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A Study of the Temperature Correction Methods for Reciprocating Engine Flight Testing under non Standard Conditions

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To the Graduate Council:

I am submitting herewith a thesis written by Juan Carlos Valer entitled "A Study of the Temperature Correction Methods for Reciprocating Engine Flight Testing under non Standard Conditions." I have examined the final electronic 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 Aerospace Engineering.

Ralph Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Frank Collins, Basil Antar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew
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A STUDY OF THE TEMPERATURE CORRECTION METHODS FOR RECIPROCATING ENGINE FLIGHT TESTING UNDER NON STANDARD CONDITIONS

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

Juan Carlos Valer
December 2003

DEDICATION

This Thesis is dedicated, above all, to my best source of love, inspiration, wisdom, courage, and strength: God.

To my mother, to whom I owe and love so much.

To my aunts Luisa and Rebeca, constant sources of love, advice, and support.

To my uncle Hector, a permanent presence in my life.

ACKNOWLEDGEMENTS

I have been very fortunate in having Dr. Kimberlin as my major professor, advisor, and work supervisor. He opened for me the doors of graduate education and has been an enormous source of support.

I want to thank Michael Leigh and Greg Heatherly, who very diligently worked in the instrumentation and aircraft maintenance of the aircraft used for the test.

ABSTRACT

Federal Aviation Regulations require aircraft reciprocating engines to comply with temperature limits under pre-defined hot-day conditions. When the test is conducted on other than those conditions, the Regulations provide equations to convert the temperature registered into values considered to be corresponding to a hot-day scenario.

It is known by the flight test community that those equations over compensate for flying in non-hot day conditions. As a consequence of that, an aircraft that could be certified under hot day conditions may not be certifiable in a colder atmosphere.

This thesis confirmed that the Piper Saratoga complies with the regulations on cooling for cylinder head temperatures, and provides a better rationale to correct for other than hot-day conditions.

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NOMENCLATURE

CG	Center of Gravity
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
ft	feet
HP_c	Calibrated Pressure Altitude
HP_i	Indicated Pressure Altitude
HP_o	Observed Pressure Altitude
HIE	Altimeter Instrument Error
HPE	Altimeter Position Error
MP_i	Indicated Pressure Altitude
MP_o	Observed Pressure Altitude
MPIE	Manifold Pressure Instrument Error
OAT	Outside Air Temperature
OAT_h	Outside Air Temperature at Altitude
RPM	Revolutions Per Minute
T	Observed Temperature
T_c	Corrected Temperature
V_c	Calibrated Airspeed
V_i	Indicated Airspeed
V_o	Observed Airspeed

CHAPTER I

INTRODUCTION

Due to safety, operational, and performance considerations, engines should perform within limits specified by both the certifying authority and the manufacturer. Some of the most important considerations are the heat limits that a reciprocating engine can endure during maximum demanding conditions.

Federal Aviation Regulation 23 requires aircraft reciprocating engines to comply with temperature limits under pre-defined hot-day conditions. When the test is conducted on other than those conditions, the Regulations provide equations to convert the temperature registered into values considered to be corresponding to a hot-day scenario.

FAR 23 also provides a proposed method to demonstrate by test flights the compliance of an engine with the regulations and manufacturer limits.

It is known by the flight test community that those equations over compensate for test conducted in non-hot day conditions. As a consequence of that, an aircraft that could be certified under hot day conditions may not be certifiable in a colder atmosphere.

Some of the requirements of the regulations, are that cylinder head temperatures should always be under a specified limit under “hot day” conditions. The regulations also provide means to correct the data taken under “non hot day” conditions.

The purposes of the flight tests described in this thesis are:

1. To demonstrate the compliance of the Piper Saratoga model to the cylinder head temperature limits set in FAR 23.

2. To investigate more accurate means than the ones provided in FAR 23 to correct data taken under “non hot day” conditions to “hot day conditions”.

CHAPTER II
THE REGULATIONS

What follows is a transcript from Reference 1, “Engineering Flight Test Training Guide for Small Airplanes”, on those parts that pertain to this test. Some portions as noted have been omitted, since they are out of the scope of the present test, that is, the cylinder heads of reciprocating engines.

FAR 23.1047 Cooling Test Procedures for Reciprocating Engine-Powered Airplanes.

a **<u>Explanation:</u>**

1. Cooling tests are conducted to determine the ability of the power plant cooling provisions to maintain the temperatures of powerplant components and engine fluids within the temperature limits for which they have been certified. These limits will normally be specified on the Type Inspection Authorization. They are also listed on any recent Approved Engine Specification. For all obsolete reciprocating engines or those previously certificated for which temperature limits have not been established, the following are applicable:

(a) Cylinder Head:	550 F
(b) Cylinder Barrel:	300 F
(c) Oil Inlet to Engine:	200 F

2. The tests must be conducted under critical ground, water, and flight operating conditions to the maximum altitude for which approval is requested. For turbosupercharged engines, each turbosupercharger must be operated through that part of the climb profile for which the turbosupercharger is requested and in a manner consistent with its intended operation.

b **Procedures:**

The cooling tests for normal category airplanes must be conducted in accordance with the applicable performance requirements of 23.51, 23.65, 23.75, and 23.77. The test conditions are:

1. The tests should be conducted in air free of visible moisture.
2. The fuel used during the cooling tests must be of the minimum grade approved for the engines, and the mixture settings must be those used in normal operations.
3. No special c.g. conditions are required for the test, but the gross weight of the airplane at takeoff should be the maximum allowable for the particular ambient condition.
4. For airplanes with propellers, the propeller used during the cooling must be that permitting the highest static RPM recommended for approval.
5. Since it is possible that a full oil sump may provide sufficient heat transfer to give satisfactory cooling characteristics while a minimum oil quantity may provide unsatisfactory cooling, the oil quantity for the cooling tests should be maintained at the minimum allowable quantity in order to cover the most critically possible operation.
6. The settings of the carburetor or fuel control should not be altered unless specifically approved by the certificating region engineering personnel.
7. If changes in propeller, cowling, oil, cooler, or other features of the airplane such that cooling characteristics may be adversely affected are desired by the applicant, subsequent to the original certification, such changes should be substantiated by submittal of data covering the changes, and by flight tests, if considered necessary to demonstrate adequate cooling.
8. Accurate temperature measuring devices should be used along with acceptable thermocouples or temperature pickup devices. The proper pickup should be located at critical engine positions, i.e., where highest temperatures occur. For reciprocating engine-powered airplanes, at minimum, cylinder head pickups,

cylinder barrel pickups, oil inlet pickups, and ambient air pickups will be required to accomplish these tests. Airplanes which incorporate a thermostat in the engine oil system must have the thermostat removed or blocked open in order to conduct cooling tests.

9. All instruments used during the cooling tests shall be calibrated and all calibration curves submitted with the Type Inspection Report. Calibrations shall be made of complete units as installed for the tests and shall cover the temperature range expected during the tests. The calibrations shall be witnessed by an FAA inspector immediately prior to or following the official type tests. In lieu pf witnessing the calibrations, the Inspector may, at his discretion, accept the applicant’s calibration providing evidence is produced to his satisfaction that the calibration is adequate at the time of the official type tests.
10. For cooling tests of reciprocating engines, the maximum anticipated temperature (hot-day condition) is 100 F at sea level. Decreasing from this value at the rate of 3.6 F per thousand feet of altitude above sea level up to the altitude at which a temperature of –69.7 F is reached, above which altitude the temperature is constant at –69.7 F. However, cooling tests for winterization installations may be corrected to any desired temperature.
11. *Text pertains to turbine-engines.*
12. If tests are conducted under conditions deviating from the maximum anticipated air temperatures specified in (10) and (11) above, the recorded temperatures must be corrected as follows:

    (a) *Text pertains to test of cylinder barrel temperatures.*

    (b) Unless a more rational correction applies, temperatures of engine fluids and powerplant components (except cylinder barrels) for which temperature limits are established, must be corrected by adding to them the difference between the maximum anticipated ambient atmospheric temperature and the temperature of the ambient air at the time of the first occurrence of the maximum component or fluid temperature recorded during the cooling tests.

13. For the cooling tests, a temperature is considered stabilized when its rate of change is less than 2 F per minute.

i **Test Procedures for Reciprocating Engine-Powered Airplanes:**

1. The required cooling tests for single-engine-airplanes should be conducted in accordance with 23.1047(a).
    (a) At the lowest practical altitude established, a level flight condition at not less than 75% maximum continuous power until temperatures stabilize. Record cooling data.
    (b) Increase engine power to takeoff rating and climb at a speed not greater that best rate-of-climb speed unless the speed chosen complies with the requirements of 23.65(a)(1). Maintain take-off power for one (1) minute. Record cooling data.
    (c) At the end of one minute, reduce engine power to maximum continuous and continue to climb for at least five (5) minutes after temperatures peak or stabilize. Record cooling data at one (1) minute intervals.
    (d) Text pertains to super-charged engines.

j **Data Acquisition:**

1. The following data should be recorded at the time intervals specified in the applicable test programs. The data must be manually recorded unless the quantity and frequency necessitate automatic or semiautomatic means.

    Time
    Hottest cylinder head temperature
    Hottest cylinder barrel temperature
    Oil inlet temperature
    Outside air temperature
    Indicated airspeed
    Pressure altitude
    Engine RPM

Propeller RPM
Manifold Pressure
Carburetor air temperature
Mixture setting
Throttle setting

2. Temperatures of components or accessories which have established limits that may be affected by power plant heat generation.

n To Correct Cylinder Head or Other Temperature to Anticipated Hot Day Conditions:

1. Corrected temperature = true observed temperature + 100 – 0.0036 (pressure altitude) – true outside air temperature.
2. For example: True maximum cylinder barrel temperature: 200 F
   Pressure altitude: 12500 ft
   True OAT: 7 F
3. Corrected cylinder head temperature = 200 + 100 –0.0036(12500) – 7 = 248 F
4. The corrected temperatures are then compared with the maximum permissible temperatures to determine compliance with cooling requirements.

o Other Information:

1. *Text pertains to the testing of engines in flying boats.*
2. *Text pertains to the test of engines in multiengine aircrafts*.
3. If at any time during the test, temperatures exceed the manufacturer's specified limits, the test is to be terminated.
4. For reciprocating engine-powered airplanes on which the climb speed for the cooling test is greater than best rate-of-climb speed, a cylinder head temperature indicator is required.
5. In addition to the temperature pickups described, other acceptable methods may be used, e.g., templac for skin and cowl temperatures.

6. At the beginning of the cooling climb, caution should be used in depleting the kinetic energy of the airplane while establishing the climb speed. “zooming” into the climb should not start the climb. The power may be momentarily reduced provided that the stabilized temperatures are not allowed to drop excessively. This means that a minimum of time should be used in slowing the airplane form the high cruise speed to the selected cooling climb speed. This may be accomplished by maneuver loading the airplane or any other means that provide minimum slow-down time.
7. *Text pertains to the test of turbine-engines.*
8. Accessories or components on the engine or in the engine compartment which have temperature limits should be tested and should be at their maximum anticipated operating conditions during the cooling test, e.g., generators should be at maximum anticipated loads.

CHAPTER III
THE AIRCRAFT

The aircraft used for this test was a Piper Saratoga, tail number N22UT, an airplane of the Flight Research Group of the University of Tennessee Space Institute. Follows a description from Reference 1.

The Piper Saratoga is a versatile, single engine, low-wing monoplane of all-metal construction. The fuselage is a semi-monocoque structure that consists of three basic units: the nose section, the cabin section and the tail cone section. The wings are of all-metal stressed-skin, full cantilever design, consisting of two wing panels bolted together at the center of the fuselage. The wing tips are removable.

The aileron are cable and push rod controlled and are statically balanced. The trailing edge wing flaps are mechanically operated. The empennage consists of the vertical stabilizer (fin), rudder, and stabilator with trim tab. The control surfaces are cable controlled, and are statically balanced.

The flight controls of this aircraft are conventional, consisting of dual control wheels that operate the ailerons and stabilator, and dual foot pedals that operate the rudder.

The tricycle landing gear system is fixed and non-retractable.

The airplane is powered by one Lycoming six cylinder, direct drive, horizontally opposed, fuel injected, air-cooled engine. It has a displacement of 541.5 cubic inches and a rated horsepower of 300 with 2700 RPM. The propeller is a constant speed three bladed units controlled by a governor mounted on the engine.

The fuel system consists of two tanks located in the wings with a total fuel capacity of 107 U.S. gallons with 102 gallons of usable fuel. The minimum grade is 100 LL blue aviation fuel.

This airplane has an oil capacity of 12 U.S. quarts. Its maximum Takeoff Weight is 3600 lbs. and maximum ramp weight is 3615 lbs. The maximum weight in baggage compartment is 100 lbs. The wing loading is 20.2 lbs. per sq. ft.

Provisions for the instrument installation includes panels for engine instruments and advance flight instruments, as well as space for an optional second set of flight instruments for the copilot.

A special panel with instrument indicators for flight-testing have been installed in a console between the center and the aft seats. Some indicators are also available in the copilot's seat.

Pictures of this airplane can be found as Figures 1 and 2.

Figure 1. Piper Saratoga N22UT, front view.

Figure 2. Piper Saratoga N22UT, rear view.

CHAPTER IV
THE TEST

All test flights were performed from the Tullahoma's Municipal Airport, Tullahoma, Tennessee (see Figures 3 and 4). To obtain "true data" that could be used for reference, a hot day (according to the regulations) test flight was performed on August 17, 2000. Data on what we could call "Warm Day" (Flight 2) were collected on November 2, 2000. The third and last flight (or "Cold Day" flight) took place on December 18, 2000. The ground temperatures at the start of the tests are, respectively: 100 C, 73 C, and 40 C. The resulting spread of temperatures would allow to evaluate the accuracy of the equation provided by the FAA and also, would provide the means to estimate a better means to correct for non-hot day conditions.

For the most part, the procedures described in the regulations were followed. Only minor changes that would have no noticeable effect on the cooling of the engine or temperature readings were done. Follow a description of these exceptions:

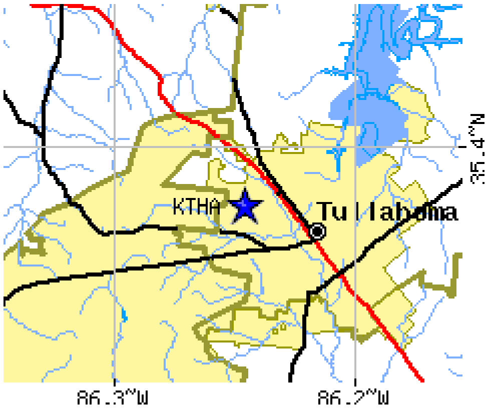

Figure 3. Location of the Tullahoma Municipal Airport.

Figure 4. Tullahoma Municipal Airport.

- The oil tank was not taken to a minimum.

- The thermostat that regulates the flow of oil to the engine should have been removed or blocked for the test. According to the maintenance manual, the thermostat is always open above 180 F of oil temperature. Since all the data taken was well above 300 F, it can be safely assumed that the thermostat remained open during the duration of the test.

- Since only the cylinder heads were the subject of this research, the cylinder barrel temperatures were not recorded.

The cylinder head temperatures were observed by means of a hand-held device externally connected to the temperature pickups in the engine, and manually recorded. The device is a HH22/23, with an accuracy of about 0.1% per degree Celsius. Thermocouples were the sensors used, the ones that were connected to the two ports of the instrument.

All other data was recorded manually as well, either from the main instrument panel or from one of the instrumented consoles in the aircraft. Wet and dry bulb thermometers were used to evaluate the relative humidity; the bulbs were exposed from a small window in the cabin to the ram air, being the readings recorded manually.

As can be seen from Appendix 2, the take-off weight in every flight was always very close to the maximum permitted by the Pilot's Manual. When the weight of the crew was not enough to reach this value, ballast bags were placed in different cargo compartments or in the cabin.

The flights were conducted in air free of visible moisture. The fuel used was 100 LL, the minimum approved for the Saratoga.

The test proceeded as follow: after the pre-flight check, a normal take-off operation proceeded until a level flight was achieved at an altitude of about 1300 feet of calibrated pressure altitude. In this condition the flight proceeded with no less than 75% of maximum continuous until the temperatures stabilized (to remain within a 1 F value).

After that, the engine power was increased to take-off power and climbed at a speed of one thousand feet per a minute; data as recorded. Then the power was reduced to maximum continuous power and the climb continued until an altitude of about seven thousand feet of calibrated pressure altitude was reached. Data was collected about every thousand feet.

The data collected in each "data point" consisted at least of:

Time
Hottest cylinder head temperature
Outside air temperature
Indicated airspeed
Pressure altitude
Engine RPM

Propeller RPM
Manifold Pressure

Wet and dry bulbs temperatures were also recorded at intervals of about two thousand feet.

As can be seen from the data in Appendix 3, it was determined in the first flight that the hottest cylinder head of cylinder 1, and the second hottest cylinder head is of cylinder number 2. Therefore, data on the other cylinder heads was not recorded in the successive flights.

When all the data necessary for the test was acquired, a normal descent and landing in Tullahoma was performed.

CHAPTER V
DATA REDUCTION

The following equations were used for the data reduction; the temperatures are in degrees Fahrenheit:

$$\mathbf{HP_c = HP_o + HPE + HIE}$$

$$\mathbf{MP_i = MP_o + MPIE}$$

$$\mathbf{V_i = V_o + Airspeed\ Indicator\ Instrument\ Error}$$

$$\mathbf{V_c = V_i + Airspeed\ Indicator\ Position\ Error}$$

$$\mathbf{TC = T + 100 - 0.0036 * HP_c - OAT}$$

The charts used for the corrections on position error and instrument error can be found in Appendix 1.

No correction due to total temperature was applied to the OAT reading, since the speed of the aircraft is not sufficient to make a significant difference between static and total temperature. The RPM readings were taken from the panels as such with no further corrections.

The weight and balance of the aircraft was performed according to the Pilot's Manual, and the details for each flight can be found in Appendix 2.

CHAPTER VI
DATA ANALYSIS

From the data gathered in the first flight (see Appendix 3), it became very clear that the hottest head cylinder is number 1, and the second hottest is number 2. Since we are trying to stay on the “safe side” (just as the FARs), we will limit our study to the hottest head cylinders, the ones that would pose the most severe conditions for certification. To simplify the tests, data on the other cylinders was not gathered in flights two and three. The analysis that follows will be limited to cylinder heads one and two.

Several plots of cylinder head temperature versus calibrated pressure altitude can be found in the next several pages.

Figures 5 and 6 show the plots of the cylinder head temperatures of cylinders one and two (respectively) vs. calibrated pressure altitude for the first test flight, the one conducted on a hot day condition as defined by FAR 23. It can be seen that none of the cylinder heads gets hotter than 431 F, thus satisfying the regulations that request a temperature not higher than 550 F for cylinder heads of reciprocating engines. It needs to said that the manufacturer has put a temperature limit of 500 F for this engine.

The equation provided in FAR 23 to correct for non-standard conditions was applied to the temperature data of the first flight, and is also plotted in Figures 5 and 6. It can clearly be seen that the corrected temperatures can be as much as 15 F higher than the data directly recorded from the cylinder heads. If the equation would accurately correct for non-standard conditions, we should expect to obtain no change in the data when applied to the readings of a hot day condition, but Figures 5 and 6 tells us otherwise.

The same analysis was performed for the data gathered in the second flight, done

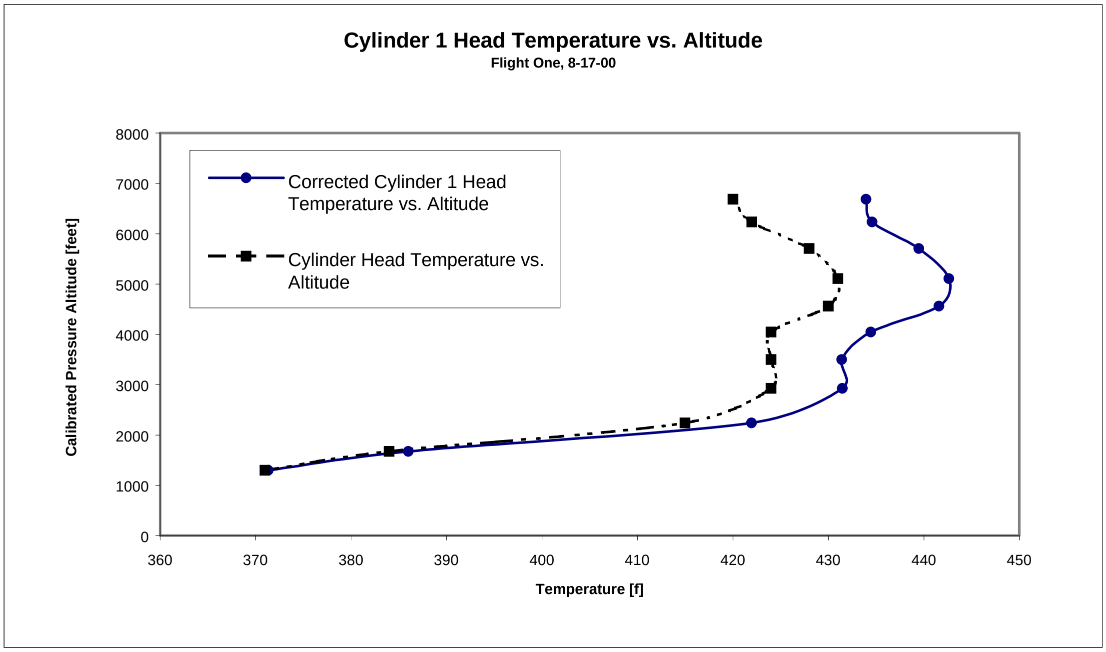

Figure 5. Cylinder 1 Head Temperature vs. Altitude, Flight One.

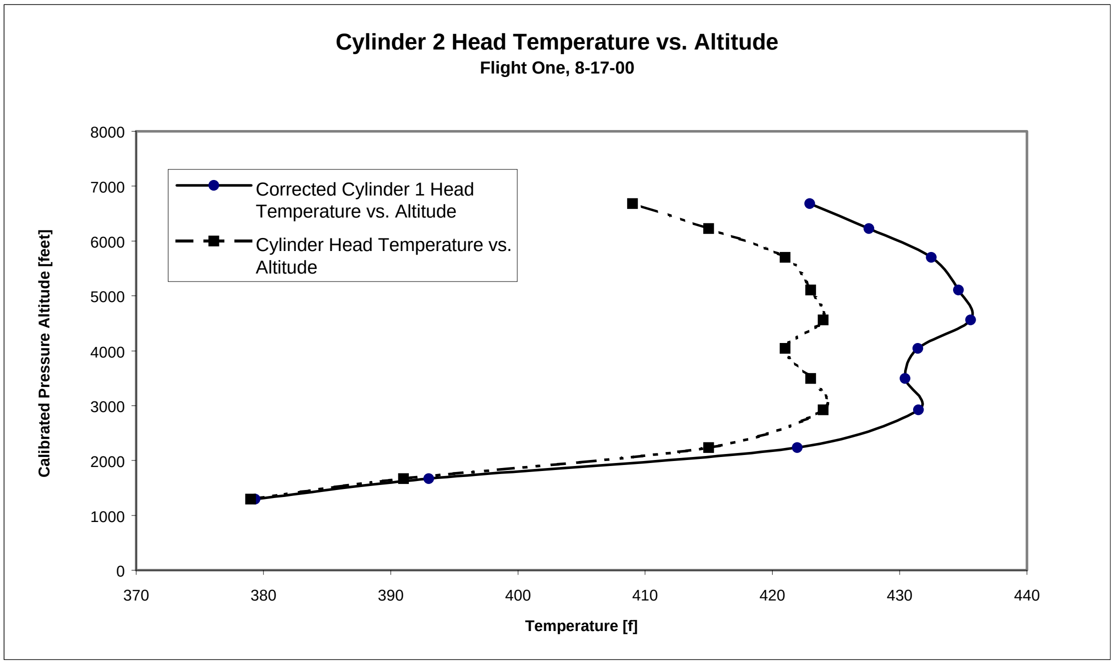

Figure 6. Cylinder 2 Head Temperature vs. Altitude, Flight One.

under what we have called “warm day conditions”. Since the OAT at ground level was about 30 F lower than the one of a hot day, we would expect the highest temperature of the cylinder heads to be lower than the ones recorded on the first (hot) flight. Figure 7 shows us that the temperature of the hottest cylinder head (number one) is as high as 476 F, that is, 45 F hotter than during the first flight. A similar result can be found for cylinder head two. This may suggest that the highest temperature of a cylinder head does not necessarily occur in what FAR 23 defines as a hot day.

The equation to correct for non-standard conditions was also applied to the data of the second flight, and the results can be found in Figures 7 and 8, plotted vs. calibrated pressure altitude. It can be seen that the corrected temperatures can be as 35 F higher than the uncorrected ones.

Since the highest corrected temperature achieved by the hottest cylinder head (number one) is still below 550 F, we can conclude that the Piper Saratoga satisfies the cooling requirements defined in FAR 23 for cylinder heads of reciprocating engines. This temperature also complies with the manufacturer requirement of being under 500 F.

The third and last test flight was conducted in what we have chosen to call a “cold day”. The data collected can be found in Appendix 3. The direct measurements of cylinder head temperature and the corrected temperature according to FAR 23 can be found plotted vs. calibrated pressure altitude in Figures 9 and 10 for cylinders one and two, respectively.

We find that both the recorded temperatures and the corrected temperatures are well within the 550 F limit set by FAR 23, and also under the 500 F limit set by the manufacturer. We can also see in the next two figures, that the corrected temperature is about 60 F higher than the directly measured temperatures of the cylinder heads.

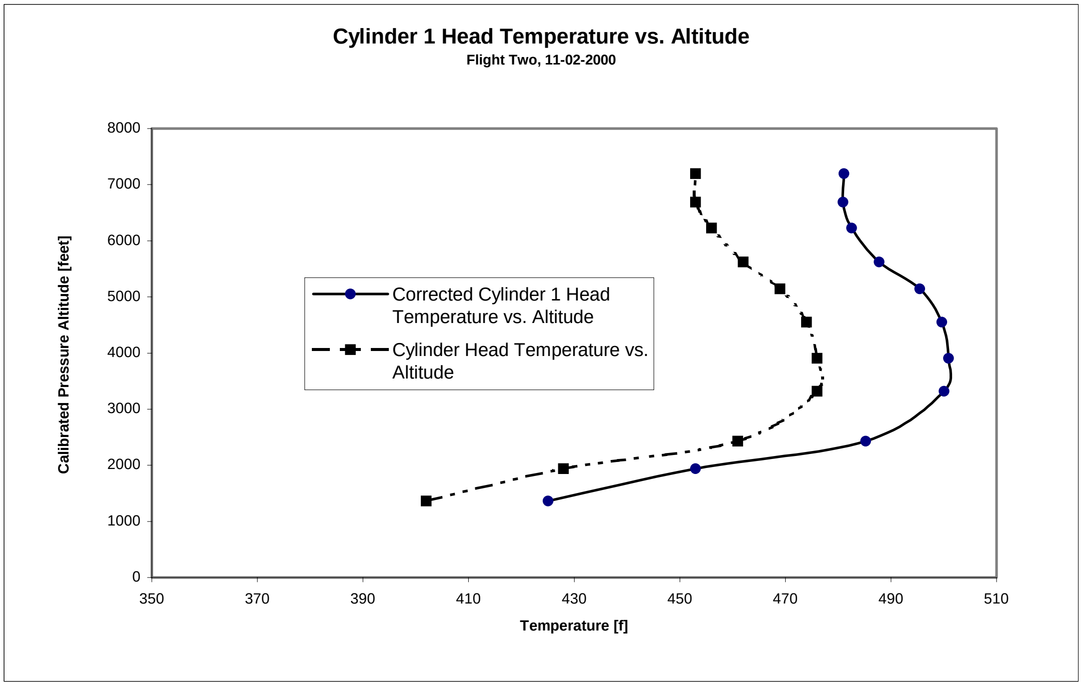

Figure 7. Cylinder 1 Head Temperature vs. Altitude, Flight Two.

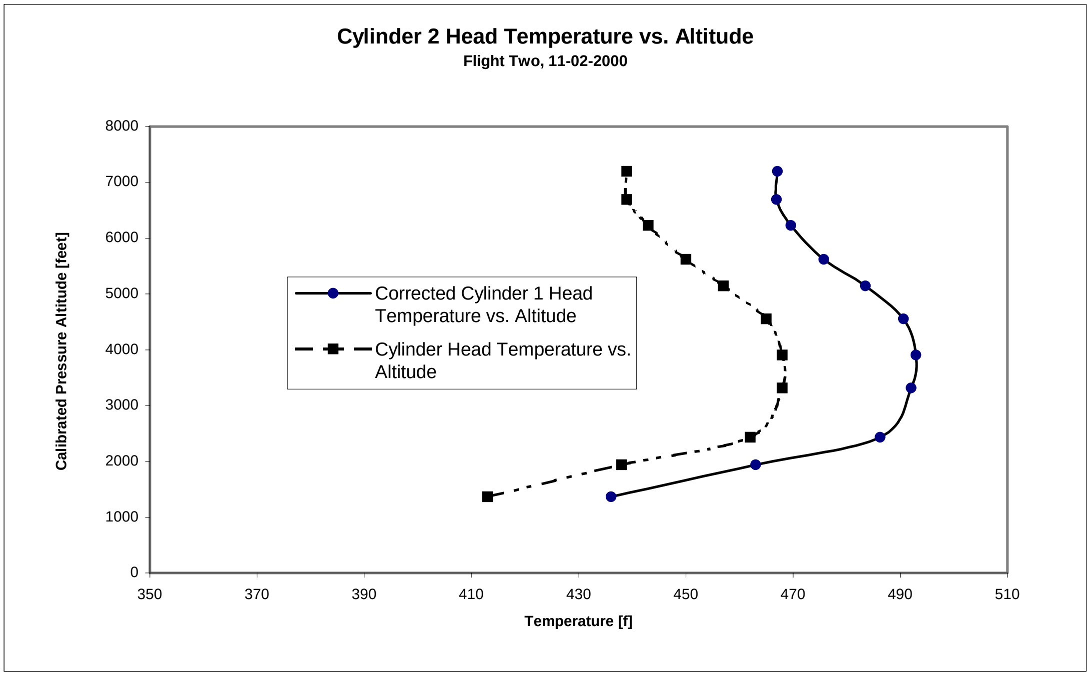

Figure 8. Cylinder 2 Head Temperature vs. Altitude, Flight Two.

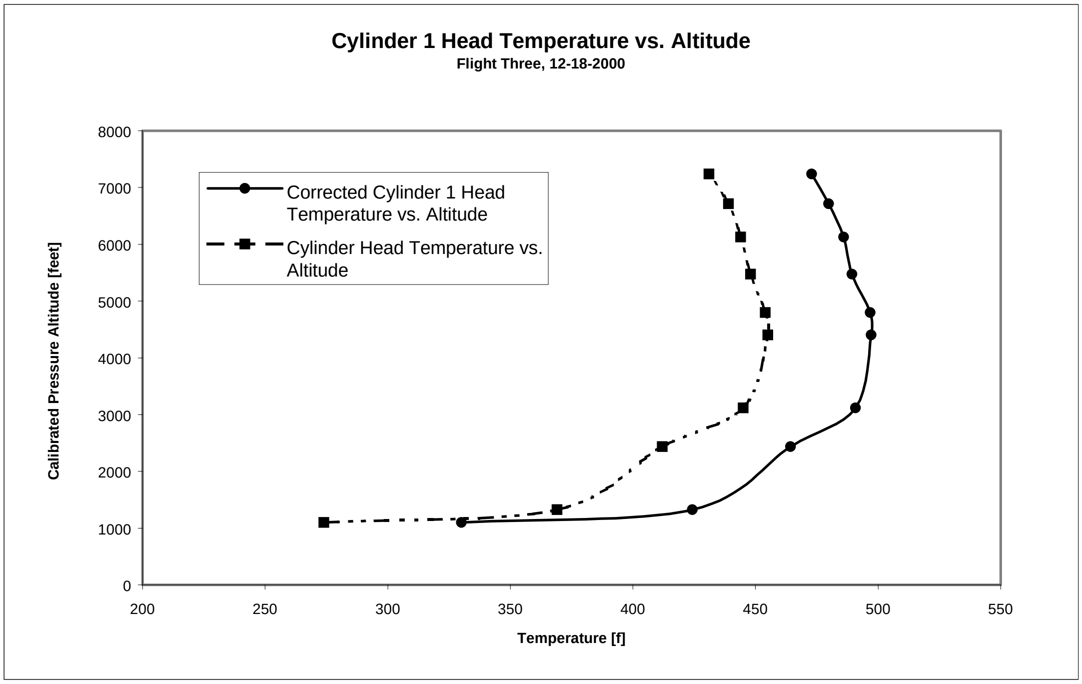

Figure 9. Cylinder 1 Head Temperature vs. Altitude, Flight Three.

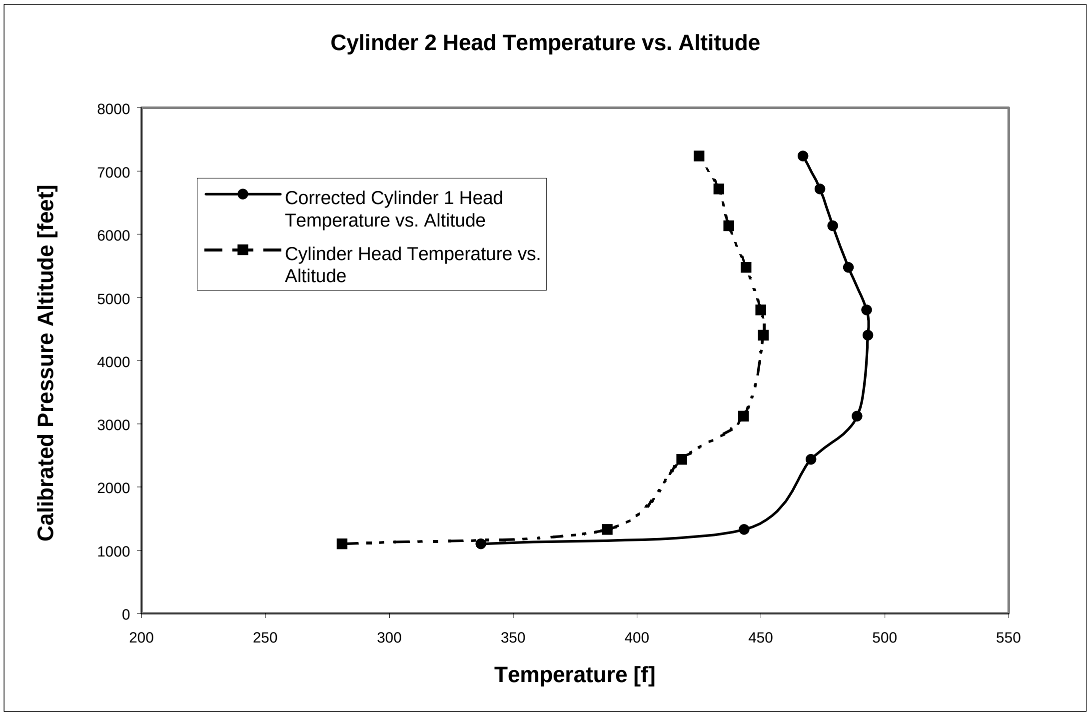

Figure 10. Cylinder 2 Head Temperature vs. Altitude, Flight Three.

The temperature data gathered in the three flights showed us that the highest temperature achieved by a cylinder head was on the warm (second) flight. This may suggest that the absolute highest temperature of a cylinder head does not necessarily occur in what FAR 23 defines as a hot day. And there are thermo dynamical reasons to back this claim. The highest temperature in any combustion engine occurs when a combination of factors is achieved to produce the highest release of caloric energy (per unit time) from the combustion process. Variables like OAT, humidity, altitude and air density, combustion mixture, and others, work together to create that "best scenario", and not just the ground OAT. The data collected in this test suggests that the combination of those variables that would render the hottest cylinder head temperature may occur at a temperature other than "hot day" as defined by FAR 23.

Plots of highest temperature achieved by cylinder heads one and two as a function of ground and "at altitude" OAT can be found in Figures 11 and 12. The data points have been connected by means of a "smooth" curve produced by Microsoft Excel (the software used to develop the plots). These figures suggest that there may be a condition around 65 F of ground (55 F at altitude) of OAT in which the maximum cylinder head temperatures occur. Evidently, there are not enough data points to draw the curves with confidence (no data point at the inflection point in the curves). Several test flights at different conditions are needed to confirm this finding and to increase the level of confidence on the temperatures found.

There can be very grave consequences for cylinder heads to have their highest temperatures at conditions other than what is defined as a hot day by FAR 23. An aircraft whose certification flights occurred on a hot day may experience hotter temperatures than the approved limits, with the corresponding threat to safe operations. This possibility is serious enough to warrant further study.

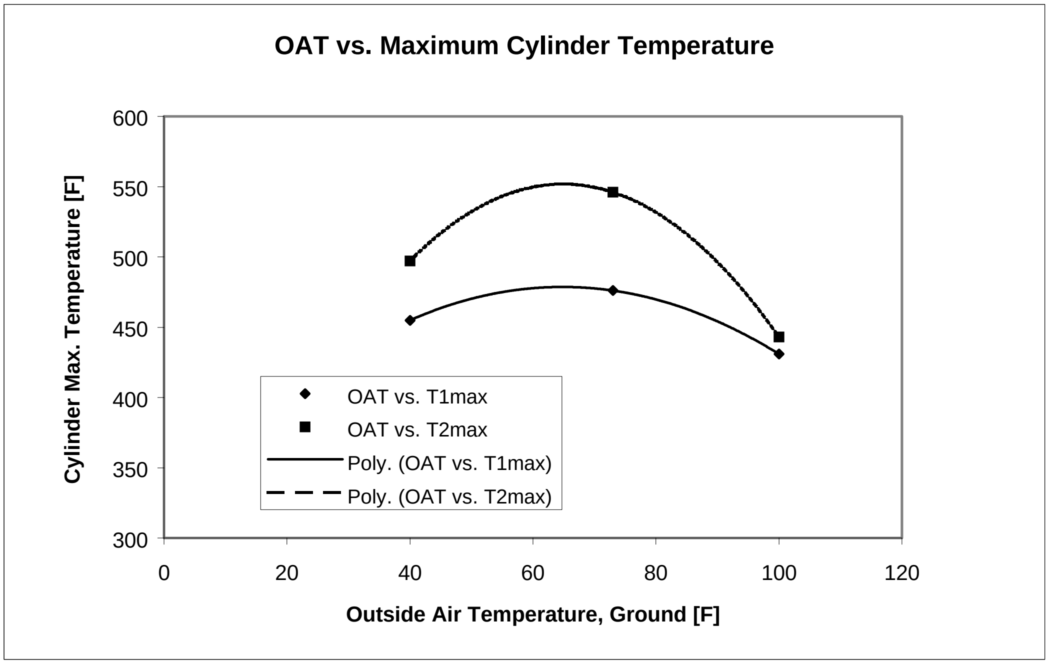

Figure 11. OAT at Ground vs. Maximum Cylinder Head Temperature.

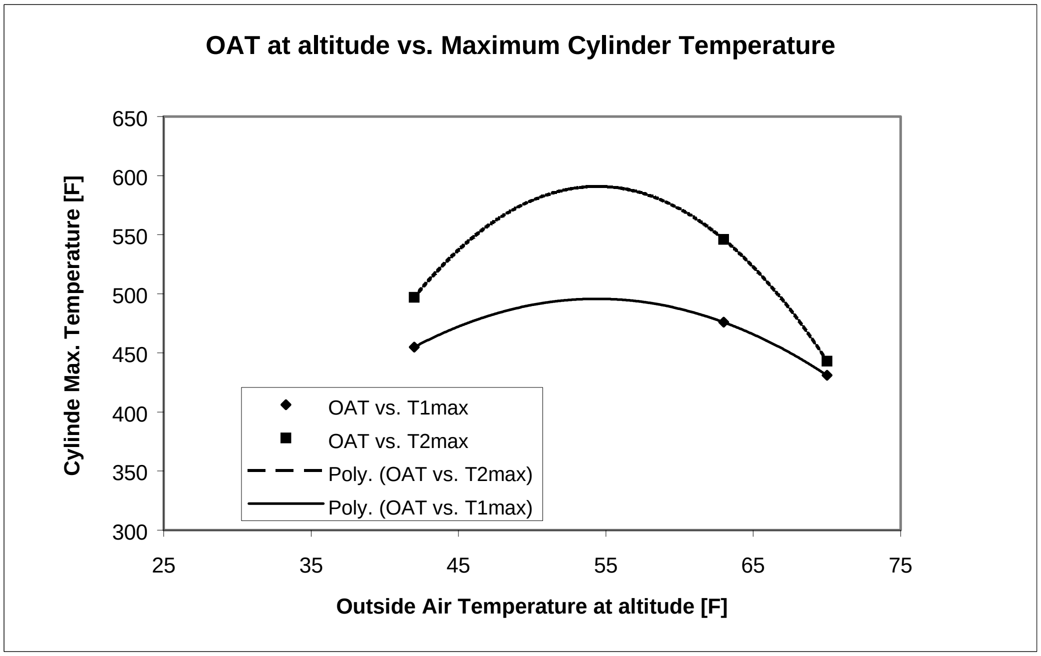

Figure 12. OAT at Altitude vs. Maximum Cylinder Head Temperature.

To investigate the qualities of the equation to correct for non-hot day condition provided by FAR 23, the data obtained in the first flight (true values on a hot day) and the corrected temperature values are plotted vs. calibrated pressure altitude for the heads of cylinders one and two in Figures 13 and 14. It can be seen that the equation over compensates for not flying in a hot day for as much as 70 F.

This over compensation of the equation may create the following problem: the same engine could be certified if flown on a hot day, but not if tested in different conditions.

It is evident that better means to correct data to standard conditions is required to be found.

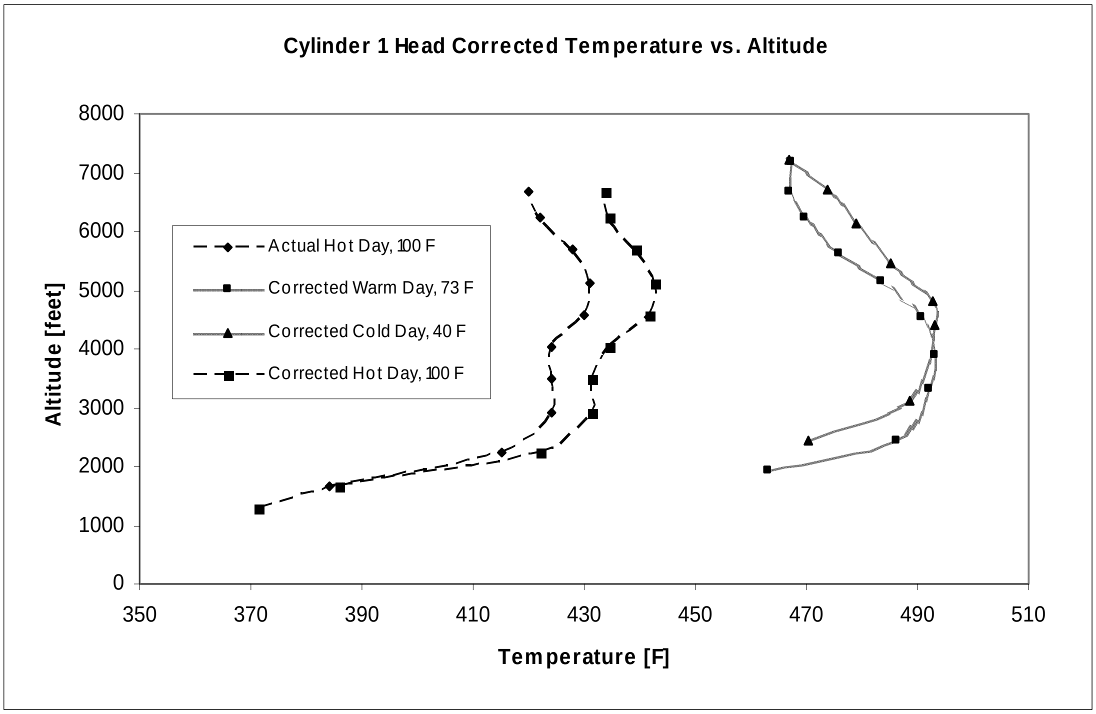

Figure 13. Corrected Cylinder 1 Head Temperature vs. Altitude.

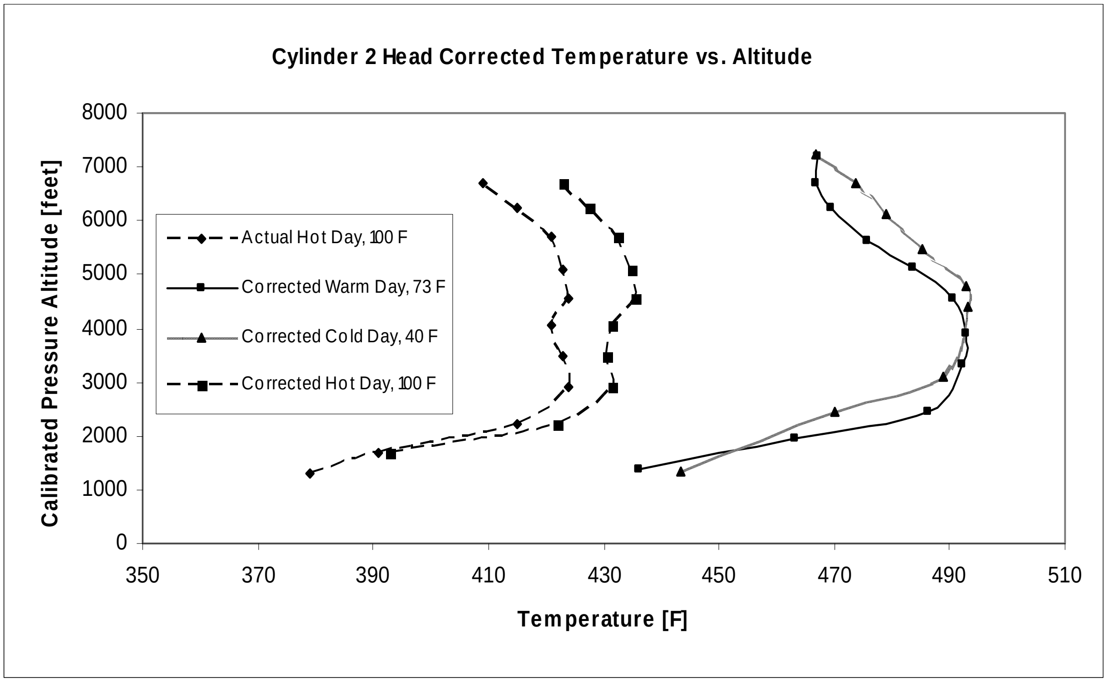

Figure 14. Corrected Cylinder 2 Head Temperature vs. Altitude.

The uncorrected cylinder head temperatures taken in all three flights was plotted vs. calibrated pressure altitude in Figures 15 and 16, for cylinders one and two respectively. It can be seen that as compared to the "true data" of the first flight, the temperatures of the second and third flights are still higher than this one, but for no more than 45 F.

It appears to be a better rationale not to use any equation at all to correct for flying in other than a hot day. The values obtained in the second and third flights are closer to the data collected on the first one, but still are conservative ones (we want to approximate the standard values from above to make sure an the cylinder heads are under 500 F for this aircraft).

Figure 17, a plot of OAT vs. Calibrated Pressure Altitude, shows that there was no significant temperature inversion during any of the three flights. The results presented above would have been in need of correction otherwise.

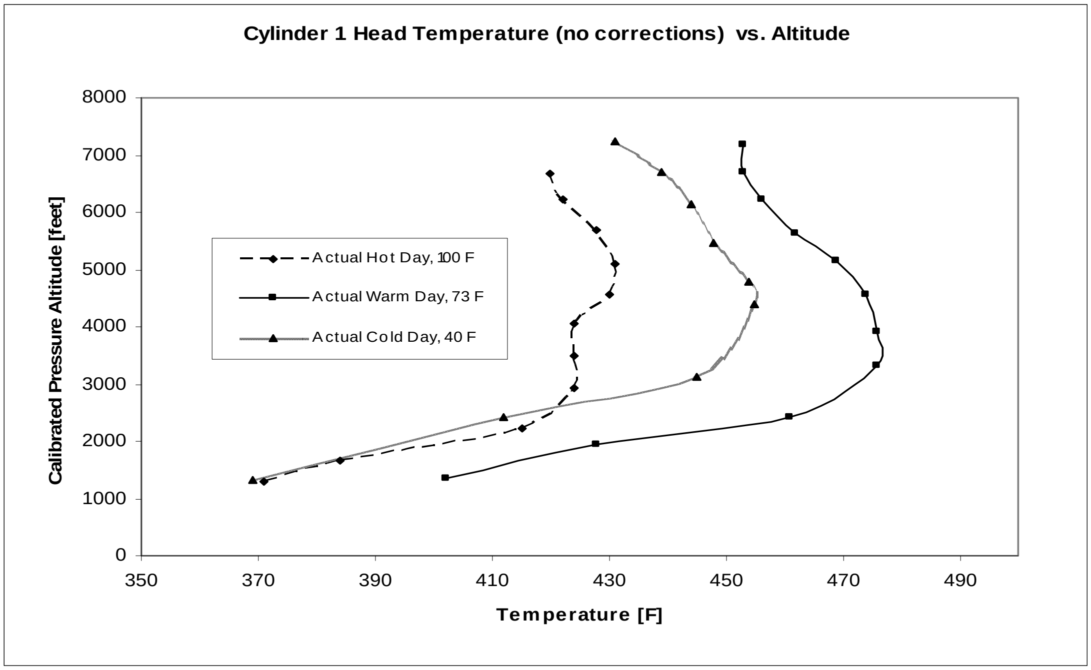

Figure 15. Uncorrected Cylinder 1 Head Temperature vs. Altitude.

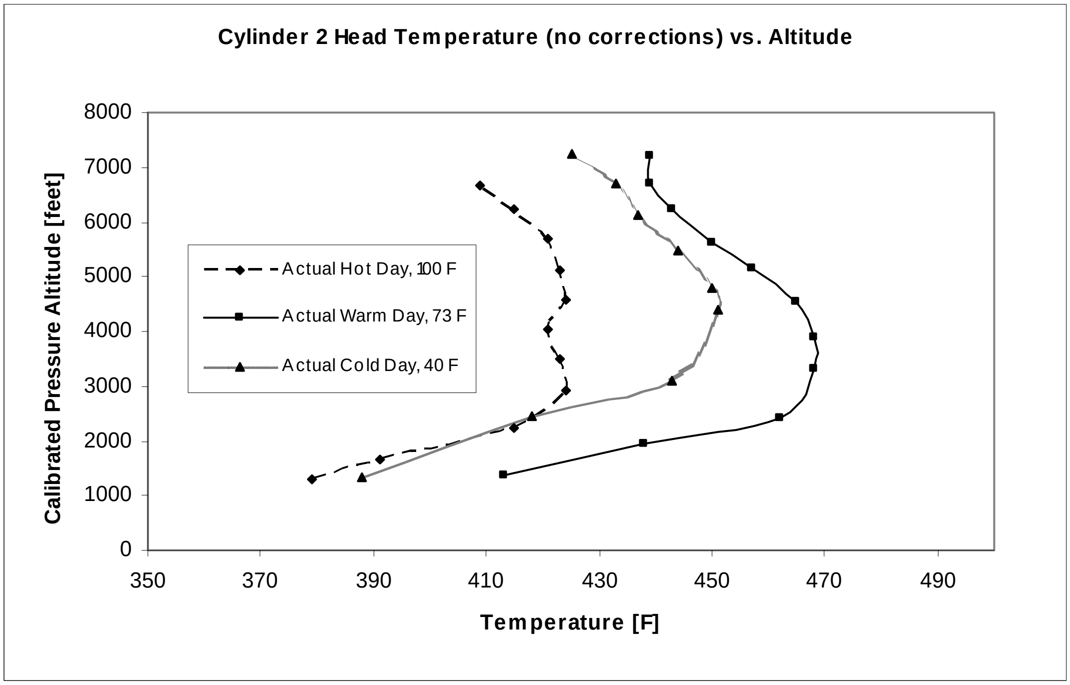

Figure 16. Uncorrected Cylinder 2 Head Temperature vs. Altitude.

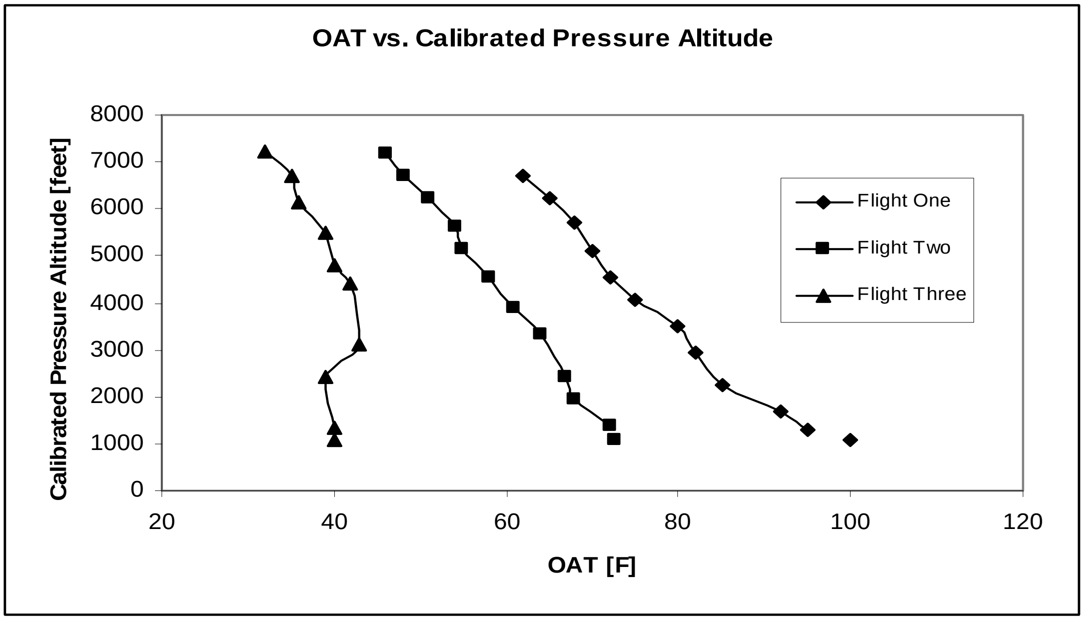

Figure 17. OAT vs. Calibrated Pressure Altitude.

CHAPTER VII

CONCLUSIONS

The Piper Saratoga complies with the cooling requirements of FAR 23 for cylinder head temperature.

From the first flight test, it was determined that the hottest cylinder was number one, and that the second hottest was number two. As a consequence of that, only the temperature of these two cylinders was recorded in subsequent flights.

The data analysis clearly shows that the equation to correct for non-standard conditions provided by the FARs overly compensates for an atmospheric temperature less than the one in a “hot day” condition. The error can mount up to 70 F. This equation over compensates even when applied to the data taken on a hot day as can be seen in Figures 5 and 6.

It has been found that if no correction is applied to the data taken on other than standard conditions, this data is still above the temperature recorded on a hot day, but by a much smaller margin than by the FARs. The error is no bigger than 45 F. I would consider this not to be a big value taken in consideration that the engine is operating in a temperature range of roughly 370 F to 480 F.

The above finding suggests that the atmospheric temperature has a minor role in determining the maximum temperature of a reciprocating engine. This is consistent with the fact that seasonal atmospheric variations are small in magnitude in comparison with the temperature ranges in which typical conventional engines operate.

The OAT vs. temperature both at ground and at altitude, suggests that there may be a OAT other that the one achieved during a hot day condition in which the highest temperature of the head of the cylinder will occur. This highest temperature produced by the engine may be due to an optimal combination of OAT and fuel mixture that results in a maximum rate of heat production from the engine.

CHAPTER VIII
RECOMMENDATIONS

A much broader investigation needs to be conducted to validate the results presented here. This research should encompass different engine models, as well as different aircrafts and different configurations. This comprehensive test plan should also consider different climate profiles.

If the proposed research confirms that there is an atmospheric temperature range other than the “hot day” condition in which reciprocating engines will have the highest operating temperature, some statistical analysis should be conducted to find a temperature range in which different engines can be tested. This has the potential to be a more reliable test rationale than the one currently in use: it will reduce the uncertainty of the FAR equation, would be a more demanding test, and would provide not just one temperature but a range in which the test could be conducted with confidence.

This thesis dealt only with cylinder head temperatures. Future research should also address the other engine components that require certification, such as the cylinders, bases, and oil temperature.

The occurrence of the maximum cylinder head temperature in a condition other than in a hot day should be investigated.

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REFERENCES

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7. **Website of the Tullahoma Municipal Airport**
   http://www.airnav.com/airport/KTHA

APPENDICES

APPENDIX 1

CALIBRATION CHARTS

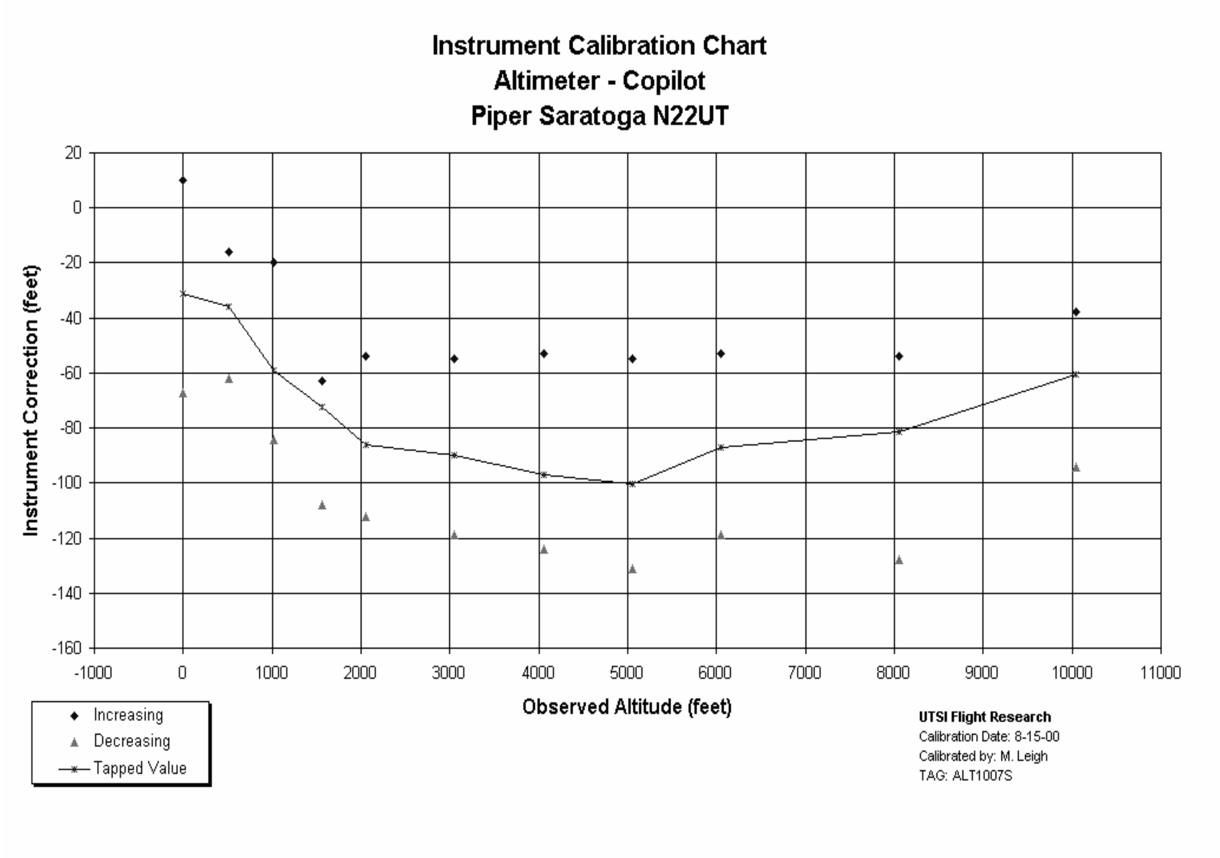


Figure 18. Copilot Altimeter Instrument Calibration Chart

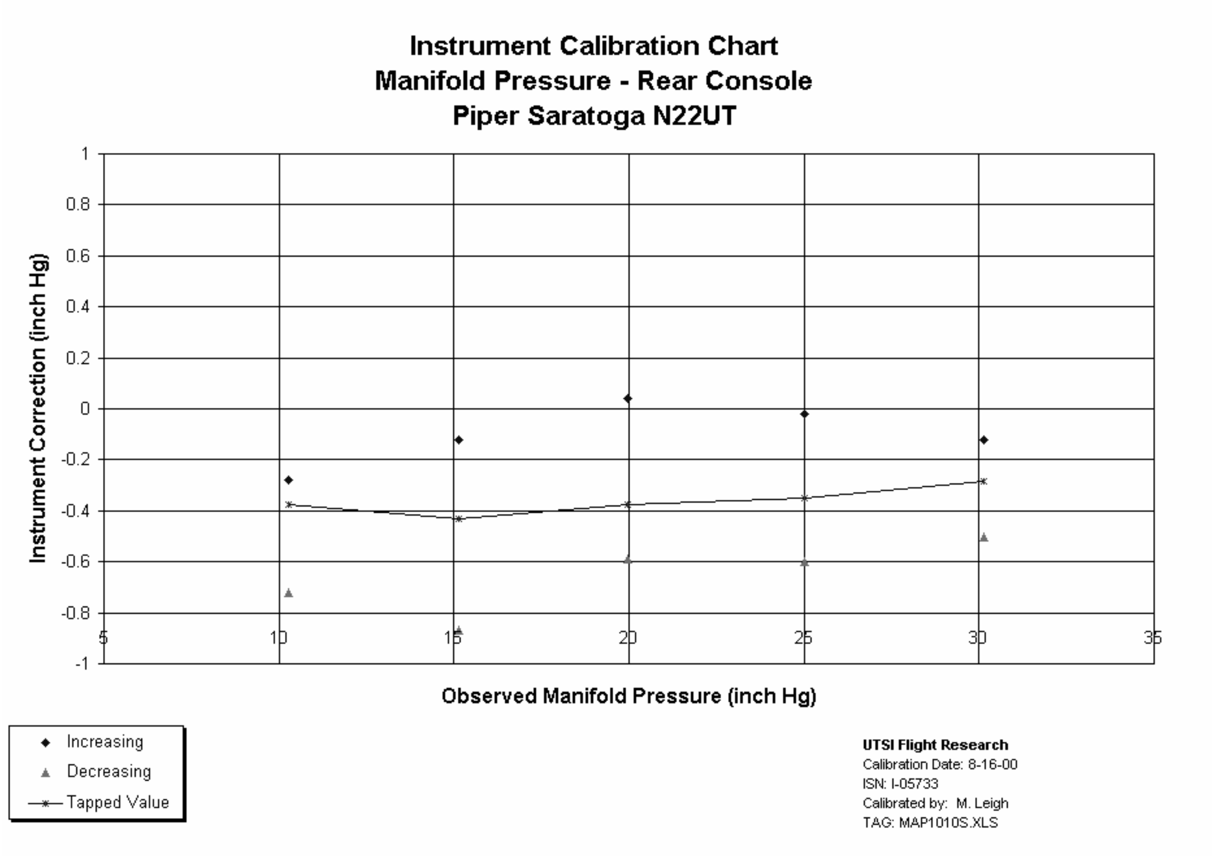


Figure 19. Rear Console Manifold Pressure Instrument Calibration Chart

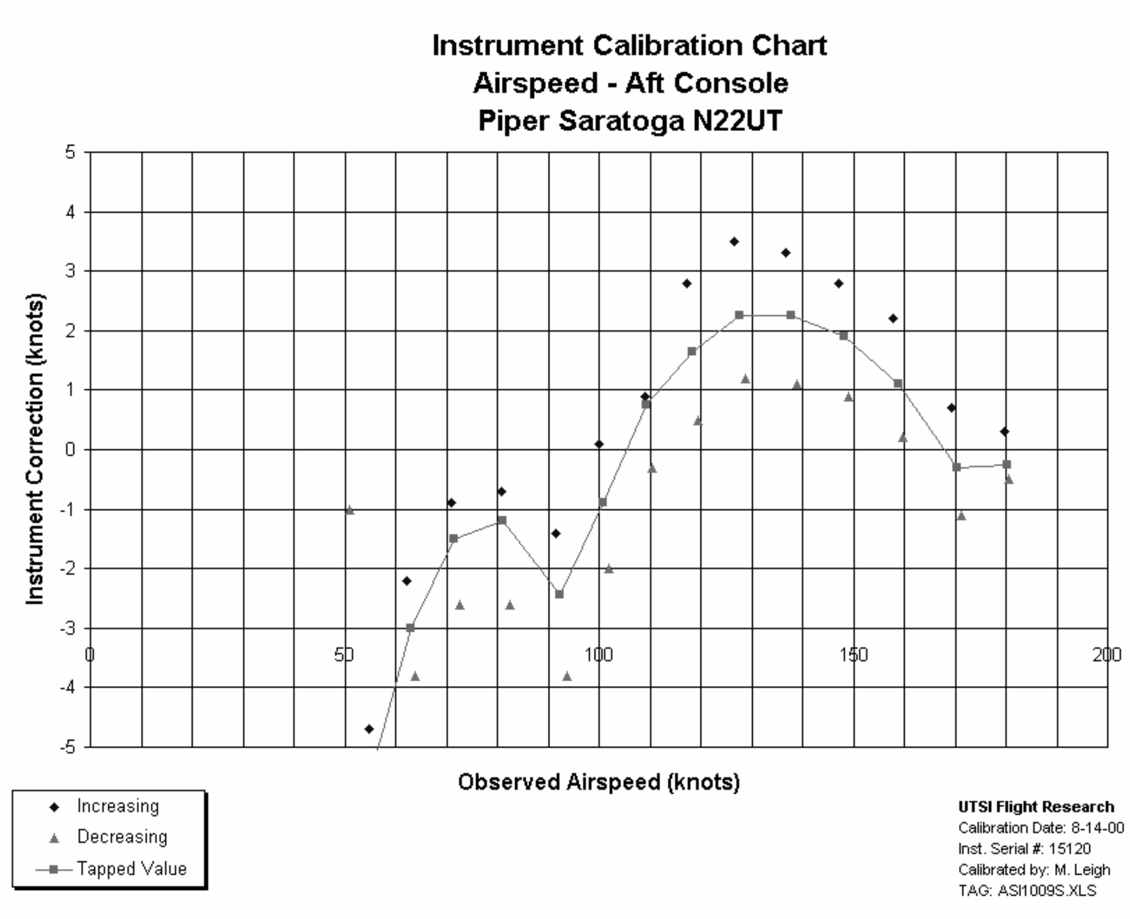
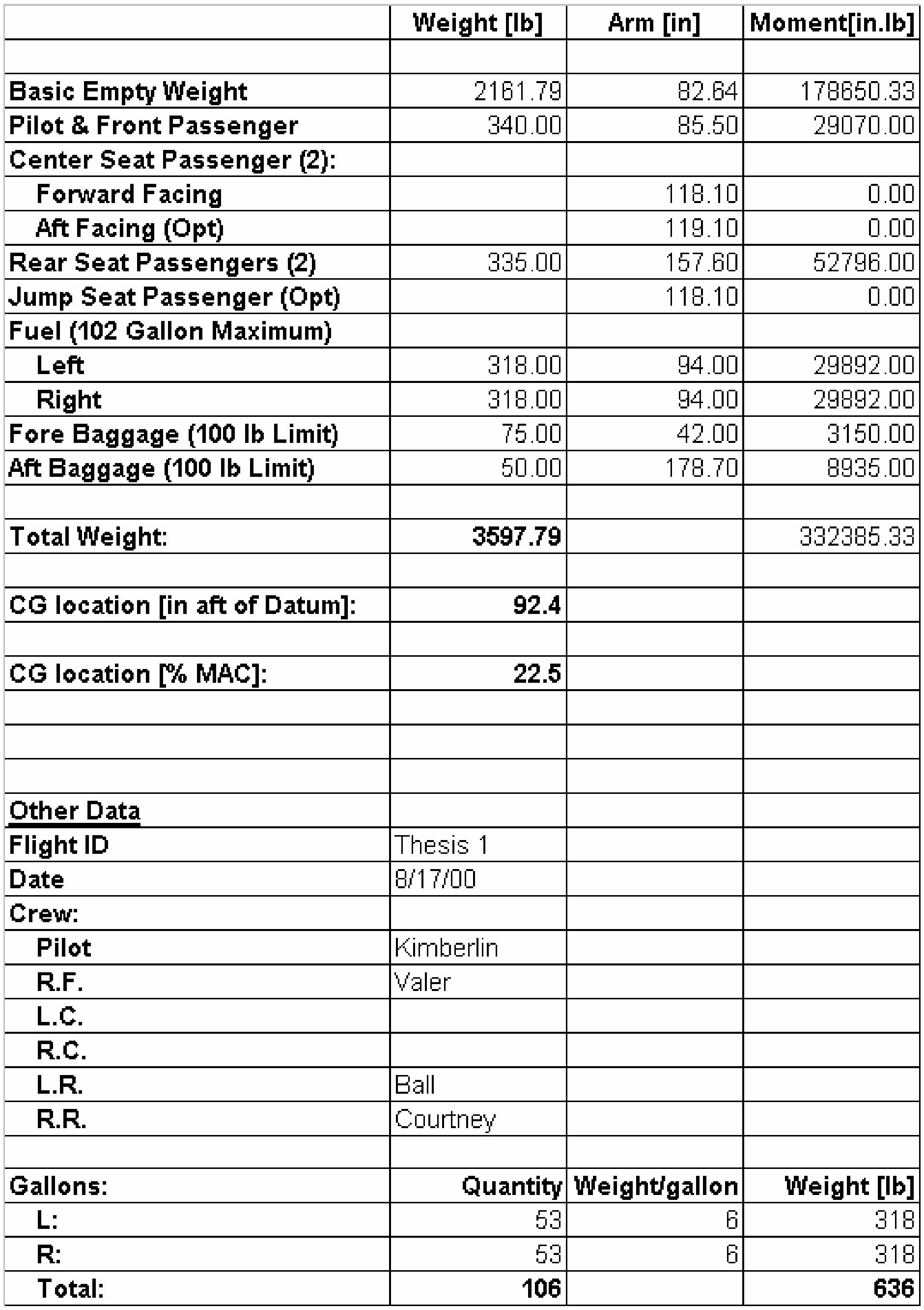


Figure 20. Aft Console Airspeed Instrument Calibration Chart

APPENDIX 2

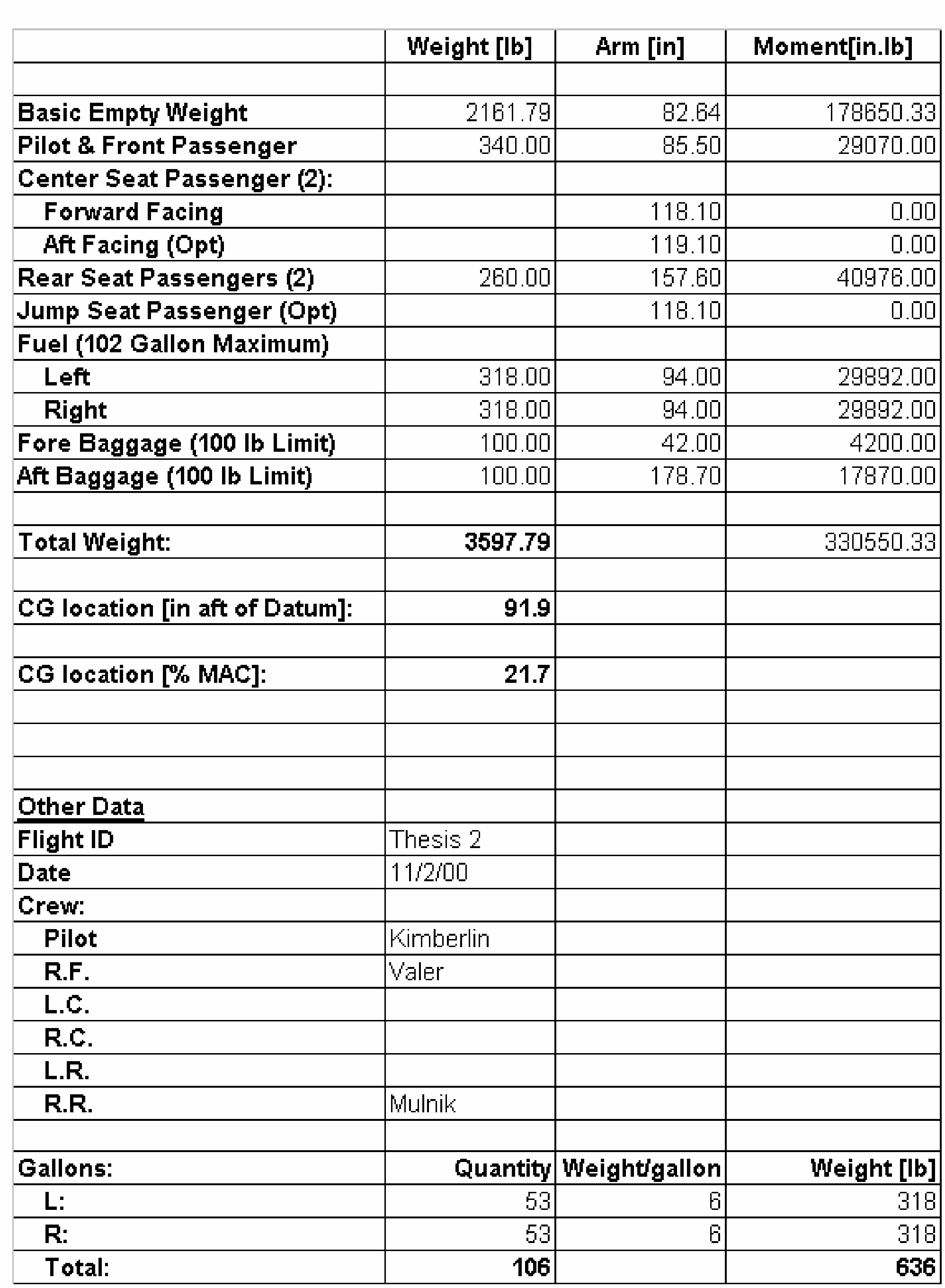
WEIGHT AND BALANCE

Table 1. Weight and Balance Flight 1.



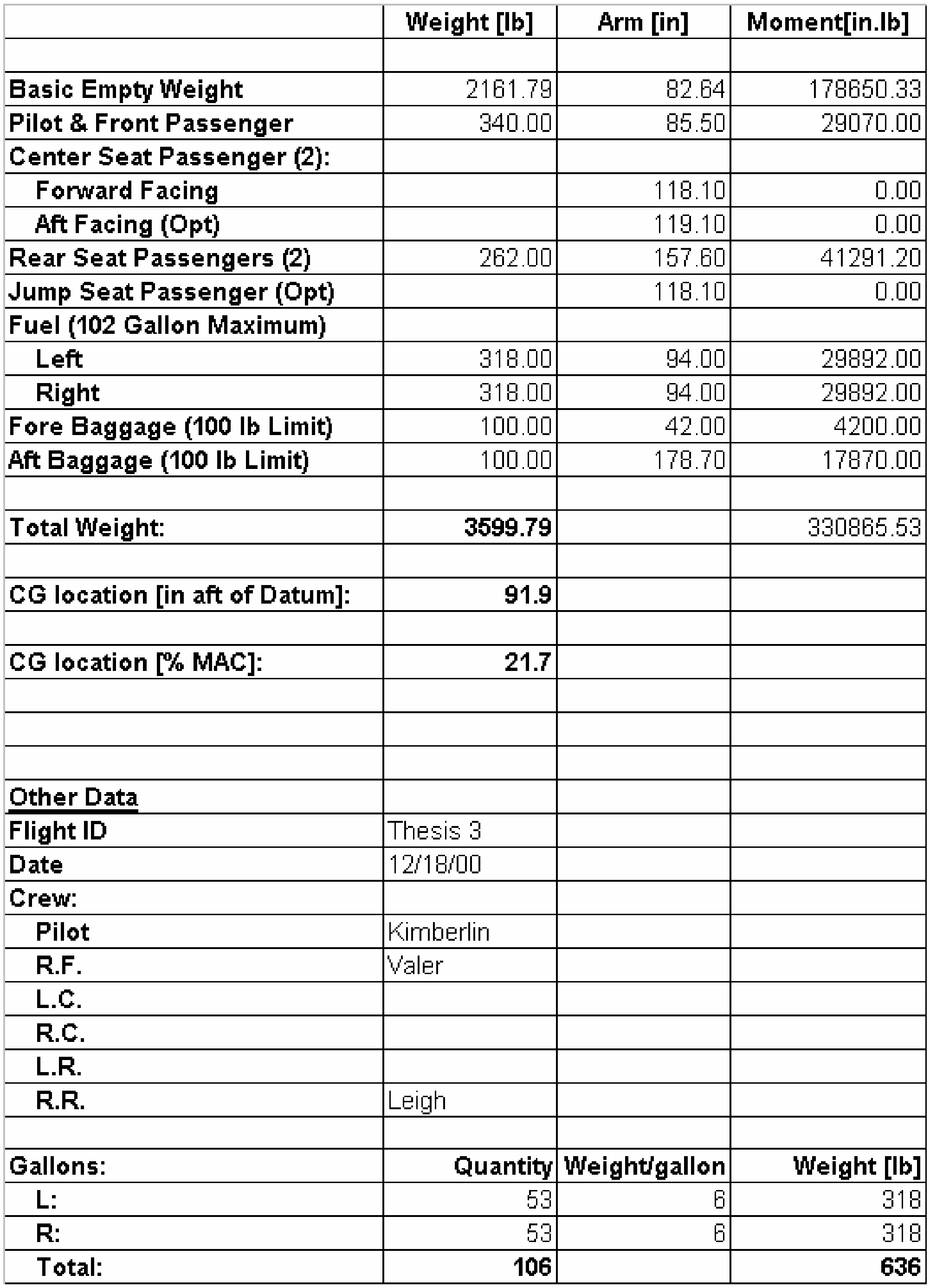
	Weight [lb]	Arm [in]	Moment[in.lb]
Basic Empty Weight	2161.79	82.64	178650.33
Pilot & Front Passenger	340.00	85.50	29070.00
Center Seat Passenger (2):			
Forward Facing		118.10	0.00
Aft Facing (Opt)		119.10	0.00
Rear Seat Passengers (2)	335.00	157.60	52796.00
Jump Seat Passenger (Opt)		118.10	0.00
Fuel (102 Gallon Maximum)			
Left	318.00	94.00	29892.00
Right	318.00	94.00	29892.00
Fore Baggage (100 lb Limit)	75.00	42.00	3150.00
Aft Baggage (100 lb Limit)	50.00	178.70	8935.00
Total Weight:	**3597.79**		332385.33
CG location [in aft of Datum]:	**92.4**		
CG location [% MAC]:	**22.5**		
Other Data			
Flight ID	Thesis 1		
Date	8/17/00		
Crew:			
Pilot	Kimberlin		
R.F.	Valer		
L.C.			
R.C.			
L.R.	Ball		
R.R.	Courtney		
Gallons:	Quantity	Weight/gallon	Weight [lb]
L:	53	6	318
R:	53	6	318
Total:	**106**		**636**

Table 2. Weight and Balance Flight 2.



	Weight [lb]	Arm [in]	Moment[in.lb]
Basic Empty Weight	2161.79	82.64	178650.33
Pilot & Front Passenger	340.00	85.50	29070.00
Center Seat Passenger (2):			
Forward Facing		118.10	0.00
Aft Facing (Opt)		119.10	0.00
Rear Seat Passengers (2)	260.00	157.60	40976.00
Jump Seat Passenger (Opt)		118.10	0.00
Fuel (102 Gallon Maximum)			
Left	318.00	94.00	29892.00
Right	318.00	94.00	29892.00
Fore Baggage (100 lb Limit)	100.00	42.00	4200.00
Aft Baggage (100 lb Limit)	100.00	178.70	17870.00
Total Weight:	**3597.79**		330550.33
CG location [in aft of Datum]:	**91.9**		
CG location [% MAC]:	**21.7**		
Other Data			
Flight ID	Thesis 2		
Date	11/2/00		
Crew:			
Pilot	Kimberlin		
R.F.	Valer		
L.C.			
R.C.			
L.R.			
R.R.	Mulnik		
Gallons:	**Quantity**	**Weight/gallon**	**Weight [lb]**
L:	53	6	318
R:	53	6	318
Total:	**106**		**636**

Table 3. Weight and Balance Flight 3.



	Weight [lb]	Arm [in]	Moment[in.lb]
Basic Empty Weight	2161.79	82.64	178650.33
Pilot & Front Passenger	340.00	85.50	29070.00
Center Seat Passenger (2):			
Forward Facing		118.10	0.00
Aft Facing (Opt)		119.10	0.00
Rear Seat Passengers (2)	262.00	157.60	41291.20
Jump Seat Passenger (Opt)		118.10	0.00
Fuel (102 Gallon Maximum)			
Left	318.00	94.00	29892.00
Right	318.00	94.00	29892.00
Fore Baggage (100 lb Limit)	100.00	42.00	4200.00
Aft Baggage (100 lb Limit)	100.00	178.70	17870.00
Total Weight:	**3599.79**		330865.53
CG location [in aft of Datum]:	**91.9**		
CG location [% MAC]:	**21.7**		
Other Data			
Flight ID	Thesis 3		
Date	12/18/00		
Crew:			
Pilot	Kimberlin		
R.F.	Valer		
L.C.			
R.C.			
L.R.			
R.R.	Leigh		
Gallons:	**Quantity**	**Weight/gallon**	**Weight [lb]**
L:	53	6	318
R:	53	6	318
Total:	**106**		**636**

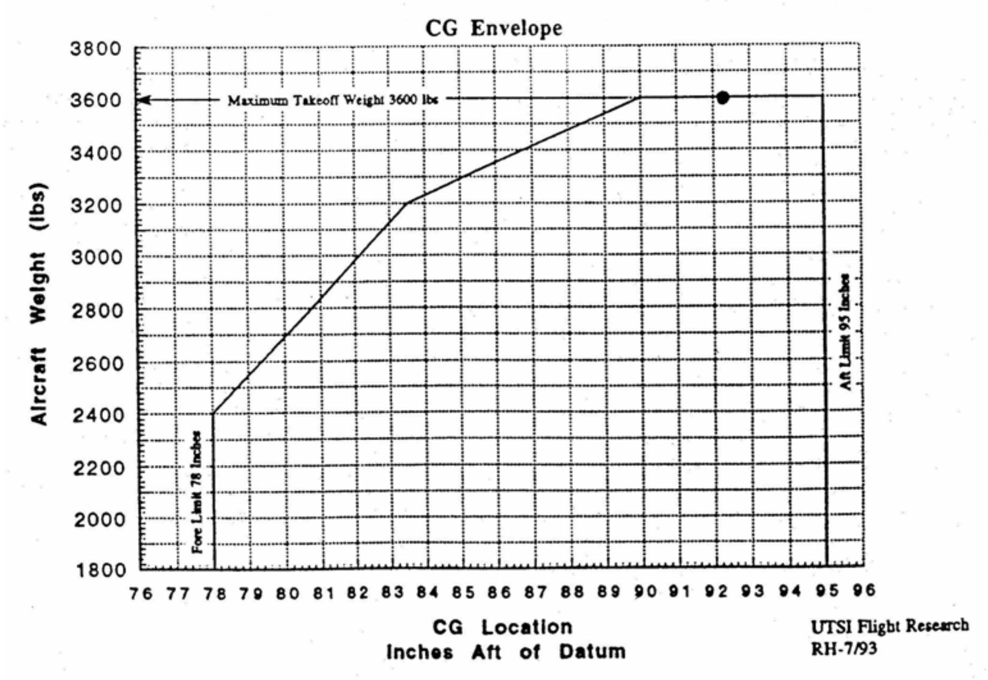


Figure 21. CG Location for Flight 1.

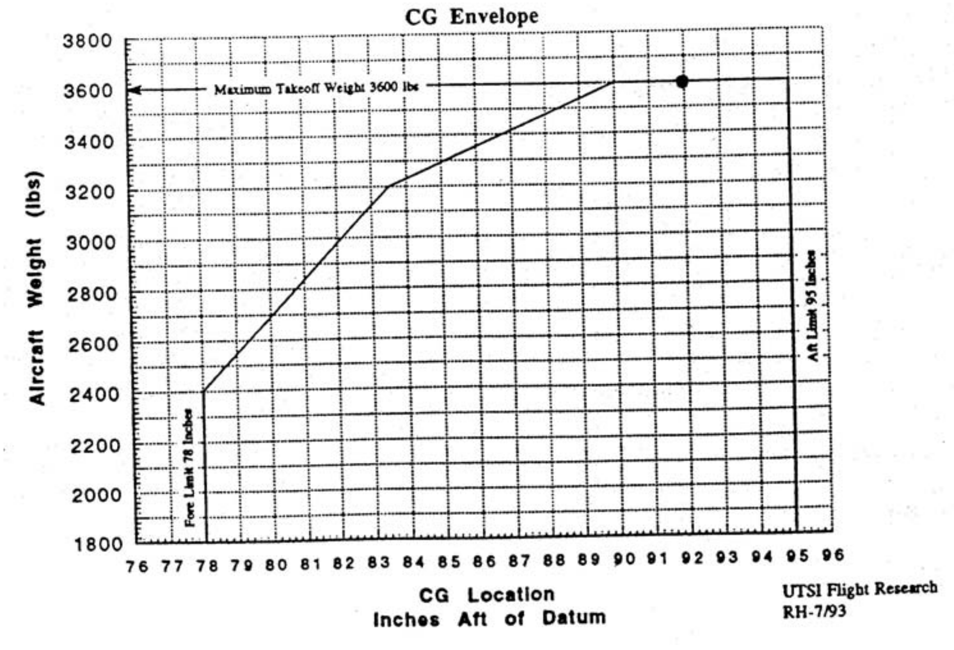
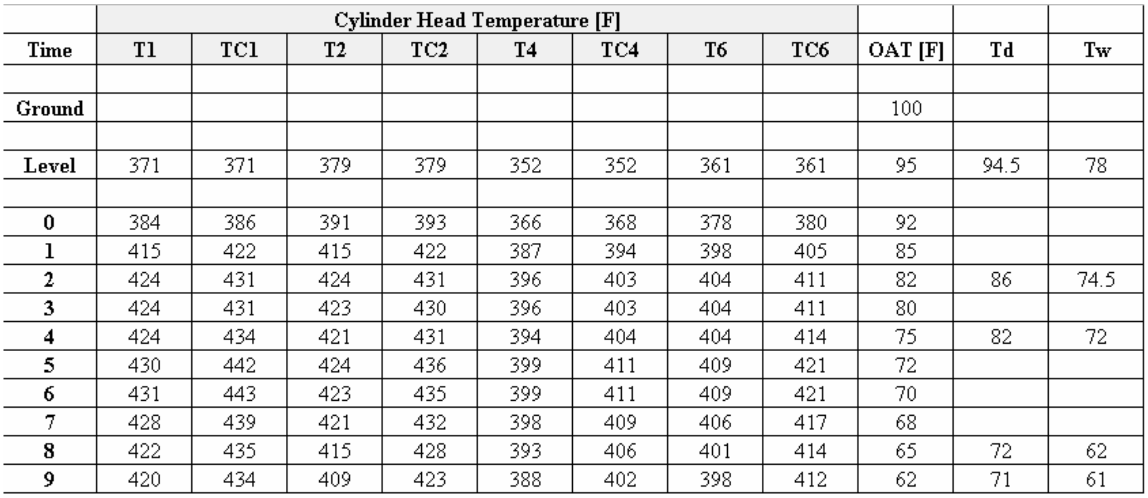


Figure 22. CG Location for Flights 2 and 3.

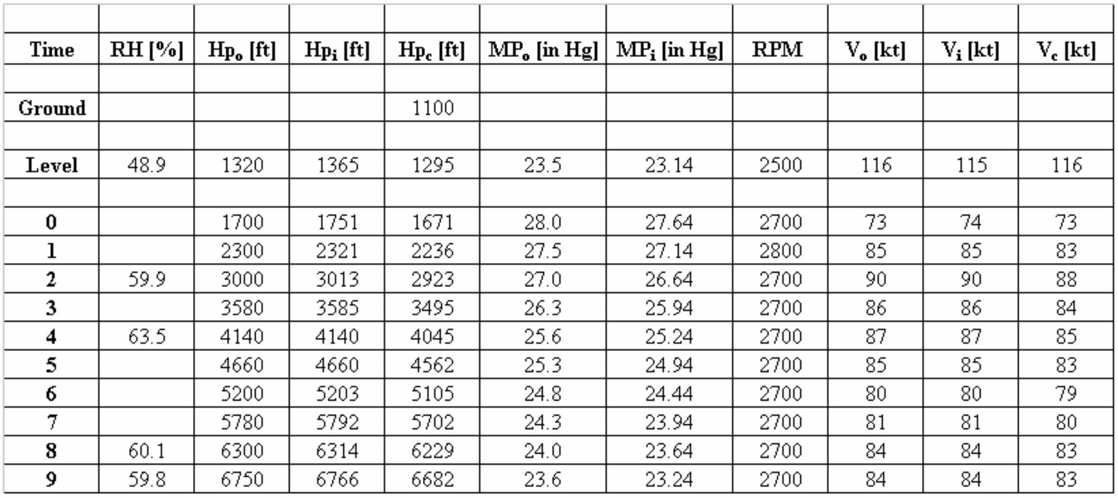
APPENDIX 3

DATA

Table 4. Data from Flight “Thesis 1”.

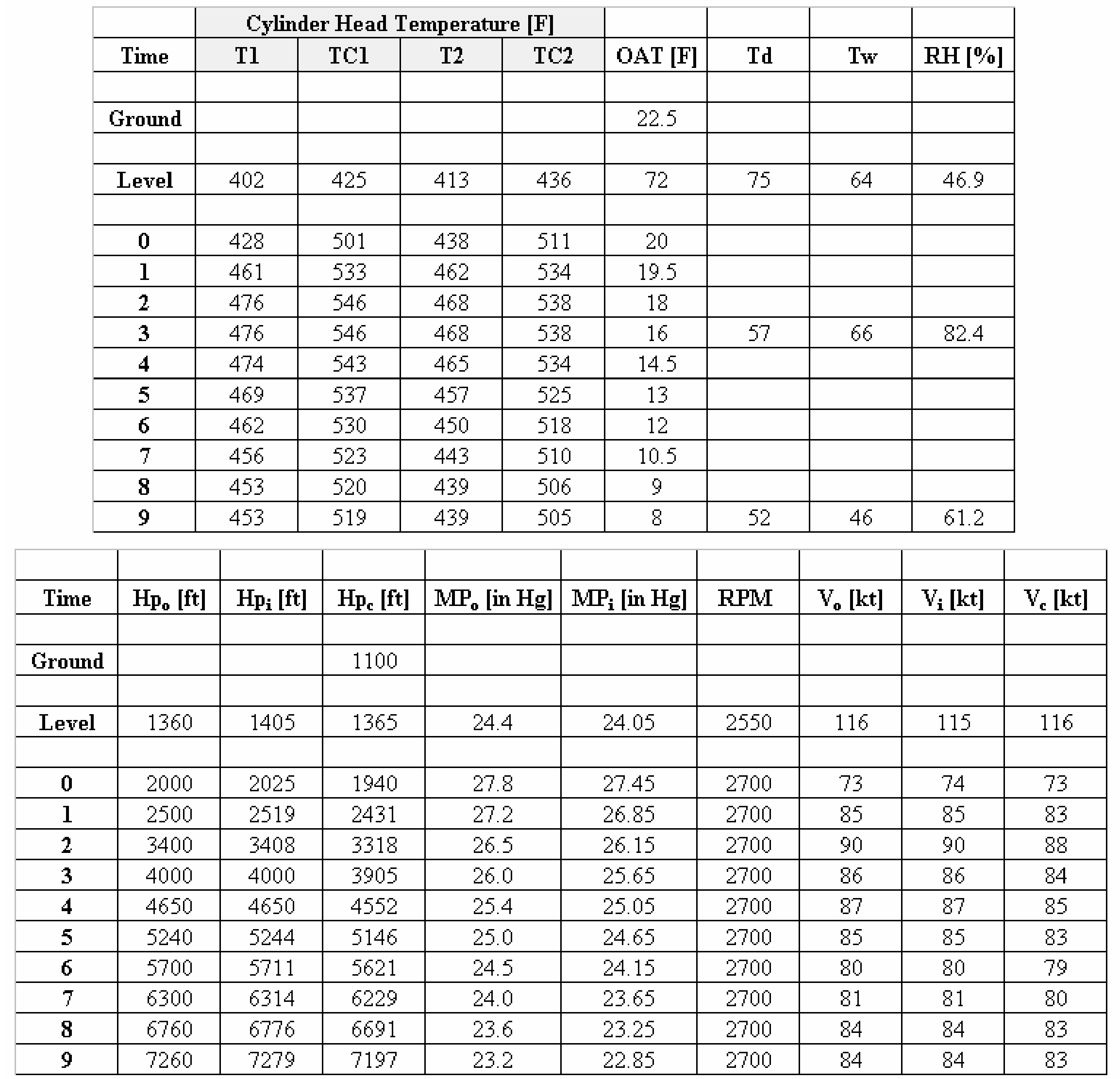


	Cylinder Head Temperature [F]										
Time	**T1**	**TC1**	**T2**	**TC2**	**T4**	**TC4**	**T6**	**TC6**	**OAT [F]**	**Td**	**Tw**
Ground									100		
Level	371	371	379	379	352	352	361	361	95	94.5	78
0	384	386	391	393	366	368	378	380	92		
1	415	422	415	422	387	394	398	405	85		
2	424	431	424	431	396	403	404	411	82	86	74.5
3	424	431	423	430	396	403	404	411	80		
4	424	434	421	431	394	404	404	414	75	82	72
5	430	442	424	436	399	411	409	421	72		
6	431	443	423	435	399	411	409	421	70		
7	428	439	421	432	398	409	406	417	68		
8	422	435	415	428	393	406	401	414	65	72	62
9	420	434	409	423	388	402	398	412	62	71	61



Time	**RH [%]**	**Hp_o [ft]**	**Hp_i [ft]**	**Hp_c [ft]**	**MP_o [in Hg]**	**MP_i [in Hg]**	**RPM**	**V_o [kt]**	**V_i [kt]**	**V_c [kt]**
Ground				1100						
Level	48.9	1320	1365	1295	23.5	23.14	2500	116	115	116
0		1700	1751	1671	28.0	27.64	2700	73	74	73
1		2300	2321	2236	27.5	27.14	2800	85	85	83
2	59.9	3000	3013	2923	27.0	26.64	2700	90	90	88
3		3580	3585	3495	26.3	25.94	2700	86	86	84
4	63.5	4140	4140	4045	25.6	25.24	2700	87	87	85
5		4660	4660	4562	25.3	24.94	2700	85	85	83
6		5200	5203	5105	24.8	24.44	2700	80	80	79
7		5780	5792	5702	24.3	23.94	2700	81	81	80
8	60.1	6300	6314	6229	24.0	23.64	2700	84	84	83
9	59.8	6750	6766	6682	23.6	23.24	2700	84	84	83

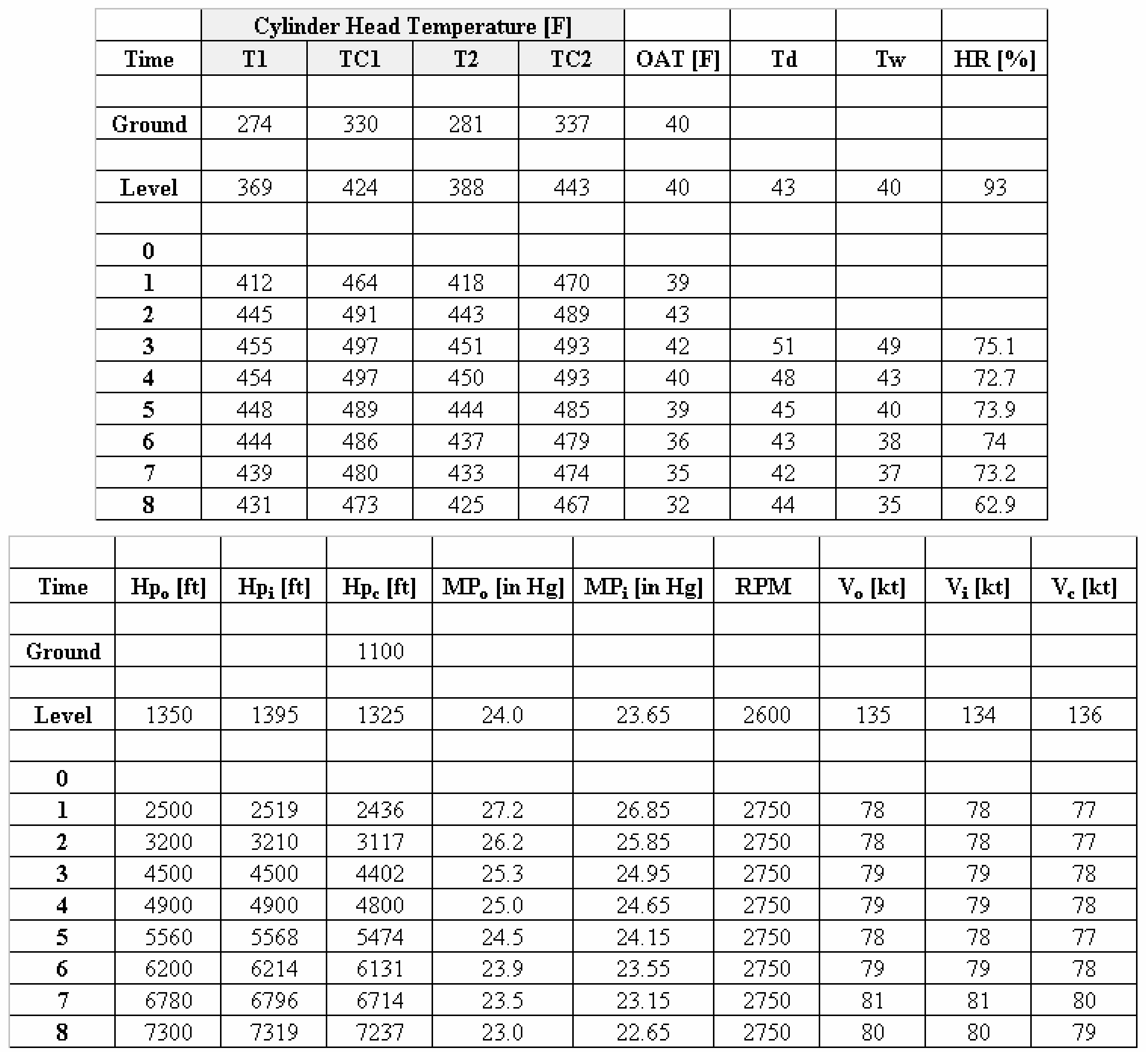
Table 5. Data from Flight “Thesis 2”.



	Cylinder Head Temperature [F]							
Time	**T1**	**TC1**	**T2**	**TC2**	**OAT [F]**	**Td**	**Tw**	**RH [%]**
Ground					22.5			
Level	402	425	413	436	72	75	64	46.9
0	428	501	438	511	20			
1	461	533	462	534	19.5			
2	476	546	468	538	18			
3	476	546	468	538	16	57	66	82.4
4	474	543	465	534	14.5			
5	469	537	457	525	13			
6	462	530	450	518	12			
7	456	523	443	510	10.5			
8	453	520	439	506	9			
9	453	519	439	505	8	52	46	61.2

Time	**Hp_o [ft]**	**Hp_i [ft]**	**Hp_c [ft]**	**MP_o [in Hg]**	**MP_i [in Hg]**	**RPM**	**V_o [kt]**	**V_i [kt]**	**V_c [kt]**
Ground			1100						
Level	1360	1405	1365	24.4	24.05	2550	116	115	116
0	2000	2025	1940	27.8	27.45	2700	73	74	73
1	2500	2519	2431	27.2	26.85	2700	85	85	83
2	3400	3408	3318	26.5	26.15	2700	90	90	88
3	4000	4000	3905	26.0	25.65	2700	86	86	84
4	4650	4650	4552	25.4	25.05	2700	87	87	85
5	5240	5244	5146	25.0	24.65	2700	85	85	83
6	5700	5711	5621	24.5	24.15	2700	80	80	79
7	6300	6314	6229	24.0	23.65	2700	81	81	80
8	6760	6776	6691	23.6	23.25	2700	84	84	83
9	7260	7279	7197	23.2	22.85	2700	84	84	83

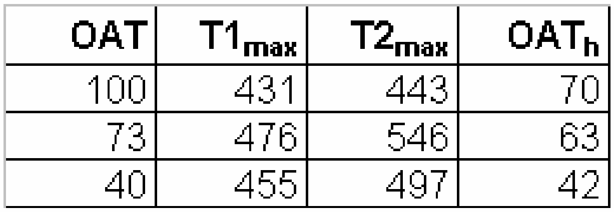
Table 6. Data from Flight “Thesis 3”.



	Cylinder Head Temperature [F]							
Time	T1	TC1	T2	TC2	OAT [F]	Td	Tw	HR [%]
Ground	274	330	281	337	40			
Level	369	424	388	443	40	43	40	93
0								
1	412	464	418	470	39			
2	445	491	443	489	43			
3	455	497	451	493	42	51	49	75.1
4	454	497	450	493	40	48	43	72.7
5	448	489	444	485	39	45	40	73.9
6	444	486	437	479	36	43	38	74
7	439	480	433	474	35	42	37	73.2
8	431	473	425	467	32	44	35	62.9

Time	Hp_o [ft]	Hp_i [ft]	Hp_c [ft]	MP_o [in Hg]	MP_i [in Hg]	RPM	V_o [kt]	V_i [kt]	V_c [kt]
Ground			1100						
Level	1350	1395	1325	24.0	23.65	2600	135	134	136
0									
1	2500	2519	2436	27.2	26.85	2750	78	78	77
2	3200	3210	3117	26.2	25.85	2750	78	78	77
3	4500	4500	4402	25.3	24.95	2750	79	79	78
4	4900	4900	4800	25.0	24.65	2750	79	79	78
5	5560	5568	5474	24.5	24.15	2750	78	78	77
6	6200	6214	6131	23.9	23.55	2750	79	79	78
7	6780	6796	6714	23.5	23.15	2750	81	81	80
8	7300	7319	7237	23.0	22.65	2750	80	80	79

Table 7. OAT vs. Maximum Cylinder Head Temperature.



OAT	$T1_{max}$	$T2_{max}$	OAT_h
100	431	443	70
73	476	546	63
40	455	497	42

VITA

Juan Carlos Valer was born in Lima, Peru, on May 13, 1968. He attended grades one to twelve at the Peruvian-British school. From there, he went to the Pontifical Catholic University of Peru, Lima, Peru, and received a B.S. in Chemistry. He was later admitted to the National Air Academy of Peru, Lima, Peru, where he got a Private Pilot's License.

Juan Carlos was admitted to the University of Tennessee Space Institute, Tullahoma, Tennessee, USA, where he got a M.S. in Aerospace Engineering in August 2002 and a M.S. in Aviation Systems in Decmeber 2003. He is expected to obtain a M.S. in Mechanical Engineering in December 2003.

Juan Carlos started his doctoral studies in Aerospace Engineering at the University of Tennessee Space Institute, and will conclude them in the University of Southampton, United Kingdom.