11)[1-(12)/Wc]		31.5003233	28.12256763
14	q π e b^2	(7)^2*πe b^2/295		92405.44117	89984.44316
15	Δ Di	Wc^2-(12)^2/(14)		7.905893887	8.939471582
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		23.5335794	28.06165028
17	Calibrated RPM		RPM	2700	2700
18	Calibrated MP		in. Hg.	26.2	23.06
19	Inlet Air Temp.		°F	28	33
20	BHP cor. for Temp. at Hp		HP	267.63	235.8759
21	BHPc cor. for Temp. at Hd		HP	262.7877	234.9012
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-4.019109	-0.809001
24	Δ R/C Δ p	(23)*33,000/Wc		-41.4470616	-8.34282281
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	770.550126	637.1119458

Figure O.2. Piper Saratoga N22UT

Density Altitude Data Reduction Results 3,200 pounds.

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	3490	6760
2	Outside Air Temp.		°F	28	33
3	Atmospheric Density Ratio		σ	0.935988261	0.819618153
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2244.548201	6645.335598
5	Std. Temp. at Hp (Ts)	°F + 460	°F	506.59	494.94
6	Indicated Airspeed		knots	92.6	92.4
7	Calibrated Airspeed		knots	91	89.8
8	True Airspeed	(7)/(3)^.5	knots	94.06025996	99.19060247
9	Observed Rate of Climb		ft./min.	900.06	704.4
10	T/Ts	(2)+460/(5)		0.963303658	0.996080333
11	Actual R/C	(9) * (10)		867.0310902	701.6389865
12	Test Weight		lbs.	3083.74	3071.74
13	Δ R/C Δw	(11)[1-(12)/Wc]		-24.20173	-16.845
14	q π e b^2	(7)^2*πe b^2/295		92405.44117	89984.44316
15	Δ Di	Wc^2-(12)^2/(14)		-5.51322932	-4.84068815
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		-17.5053899	-16.2082896
17	Calibrated RPM		RPM	2700	2700
18	Calibrated MP		in. Hg.	26.2	23.06
19	Inlet Air Temp.		°F	28	33
20	BHP cor. for Temp. at Hp		HP	267.63	235.8759
21	BHPc cor. for Temp. at Hd		HP	262.7877	234.9012
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-4.019109	-0.809001
24	Δ R/C Δ p	(23)*33,000/Wc		-44.210199	-8.899011
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	864.5280111	725.7932652

Figure O.3. Piper Saratoga N22UT

Density Altitude Data Reduction Results 3,000 pounds.

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	3490	6760
2	Outside Air Temp.		°F	28	33
3	Atmospheric Density Ratio		σ	0.935988261	0.819618153
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2244.548201	6645.335598
5	Std. Temp. at Hp (Ts)	°F + 460	°F	506.59	494.94
6	Indicated Airspeed		knots	92.6	92.4
7	Calibrated Airspeed		knots	91	89.8
8	True Airspeed	(7)/(3)^.5	knots	94.06025996	99.19060247
9	Observed Rate of Climb		ft./min.	900.06	704.4
10	T/Ts	(2)+460/(5)		0.963303658	0.996080333
11	Actual R/C	(9) * (10)		867.0310902	701.6389865
12	Test Weight		lbs.	3083.74	3071.74
13	Δ R/C Δw	(11)[1-(12)/Wc]		-87.8612145	-68.09406
14	q π e b^2	(7)^2*πe b^2/295		92405.44117	89984.44316
15	Δ Di	Wc^2-(12)^2/(14)		-18.0666026	-17.7318053
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		-61.4618242	-63.6130562
17	Calibrated RPM		RPM	2700	2700
18	Calibrated MP		in. Hg.	26.2	23.06
19	Inlet Air Temp.		°F	28	33
20	BHP cor. for Temp. at Hp		HP	267.63	235.8759
21	BHPc cor. for Temp. at Hd		HP	262.7877	234.9012
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-4.019109	-0.809001
24	Δ R/C Δ p	(23)*33,000/Wc		-47.3680704	-9.53465464
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	968.9860586	823.8114481

Figure O.4. Piper Saratoga N22UT

Density Altitude Data Reduction Results 2,800 pounds.

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	2140	4150
2	Outside Air Temp.		°F	50	50
3	Atmospheric Density Ratio		σ	0.941374228	0.873964571
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2051.246241	4534.372784
5	Std. Temp. at Hp (Ts)	°F + 460	°F	511.4084143	504.2404296
6	Indicated Airspeed		knots	67.782	67.782
7	Calibrated Airspeed		knots	65.4357	65.4357
8	True Airspeed	(7)/(3)^.5	knots	67.44249166	69.99513117
9	Observed Rate of Climb		ft./min.	427.11	333.588
10	T/Ts	(2)+460/(5)		0.997246009	1.01142227
11	Actual R/C	(9) * (10)		425.9337428	337.3983322
12	Test Weight		lbs.	1537.56	1532.83
13	Δ R/C Δw	(11)[1-(12)/Wc]		16.62206431	14.16440373
14	q π e b^2	(7)^2*πe b^2/295		40188.63834	40188.63834
15	Δ Di	Wc^2-(12)^2/(14)		4.874742079	5.236111493
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		20.80875402	23.19730563
17	Calibrated RPM		RPM	2400	2400
18	Calibrated MP		in. Hg.	26.3	24.48
19	Inlet Air Temp.		°F	50	50
20	BHP cor. for Temp. at Hp		HP	81.2854766	75.33776
21	BHPc cor. for Temp. at Hd		HP	80.2941903	74.84211
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-0.82276763	-0.4113895
24	Δ R/C Δ p	(23)*33,000/Wc		-16.9695823	-8.48490844
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	371.5333421	291.5517145

Figure O.5. Cessna 150M N66525

Density Altitude Data Reduction Results 1,600 pounds.

No.	Item	Ref.	Units	1	2
1	Pressure Altitude Hp		Feet	2140	4150
2	Outside Air Temp.		°F	50	50
3	Atmospheric Density Ratio		σ	0.941374228	0.873964571
4	Density Alt.	Hd=145539[1-(σ^.5)^.4699]	Feet	2051.246241	4534.372784
5	Std Temp. at Hp (Ts)	°F + 460	°F	511.4084143	504.2404296
6	Indicated Airspeed		knots	67.782	67.782
7	Calibrated Airspeed		knots	65.4357	65.4357
8	True Airspeed	(7)/(3)^.5	knots	67.44249166	69.99513117
9	Observed Rate of Climb		ft./min.	427.11	333.588
10	T/Ts	(2)+460/(5)		0.997246009	1.01142227
11	Actual R/C	(9) * (10)		425.9337428	337.3983322
12	Test Weight		lbs.	1537.56	1532.83
13	Δ R/C Δw	(11)[1-(12)/Wc]		-10.6653809	-7.3845249
14	q π e b^2	(7)^2*πe b^2/295		40188.63834	40188.63834
15	Δ Di	Wc^2-(12)^2/(14)		-2.8388808	-2.47751138
16	Δ R/C Δ Di	101.27*(15)*(8)/Ws		-12.9261834	-11.7077392
17	Calibrated RPM		RPM	2400	2400
18	Calibrated MP		in. Hg.	26.3	24.48
19	Inlet Air Temp.		°F	50	50
20	BHP cor. for Temp. at Hp		HP	81.2854766	75.33776
21	BHPc cor. for Temp. at Hd		HP	80.2941903	74.84211
22	ηp propeller efficiency			0.83	0.83
23	Δ THP	(22)[(21)-(20)]		-0.82276763	-0.4113895
24	Δ R/C Δ p	(23)*33,000/Wc		-18.1008878	-9.050569
25	R/C std.	(11)-(13)-(16)+(24)	ft./min.	431.4244192	347.4400274

Figure O.6. Cessna 150M N66525

Density Altitude Data Reduction Results 1,500 pounds.

VITA

Scott Sowles was born in Memphis, Tennessee, on March 29, 1975. He attended a private school for most of elementary education and then proceeded to attend a school in the Shelby County Public School system, graduating from Germantown High School in May of 1993. While attending Middle Tennessee State University in Murfreesboro, Tennessee, he acquired a private and instrument certificate. In December of 1997, he graduated from Middle Tennessee State University with a Bachelor of Science Degree in Aerospace Maintenance Management and obtained his Airframe and Powerplant Mechanic certificates in January of 1998. While attending MTSU, he worked as a student worker of the Aerospace Department from August of 1995 to December of 1997. Currently employed by the University of Tennessee Space Institute as a graduate research assistant of Aviation Systems, he has flown over 260 hours in single engine land aircraft. Scott graduated from the University of Tennessee Space Institute in December of 1999 with a Masters of Science Degree in Aviation Systems.