ABSTRACT

Flight Performance Testing of Ethanol/100LL Fuel Blends During Cruise Flight

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Aviation gasoline, 100LL, is the last fuel in the U.S. containing lead. Additionally, the cost of 100LL avgas now averages $4.64/gal. This combination will eventually require an operational transition within the general aviation (GA) community. A contract was awarded to the Baylor Institute for Air Science to determine the feasibility of operating piston engine aircraft on all blends of ethanol and 100LL avgas during the transition period. This thesis focused on engine performance associated with multiple engine power settings on a Cessna 152 /Lycoming O-235 airframe/power plant combination. Flight performance data was collected with an engine data monitor (EDM) augmented by flight crew observations. Results indicate linear-like trends in temperature correlation through a set of pre-determined fuel blends. Engine performance limits were not exceeded during this investigation.

Flight Performance Testing of Ethanol/100LL Fuel Blends During Cruise Flight

by

Timothy James Compton, B.S.

A Thesis

Approved by the Institute for Air Science

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NOMENCLATURE

CONSTANTS

Symbol	Name	Value
d	density of water	8.33 lbs./gal. at 25°C
W_{empty}	empty container weight	pounds
P_0	Mean sea level pressure	29.92 in. Hg

VARIABLES

Symbol	Name	Units
t	elapsed time	seconds
W*	weight of the container after 60 seconds of filling	pounds
SG_{blend}	specific gravity of the fuel blend being calculated	unitless
FlowRate	flow rate	gallons/hour
Δ_{mass}	$W^* - W_{empty}$	pounds
P	Pressure	in. Hg
h	Height	feet

ABREVIATIONS

100LL	100 Octane Low Lead Aviation Fuel
A & P	Airframe and Powerplant
AWOS	Automated Weather Observation System
AVGAS	Aviation Gasoline
BTU	British Thermal Unit
CRM	Cockpit Resource Management
CHT	Cylinder Head Temperature
EDM	Engine Data Monitor
EGT	Exhaust Gas Temperature
GA	General Aviation
GPS	Global Positioning System
MSL	Mean Sea Level
PA	Pressure Altitude
RPM	Revolutions Per Minute
SRT	Standard Rate Turn
STC	Supplemental Type Certificate
TAS	True Air Speed
TBO	Time Between Overhaul
V_{S0}	Stalling Speed in the Landing Configuration
V_{S1}	Stalling speed in a Specific Configuration
VSI	Vertical Speed Indicator

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CHAPTER ONE

Introduction and Background

Problem Statement

The purpose of this study is to develop an understanding of blends of ethanol and 100 low-lead aviation gasoline (100LL or 100LL avgas) and to determine to what extent this use of ethanol effects performance and safety.

Increasing environmental awareness has brought with it the awareness of a need for alternative fuels within the world's transportation industry. A couple of problems face general aviation (GA) pilots who wish to make the transition to ethanol fueled aircraft. These problems include a lack of an existing GA ethanol fuel infrastructure and the need for proven real-world data. Although the world has seen several pioneering efforts successfully demonstrate the practicality of alternative fuels in the field, the mindset of the aviation community is just recently beginning to shift in that direction.

The fuel currently used by the general aviation segment is known as 100LL or avgas, short for aviation gasoline. 100LL avgas stands for 100 octane, low-lead, since the fuel contains Tetraethyl Lead (TEL), an anti-knocking additive that improves octane rating. The American Society for Testing and Materials (ASTM) specifications limit the maximum amount of lead contained in 100LL avgas to 2 grams per US gallon, which is equivalent to 0.56 grams/liter.[1] Lead, a neurotoxin, has been removed from all other forms of conventional gasoline. 100LL avgas is now the only fuel in the United States still containing lead.

Estimates provided by the Federal Aviation Administration (FAA) cite that 262.2 million gallons of 100LL avgas were consumed in 2006; a 2.6% increase in consumption from 2005. Furthermore, forecasts estimate the consumption will increase to 286 million gallons in 2010 and 301 million gallons by 2015.[2] These numbers would result in a 9.2% and 13% increase, respectively, from today's usage. Figure 1 shows historic and forecast aviation aircraft fuel consumption values.

GENERAL AVIATION AIRCRAFT FUEL CONSUMPTION

(In Millions of Gallons)

	FIXED WING										
	PISTON		TURBINE		ROTORCRAFT		EXPERI-MENTAL/		TOTAL FUEL CONSUMED		
CALENDAR YEAR	SINGLE ENGINE	MULTI-ENGINE	TURBO-PROP	TURBO-JET	PISTON	TURBINE	OTHER	SPORT	AVGAS	JET FUEL	TOTAL
Historical											
2000	200.8	108.4	176.3	736.7	8.4	59.0	15.2	NA	332.8	972.0	1,304.8
2001	180.4	76.4	149.1	726.7	7.2	42.6	15.3	NA	279.2	918.3	1,197.6
2002	177.9	74.2	152.3	745.5	6.8	40.5	17.8	NA	276.7	938.3	1,215.0
2003	181.8	66.7	154.5	729.0	6.8	48.8	17.1	NA	272.4	932.3	1,204.7
2004	167.5	80.1	167.0	1,004.9	7.9	59.0	17.5	NA	272.9	1,230.9	1,503.8
2005	149.8	77.6	166.5	1,017.1	10.4	71.7	17.7	0.0	255.4	1,255.3	1,510.7
2006E	152.4	77.9	165.3	1,048.7	11.7	74.8	19.6	0.7	262.2	1,288.8	1,551.0
Forecast											
2007	155.3	78.5	166.6	1,162.3	13.0	77.4	20.7	0.9	268.3	1,406.3	1,674.6
2008	158.4	79.1	168.1	1,304.4	14.3	79.9	21.4	1.2	274.4	1,552.5	1,826.9
2009	161.7	79.7	169.5	1,460.0	15.6	81.9	22.5	1.5	280.9	1,711.4	1,992.3
2010	165.2	79.9	168.6	1,633.2	16.9	83.8	22.9	1.8	286.5	1,885.6	2,172.1
2011	168.7	80.5	170.0	1,826.8	18.2	85.9	23.4	2.1	292.9	2,082.7	2,375.5
2012	167.9	80.2	171.4	2,013.4	19.2	87.9	24.1	2.4	293.8	2,272.7	2,566.5
2013	167.0	79.9	170.3	2,203.6	20.2	89.9	24.4	2.7	294.3	2,463.8	2,758.0
2014	165.9	79.6	171.4	2,382.1	21.4	92.1	24.7	3.1	294.7	2,645.7	2,940.4
2015	166.3	79.3	172.6	2,554.7	22.3	94.3	25.0	3.5	296.3	2,821.6	3,117.8
2016	166.5	79.0	171.5	2,726.3	23.0	96.4	25.2	3.7	297.4	2,994.3	3,291.7
2017	166.5	78.7	173.2	2,899.0	23.9	98.2	25.6	4.0	298.7	3,170.4	3,469.1
2018	166.5	78.3	174.9	3,073.0	24.6	100.3	26.0	4.2	300.1	3,348.2	3,648.3
2019	166.4	78.0	174.4	3,246.0	25.4	102.1	26.4	4.4	300.5	3,522.5	3,823.0
2020	166.3	77.7	176.2	3,418.5	25.9	104.0	26.7	4.6	301.2	3,698.7	3,999.9
Avg Annual Growth:											
2000-06	-4.5%	-5.4%	-1.1%	6.1%	5.7%	4.0%	4.3%		-3.9%	4.8%	2.9%
2006-10	2.0%	0.6%	0.5%	11.7%	9.6%	2.9%	4.0%	27.9%	2.2%	10.0%	8.8%
2010-20	0.1%	-0.3%	0.4%	7.7%	4.4%	2.2%	1.6%	10.1%	0.5%	7.0%	6.3%
2006-20	0.6%	0.0%	0.5%	8.8%	5.8%	2.4%	2.2%	14.9%	1.0%	7.8%	7.0%

Source: FAA APO Estimates.
Note: Detail may not add to total because of independent rounding.

Figure 1. Historical and forecast general aviation aircraft fuel consumption values. Calendar years include 2000 – 2020.

The presence of lead, the increase in consumption of petroleum-based 100LL avgas and the positive economical benefits associated with the transition to ethanol in the

GA fleet all support the case for ethanol. At this time, ethanol emerges as the most sensible replacement for 100LL avgas.

Additionally, the general aviation community needs to have reliable data concerning ethanol. Understanding the full scope of operational engine performance using ethanol will aid the GA pilot in making the best possible decisions in the field. Characteristic differences in fuel types, such as energy content, vapor pressure, latent heat of vaporization, and stoichiometric values, to name a few, should be understood throughout the industry.

This study focuses on aircraft engine cruise performance when including ethanol as a fuel. Performance parameters including cylinder head temperatures (CHT), exhaust gas temperatures (EGT), fuel consumption, and power available are discussed. To collect data, this study utilized an engine data management system (EDM) and global positioning satellites (GPS), in conjunction with data reduction software. Aircraft and engine performance data were analyzed for a range of blends of ethanol and 100LL avgas.

Background

Initial United States ethanol programs operated well into the 1930's before giving way to petroleum based fuels. Several decades later, the Arab oil embargo of 1973 led to a decrease in crude supply. This prompted interest in conventional fuel substitutes and renewable energies. Since that time, a series of federal government incentives, including the 1978 Energy Tax Act have kept ethanol development on the radar.[3] More recently, the Energy Policy Act of 1992 set a national goal to see 30% of all light-duty vehicles using alternative fuels by 2010.[4] Throughout these efforts, the government's major focus has been toward ground transportation.

Aviation fuel, specifically aviation gasoline, represents only a fraction of all transportation fuel consumed. The Bureau of Transportation Statistics (BTS) released the latest fuel consumption statistics in April of 2007. The publication, *National Transportation Statistics (NTS)* [5], shows aviation gasoline accounting for only a very small part of the larger fuel consumption picture. In fact, aviation gasoline and jet fuel combine for only 7.3% of all transportation fuel consumed. 100LL, on its own accord, makes up only 0.1 % of all transportation fuel consumed.

The small contribution percentage of 100LL helps to foster an "it's not important enough" stance. Consequently, 100LL continues to elude the list of fuels to be banned and the hazards associated with it are simply disregarded. In short, U.S. policy treatment does not address the need for replacement of 100LL as a result of it's of non-significant output.

Aviation has however flirted with alternative fuels such as ethanol and bio-diesel. Ethanol began a vital wartime role during World War II by replacing the shrinking supply of gasoline. Both the German and United States armies fueled many of their ground vehicles with ethanol. Japanese aviation fuel did contain some ethanol.[6] The United States conducted a joint Army-Navy aeronautic fuel specification testing program during World War II.[7, 8] However, literature research provides no proof that ethanol was ever used by the United States as an operational aviation fuel during WWII.

Beginning in the early 1980's, the general aviation community became increasingly aware of the potential benefits that ethanol had to offer through the work of Dr. Maxwell Shauck.[9, 10, 11, 12, 13, 14, 15] In order to demonstrate that ethanol was a viable replacement for the lead-containing 100LL avgas 100LL avgas, Dr. Shauck began modifying engines and demonstrating the safety and performance enhancement of ethanol. His work led to the 1990 Supplemental Type Certificate (STC) granted for a series of aircraft engines to run on ethanol fuel. In 1996 the FAA granted the world's first full certification for an entire series of aircraft to run on ethanol.[16]

Several other entities, both commercial and academic, have followed Dr. Shauck's lead. Industria Aeronautica Neiva of Brazil began production of its ethanol-powered agricultural spray aircraft. Completion and delivery of the *Ipanema* in March of 2005 marked the world's first manufactured ethanol-powered aircraft.[17] Information from an earlier study was used as a guide during this endeavor.[18] A timeline of ethanol events and findings is shown in Figure 2.

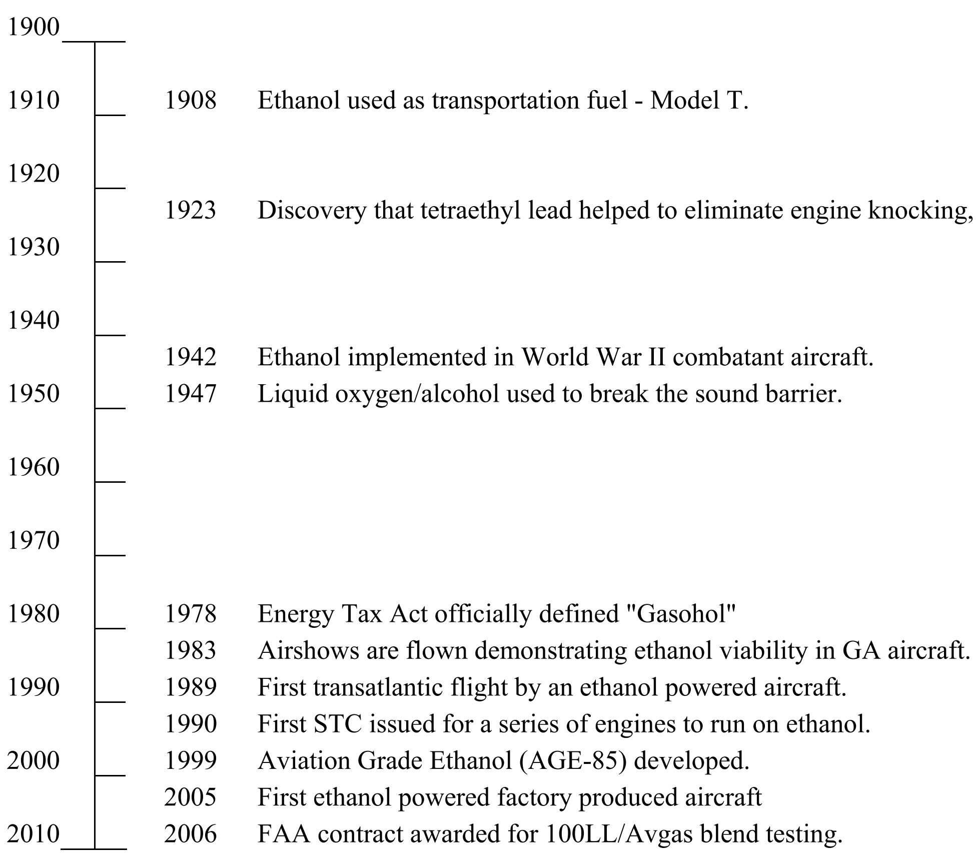

Figure 2. Timeline of aviation related ethanol events.

South Dakota State University's work to improve ethanol's cold start and corrosive characteristic has led to a product named Aviation Grade Ethanol (AGE-85).[19] Ethanol's low vapor pressure leads to difficult starting sequences in cold weather as the fuel needs to vaporize in order to be ignited. In AGE-85, between 10% and 20% pentane isomerate is added to fuel grade ethanol to improve the cold-start. Pentane isomerate's high vapor pressure helps to offset the lower vapor pressure of ethanol. The corrosive nature of ethanol, specifically its ability to oxidize, can lead to corrosion. Components made of aluminum are most likely to experience corrosion. AGE-85 contains less than 1% bio-diesel. The bio-diesel acts as a corrosion inhibitor by coating internal fuel system components. The experience previously gained in aircraft engine modification and STC acquisition was also used in this work.

Performance Analysis

In addition to the foundation that previous usage provides, the detailed operational characteristics of ethanol's performance must be analyzed. Engine performance differences between ethanol and 100LL avgas measured in the aircraft are most visible at three parameters. They are (1) aircraft range, (2) cylinder head temperature and (3) exhaust gas temperature. The major difference between ethanol and 100LL avgas is the difference in energy density. Fuel grade ethanol contains 76,100 BTUs per gallon[20] while 100LL avgas contains 112, 500 BTUs per gallon.[21] Energy density is defined as the amount of energy per mass or per volume. It can be thought of as the heat released when a given amount of fuel is burned.

Ethanol has an increased detonation resistance compared to 100LL avgas. Ethanol's higher latent heat of vaporization is responsible for an increase in power. A power plant similar to the one used in this work was tested on an FAA approved test stand, during certification testing. Comparison runs were made on 100LL avgas and ethanol. The maximum horsepower achieved by the engine when fueled by 100LL avgas was approximately 125 horsepower. A 20% increase in horsepower (25 h.p.) was gained when the fuel was changed to ethanol.[22]

The heat released as a result of internal combustion in each cylinder can be measured at the engine and monitored inside the cockpit. This temperature measurement is referred to as exhaust gas temperature (EGT). When used properly, EGT aids the pilot in fine tuning the air/fuel mixture setting. Properly fine tuning the air/fuel ratio yields significant benefits. For example, the pilot can set a predetermined air/fuel ratio providing either best possible power or best possible fuel economy. Recently, the increasing accessibility and decreasing cost for advanced engine performance monitoring devices has led to an increased use of these systems.

Thesis Overview

The next chapter introduces the background and expands on the procedure for setting the air/fuel mixture in a GA aircraft piston-driven engine. This leads to a discussion of the specific techniques chosen for this investigation as well as an explanation for test bed selection. Chapter 3 describes the experiment setup, instruments used to collect the data, and the procedures followed. Chapters 4 and 5 contain the experiment results for the Recommended Lean power setting and the Peak EGT power setting methods respectively. Exhaust gas temperatures, cylinder head temperatures, fuel flow and fuel consumption figures are presented. Full-throttle, shaft revolution (RPM) results are also presented. Conclusions and recommendations are found in Chapter 6. Several recommendations are made for future studies.

CHAPTER TWO

Engine Power Setting Techniques

Varying altitudes flown by GA aircraft combined with the ability to transition through differing weather systems cause changes in ambient air pressure and temperature. A main reason for this is the decrease in atmospheric pressure with increases in altitude. Approximately fifty percent of the ground level atmospheric pressure exists at 18,000 ft. mean sea level (MSL). The rate of pressure decrease can be determined from the following equation, under standard conditions of temperature and pressure.

$$P = Po(1 - .689x10^{-5}h)^{5.256}$$

Temperature also decreases with increasing altitude. This is called the atmospheric adiabatic lapse rate. Under standard conditions of temperature and pressure, the atmospheric adiabatic lapse rate is defined as a temperature decrease of 3.5°F or 2.0°C for every 1,000 foot increase in altitude up to 36,089 ft MSL.[23] The combination of temperature and pressure variation and changes in atmospheric density require manual leaning procedures be incorporated in all piston-driven aircraft.

Different fuels have different stoicheometric air/fuel ratios. The stoicheometric value is the air/fuel ratio which fosters complete combustion. 100LL avgas has a high stoicheometric air/fuel value between 14.5:1 and 15.0:1, which is close to that of 87 octane Gasoline. Ethanol's chemical make-up includes oxygen. This oxygen component is responsible for the lower 9:1 stoicheometric air/fuel ratio value.[24]

In piston-driven GA aircraft, the air/fuel mixture is manually adjusted to maintain a constant air/fuel ratio while atmospheric pressures and temperatures vary. This mechanical characteristic inherently makes piston-driven GA aircraft flex-fuel vehicles.

Setting Air/Fuel Mixture

The exhaust gas temperature changes as the air/fuel ratio changes. The EGT gauge provides the pilot with the ability to fine tune the engine air/fuel mixture setting. This gauge also provides trend and combustion efficiency information that can be used to detect or prevent an undesirable situation before it manifests itself fully. The benefits for setting proper mixture control include:

- Improved combustion
- Greater fuel economy
- Longer spark plug life
- Reduced maintenance cost
- Reduced operating cost
- Proper engine temperatures
- Reduced engine vibration

Accurate leaning yields optimal engine temperatures. These engine temperatures are indications of how the engine is performing and where on the power available curve the engine is operating. The pilot precisely adjusts the air/fuel mixture to establish a desired power output. Air/fuel mixture, consequently power output, can be set at any point along the power curve. It can also be set to achieve the most efficient fuel economy or the maximum power available.

The red colored region in Figure 3 displays a generic correlation between percent power, cylinder head temperatures and exhaust gas temperatures and the anti-correlation of specific fuel consumption during operations at a "Best Economy" mixture setting or near peak EGT. The blue colored region in Figure 3 displays the same correlation between percent power, cylinder head temperatures and exhaust gas temperatures and the anti-correlation of specific fuel consumption during operations at a "Best Power" mixture setting or 25º F to 50º F rich of peak EGT.

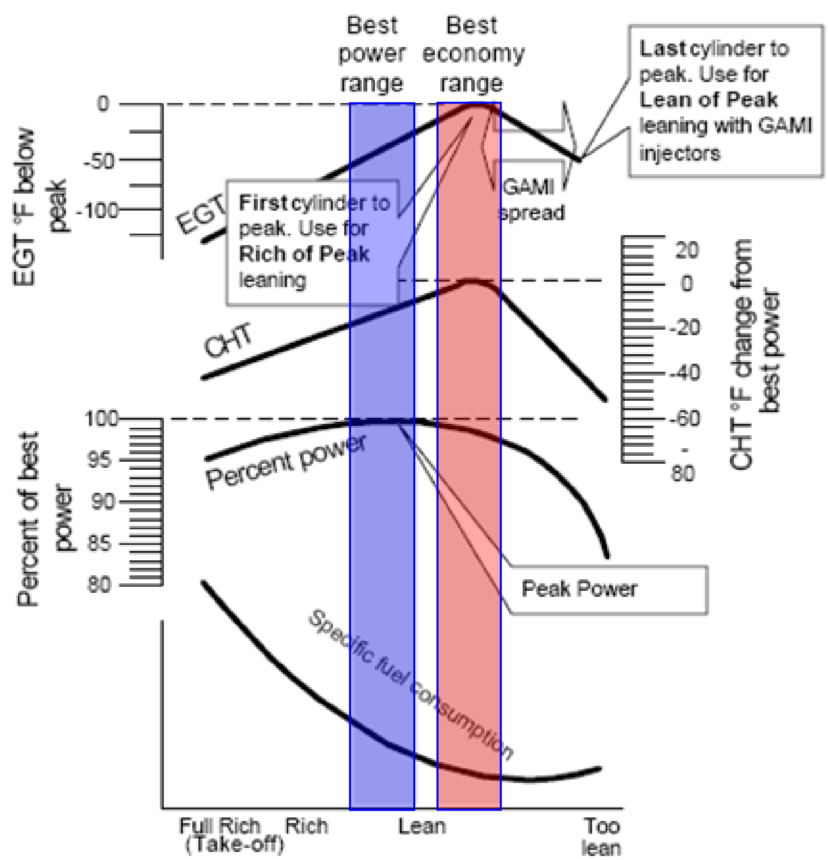

Figure 3. "Best Power" (blue) and "Best Economy" (red) mixture settings from the J.P. Instruments EDM-800 manual.

For those aircraft not equipped with an EGT gauge, engine manufacturer's recommend procedures that help the pilot approximate a "peak EGT" or "rich of peak EGT" power setting.

At any given RPM and manifold pressure, exhaust gas temperatures are lower for ethanol than for 100LL avgas. This decrease in exhaust gas temperature provides an increased margin for red-line temperatures during operation. The decrease in EGT is due to ethanol's higher latent heat of vaporization. While the latent heat of vaporization of ethanol is 364 Btu/lb_m, it is only 150 Btu/lb_m for 100LL avgas. The higher latent heat of vaporization value is responsible for the fuels ability to remove heat during phase change.

In this investigation, two common air/fuel mixture settings were chosen to provide comparative demonstrations of operational performance parameters between the fuels blends tested. They are the Peak EGT and the Recommended Lean mixture settings.

Peak EGT Mixture Setting

To maximize the time aloft and distance that an aircraft can travel, fuel economy is paramount. Engine manufacturers are not consistent in their published operating procedures when it comes to operating at peak EGT setting. For example, Continental recommends operating at peak EGT for power settings of 65% or lower, while Lycoming extends the limit to power settings of 75% or lower.[25]

In GA aircraft not equipped with an EGT gauge, operating handbooks recommend the pilot lean the mixture setting to engine roughness, then, enrich the mixture setting knob approximately one-half of a turn. The inclusion of an EGT gauge enables the pilot to determine the exact peak EGT with precision (increments as small as 1ºF). This setting becomes the most effective setting with respect to fuel consumption.

Recommended Lean Power Setting

To maximize the potential power that an engine can produce, it is necessary to optimize the air/fuel mixture setting. As mentioned earlier, EGT rises to a peak temperature as the mixture is leaned and then decreases as the mixture is further leaned. As shown on the power curve, labeled percent power, in Figure 5, the power curve reaches peak power at an EGT setting between 25º F and 50º F rich of peak. Cylinder head temperature trend resembles EGT trend. Engine bore, stroke, displacement and compression ratio all affect the EGT variation spread. Therefore, every engine will produce best power at its own particular EGT.

In GA aircraft not equipped with an EGT gauge, most manuals recommend that the pilot lean the mixture setting to engine roughness and then to increase the mixture setting control by richening the mixture approximately one turn of the mixture control knob. This results in an EGT between 25º F and 50º F rich of peak EGT. Some pilots, when familiar with the aircraft they are flying, have been known to approximate this setting by listening for the engine to make maximum RPM. For the test-bed aircraft used in this investigation, the aircraft manufacturer's recommended leaning procedure to obtain best power is to set the EGT 25º F rich of peak EGT. [26]

CHAPTER THREE

Investigation

Experiment Setup

During flight testing, a Cessna 152 was flown on ethanol, 100LL avgas, and blends of the two fuels. The aircraft was equipped with a fuel flow meter, fuel flow totalizer, and engine data monitor (EDM), and GPS. These instruments, in conjunction with the RPM, manifold pressure gauge, airspeed indicator, vertical speed indicator, outside air temperature gauge, and altimeter were used to record engine and aircraft performance characteristics.

Because it is not practical to test every possible ethanol/100LL avgas blend, a certain number of blends were selected and explored in depth. The two previously mentioned air/fuel mixture settings were used. Ethanol/100LL avgas blends of 10%, 20%, 40%, 60%, 80%, and 90% ethanol were explored. These blends will be referred to as E10, E20, E40, E60, E80, and E90 respectively. The fuel referred to as E95 ethanol is denatured before reaching the consumer. Denaturing is accomplished by blending 2-5% (by volume) conventional gasoline with pure ethanol.[27] This process is performed to comply with the Bureau of Alcohol Tobacco and Firearms requirements.[28] See TABLE 1, below, for fuel details.

TABLE 1. FUEL DETAILS

Characteristic		100LL	EtOH
Density	lbs/gallon	5.91	6.54
Specific Gravity	-----	0.71	0.785
Motor Octane Number	M.O.N.	100	-----
Lead Content	grams/L	0.53	0
Latent Heat of Vaporization	Btu/gallon	150	364
Power Stoichiometric	-----	15:01	9:01
Vapor Pressure	Pounds/in^2	5.5-7.0	2.5
BTU content	Btu	125,000	75,000

The fuels were volumetrically blended before being added to the wing tanks of the Cessna 152. Using both the onboard fuel flow totalizer and a fuel level measuring stick, the amount of ethanol or 100LL avgas to be added to the tanks was calculated. The ethanol was obtained from the Baylor Institute for Air Sciences (BIAS) fuel storage tank. 100LL avgas was purchased from a local fixed base operator at the Texas State Technical College airport (KCNW).

Airframe

N152BU, shown in Figure 4, was utilized in the fuel blend flight testing and data acquisition. This is the same aircraft that received the June 1996 STC for a non-petroleum fuel, specifically 100% Ethanol. The power plant is a 125 HP Lycoming O-235 with a compression ratio of 9.7:1. There were no additional engine modifications conducted for the fuel blend flight testing. This airframe has been widely recognized by the general aviation population as the workhorse of flight training facilities world-wide.

Figure 4. Test Bed Aircraft (N152BU)

Powerplant

A four cylinder, air-cooled, horizontally-opposed piston driven Lycoming O-235 was used in this experiment. The engine is carbureted with a dual magneto ignition. Engine displacement is 235 cubic inches (3.85L). The power plant is shown below in Figure 5. The fuel system has been modified to burn fuel grade ethanol in accordance with STC SE8707SW. Internal carburetor component modifications involve the float valve needle, needle seat, main jet, idle jet and float. Other fuel system modifications to the airframe are covered by the airframe STC. Powerplant details are found in TABLE 2.

Engine Data Monitor

An Engine Data Management (EDM) system was installed on the aircraft specifically for this experiment. The system installed was the J.P. Instruments EDM-800 panel mounted data management unit. This device is equipped to capture the following data sets.

- Battery voltage
- EGT (to stable 1 °F resolution)
- CHT (to stable 1 °F resolution)
- Outside air temperature
- Fuel quantity
- Percent horsepower
- RPM
- Fuel flow
- Oil temperature

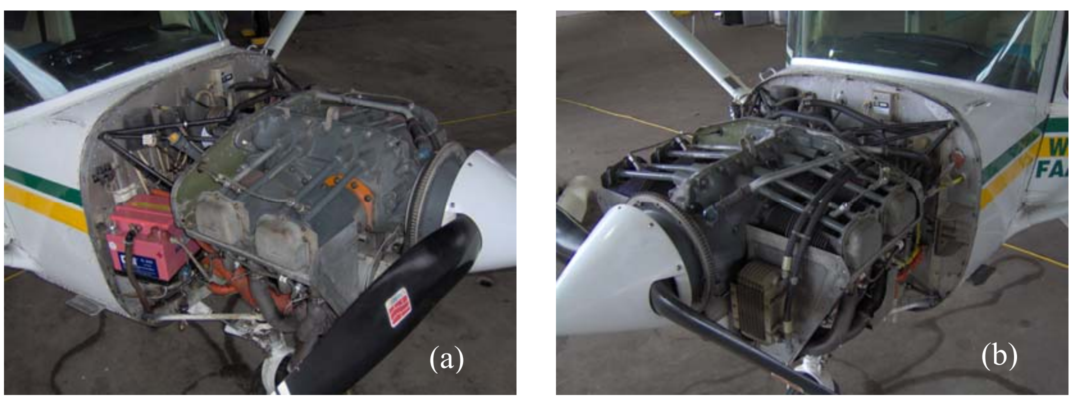

Figure 5. Test Bed Powerplant, (a) starboard side showing cylinders 1 and 3 (b) port side showing cylinders 2 and 4.

TABLE 2. TEST BED POWERPLANT DETAILS

Engine Model	Engine Serial Number	Rated HP at S.L.	RPM @ S.L. rated HP	Maximum RPM	Fuel System STC
O-235-N2C	RL-23038-15	126	2600	2800	SE8707SW
Bore (in)	Stroke (in)	Displacement (in3)	Compression Ratio	Total time on the engine (hrs.)	Total time since overhaul (hrs.)
4.375	3.875	233	9.7:1	564.7	370.9

In addition to the above recorded data, the EDM contains logic giving the pilot the ability to conduct a LeanFind™. This function notifies the aircrew when the first cylinder in the engine reaches peak EGT. The LeanFind™ function removes the guess-work associated with the generic leaning procedure mentioned earlier.

The EDM is able to record and store data at intervals between 2 and 500 seconds. Recording begins when the first cylinder reaches 500°F EGT. Total recording ability is limited to approximately 20 hours at 0.1 minute intervals and 1600 hours at 8 minute intervals. An example of an EGT/CHT data set is shown in Figure 6.

Post flight data retrieval is accomplished via a downloading sequence to either a palm pilot computer, a USB data flash drive memory stick, or directly to a laptop equipped with the appropriate software. This experiment used the USB data flash drive memory stick by setting up a structured downloading timeframe and procedure. Timeliness of the download is important so as to reduce the possibility of inadvertent data deletion.

Data Acquisition

The data acquisition sequence was carried out by utilizing pre-planned and coordinated cockpit resource management (CRM) criteria. The cockpit was divided symmetrically in half, minimizing analog gauge parallax discrepancies at acquisition call-outs. Call outs were performed by the pilot and by the observer. The observer recorded the flight parameters, allowing the pilot to remain focused on maintaining a steady state flight platform.

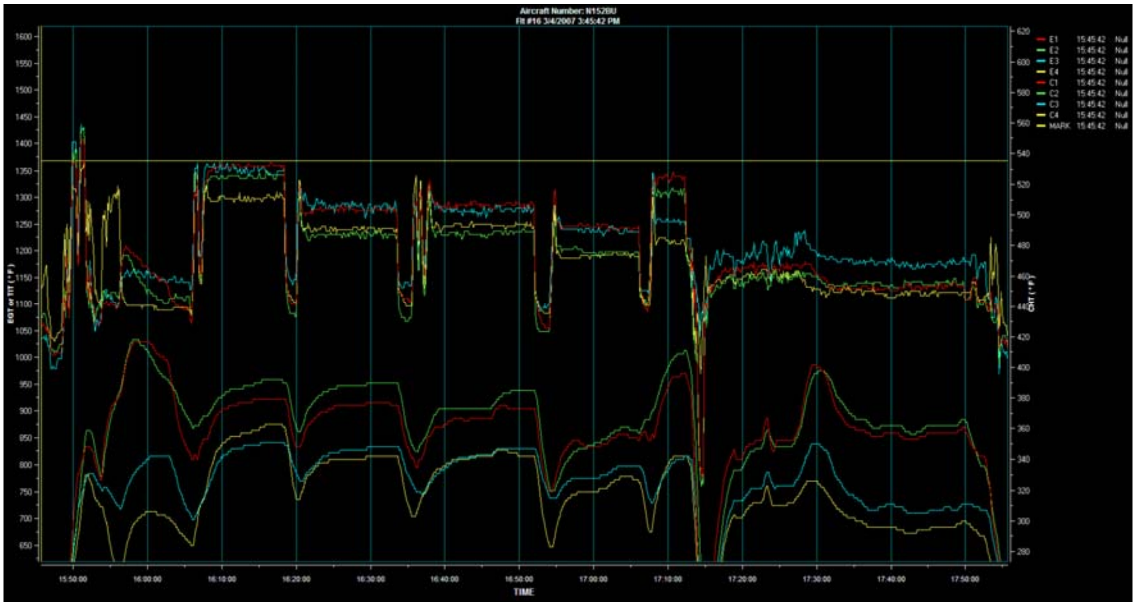

Figure 6. Downloaded raw data from the Recommended Lean (25°F Rich of Peak EGT) E40 flight conducted on 04 March 2007. EGT data is grouped higher on the chart with the CHT data grouped on the lower portion.

Prior to engine start, the date and sequential flight number were recorded along with the empty weight, pilot and observer weights, and fuel-blend percentage being tested. The Automatic Weather Observation System (AWOS) on the airfield provided real time weather measurements including barometric pressure, wind speed and wind direction. Both tachometer and engine start time were recorded as soon as post-start engine stabilization parameters were observed and confirmed.

RPM and indicated airspeed were observed from cockpit installed analog gauges and were recorded with precision to the nearest whole number. The Garmin 195 GPS receiver displayed ground speeds. The ground speeds were recorded with precision to the nearest whole number. Post flight calculations were made using ground speed observations to determine true airspeed values. True airspeed values were calculated to the nearest one-tenth knot. Exhaust gas temperatures (EGTs), and cylinder head temperatures (CHTs) were digitally observed and recorded with precision to the nearest whole number. Fuel flow and fuel remaining were both observed digitally and were recorded with precision to the nearest one-tenth gallon. Post flight calculations utilized the aircraft zero-fuel weight, fuel remaining recording, in U.S. gallons, along with the specific gravity of Ethanol (.789) to determine the weight of the aircraft at each data acquisition point. Manifold pressures were observed from cockpit installed analog gauges and were recorded with precision to the nearest one-quarter inch of Mercury.

Global Positioning System

The Garmin GPSMAP 195 was used to acquire groundspeed data used for the true airspeed (KTAS) calculation. The GPS unit was also integral to sustaining flight plan profile and overall situational awareness. The 195 includes a high-resolution, 4-gray, 38,400 pixel display moving map. The unit was dash mounted and located on the longitudinal axis of the aircraft. Waypoints were programmed into the unit to ensure repeatability of test plan and flight profiles.

Test Plan

Testing was initiated by validating the flight profile and air/fuel mixture setting with a baseline (100LL) run. Multiple data sets were recorded and compared to performance characteristics published for the aircraft/powerplant combination for each of the two air/fuel mixture settings used in this experiment. The published operation information came directly from the aircraft's pilot operating handbook (POH).[26] The baseline fuel (100LL avgas), E10, E20, E40, E60, E80, E90, and E95 (100% denatured ethanol) were tested for each of the pre-planned air/fuel ratio settings employed during this experiment. Refer to TABLE A.1 and B.1 for an itemized run log of fights. Test runs were completed at power settings of 2100, 2300, 2400 and 2500 RPM for each of the tested fuel blends.

The first objective of the test was to show linear-like correlation in operating parameters within each of the fuel blends. A set of standardized course rules was designed and implemented to limit the increase or decrease in engine operating time from engine start to arrival at the test run entry waypoint.

Next, a steady flight platform was established to record reliable data points. CRM techniques were employed ensuring both pilot and observer were in agreement concerning the stability of the atmosphere and the aircraft flight path.

Flight Test Procedure

Testing began by ensuring proper fuel blends were loaded in the aircraft. All take-offs were pre-coordinated with local air traffic control authorities to prevent take-off delays. The purpose of this additional step in communication was to avoid prolonged engine run time before data acquisition began. Actual departures remained standard with flap configuration set to zero degrees. Take off roll commenced without the breaks set followed by a smooth application of power up to a Full Throttle power setting. Rotation commenced at 50 KIAS with liftoff occurring at 55 KIAS +/- 5 KIAS. The enroute climb technique remained standard with the pilot maintaining a shallow angle of climb at 80 KIAS throughout the climb.

Passing 500 ft AGL, the altimeter was set to 29.92 “Hg. The aircraft was flown to a PA of 4,000 ft. At this time, the pilot selected 2,500 RPM, on a heading of magnetic

South. The aircraft was trimmed for straight and level un-accelerated flight and the engine was allowed to stabilize for 5 minutes. At the end of the 5 minute stabilization period, the first test RPM setting (2,500 RPM) was confirmed. Depending on the mixture setting needed for the particular flight, the mixture was leaned for either a Peak EGT power setting or a recommended lean (25° F rich of peak EGT). A change of less than 30 RPM occurred during the leaning procedure. After the proper mixture setting was obtained, the throttle was fine tuned so as to maintain test RPM setting +/- 10 RPM. The aircraft was re-trimmed at PA 4,000 ft. and remained at that altitude for the remainder of the data gathering portion of the flight. Once the flight crew established a stable, steady-state, zero VSI flight profile, timing and data acquisition began with the observer's time-hack callout. The second and third data sets were recorded at + 3:00 and + 6:00 minutes from the observers first call out. At the end of the third data set, a 180 degree procedure turn was made. After rolling wings level, a 1 minute stabilization period commenced followed by ground speed acquisition at two minute intervals. Ground speeds in both directions were recorded to offset the effect of a headwind or a tailwind. These airspeeds would be recorded for two reasons. The first was to establish the true airspeed (TAS) at the given power setting. The second was to establish uniformity of the power setting from flight to flight. The same procedure was repeated for the remaining power settings of 2,400 RPM, 2,300 RPM, and 2,100 RPM. Additionally, an abbreviated but complete data set was taken at the full throttle power setting. Maximum RPM at this power setting was recorded for all blends.

Course Rules

For standardization of the test plan, two sets of course rules were developed to ensure consistent engine run time throughout each test flight. Active runways at TSTC airport (KCNW) are magnetically oriented at 170°/350°, as shown in Figure 7.

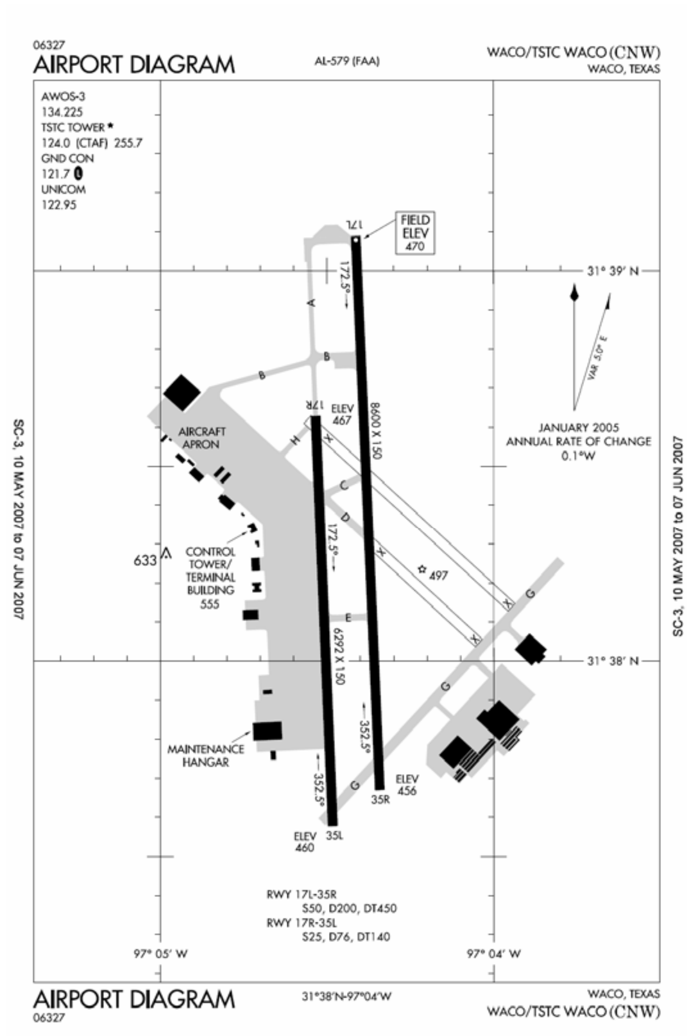

Figure 7. Airport diagram of TSTC Waco Airport (KCNW)

With shifting winds throughout the flight test timeline, departures occurred both to the North and to the South. Two separate geographic waypoints were designated as test run reference points. This ensured relative uniformity in time aloft and engine run time at the beginning of the first run on each flight. Distance from take-off to waypoint A (if on a South departure) or take-off to waypoint B (if on a North departure) is standardized at 20 nm. Figure 8 shows North and South departure course rules.

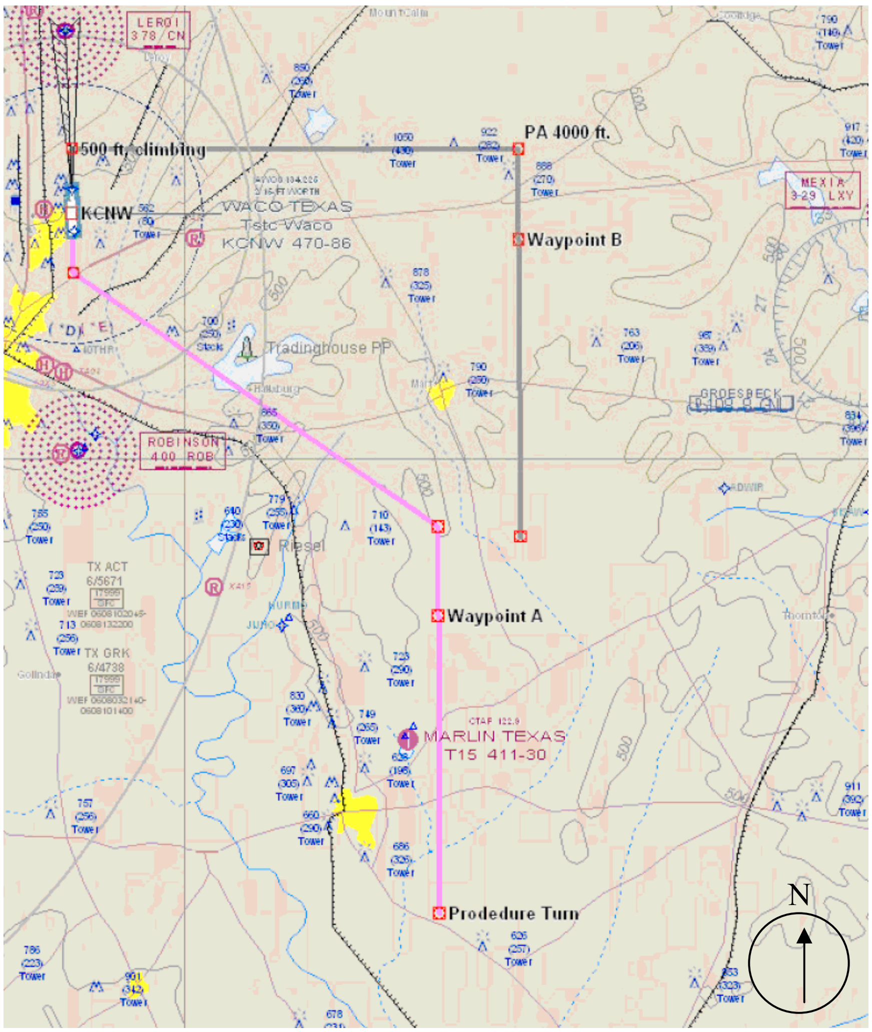

Figure 8. Course rules for a North departure (gray line) and South departure (pink line) out of TSTC airport (CNW).

Launch sequence. South Departure: Climb RNWY HDG to 500 ft.., then, climbing left turn to HDG 120. Monitor practice area radio frequency (123.0). Level off at PA 4,000 ft. Make right turn HDG 180 to arrive at WAYPT A. Configure for run #1. Commence run #1 upon reaching WAYPT A flying magnetic HDG 180. North Departure: Climb RNWY HDG to 500 ft., then, climbing right turn to HDG 090. Monitor practice area radio frequency (123.0). Level off at PA 4,000 ft. Make right turn HDG 180 to arrive at WAYPT B. Configure for run #1. Commence run #1 upon reaching WAYPT B flying magnetic HDG 180.

Waypoint turns. At PROCEDURE TURN WAYPT, make initial 90° SRT to the East followed by a 270° SRT in the opposite direction. Role out and fly magnetic HDG 360.

Recovery sequence. At completion of last run, re-establish radio contact with TSTC tower and announce intention to land.

Uncertainty / Repeatability

Recorded parameters deemed critical to this investigation were verified to ensure the data was accurate, precise, and reliable. These critical data parameters include RPM variability, EGT/CHT probe accuracy, and fuel flow meter accuracy.

RPM Variability

To determine the stability and reporting accuracy of RPM data, the average RPM was calculated for each of the four test power settings. Corresponding fuel flow data and flight notes ensured that the RPM's averaged were taken during power-specific test runs and not during power adjustments. It is important to note that RPM data recorded from the cockpit was displayed in 10 RPM increments. However, the RPM data analyzed for RPM variability was recorded by the EDM in 1 RPM increments. See TABLE 3 for RPM variability details, including; the target RPM, the average recorded RPM with standard deviation, and the difference between target revolutions and average revolutions per minute.

TABLE 3. RPM VARIABILITY RESULTS

Target RPM	Avg. RPM (stnd. dev.)	Target RPM - Avg RPM
2500	2493 (+/- 13)	7
2400	2391 (+/- 15)	9
2300	2301 (+/- 19)	1
2100	2104 (+/- 14)	4

EGT/CHT Probe Accuracy

The EGT probes are fast response aviation quality Chrome/Alumel K types. All probes have stainless steel housings and flexible stainless steel braided sheaths. Figure 9 shows the mounting location for the EGT probe mounted on the #2 cylinder exhaust pipe.

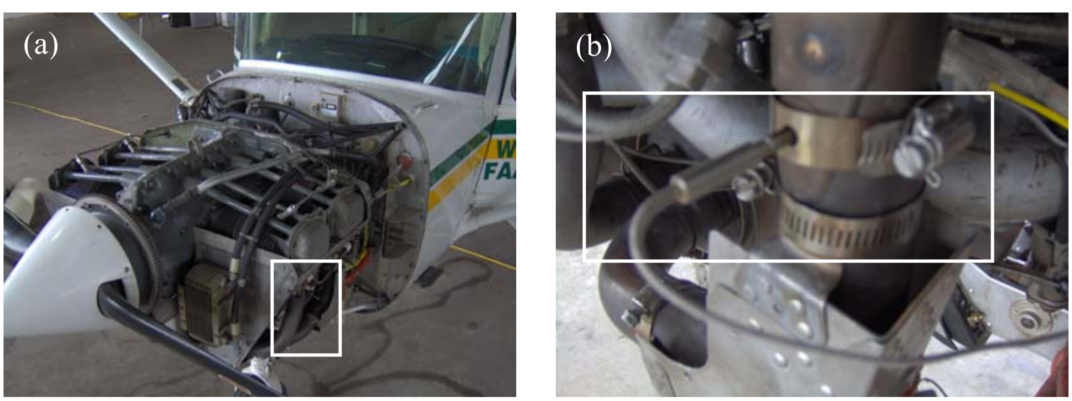

Figure 9. EGT #3 mounting location, (a) area inside block denotes location of #2 exhaust pipe on test bed power plant and (b) close-up of EGT probe on the #2 exhaust pipe.

The CHT temperature probes were shown to be within 0.1 degrees Fahrenheit and the EGT temperature probes yielded similar calibration results. The EGT/CHT probes were calibrated at both a high and a low temperature. The low temperature calibration was conducted at 32°F. This was accomplished by cold soaking each instrument probe in ice-water. A hot plate brought normalized tap water up to boiling point. The boiling water was used for the high temperature calibration taking into account the nonstandard atmospheric pressure and its effect on the boiling point of water. Results for both the hot and the cold soak calibration can be found in TABLE 4.

TABLE 4. EGT/CHT TEMPERATURE PROBE CALIBRATION RESULTS

CHT	1	2	3	4	EGT	1	2	3	4
Mercury (°C)	0	0	0	0	Mercury (°C)	0	0	0	0
Digital (°F)	32.1	32.1	32.1	32.1	Digital (°F)	32.1	32.1	32.1	32.1
EDM (°F)	32	32	33	32	EDM (°F)	32	32	32	32
Δ	0.1	0.1	0.9	0.1	Δ	0.1	0.1	0.1	0.1
Mercury (°C)	100	100	100	100	Mercury (°C)	100	100	100	100
Digital (°F)	211.6	211.7	211.7	211.6	Digital (°F)	211.6	211.7	211.7	211.6
EDM (°F)	211	210	210	211	EDM (°F)	209	211.5	208	212
Δ	0.6	1.7	1.7	0.6	Δ	2.6	0.2	3.7	0.4

Each probe was allowed to heat up or down and kept in equilibrium for 60 seconds before indications were recorded. Digital indications on the EDM display were recorded for each of the probes (4 EGT and 4 CHT). A digital k-type thermometer and a conventional mercury thermometer were employed as back-up devices for fluid temperature collaboration. All probes were found to be within precision specifications for this project: However, the margin of difference was noted to be larger at the higher temperatures. Because flight test ambient temperatures varied from 35°F to 53°F, cylinder head temperatures were corrected for non-standard temperatures.

Fuel Flow Meter Calibration

It is common for general aviation pilots in the field to use volumetric units for fuel consumption purposes, although the mass of the fuel is typically used for weight and balance procedures.

The fuel flow metering device associated with the EDM 800 installed on the test bed makes use of the fuel flow transducer added to the fuel system as part of the STC. Ensuring fuel flow displayed was indeed the accurate fuel flow, the fuel line down stream from the electrically-driven boost pump and fuel flow transducer was disconnected at the carburetor connecting device. An inline ball valve, shown in Figure 10, was added to vary the restriction of fuel flow.

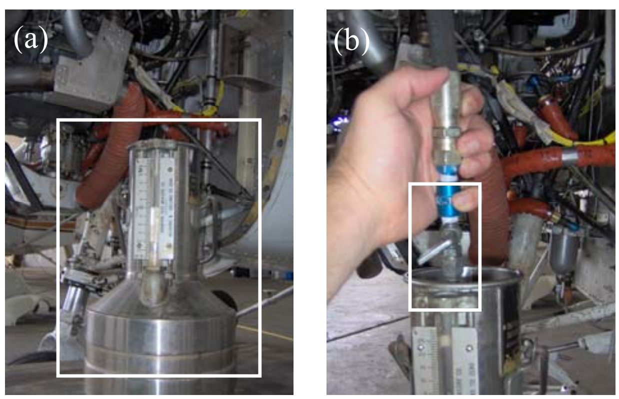

Figure 10. Fuel Calibration Procedure in Progress, (a) calibrated fuel catch can and (b) ball valve extension to fuel line enabling regulation of fuel flow during calibration procedure.

With the Master Switch-ON, the EDM was powered up allowing digital display of fuel flow. Fuel flow was restricted via the ball valve so that a low, medium and high fuel flow rate could be achieved. These calibration fuel flow rates were chosen to mimic actual flow rates during flight testing. The flow rate in gallons/hour for each individual test can be easily calculated as follows:

$$FlowRate = \frac{W - W_{empty}}{(d \times sg_{blend}) * T_{meas}}$$

A time hack was taken while a calibrated 1 gallon container, shown in figure 9a, was filled. “Time to fill” data was used to determine the accuracy of the EDM fuel flow monitoring feature. The fuel volume flow meter had an uncertainty of +/- .02 gallons per hour. The percent error of the fuel flow calibration was found to be less than 1%. Results from the fuel flow calibration procedure are shown in TABLE 5.

TABLE 5. FUEL SYSTEM CALIBRATION RESULTS

Displayed Flow Rate (gal/hr)	Fuel Blend	Specific Gravity	Converted Flow Rate (lbs/hr)	Converted Flow Rate (lbs/min)	Δ mass (lbs.)	T_{meas} (s.)	T_{meas} (hrs.)	Calculated Flow Rate (lbs/hr)	Calculated Flow Rate (gal/hr)
4.8	100LL	0.71	28.4	0.5	5.91	760	0.21	28.0	4.7
7.2	100LL	0.71	42.6	0.7	5.91	500	0.14	42.6	7.2
9.8	100LL	0.71	58.0	1.0	5.91	365	0.10	58.3	9.9
5.1	E60	0.75	31.9	0.5	6.29	716	0.20	31.6	5.0
7.6	E60	0.75	47.5	0.8	6.29	477	0.13	47.5	7.5
9.9	E60	0.75	61.9	1.0	6.29	363	0.10	62.4	9.9
4.9	E95	0.79	32.0	0.5	6.54	728	0.20	32.3	4.9
7.3	E95	0.79	47.7	0.8	6.54	502	0.14	46.9	7.2
9.8	E95	0.79	64.1	1.1	6.54	366	0.10	64.3	9.8

CHAPTER FOUR

Results and Discussions: 25°F Rich of Peak EGT

The goal of this investigation was to document the variation of aircraft operational parameters through a range of ethanol/100LL avgas fuel blends. Observations of any identifiable advantageous attributes or detrimental characteristic associated with a particular blend or group of blended fuels will be discussed.

Normal piston-driven general aviation flight operations must be conducted at a wide variety of air/fuel mixture and throttle settings. To narrow the scope of this study, half of the experimental flights were conducted at an air/fuel mixture set to an exhaust gas temperature (EGT) of 25ºF rich of peak EGT and half of the runs were conducted at an air/fuel mixture setting set to the maximum exhaust gas temperature. This chapter analyzes those runs conducted at 25ºF rich of peak EGT.

True Airspeed

Any air mass possesses a magnitude and direction. By definition, the magnitude and direction of the wind is referred to as the wind vector. An aircraft flies a true heading and true airspeed, referred to as the air vector. The ground vector, made up of the actual ground track and the actual speed the aircraft is making over the ground is obtained by adding the air vector and the wind vector.

This experiment makes uses of the true airspeed calculated from groundspeeds recorded at reciprocal headings for power output comparison throughout the scope of tested fuel blends. The correlation of true air speeds between fuel mixtures at similar RPM validates engine power settings from flight to flight. Thrust power output remains consistent with constant RPM due to the fixed-pitch propeller configuration. Cross checking airspeed within a single RPM band confirms consistency of flight operations throughout the test plan. TABLE 6 shows an RPM setting specific chart of recorded true airspeeds (TAS) for the array of fuel blends including average true airspeed and standard deviation per RPM setting.

TABLE 6. TRUE AIRSPEED PER RPM

Power Setting	100LL	E10	E20	E40	E60	E80	E90	E95	AVG TAS	STD DEV
2500	100.2	100.2	98.7	98.4	98.3	101.5	99.1	99.4	99.5	1.03
	0.73	0.73	-0.77	-1.07	-1.18	2.03	-0.38	-0.07		
2400	96.5	94.3	93.9	93.8	93.6	94.0	93.5	95.3	94.4	0.96
	2.14	-0.06	-0.46	-0.56	-0.76	-0.36	-0.86	0.94		
2300	90.5	90.1	83.9	90.1	90.1	89.2	89.5	87.3	88.8	2.09
	1.66	1.26	-4.94	1.26	1.26	0.36	0.66	-1.54		
2100	77.5	81.7	82.3	78.4	74.9	78.2	77.0	79.0	78.6	2.27
	-1.13	3.08	3.68	-0.22	-3.72	-0.42	-1.63	0.38		
Full Throttle	102.1	103.1	105.6	100.7	102.0	104.3	102.2	104.3	103.0	1.49
	-0.94	0.06	2.56	-2.34	-1.04	1.26	-0.84	1.26		
RPM Spread	22.7	18.5	16.4	20.0	23.4	23.3	22.1	20.4		

A standard deviation is included for each RPM setting. The largest airspeed difference for the 2500 RPM runs was 2.73 KTAS. This power setting also had the lowest associated airspeed standard deviation. The largest difference between test run airspeed and average RPM airspeed was seen at the 2100 RPM power setting during the E60 flight. Consequently, the associated standard deviation for 2100 RPM was the greatest at 2.89 KTAS. Average airspeed difference between a low test-profile power-setting (2100 rpm) and the high test-profile power-setting (2500 rpm) was 21.3 knots true airspeed. The minimum airspeed spread occurred during the E20 runs, with an airspeed spread of 16.8 KTAS. The maximum airspeed spread occurred during the E80 runs, with an airspeed spread of 23.7 KTAS. There was no identifiable trend in airspeed spread along the fuel blend axis.

Other studies have utilized a LeBow torque meter attached between the propeller and the power plant to determine power being produced by the engine.[29] Access to a Lebow torque meter was not within the scope of this experiment. Increase in power output with increasing ethanol content per blend is characterized through the analysis of Full power RPM.

Full Throttle RPM

Immediate indication of horsepower produced shows itself in the speed of the propeller when the throttle is set to full open. There is an increase of 40 rpm between the two neat fuels. Between E10 and E80, an increasing trend of 10 rpm exists between each tested fuel with an exception to this trend occurring between E60 and E80.

Full throttle power is used approximately 16% of a typical cross country flight profile (during the take-off, initial climb, climb and go-around phases of flight) and therefore will not constitute a great increase in overall fuel consumption. The overall benefit of increased RPM at full throttle comes in the form of additional thrust available. This increase in thrust available aids a pilot by decreasing ground roll during take-off. It also increases the safety margin available should a pilot ever find himself in a dangerously slow situation, such as during the short final approach. Other critical phases of flight include stall and drag demonstrations reaching Vs0 (full flap) or Vs1 (clean) stall speeds. Figure 11 shows the relationship between fuel blend and RPM with the associated fuel flow included.

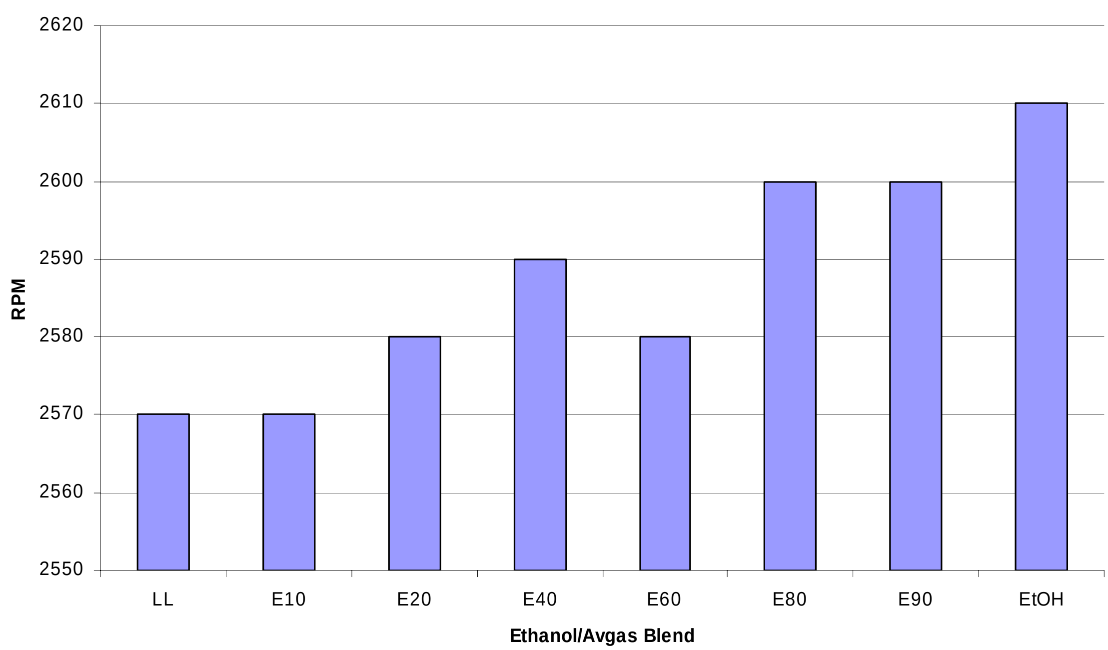

Figure 11. Increasing RPM trend with increased ethanol content at Full Throttle.

A negative result is seen in the form of increased fuel flow following the increase in ethanol content per fuel blend. The greatest fuel flow increase across the fuel blend range occurs at the full throttle RPM setting. TABLE 7 shows both the change in RPM and the change in fuel flow (gallons per hour and % increase in consumption).

TABLE 7. FULL THROTTLE RPM AND FUEL FLOW

Blend	RPM	Δ RPM	FF	Δ FF	% Δ FF
LL	2570	---	8.1	---	---
E10	2570	0	8.6	0.5	0.06
E20	2580	10	8.8	0.7	0.09
E40	2590	20	9.1	1	0.12
E60	2580	10	9.7	1.6	0.2
E80	2600	30	11.7	3.6	0.44
E90	2600	30	10.9	2.8	0.35
EtOH	2610	40	11.6	3.5	0.43

Exhaust Gas Temperature (EGT)

The most critical data output component, both from the pilot's and the engine operation perspective, is the exhaust gas temperatures. As previously mentioned, exhaust gas temperatures provide an immediate indication of the efficiency of fuel burn per cylinder. An exhaust gas temperature gauge can tell a pilot if the cylinder's combustion chamber is running to hot or to cold, to lean or to rich. It can also indicate problems with the engine, such as burnt valves or worn cylinder walls. TABLE 8 shows the detail chart for EGT averaged across all four cylinders, the temperature difference between the blended fuel average EGT and the average EGT of the baseline fuel (100LL avgas 100LL avgas), and the percentage decrease in EGT through the test fuel range.

TABLE 8. EXHAUST GAS TEMPERATURE RESULTS
(25 degrees Rich of Peak EGT)

2100 RPM	Average EGT	% Decrease EGT	ΔT	2300 RPM	Average EGT	% Decrease EGT	ΔT
100LL	1264.0	---	---	100LL	1326.6	---	---
10%	1245.6	0.01	18.4	10%	1301.1	0.02	25.5
20%	1258.8	0.00	5.2	20%	1274.8	0.04	51.8
40%	1219.1	0.04	44.9	40%	1258.8	0.05	67.8
60%	1228.6	0.03	35.4	60%	1246.4	0.06	80.2
80%	1214.1	0.04	49.9	80%	1221.3	0.08	105.3
90%	1180.2	0.07	83.8	90%	1228.7	0.07	97.9
E95	1190.2	0.06	73.8	E95	1211.6	0.09	115.0

2400 RPM	Average EGT	% Decrease EGT	ΔT	2500 RPM	Average EGT	% Decrease EGT	ΔT
100LL	1302.3	---	---	100LL	1283.6	---	---
10%	1286.9	0.01	15.4	10%	1310.5	-0.02	-26.9
20%	1273.2	0.02	29.2	20%	1296.7	-0.01	-13.1
40%	1261.1	0.03	41.3	40%	1336.8	-0.04	-53.3
60%	1267.6	0.03	34.8	60%	1260.0	0.02	23.6
80%	1253.0	0.04	49.3	80%	1287.8	0.00	-4.2
90%	1229.3	0.06	73.1	90%	1286.2	0.00	-2.6
E95	1230.8	0.05	71.6	E95	1269.5	0.01	14.1

Generally speaking, EGTs at the same RPM settings decrease as more ethanol is added to an 100LL avgas/ethanol fuel blend. Results from this air/fuel mixture setting provide a consistent decreasing trend in EGTs at the 2100, 2300, and 2400 RPM settings with an overall 7% decrease from conventional 100LL avgas to 100% denatured ethanol at those power settings. A standard deviation of only 0.02 for these three power settings provide very little doubt as to the stability of the data measured. However, instabilities surface in the 2500 RPM data set. No consistent trend was observed at the high-end power setting.

Cylinder Head Temperature (CHT)

An ongoing topic of discussion in the aviation community is the debate over the usefulness of having CHT information available in the cockpit. Cylinder head temperature results for the recommended lean mixture setting are shown in TABLE 9.

TABLE 9. CYLINDER HEAD TEMPERATURE RESULTS
(25°F Rich of Peak EGT)

2100 RPM	Average CHT	% Decrease CHT	ΔT	2300 RPM	Average CHT	% Decrease CHT	ΔT
100LL	359	---	---	100LL	373	---	---
10%	352	0.02	-7	10%	367	0.02	-6
20%	353	0.02	-6	20%	377	-0.01	4
40%	347	0.03	-12	40%	366	0.02	-7
60%	367	-0.02	8	60%	370	0.01	-3
80%	351	0.02	-8	80%	358	0.04	-15
90%	339	0.06	-20	90%	352	0.06	-21
E95	343	0.04	-16	E95	347	0.07	-26

2400 RPM	Average CHT	% Decrease CHT	ΔT	2500 RPM	Average CHT	% Decrease CHT	ΔT
100LL	379	---	---	100LL	383	---	---
10%	375	0.01	-4	10%	381	0.01	-2
20%	373	0.02	-6	20%	385	-0.01	2
40%	372	0.02	-7	40%	375	0.02	-8
60%	356	0.06	-23	60%	381	0.01	-2
80%	369	0.03	-10	80%	374	0.02	-9
90%	359	0.05	-20	90%	374	0.02	-9
E95	356	0.06	-23	E95	367	0.04	-16

Although heated discussion exists for both the pro and the con argument, the general consensus is that possession of real time CHT data can aid a pilot in determining an existing power plant problem. The pilot must identify the engine discrepancy early on and be able to troubleshoot the problem or divert to the nearest suitable landing field before the problem manifests. On a liquid cooled engine the reading may be lowered by the water circulating through the cylinder wall. CHT can tell you when you are losing or are low on engine coolant. In air-cooled engines, ambient air temperatures dictate the variation in discernable cylinder head temperature. For this reason, CHT data is corrected for non standard flight altitude temperatures.

Fuel Flow and Range

Based on previous work [30], it was hypothesized that consumption rates would increase as the concentration of ethanol in the fuel blend increased. Indeed, this hypothesis was confirmed with fairly consistent results. TABLE 10, TABLE 11,

TABLE 12, and TABLE 13 show comprehensive overview of fuel flow and range (nautical mile/gallon) data presented at the four tested RPM settings. True airspeed (KTAS) is included as a function of the range formula and remains in place as a standard comparison to the stability of actual RPM power setting and stability or instability of the air mass in which the aircraft was flown. Instability or turbulence, however slight, could cause a shift in the stability of these parameters. All efforts were made to choose only flight days and flight times where air mass stability was prominent. To avoid any data integrity issues, flights were cancelled all together if unstable atmospheric flight conditions were forecast or became remotely marginal.

At the 2100 RPM setting, fuel flows trend toward increasing flow rates as the amount of ethanol within the blended fuel increases. For each 10% increase in ethanol per blend, an approximate 5% increase in fuel flow is noted. A 3.2% decrease in range can be expected with each 10% increase in ethanol per blend. The results for the 2400

RPM setting data appear to be the most consistent. Splash blends exceeding 20% ethanol resulted in almost linear 8% increase in fuel flows for every 20% by volume ethanol concentration per blend. Data was somewhat inconsistent at the 2500 RPM setting. Both increases and decreases in trend information for range and fuel flow occurred. These inconsistencies at 2500 RPM should be further investigated. This recommendation is noted again in Section 6.

TABLE 10. 2500 RPM FUEL FLOW AND RANGE DATA

2500 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	7.3	7.6	7.6	7.4	9.1	8.9	9.2	9.9
Δ FF (gal/hr)	n/a	0.3	0.3	0.1	1.8	1.6	1.9	2.6
Δ FF (%)	n/a	4.11%	4.11%	1.37%	24.66%	21.92%	26.03%	35.62%
KTAS	100.2	100.2	98.7	98.4	98.3	101.5	99.1	99.4
Δ KTAS	n/a	0	-1.5	-1.8	-1.9	1.3	-1.1	-0.8
Range (nm/gal)	13.73	13.18	12.99	13.3	10.8	11.4	10.77	10.04
Δ Range (nm/gal)	n/a	-0.54	-0.74	-0.43	-2.92	-2.32	-2.95	-3.69
Δ Range (%)	n/a	-3.95%	-5.39%	-3.12%	-21.30%	-16.91%	-21.52%	-26.85%

TABLE 11. 2400 RPM FUEL FLOW AND RANGE DATA

2400 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	6.5	6.7	6.8	7.2	7.7	8.2	8.8	9.3
Δ FF (gal/hr)	n/a	0.2	0.3	0.7	1.2	1.7	2.3	2.8
Δ FF (%)	n/a	3.08%	4.62%	10.77%	18.46%	26.15%	35.38%	43.08%
KTAS	96.5	94.3	93.9	93.8	93.6	94	93.5	95.3
Δ KTAS	n/a	-2.2	-2.6	-2.7	-2.9	-2.5	-3.0	-1.2
Range (nm/gal)	14.85	14.07	13.81	13.03	12.16	11.46	10.63	10.25
Δ Range (nm/gal)	n/a	-0.77	-1.04	-1.82	-2.69	-3.38	-4.22	-4.6
Δ Range (%)	n/a	-5.20%	-6.99%	-12.25%	-18.12%	-22.79%	-28.43%	-30.98%

TABLE 12. 2300 RPM FUEL FLOW AND RANGE DATA

2300 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	5.5	5.8	6.3	6.5	6.9	7.5	7.7	8.4
Δ FF (gal/hr)	n/a	0.3	0.8	1.0	1.4	2.0	2.2	2.9
Δ FF (%)	n/a	5.45%	14.55%	18.18%	25.45%	36.36%	40.00%	52.73%
KTAS	90.5	90.1	83.9	90.1	90.1	89.2	89.5	87.3
Δ KTAS	n/a	-0.4	-6.6	-0.4	-0.4	-1.3	-1.0	-3.2
Range (nm/gal)	16.45	15.53	13.32	13.86	13.06	11.89	11.62	10.39
Δ Range (nm/gal)	n/a	-0.92	-3.14	-2.59	-3.4	-4.56	-4.83	-6.06
Δ Range (%)	n/a	-5.59%	-19.07%	-15.76%	-20.64%	-27.72%	-29.36%	-36.84%

TABLE 13. 2100 RPM FUEL FLOW AND RANGE DATA

2100 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	4.6	4.9	4.9	5.3	5.7	6	6.6	6.9
Δ FF (gal/hr)	n/a	0.3	0.3	0.7	1.1	1.4	2.0	2.3
Δ FF (%)	n/a	6.52%	6.52%	15.22%	23.91%	30.43%	43.48%	50.00%
KTAS	77.5	81.7	82.3	78.4	74.9	78.2	77	79
Δ KTAS	n/a	4.2	4.8	0.9	-2.6	0.7	-0.5	1.5
Range (nm/gal)	16.85	16.67	16.8	14.79	13.14	13.03	11.67	11.45
Δ Range (nm/gal)	n/a	-0.17	-0.05	-2.06	-3.71	-3.81	-5.18	-5.4
Δ Range (%)	n/a	-1.03%	-0.31%	-12.20%	-22.01%	-22.64%	-30.75%	-32.04%

Typical Cruise Performance Summary

During the transition from 100LL avgas to ethanol, it is anticipated that pilots will splash blend fuels. As a result, pilots will reference performance charts based on the post refueling blend. Figure 12 contains comprehensive operational and performance data associated with each of the blends tested during this study. This performance chart may be indicative of the charts used by GA pilots during the transition phase.

CESSNA
MODEL 152
Lycoming O-235
Compression Ratio: 9.7:1

TYPICAL CRUISE PERFORMANCE

Recommended Mixture (25°rich of peak EGT)

CONDITIONS:
Aircraft weight varied from 1,526-1,817 pounds
Best Economy Mixture (Peak EGT)
Ambient temperatures during testing varied from -11°C to 20°C (12°F to 68°F).

NOTE:
True airspeed are computed via reciprical groundspeed calculations and an average of individual data points.
Δ range information is developed using 100LL data as the baseline.
Δ range information will be available after 100LL baseline has been established.
Assume total aircraft flight weight is 1671.5 lbs.

100 LL	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19.5	2100	4.6	4000	78	17.0	1264	350
	22	2300	5.5	4000	91	16.5	1327	364
	22.5	2400	6.5	4000	97	14.9	1302	370
	23.5	2500	7.3	4000	100	13.7	1284	374
	24.6	Full Throttle	8.1	4000	---	---	1293	385

10% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19.5	2100	4.9	4000	82	16.7	1247	359
	21.5	2300	5.8	4000	90	15.5	1301	373
	22.3	2400	6.7	4000	94	14.0	1287	379
	23.5	2500	7.6	4000	100	13.2	1311	383
	24.5	Full Throttle	8.6	4000	---	---	1271	379

20% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19.5	2100	4.9	4000	82	16.7	1259	352
	21.5	2300	6.3	4000	84	13.3	1274	367
	22	2400	6.8	4000	94	13.8	1273	374
	24	2500	7.6	4000	99	13.0	1297	381
	24.6	Full Throttle	8.8	4000	---	---	1267	377

40% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19	2100	5.3	4000	78	14.7	1219	353
	21	2300	6.5	4000	90	13.8	1259	377
	22	2400	7.2	4000	94	13.1	1261	372
	23.6	2500	7.4	4000	98	13.2	1337	384
	24.6	Full Throttle	9.1	4000	---	---	1280	371

60% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19	2100	5.7	4000	75	13.2	1227	367
	21	2300	6.9	4000	90	13.0	1246	370
	22	2400	7.7	4000	94	12.2	1267	356
	23.5	2500	9.1	4000	98	10.8	1260	381
	24.5	Full Throttle	9.7	4000	---	---	1270	380

80% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19	2100	6.0	4000	78	13.0	1214	351
	21	2300	7.5	4000	89	11.9	1221	359
	22	2400	8.2	4000	94	11.5	1253	369
	23	2500	8.9	4000	102	11.5	1287	374
	24.5	Full Throttle	11.7	4000	---	---	1277	352

90% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19	2100	6.6	4000	77	11.7	1180	339
	20.6	2300	7.7	4000	90	11.7	1229	352
	21.6	2400	8.8	4000	94	10.7	1229	358
	23.3	2500	9.2	4000	99	10.8	1286	374
	24.5	Full Throttle	10.9	4000	---	---	1266	366

100% Ethanol	Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	19.5	2100	6.9	4000	79	11.4	1190	343
	20.7	2300	8.4	4000	87	10.4	1212	346
	22	2400	9.3	4000	95	10.2	1231	355
	23	2500	9.9	4000	99	10.0	1270	367
	24.5	Full Throttle	11.6	4000	---	---	1258	365

Figure 12. Typical cruise performance parameters at the "Recommended Mixture" air/fuel ratio.

CHAPTER FIVE

Results and Discussions: Peak EGT

As with the first experiment, the objective of this investigation was to document the variation of aircraft operational parameters through the same range of ethanol/100LL avgas fuel blends but at an air/fuel mixture setting set to the maximum exhaust gas temperature available, peak EGT.   A peak exhaust gas temperature provides the least amount of fuel burn and is defined as Best Economy. It is noted that data gathered during the E10 run was lost and therefore will be seen as a gap in gathered data. Data interpolation between the100LL avgas and the E20 runs could be a method employed by the reader in an attempt to extract E10 data. However, caution should be exercised as ongoing test-stand results (data not included in this writing)[30] show inconsistencies in straight line performance trends between fuel blends containing lesser amounts of ethanol (E10 and E20). These inconsistencies are believed to be caused by a change in the vapor pressure resulting from the blend of each of the neat fuels. Nonetheless, this chapter analyzes those runs conducted at peak EGT.

True Airspeed

The use of calculated true airspeed from groundspeeds recorded at reciprocal headings remained the same for the Peak EGT runs as a standard comparison for flight test procedural accuracy. Consistency in TAS was seen at each of the tested RPM with the Peak EGT air/fuel mixture. When average true airspeed was compared between the two mixture settings, there was a trend towards a slight increased average true airspeed in the Peak EGT investigation over the 25°F rich of peak results. At 2500 RPM there was a 2.1% increase in TAS and a 1.9%, 3.0%, and 3.2% increase at 2400, 2300, and 2100 RPM respectively. At full throttle, the increase was only 0.3%. Because thrust power output remains consistent with constant RPM due to the fixed-pitch propeller configuration, it is difficult to explain this consistent increase in TAS between the two air/fuel mixtures. A RPM setting specific chart documenting true airspeeds for the array of fuel blends is shown in TABLE 14.

TABLE 14. TRUE AIRSPEED PER RPM

Power Setting	100LL	E10	E20	E40	E60	E80	E90	E95	AVG TAS	STD DEV
2500	100.6	NO DATA AVAILABLE	101.4	102.1	103.2	104.0	104.0	102.1	102.5	1.20
	-1.89		-1.09	-0.39	0.71	1.51	1.51	-0.39		
2400	94.8		93.2	97.0	97.7	98.8	98.5	97.0	96.7	1.88
	-1.91		-3.51	0.29	0.99	2.09	1.79	0.29		
2300	91.2		84.3	93.5	94.4	93.6	94.1	93.5	92.1	3.32
	-0.89		-7.79	1.41	2.31	1.51	2.01	1.41		
2100	78.3		79.4	82.4	83.9	84.3	82.6	82.4	81.9	2.07
	-3.60		-2.50	0.50	2.00	2.40	0.70	0.50		
Full Throttle	102.8		105.1	101.4	105.7	104.5	106.0	101.4	103.8	1.82
TAS Spread	22.3		22.0	19.7	19.3	19.7	21.4	19.7		

True airspeed data trended within individual flights between RPM power settings as anticipated. Average airspeed difference between a low test-profile power-setting (2100 rpm) and the high test-profile power-setting (2500 rpm) was 20.9 knots. This is a 0.4 knot decrease in deltas from the 25°F rich of peak results. The minimum airspeed spread occurred during the E40 runs, with an airspeed spread of 19.6 knots. The maximum airspeed spread occurred during the 100LL avgas run, with an airspeed spread of 22.7 knots. A maximum standard deviation of 2.59 KTAS at 2300 RPM and a minimum standard deviation of 1.18 KTAS at 2500 RPM were noted in this experiment. There was no identifiable trend in airspeed spread along the fuel blend axis nor was there a pronounced trend when data was compared between the two tested air/fuel mixture settings.

Full Throttle RPM

During operations at full throttle, maximum achieved RPM data trended very similarly to the previous experiment. The relationship between fuel blend and RPM with the associated fuel flow included is shown in Figure 13. There is an increase of 30 rpm between the two neat fuels. This increase in RPM at the full throttle position is the best indicator of the increased power benefit associated with ethanol. Between E20 and E95, an increasing trend of approximately 5 rpm exists between each tested fuel with an exception to this trend occurring between E80 and E90, where a small decrease was recorded. This anomaly is believed to be the result of minor platform instability.

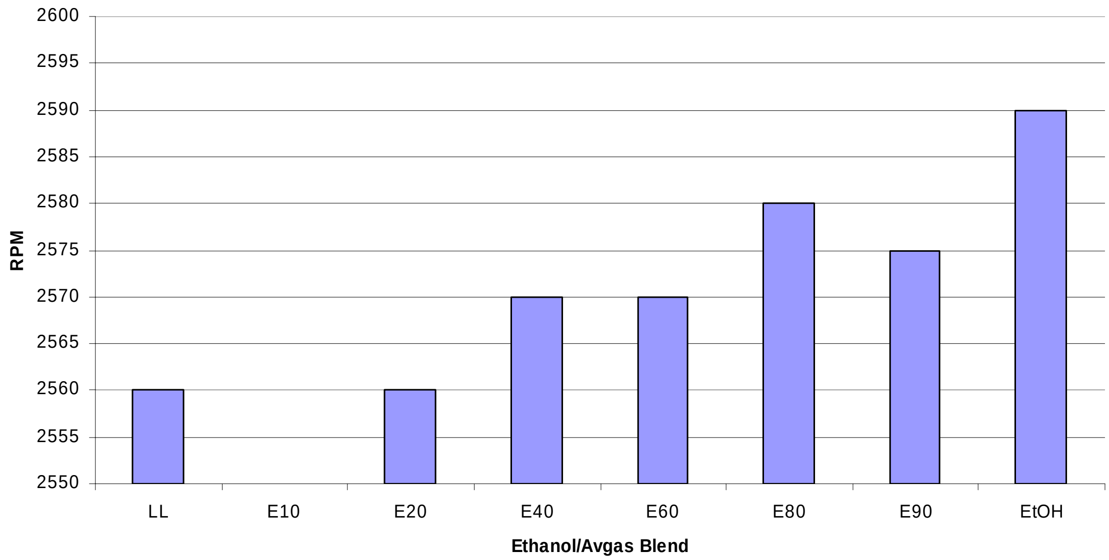

Figure 13. Increasing RPM trend with increased ethanol content at Full Throttle**.**

The same increasing fuel flow side effect mirroring the increase in ethanol content per fuel blend is apparent. The greatest fuel flow increase across the fuel blend range occurs at the full throttle RPM setting. TABLE 15 shows both the change in RPM and the change in fuel flow (gallons per hour and % increase in consumption). Fuel flow information is expanded later in this chapter.

TABLE 15. FULL THROTTLE RPM AND FUEL FLOW

Blend	RPM	Δ RPM	FF	Δ FF	% Δ FF
LL	2560	---	5.2	---	---
E10		N O D A T A	A V A I L A B L E		
E20	2560	0	5.5	0.3	0.06
E40	2570	10	5.3	0.1	0.02
E60	2570	10	5.9	0.7	0.13
E80	2580	20	6.3	1.1	0.21
E90	2575	15	6.7	1.5	0.29
EtOH	2590	30	7.1	1.9	0.37

Exhaust Gas Temperature (EGT)

As ethanol is increased, a decrease in EGT becomes apparent within constant RPM settings. Results from this air/fuel mixture setting provide a consistent decreasing trend in EGT at the 2100, 2300, and 2400 RPM settings with a corresponding 161.5°F, 151.8°F and 166.4°F decrease in temperature from conventional 100LL avgas to 100% denatured ethanol. Unlike the previous experiment, a consistent trend is detectable at the 2500 power setting. At the high-end, 2500 RPM power setting; a total decrease in EGT of 138°F (10%) across the blend spectrum was observed. See TABLE 16 for EGT detail information.

TABLE 16. EXHAUST GAS TEMPERATURE RESULTS
(Peak EGT)

2100 RPM	Average EGT	% Decrease EGT	ΔT	2300 RPM	Average EGT	% Decrease EGT	ΔT
100LL	1326.0	---	---	100LL	1349.0	---	---
10%	data not available			10%	data not available		
20%	1302.5	0.02	-23.5	20%	1339.7	0.01	-9.3
40%	1239.5	0.07	-86.5	40%	1272.2	0.06	-76.8
60%	1214.5	0.08	-111.5	60%	1249.2	0.07	-99.8
80%	1200.4	0.09	-125.6	80%	1237.0	0.08	-112.0
90%	1135.1	0.14	-190.9	90%	1183.5	0.12	-165.5
E95	1164.5	0.12	-161.5	E95	1197.2	0.11	-151.8

2400 RPM	Average EGT	% Decrease EGT	ΔT	2500 RPM	Average EGT	% Decrease EGT	ΔT
100LL	1364.0	---	---	100LL	1338.0	---	---
10%	data not available			10%	data not available		
20%	1351.0	0.01	-13.0	20%	1324.0	0.01	-14.0
40%	1272.6	0.07	-91.4	40%	1275.0	0.05	-63.0
60%	1254.3	0.08	-109.7	60%	1253.9	0.06	-84.1
80%	1254.8	0.08	-109.2	80%	1247.2	0.07	-90.8
90%	1252.5	0.08	-111.5	90%	1232.3	0.08	-105.7
E95	1197.6	0.12	-166.4	E95	1200.0	0.1	-138.0

Cylinder Head Temperature (CHT)

Overall cooler CHT operating parameters associated with combustion related temperatures are more pronounced at the Peak EGT air/fuel mixture. Observed cylinder head temperatures were corrected for non-standard atmospheric temperatures. An average difference in cylinder head temperature across the tested RPM settings show an increase of 28.7°F cooling ability at the Peak EGT setting when compared to the recommended lean power setting. The average cooling effect of E95 equates to 48.9°F with a standard deviation of 2.3°F. A RPM setting specific chart documenting cylinder head temperature for the array of fuel blends is shown in TABLE 17.

TABLE 17. CYLINDER HEAD TEMPERATURE RESULTS (Peak EGT)

2100 RPM	Average CHT	% Decrease CHT	ΔT	2300 RPM	Average CHT	% Decrease CHT	ΔT
100LL	354.1	---	---	100LL	369.5	---	---
10%	data not available			10%	data not available		
20%	362.7	-0.02	8.6	20%	375.6	-0.02	6.1
40%	335.6	0.05	-18.5	40%	347.4	0.06	-22.1
60%	348.3	0.02	-5.8	60%	346.4	0.06	-23.1
80%	323.9	0.09	-30.2	80%	328.2	0.11	-41.3
90%	333.5	0.06	-20.6	90%	345.6	0.06	-23.9
E95	305.6	0.14	-48.5	E95	317.4	0.14	-52.1

2400 RPM	Average CHT	% Decrease CHT	ΔT	2500 RPM	Average CHT	% Decrease CHT	ΔT
100LL	375.3	---	---	100LL	378.8	---	---
10%	data not available			10%	data not available		
20%	381.8	-0.02	6.5	20%	374.1	0.01	-4.8
40%	356.5	0.05	-18.8	40%	362.4	0.04	-16.4
60%	355.3	0.05	-20.1	60%	359.3	0.05	-19.5
80%	334.4	0.11	-40.9	80%	336.8	0.11	-42.0
90%	350.8	0.07	-24.5	90%	353.4	0.07	-25.4
E95	326.5	0.13	-48.8	E95	332.4	0.12	-46.4

Fuel Flow and Range

At the 2100 RPM setting, fuel flows trend toward increasing flow rates as the amount of ethanol within the blended fuel increases. For each 10% increase in ethanol per blend, an approximate 3.5% increase in fuel flow is noted. A 2.2% decrease in range can be expected with each 10% increase in ethanol per blend at this low-end power setting.

Intermediate RPM power settings confirmed hypothesis and correlated results. At the 2300 RPM setting, each 10% increase in ethanol per blend saw an approximate 4.0% increase in fuel flow. A 2.6% decrease in range can be expected with each 10% increase in ethanol per blend at 2300 RPM. Every 10% increase in ethanol per blend yielded a 3.5% increase in fuel flow and a 2.4% decrease in range at 2400 RPM.

The 2500 RPM power setting shows a 26.8% total decrease in range across the tested fuel blends. This was the result of a 39.2% increase in fuel flow. A comprehensive overview of fuel flow and a closely accompanying range (nautical mile/gallon) data set at the four tested RPM settings is shown in TABLE 18, TABLE 19, TABLE 20, and TABLE 21.

TABLE 18. 2500 RPM FUEL FLOW AND RANGE DATA

2500 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	5.1	N	5.3	5.6	5.9	6.3	6.6	7.1
Δ FF (gal/hr)	n/a	O	0.2	0.5	0.8	1.2	1.5	2.0
Δ FF (%)	n/a		3.92%	9.80%	15.69%	23.53%	29.41%	39.22%
KTAS	100.6	D	101.4	102.1	103.2	104.0	104.0	102.1
Δ KTAS	n/a	A	0.8	1.5	2.6	3.4	3.4	1.5
Range (nm/gal)	19.73	T	19.13	18.23	17.49	16.51	15.76	14.38
Δ Range (nm/gal)	n/a	A	-0.59	-1.49	-2.23	-3.22	-3.97	-5.35
Δ Range (%)	n/a		-3.01%	-7.57%	-11.33%	-16.31%	-20.12%	-27.10%

TABLE 19. 2400 RPM FUEL FLOW AND RANGE DATA

2400 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	4.5	N	4.6	4.8	5.1	5.4	5.6	6.1
Δ FF (gal/hr)	n/a	O	0.1	0.3	0.6	0.9	1.1	1.6
Δ FF (%)	n/a		2.22%	6.67%	13.33%	20.00%	24.44%	35.56%
KTAS	94.8	D	93.2	97.0	97.7	98.8	98.5	97.0
Δ KTAS	n/a	A	-1.6	2.2	2.9	4.0	3.7	2.2
Range (nm/gal)	21.07	T	20.26	20.21	19.16	18.3	17.59	15.9
Δ Range (nm/gal)	n/a	A	-0.81	-0.86	-1.91	-2.77	-3.48	-5.17
Δ Range (%)	n/a		-3.82%	-4.07%	-9.07%	-13.15%	-16.51%	-24.52%

TABLE 20. 2300 RPM FUEL FLOW AND RANGE DATA

2300 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	4	N	4.2	4.3	4.7	4.9	5.6	5.6
Δ FF (gal/hr)	n/a	O	0.2	0.3	0.7	0.9	1.6	1.6
Δ FF (%)	n/a		5.00%	7.50%	17.50%	22.50%	40.00%	40.00%
KTAS	91.2	D	84.3	93.5	94.4	93.6	94.1	93.5
Δ KTAS	n/a	A	-6.9	2.3	3.2	2.4	2.9	2.3
Range (nm/gal)	22.8	T	20.07	21.74	20.09	19.1	16.8	16.7
Δ Range (nm/gal)	n/a	A	-2.73	-1.06	-2.71	-3.7	-6	-6.1
Δ Range (%)	n/a		-11.97%	-4.63%	-11.91%	-16.22%	-26.30%	-26.77%

TABLE 21. 2100 RPM FUEL FLOW AND RANGE DATA

2100 RPM	100LL	E10	E20	E40	E60	E80	E90	E95
Fuel Flow (gal/hr)	3.4	N	3.5	3.4	3.8	4.1	4.6	4.6
Δ FF (gal/hr)	n/a	O	0.1	0.0	0.4	0.7	1.2	1.2
Δ FF (%)	n/a		2.94%	0.00%	11.76%	20.59%	35.29%	35.29%
KTAS	78.3	D	79.4	82.4	83.9	84.3	82.6	82.4
Δ KTAS	n/a	A	1.1	4.1	5.6	6.0	4.3	4.1
Range (nm/gal)	23.03	T	22.69	24.24	22.08	20.56	17.96	17.91
Δ Range (nm/gal)	n/a	A	-0.34	1.21	-0.95	-2.47	-5.07	-5.12
Δ Range (%)	n/a		-1.49%	5.24%	-4.13%	-10.72%	-22.03%	-22.22%

Typical Cruise Performance Summary

Comprehensive operational and performance data is presented in industry standard tables applicable to published literature utilized for flight planning purposes. Figure 14 shows the typical cruise performance, specific to the aircraft and powerplant used in this study, for a mixture setting that produces a peak exhaust gas temperature. This mixture setting duplicates the manufacturers suggested “BEST ECONOMY” leaning procedure.

MODEL 152
Lycoming O-235
Compression Ratio: 9.7:1

TYPICAL CRUISE PERFORMANCE

Best Economy (Peak EGT)

CONDITIONS:
Aircraft weight varied from 1,526-1,817 pounds
Best Economy Mixture (Peak EGT)
Ambient temperatures during testing varied from -11°C to 20°C (12°F to 68°F).

NOTE:
True airspeed are computed via reciprocal groundspeed calculations and an average of individual data points.
Δ range information is developed using 100LL data as the baseline.
Δ range information will be available after 100LL baseline has been established.
Assume total aircraft flight weight is 1671.5 lbs.
E10 data not available

100 LL

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
20.00	2100	3.4	4000	78	22.9	1326	354
22.00	2300	4.0	4000	91	22.8	1349	369
23.25	2400	4.5	4000	95	21.1	1364	377
24.00	2500	5.1	4000	101	19.8	1338	379
24.75	Full Throttle	5.2	4000	---	---	1325	383

10% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
	2100		4000				
	2300		4000				
	2400		4000				
	2500		4000				
	Full Throttle		4000				

20% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
19.50	2100	3.5	4000	79	22.6	1303	363
21.50	2300	4.2	4000	84	20.0	1340	376
22.50	2400	4.6	4000	93	20.2	1351	382
24.75	2500	5.3	4000	101	19.1	1324	274
24.75	Full Throttle	5.5	4000	---	---	1340	391

40% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
20.50	2100	3.4	4000	82	24.1	1240	336
22.75	2300	4.3	4000	94	21.9	1272	347
23.00	2400	4.8	4000	97	20.2	1273	357
24.75	2500	5.6	4000	102	18.2	1275	362
24.75	Full Throttle	5.3	4000	---	---	1279	346

60% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
20.50	2100	3.8	4000	84	22.1	1215	348
22.00	2300	4.7	4000	94	20.0	1249	346
23.00	2400	5.1	4000	98	19.2	1254	355
24.50	2500	5.9	4000	103	17.5	1254	359
24.50	Full Throttle	5.9	4000	---	---	1253	358

80% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
20.00	2100	4.1	4000	84	20.5	1200	324
22.50	2300	4.9	4000	94	19.2	1237	328
23.00	2400	5.4	4000	99	18.3	1255	334
25.00	2500	6.3	4000	104	16.5	1247	337
25.00	Full Throttle	6.3	4000	---	---	1244	339

90% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
19.50	2100	4.6	4000	83	18.0	1135	334
22.00	2300	5.6	4000	94	16.8	1184	346
23.25	2400	5.6	4000	99	17.7	1253	351
24.25	2500	6.6	4000	104	15.8	1232	353
24.25	Full Throttle	6.7	4000	---	---	1235	348

100% Ethanol

Manifold Pressure	RPM	Fuel Flow (gal/hr)	Pressure Altitude	KTAS	Nautical MPG	Average EGT	Average CHT
20.50	2100	4.6	4000	82	17.8	1165	306
22.75	2300	5.6	4000	94	16.8	1197	317
23.00	2400	6.1	4000	97	15.9	1198	327
24.75	2500	7.1	4000	102	14.4	1200	332
24.75	Full Throttle	7.1	4000	---	---	1204	342

Figure 14. Typical cruise performance parameters at the “Peak EGT” air/fuel ratio.

CHAPTER SIX

Conclusion and Recommendations

With the mandate made in 1996 by the United States Environmental Protection Agency (EPA) to remove all lead components from motor gasoline, conventional 100 octane low-lead aviation fuel, also known as 100LL avgas, is next in line for replacement. Even though 100LL avgas is not included on the current list of fuels to be replaced, its eventual replacement requires that the aviation field agree on a suitable replacement fuel. This research supports fuel grade ethanol as that replacement, with the scope of this work demonstrating the viability, reliability and operational performance signature of a series of ethanol/100LL avgas fuel blends.

This work entailed cruise flight testing two fuels (100LL avgas and E95) and six intermediary blends (E10, E20, E40, E60, E80, E90). Two air/fuel mixture settings, peak EGT and 25ºF rich of peak EGT, were investigated. The investigation evaluated four RPM settings and a full throttle setting on each of the eight fuels. Data were gathered for flight performance and engine operating parameters including groundspeed, true airspeed, RPM, fuel flow, manifold pressure, exhaust gas temperatures and cylinder head temperatures.

The first air/fuel mixture setting employed the manufacturers recommended mixture setting. EGT decreased 73.8°F at 2100RPM, 115.0°F at 2300 RPM, 71.6°F at 2400 RPM and 14.1°F at 2500RPM. CHT decreased 16.0°F at 2100RPM, 26.0°F at 2300 RPM, 23.0°F at 2400 RPM and 16.0°F at 2500RPM. Average fuel flow increased 0.28 gal/hr for every 10% (by volume) increase in ethanol. Aircraft range (nm/gal) decreased between 26.4% and 31.8% from baseline 100LL avgas to E95. Maximum power increase in the form of 40 additional RPM at full throttle setting was recorded.

The second air/fuel mixture setting employed the Best Economy/peak EGT mixture setting. EGT decreased 161.5°F at 2100RPM, 151.8°F at 2300 RPM, 166.4°F at 2400 RPM and 138.0°F at 2500RPM. CHT decreased 48.5°F at 2100RPM, 52.1°F at 2300 RPM, 48.8°F at 2400 RPM and 46.4°F at 2500RPM. Average fuel flow increased 0.16 gal/hr for every 10% (by volume) increase in ethanol. Aircraft range (nm/gal) decreased between 21.9% and 26.8% from baseline 100LL avgas to E95. Maximum power increase in the form of 30 additional RPM at full throttle setting was recorded.

Several recommendations are made for future investigations:

- Do not limit the investigation to a single tested altitude. Because flight operations never occur at a single altitude, multiple altitudes could identify advantageous or detrimental phenomenon associated with a given blend.

- Correlate the intrinsic decrease in intake charge temperature of ethanol with perceived decrease in performance density altitude.

- Expand this research to include ethanol/gasoline fuel blends like those used in the automotive industry. Supplemental Type Certificates (STCs) exist for a variety of aircraft engines and these aircraft may eventually field blends as well.

- Employ a fleet of aircraft (flight club or flight training school) to operate long term on ethanol and blends of ethanol. The next step in the process is the fostering of industry acceptance.

- Focus additional studies on the presence or probability of the formation of carburetor icing. Although carburetor icing was never encountered during this study, ethanol has a latent heat of vaporization of 2,378 Btu/gallon compared to ~900 Btu/gal for 100LL avgas which leads speculation into the increased chances of carburetor icing.[31]

- Make use of precision machined fuel injectors and include operations at lean of peak EGT.

APPENDICES

APPENDIX A

RECOMMENDED LEAN RAW DATA
(25°F RICH OF PEAK EGT)

TABLE A. 1. SCHEDULE OF "RECOMMENDED LEAN" FLIGHT TEST

BLEND	FLIGHT DAY	AIRCREW	FLIGHT TIME
100LL	3-Mar-2007	Compton/Periman	2.4
E10	3-Mar-2007	Compton/Periman	1.9
E20	3-Mar-2007	Compton/Periman	2.1
E40	4-Mar-2007	Compton/Periman	2.2
E60	7-Mar-2007	Compton/Sugg	1.7
E80	5-Mar-2007	Compton/Banas	1.8
E90	5-Mar-2007	Compton/Periman	1.6
E95	4-Mar-2007	Compton/Graves	2.2
		TOTAL TIME	15.9

Ethanol (E95)	**0%**
Avgas	**100%**
Mixture Setting	**25° Rich of Peak EGT**

Date	3-Mar-2007	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Nick Periman	175 lbs

		Tach Time		Hobbs	
Engine On	6:30				
Engine Off	9:00	stop	4448.8	stop	105.8
PA	4000	start	4446.6	start	103.4
OAT	3.3°C	total	2.2	total	2.4

Basic Empty Weigh 1597.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	7:10:00	#2	2500	98	111	96	7.4	21.8	23.50	1741.3	103.5	
38°	7:12:00	1335	2500	99	107	96	7.3	21.4	23.50	1738.6	101.5	102.7
	7:14:00		2500	99	110	96	7.3	21.1	23.50	1736.7	103.0	
	7:25:00	#1	2400	94	84	115	6.4	19.8	22.75	1728.1	99.5	
35°	7:27:00	1341	2400	97	85	114	6.5	19.5	22.75	1726.1	99.5	99.2
	7:29:00		2400	96	82	115	6.6	19.3	22.75	1724.8	98.5	
	7:44:00	#4	2300	91	101	85	5.6	17.8	22.00	1714.9	93.0	
37°	7:46:00	1365	2300	89	96	88	5.4	17.5	22.00	1712.9	92.0	92.8
	7:48:00		2300	91	99	88	5.6	17.3	22.00	1711.6	93.5	
	8:06:00	#1	2100	79	66	94	4.6	15.9	19.50	1702.3	80.0	
35°	8:08:00	1320	2100	80	66	96	4.6	15.6	19.50	1700.4	81.0	79.7
	8:10:00		2100	78	64	92	4.6	15.4	19.50	1699.0	78.0	
	8:23:00	#2 / 1400	Full Throttle	106	115	95	8.1	14.2	24.75	1691.1	105.0	105.0
								10.0				
							Total Fuel Used	14.5				

AWOS 031051Z 35009KT 9SM -SN CLR 03/M07 A3009

Comments check pitot heat, may be inoperative

Full Throttle RPM 2570

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1305	1292	1283	1246	386	400	352	355
2500	1309	1305	1281	1259	388	402	353	355
2500	1305	1288	1272	1258	389	401	354	356
2400	1305	1272	1286	1297	380	395	349	357
2400	1309	1385	1303	1302	379	394	348	356
2400	1306	1274	1289	1300	380	393	349	357
2300	1342	1307	1314	1347	369	385	344	353
2300	1340	1308	1315	1341	371	389	347	358
2300	1343	1307	1310	1345	369	387	345	356
2100	1297	1240	1237	1267	353	362	332	342
2100	1305	1241	1245	1277	357	367	336	345
2100	1302	1237	1246	1274	357	367	335	343
Full Throttle	1376	1304	1256	1235	403	409	343	351

Temperature Averages

	EGT	CHT
2500	1284	374
2400	1302	370
2300	1327	364
2100	1264	350
Full Throttle	1293	377

Figure A.1. Recommended Lean – 100LL avgas

Ethanol (E95) **10%**
Avgas **90%**
Mixture Setting **25° Rich of Peak EGT**

Date	3-Mar-2007	
Flight (a, b, or c)	B	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Nick Periman	175 lbs

		Tach Time		Hobbs	
Engine On	10:30				
Engine Off	12:20	stop	4450.4	stop	107.7
PA	4000	start	4448.8	start	105.8
OAT	2.2°C	total	1.6	total	1.9

Basic Empty Weigh 1597.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	11:01:00	#1	2500	104	125	81	7.4	23.1	23.50	1749.9	103.0	
37°	11:03:00	1333	2500	103	127	82	7.7	22.9	23.50	1748.5	104.5	103.0
	11:05:00		2500	102	121	82	7.7	22.7	23.50	1747.2	101.5	
	11:14:00	#3	2400	96	76	119	6.7	21.7	22.25	1740.6	97.5	
36°	11:16:00	1311	2400	97	75	119	6.5	21.5	22.25	1739.3	97.0	97.0
	11:18:00		2400	95	74	119	6.8	21.2	22.25	1737.3	96.5	
	11:27:00	#3	2300	91	114	73	5.8	20.3	21.50	1731.4	93.5	
36°	11:29:00	1317	2300	90	112	73	5.8	20.1	21.50	1730.1	92.5	92.7
	11:31:00		2300	90	111	73	5.8	19.9	21.50	1728.7	92.0	
	11:41:00	#1	2100	82	63	105	5.0	19.0	19.80	1722.8	84.0	
35°	11:43:00	1308	2100	80	60	104	4.8	19.8	19.25	1728.1	82.0	84.2
	11:45:00		2100	77	69	104	5.0	18.6	19.50	1720.2	86.5	
37°	11:54:00	#1 / 1350	Full Throttle	104	84	128	8.6	17.6	24.50	1713.6	106.0	106.0
								12.9				
							Total Fuel Used	11.6				

AWOS 031451Z 35021G26KT 10SM CLR 08/M11 A3024
Comments RPM on first set of 2100 was 2160
Full Throttle RPM 2570

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1335	1330	1307	1270	384	395	352	356
2500	1342	1322	1310	1267	384	396	352	357
2500	1338	1322	1315	1268	380	399	352	359
2400	1302	1268	1294	1280	372	382	345	356
2400	1305	1259	1290	1288	374	380	348	356
2400	1307	1263	1299	1288	378	391	350	355
2300	1326	1275	1304	1318	361	372	338	350
2300	1319	1260	1296	1305	365	379	342	355
2300	1320	1271	1308	1311	366	378	343	354
2100	1278	1223	1244	1239	348	354	330	330
2100	1288	1219	1229	1235	348	352	330	332
2100	1283	1223	1241	1245	355	357	336	340
Full Throttle	1341	1275	1249	1220	392	403	340	345

Temperature Averages

	EGT	CHT
2500	1311	372
2400	1287	366
2300	1301	359
2100	1246	343
Full Throttle	1271	370

Figure A.2. Recommended Lean – E10

Ethanol (E95) **20%**
Avgas **80%**
Mixture Setting **25° Rich of Peak EGT**

Date	3-Mar-2007	
Flight (a, b, or c)	C	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Alex Greves	145 lbs

		Tach Time		Hobbs	
Engine On	14:00				
Engine Off	16:00	stop	4452.3	stop	109.8
PA	4000	start	4450.4	start	107.7
OAT	2.7°C	total	1.9	total	2.1

Basic Empty Weigh 1567.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	14:21:00		2500	106	118	82	7.5	23.1	24.00	1719.9	100.0	
37°	14:23:00		2500	100	116	88	7.8	22.5	24.00	1715.9	102.0	101.3
	14:25:00		2500	100	117	87	7.5	22.3	24.00	1714.6	102.0	
	14:39:00	#3	2400	97	85	106	6.8	21.0	22.00	1706.0	95.3	
	14:41:00	1326	2400	100	88	110	6.8	20.7	22.00	1704.0	99.0	96.4
	14:43:00		2400	96	82	108	6.9	20.2	22.00	1700.7	95.0	
	15:00:00	#	2300	87	105	81	6.4	19.0	21.50	1692.8	93.0	
	15:02:00	1323	2300	88	104	82	6.1	18.8	21.00	1691.5	93.0	86.2
	15:04:00		2300	89	105	78	6.3	18.4	22.00	1688.8	72.5	
	15:14:00	#3	2100	76	67	94	5.1	17.4	19.50	1682.2	77.0	
	15:16:00	1281	2100	75	60	95	4.9	17.0	19.50	1679.6	83.0	84.5
	15:18:00		2100	85	71	92	4.8	16.8	19.50	1678.3	93.5	
	no time recorded	#2 / 1305	Full Throttle	105	95	122	8.8	15.9	24.75	1672.3	108.5	108.5
								12.8				
							Total Fuel Used	11.7				

AWOS 031851Z 33015G21KT 10SM CLR 13/M08 A3025
Comments
Full Throttle RPM 2580

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1351	1304	1285	1257	387	401	352	356
2500	1350	1306	1286	1237	393	409	359	361
2500	1312	1285	1321	1266	390	405	354	354
2400	1298	1240	1280	1269	370	382	344	347
2400	1292	1246	1284	1261	373	385	349	352
2400	1298	1242	1292	1276	380	390	351	352
2300	1306	1252	1280	1267	385	394	355	360
2300	1300	1251	1284	1269	389	393	354	358
2300	1293	1235	1291	1269	369	380	344	349
2100	1291	1228	1264	1250	357	366	337	348
2100	1296	1229	1264	1237	346	349	328	336
2100	1294	1238	1266	1249	348	351	332	337
Full Throttle	1332	1287	1249	1201	400	400	335	339

Temperature Averages

	EGT	CHT
2500	1297	377
2400	1273	365
2300	1275	369
2100	1259	345
Full Throttle	1267	369

Figure A.3. Recommended Lean – E20

Ethanol (E95) **40%**
Avgas **60%**
Mixture Setting **25° Rich of Peak EGT**

Date	4-Mar-2007		
Flight (a, b, or c)	A		
Aircraft	N152BU	1212.4	lbs
Pilot	Tim Compton	210	lbs
Observer	Nick Periman	195	lbs

		Tach Time		Hobbs	
Engine On	9:43				
Engine Off	12:00	stop	4454.3	stop	112.0
PA	4000	start	4452.3	start	109.8
OAT	1.1°C	total	2.0	total	2.2

Basic Empty Weigh 1617.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressur	Weight	KTAS	
	start	°F										
	10:08:00	#1	2500	99	124	77	7.5	22.5	23.75	1765.9	100.5	
35°	10:10:00	1324	2500	98	124	81	7.4	22.3	23.75	1764.6	102.5	101.8
	10:12:00		2500	98	124	81	7.4	22.1	23.75	1763.3	102.5	
	10:20:00	#3	2400	94	75	119	7.2	20.8	22.00	1754.7	97.0	
34°	10:22:00	1315	2400	94	73	121	7.2	20.5	22.00	1752.7	97.0	97.2
	10:24:00		2400	96	76	119	7.3	20.2	22.00	1750.7	97.5	
	10:40:00	#3	2300	90	114	71	6.4	18.7	21.00	1740.8	92.5	
34°	10:42:00	1308	2300	93	115	73	6.5	18.4	21.00	1738.8	94.0	93.4
	10:44:00		2300	91	117	70	6.5	18.2	21.00	1737.5	93.6	
	10:54:00	#3	2100	82	63	99	5.3	17.0	19.00	1729.6	81.0	
33°	10:56:00	1277	2100	81	63	101	5.2	16.9	19.00	1728.9	82.0	81.3
	10:58:00		2100	80	57	105	5.3	16.6	19.00	1727.0	81.0	
	11:08:00	#2 / 1322	Full Throttle	106	123	86	9.1	15.6	24.75	1720.4	104.5	104.5
								8.0				
							Total Fuel Used	16.5				

AWOS 041351Z 28006KT 10SM CLR 01/M09 A3055
Comments
Full Throttle RPM 2590

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1359	1333	1351	1299	368	379	339	348
2500	1357	1339	1356	1300	375	386	346	355
2500	1357	1338	1355	1298	377	388	349	358
2400	1280	1232	1292	1244	371	383	341	339
2400	1276	1231	1283	1242	375	387	345	341
2400	1281	1237	1295	1240	374	388	345	340
2300	1280	1231	1278	1246	364	372	337	339
2300	1289	1229	1275	1252	366	373	342	341
2300	1283	1226	1268	1249	366	373	342	342
2100	1249	1204	1242	1187	348	340	326	316
2100	1248	1203	1238	1191	351	347	329	319
2100	1249	1195	1237	1186	349	352	329	321
Full Throttle	1337	1313	1256	1216	380	395	331	335

Temperature Averages

	EGT	CHT
2500	1337	364
2400	1261	361
2300	1259	355
2100	1219	336
Full Throttle	1281	360

Figure A.4. Recommended Lean – E40

Ethanol (E95) **60%**
Avgas **40%**
Mixture Setting **25° Rich of Peak EGT**

Date	7-Mar-2007	
Flight (a, b, or c)	B	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Andrew Sugg	210 lbs

		Tach Time		Hobbs	
Engine On	17:05				
Engine Off	18:50	stop	4461.9	stop	120.7
PA	4000	start	4460.3	start	119.0
OAT	11.25°C	total	1.6	total	1.7

Basic Empty Weigh 1632.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	17:28:00	#1	2500	95	89	107	9.1	22.7	23.50	1782.2	98.0	
53°	17:30:00	1329	2500	95	92	108	9.1	22.3	23.50	1779.6	100.0	99.2
	17:37:00		2500	98	92	107	9.1	22.1	23.50	1778.3	99.5	
	17:45:00	#3	2400	93	89	102	7.7	20.0	22.00	1764.4	95.5	
52°	17:47:00	1328	2400	92	88	98	7.6	19.8	22.00	1763.1	93.0	94.5
	17:49:00		2400	93	89	101	7.7	19.5	22.00	1761.1	95.0	
	18:06:00	#3	2300	88	99	84	6.9	17.9	21.00	1750.5	91.5	
52°	18:08:00	1289	2300	88	100	83	6.9	17.5	21.00	1747.9	91.5	91.0
	18:10:00		2300	88	98	82	7.0	17.3	21.00	1746.6	90.0	
	18:17:00	#3	2100	74	68	82	5.7	16.1	19.00	1738.7	75.0	
52°	18:19:00	1259	2100	76	72	80	5.8	16.0	19.00	1738.0	76.0	75.7
	18:21:00		2100	73	69	83	5.6	15.9	19.00	1737.3	76.0	
	18:32:00	#1 / 1342	Full Throttle	100	111	95	9.7	14.9	24.25	1730.7	103.0	103.0
								12.8				
							Total Fuel Used	11.7				

AWOS 072151Z 10SM CLR 23/06 A3009
Comments
Full Throttle RPM 2580

	EGT				CHT					Temperature Averages	
	#1	#2	#3	#4	#1	#2	#3	#4		EGT	CHT
RPM											
2500	1300	1238	1271	1236	405	401	381	358			
2500	1300	1237	1268	1242	410	404	384	361	2500	1260	388
2500	1296	1230	1267	1235	408	403	383	360			
2400	1287	1239	1295	1258	392	400	385	357			
2400	1288	1233	1284	1251	289	396	385	357	2400	1268	363
2400	1290	1234	1296	1256	239	404	391	363			
2300	1274	1200	1256	1239	379	388	382	360			
2300	1274	1216	1265	1241	379	385	382	360	2300	1246	377
2300	1276	1214	1256	1246	378	384	381	360			
2100	1266	1200	1250	1216	388	386	376	356			
2100	1263	1195	1241	1206	388	380	372	350	2100	1229	374
2100	1264	1202	1236	1204	383	380	374	350			
Full Throttle	1333	1281	1247	1222	401	413	379	357	Full Throttle	1271	388

Figure A.5. Recommended Lean – E60

Ethanol (E95)	**80%**
Avgas	**20%**
Mixture Setting	**25° Rich of Peak EGT**

Date	5-Mar-2007	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Daryl Banas	175 lbs

		Tach Time		Hobbs	
Engine On	8:30				
Engine Off	10:15	stop	4460.3	stop	119.0
PA	4000	start	4458.7	start	117.2
OAT	10.5°C	total	1.6	total	1.8

Basic Empty Weigh 1597.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	8:54:00	#3	2500	97	94	113	8.7	22.9	23.00	1748.5	103.5	
51°	8:56:00	1316	2500	97	94	113	9.0	22.6	23.00	1746.6	103.5	102.8
	8:58:00		2500	97	92	111	9.0	22.3	23.00	1744.6	101.5	
	9:12:00	#3	2400	90	97	95	8.4	20.5	22.00	1732.7	96.0	
50°	9:14:00	1291	2400	94	98	95	8.0	20.3	22.00	1731.4	96.5	95.3
	9:16:00		2400	90	95	92	8.2	19.9	22.00	1728.7	93.5	
	9:25:00	#3	2300	89	88	95	7.5	18.5	21.00	1719.5	91.5	
51°	9:27:00	1264	2300	87	83	97	7.5	17.8	21.00	1714.9	90.0	90.3
	9:29:00		2300	85	83	96	7.5	17.5	21.00	1712.9	89.5	
	9:43:00	#3	2100	75	86	73	5.9	16.3	19.00	1705.0	79.5	
51°	9:45:00	1262	2100	75	86	71	6.0	16.2	19.00	1704.3	78.5	79.2
	9:47:00		2100	77	86	73	6.0	16.0	19.00	1703.0	79.5	
52°	9:54:00	#4 / 1162	Full Throttle	103	100	111	11.7	14.6	24.50	1693.8	105.5	105.5
								11.6				
							Total Fuel Used	12.9				

AWOS 170/4 10 CLR BLOW 12000 11/9 30.22

Comments

Full Throttle RPM 2600

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1314	1265	1305	1239	387	395	371	355
2500	1333	1266	1315	1250	391	400	378	360
2500	1333	1269	1314	1250	390	398	378	360
2400	1273	1234	1290	1233	384	389	382	352
2400	1275	1220	1275	1227	382	389	380	348
2400	1274	1227	1279	1229	382	388	380	348
2300	1257	1186	1242	1201	370	372	376	340
2300	1254	1193	1246	1192	370	371	376	341
2300	1252	1195	1240	1197	370	371	377	340
2100	1240	1196	1247	1181	365	363	365	334
2100	1240	1197	1240	1179	365	363	365	335
2100	1241	1188	1239	1181	365	364	367	334
Full Throttle	1206	1194	1178	1131	382	397	342	309

Temperature Averages

	EGT	CHT
2500	1288	380
2400	1253	375
2300	1221	365
2100	1214	357
Full Throttle	1177	358

Figure A.6. Recommended Lean – E80

Ethanol (E95) **90%**
Avgas **10%**
Mixture Setting **25° Rich of Peak EGT**

Date	5-Mar-2007	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	Tim Compton	210 lbs
Observer	Nick Periman	175 lbs

		Tach Time		Hobbs	
Engine On	6:25				
Engine Off	8:00	stop	4457.7	stop	115.9
PA	4000	start	4456.3	start	114.3
OAT	4.7°C	total	1.4	total	1.6

Basic Empty Weigh 1597.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
	start	°F										
	6:58:00	#1	2500	98	95	107	9.2	21.5	23.25	1739.3	101.0	
41°	7:00:00	1317	2500	97	95	110	9.2	21.2	23.25	1737.3	102.5	101.8
	7:02:00		2500	98	95	109	9.3	20.9	23.25	1735.3	102.0	
	7:10:00	#3	2400	92	101	89	8.8	19.7	21.75	1727.4	95.0	
41°	7:12:00	1307	2400	94	103	90	8.8	19.4	21.75	1725.4	96.5	96.0
	7:14:00		2400	94	103	90	8.8	19.1	21.75	1723.5	96.5	
	7:23:00	#3	2300	90	87	96	7.7	17.8	20.50	1714.9	91.5	
40°	7:25:00	1287	2300	90	87	98	7.7	17.6	20.50	1713.6	92.5	92.0
	7:27:00		2300	89	87	97	7.8	17.3	20.75	1711.6	92.0	
	7:37:00	#3	2100	79	75	83	6.6	16.1	19.00	1703.7	79.0	
40°	7:39:00	1255	2100	76	75	81	6.6	15.9	19.00	1702.3	78.0	79.2
	7:41:00		2100	77	76	85	6.6	15.7	19.00	1701.0	80.5	
41°	7:49:00	#1 / 1335	Full Throttle	105	101	109	10.9	14.5	24.50	1693.1	105.0	105.0
								12.9				
							Total Fuel Used	11.6				

AWOS 051051Z 23003KT 10SM CLR M01/M07 A3047
Comments MULTIPLE RESTARTS ON TAXI, POSSIBLY DUE TO COLD FUEL. TEMP INVERSION (WARMER AT ALTITUDE THAN EXPECTED).
Full Throttle RPM 2600

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1291	1296	1318	1238	392	391	346	348
2500	1294	1288	1309	1240	393	391	346	348
2500	1300	1301	1322	1237	393	391	347	345
2400	1247	1203	1272	1196	376	372	341	331
2400	1249	1199	1272	1194	375	370	341	329
2400	1248	1210	1270	1191	374	370	342	329
2300	1259	1201	1254	1190	360	367	339	326
2300	1265	1203	1257	1190	359	363	339	324
2300	1270	1204	1259	1192	361	366	341	326
2100	1189	1165	1215	1146	345	351	334	307
2100	1188	1166	1228	1142	346	350	336	309
2100	1192	1165	1225	1141	344	350	336	306
Full Throttle	1312	1307	1250	1204	386	402	333	325

Temperature Averages

	EGT	CHT
2500	1286	369
2400	1229	354
2300	1229	348
2100	1180	335
Full Throttle	1268	362

Figure A.7. Recommended Lean – E90

Ethanol (E95) **100%**
Avgas **0%**
Mixture Setting **25° Rich of Peak EGT**

Date	4-Mar-2007		
Flight (a, b, or c)	A		
Aircraft	N152BU	1212.4	lbs
Pilot	Tim Compton	210	lbs
Observer	Alex Graves	145	lbs

		Tach Time		Hobbs	
Engine On	13:40				
Engine Off	16:00	stop	4456.2	stop	114.2
PA	4000	start	4454.3	start	112.0
OAT	2.7°C	total	1.9	total	2.2

Basic Empty Weigh 1567.4

	Time	Cylinder to Peak	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressur	Weight	KTAS	
	start	°F										
	14:02:00	#1	2500	100	115	89	9.9	23.6	23.00	1723.2	102.0	
38°	14:04:00	1323	2500	103	117	90	10.0	23.0	23.00	1719.2	103.5	102.5
	14:06:00		2500	100	114	90	9.9	22.7	23.00	1717.2	102.0	
	14:18:00	#3	2400	98	88	109	9.2	20.9	22.00	1705.3	98.5	
35°	14:20:00	1313	2400	97	89	109	9.2	20.7	22.00	1704.0	99.0	98.5
	14:22:00		2400	97	85	111	9.4	20.2	22.00	1700.7	98.0	
	14:33:00	#3	2300	94	103	77	8.7	18.7	21.00	1690.8	90.0	
37°	14:35:00	1285	2300	94	104	75	8.3	18.4	20.50	1688.8	89.5	90.2
	14:37:00		2300	90	106	76	8.3	18.1	20.50	1686.9	91.0	
	14:46:00	#3	2100	75	90	73	6.9	16.9	19.50	1678.9	81.5	
38°	14:48:00	1249	2100	75	92	70	6.9	16.7	19.50	1677.6	81.0	81.5
	14:50:00		2100	76	93	71	7.0	16.6	19.50	1677.0	82.0	
	14:58:00	#3 / 1262	Full Throttle	108	94	121	11.6	15.5	24.50	1669.7	107.5	107.5
								8.6				
							Total Fuel Used	15.9				

AWOS 041751Z 04011G15KT 10SM CLR 11/M10 A3057
Comments
Full Throttle RPM 2610

	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
RPM								
2500	1281	1257	1303	1225	384	388	332	332
2500	1291	1263	1299	1233	386	389	333	330
2500	1285	1273	1300	1224	385	387	333	330
2400	1250	1200	1276	1184	373	373	330	317
2400	1248	1200	1288	1195	372	371	331	313
2400	1244	1211	1280	1193	373	371	331	315
2300	1242	1185	1264	1176	357	362	327	309
2300	1238	1182	1243	1169	356	363	331	308
2300	1240	1183	1244	1173	354	360	330	307
2100	1199	1169	1253	1151	350	354	332	306
2100	1199	1178	1250	1152	346	352	331	304
2100	1200	1169	1224	1138	350	356	335	305
Full Throttle	1290	1318	1239	1186	385	401	328	313

Temperature Averages

	EGT	CHT
2500	1270	359
2400	1231	348
2300	1212	339
2100	1190	335
Full Throttle	1258	357

Figure A.8. Recommended Lean – E95

APPENDIX B

BEST ECONOMY RAW DATA
(PEAK EGT)

TABLE B. 1. SCHEDULE OF "PEAK EGT" FLIGHT TEST

BLEND	FLIGHT DAY	AIRCREW	FLIGHT TIME
100LL	13-Feb-2006	Compton/Slayton	2.0
E10	DATA NOT AVAILABLE		
E20	22-Dec-2006	Compton/Banas	2.1
E40	13-Feb-2006	Compton/Slayton	1.9
E60	24-Mar-2006	Compton/White	2.3
E80	25-Mar-2006	Compton	2.0
E90	26-Sep-2006	Compton/Kaufman	1.5
E100	27-Sep-2006	Compton	1.9
		TOTAL TIME	13.7

Ethanol (E95) **0%**
Avgas **100%**
Mixture Setting **Peak EGT**

Date	13-Feb-2006
Flight (a, b, or c)	A
Aircraft	N152BU
Pilot	T. Compton
Observer	J. Slayton

Aircraft	1212.4 lbs
Pilot	195 lbs
Observer	170 lbs

Engine On	14:30	Tach Time	
Engine Off	16:33	stop	
PA	4000	start	
OAT	4°C	total	2.0

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
									1577.4		
start	stop										
15:05:00		2500	100	97	106	5.1	22.4	24.00	1745.2	101.5	
15:07:00		2500	100	100	105	5.1	22.1	24.00	1743.3	102.5	102.8
15:09:00		2500	99	100	109	5.1	21.7	24.00	1740.6	104.5	
15:19:00		2400	93	101	91	4.5	20.7	23.25	1734.0	96.0	
15:21:00		2400	95	103	91	4.5	20.5	23.25	1732.7	97.0	96.8
15:23:00		2400	94	103	92	4.5	20.2	23.25	1730.7	97.5	
15:36:00		2300	90	90	97	4.0	19.3	22.00	1724.8	93.5	
15:38:00		2300	88	87	97	4.0	19.1	22.00	1723.5	92.0	93.2
15:40:00		2300	90	90	98	4.0	18.9	22.00	1722.1	94.0	
15:56:00		2100	75	87	73	3.4	18.2	20.00	1717.5	80.0	
15:59:00		2100	78	87	72	3.4	17.9	20.00	1715.5	79.5	80.0
16:01:00		2100	80	89	72	3.4	17.7	20.00	1714.2	80.5	
16:13:00		Full Throttle	102	100	110	5.2	17.1	24.75	1710.3	105.0	
							16.8				
						Total Fuel Used	7.7				

AWOS 051851Z 18016KT 10SM CLR 21/06 A2981

Comments

Full Throttle RPM: 2475

RPM	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
2550	1374	1355	1314	1295	382	400	352	359
2550	1381	1349	1310	1309	387	410	360	369
2550	1375	1348	1325	1322	385	410	362	372
2400	1362	1346	1341	1397	383	390	353	393
2400	1362	1349	1357	1394	383	390	349	370
2400	1361	1350	1359	1391	385	391	349	370
2300	1350	1336	1328	1380	374	382	344	359
2300	1350	1333	1327	1384	382	391	353	371
2300	1350	1340	1329	1378	377	386	349	368
2100	1332	1334	1295	1360	362	368	342	354
2100	1333	1325	1287	1350	354	364	342	352
2100	1336	1327	1288	1350	354	365	342	353
Full Throttle	1382	1365	1280	1274	388	409	364	372

Fuel Flow Power Curve	
105	
100	4.3
90	3.3
80	2.7
70	2.3
60	1.7
55	1.5
50	2.7
45	4.0
40	
35	

Figure B.1. Peak EGT – 100LL avgas

Ethanol (E95) **20%**
Avgas **80%**
Mixture Setting **Peak EGT**

Date	22-Dec-2006	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	D. Bannas	175 lbs
Observer	T. Compton	210 lbs

		Tach Time	
Engine On	10:08	Tach Time	
Engine Off	12:17	stop	
PA	4000	start	4439.6
OAT	7 °C	total	-4439.6

Basic Empty Weight 1597.4

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
start	stop										
10:37:00		2500	100	95	112	7.5	15.4	24.75	1699.0	103.5	
10:39:00		2500	105	90	111	7.1	15.0	24.75	1696.4	100.5	103.2
10:41:00		2500	103	94	117	8.8	14.6	24.75	1693.8	105.5	
10:57:00		2400	95	110	86	6.5	13.0	22.50	1683.2	98.0	
10:59:00		2400	94	108	83	6.2	13.3	22.50	1685.2	95.5	94.8
11:03:00		2400	93	102	80	6.2	12.4	22.50	1679.2	91.0	
11:15:00		2300	89	72	101	6.3	11.2	21.50	1671.3	86.5	
11:19:00		2300	85	63	108	5.6	10.8	21.50	1668.7	85.5	86.0
		2300							1597.4	0.0	
11:27:00		2100	79	91	74	4.7	10.1	19.50	1664.1	82.5	
11:30:00		2100	80	89	71	4.7	9.9	19.50	1662.7	80.0	81.3
		2100							1597.4	0.0	
11:37:00		Full Throttle	104	95	119	8.1	9.1	24.75	1657.5	107.0	

Total Fuel Used 6.5

AWOS 131551Z 00000KT 8SM CLR 05/02 A3028

Comments Engine start fuel load was 18.5 gallons.

Full Throttle RPM: 2480

RPM	EGT #1	#2	#3	#4	CHT #1	#2	#3	#4
2550	1346	1356	1366	1324	365	403	362	376
2550	1336	1351	1359	1330	353	390	374	386
2550	1335	1290	1239	1256	341	379	373	389
2400	1361	1311	1356	1340	393	412	357	371
2400	1365	1339	1346	1358	388	411	356	374
2400	1366	1342	1347	1381	385	408	355	374
2300	1336	1300	1334	1316	392	404	357	382
2300	1360	1338	1330	1367	381	391	350	365
2300								
2100	1324	1280	1293	1313	371	377	347	358
2100	1326	1275	1296	1313	370	376	347	358
2100								
Full Throttle	1385	1376	1307	1290	396	418	370	382

Fuel Flow Power Curve	
105	8.1
100	7.6
90	5.6
80	5.0
70	4.1
60	4.0
55	4.2
50	4.0
45	4.0
40	4.5
35	4.6

Figure B.2. Peak EGT – E20

Ethanol (E95) **40%**
Avgas **60%**
Mixture Setting **Peak EGT**

Date	13-Feb-2006	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	T. Compton	195 lbs
Observer	J. Slayton	170 lbs

Engine On	14:41	Tach Time	
Engine Off	16:57	stop	4413.0
PA	4000	start	4411.1
OAT	4°C	total	1.9

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
									1577.4		
start	stop										
15:05:00		2500	104	102	109	5.6	23.2	24.75	1730.5	105.5	
15:07:00		2500	101	102	107	5.6	23.0	24.75	1729.2	104.5	104.7
15:09:00		2500	101	101	107	5.6	22.8	24.75	1727.9	104.0	
15:19:00		2400	97	94	104	4.8	21.9	23.00	1721.9	99.0	
15:21:00		2400	96	98	103	4.7	21.8	23.00	1721.3	100.5	99.5
15:23:00		2400	96	96	102	4.8	21.6	23.00	1720.0	99.0	
15:36:00		2300	92	95	97	4.3	20.6	22.75	1713.4	96.0	
15:38:00		2300	94	95	97	4.3	20.4	22.75	1712.0	96.0	95.8
15:40:00		2300	92	96	95	4.3	20.3	22.75	1711.4	95.5	
15:56:00		2100	81	85	82	3.4	19.3	20.50	1704.8	83.5	
15:59:00		2100	82	87	82	3.4	19.1	20.50	1703.5	84.5	84.5
16:01:00		2100	84	87	84	3.4	18.9	20.50	1702.1	85.5	
16:13:00		Full Throttle	102	107	101	5.3	17.9	24.75	1695.5	104.0	
							15.3				
						Total Fuel Used	9.2				

AWOS 131851Z 14009KT 10SM CLR 13/M10 A3034

Comments

Full Throttle RPM: 2475

RPM	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
2550	1344	1279	1263	1213	389	381	335	334
2550	1344	1282	1261	1214	387	381	334	334
2550	1344	1277	1264	1215	388	381	334	335
2400	1291	1240	1295	1255	382	367	330	338
2400	1299	1242	1298	1261	383	369	326	337
2400	1294	1242	1298	1256	382	365	327	336
2300	1287	1241	1269	1298	369	359	314	341
2300	1287	1246	1265	1293	366	357	311	338
2300	1285	1245	1267	1283	367	364	312	335
2100	1280	1207	1224	1249	346	347	312	331
2100	1273	1209	1229	1252	345	346	310	328
2100	1274	1206	1224	1247	344	345	310	327
Full Throttle	1309	1253	1290	1265	355	358	329	330

Fuel Flow Power Curve	
105	
100	4.8
90	3.8
80	3.2
70	2.8
60	2.2
55	2.0
50	3.2
45	4.5
40	
35	

Figure B.3. Peak EGT – E40

Ethanol (E95) **60%**
Avgas **40%**
Mixture Setting **Peak EGT**

Date	24-Mar-2006	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	T. Compton	195 lbs
Observer	J. White	200 lbs

Engine On	6:23	Tach Time	
Engine Off	8:52	stop	4422.1
PA	4000	start	4419.8
OAT	negative 11°C	total	2.3

Basic Empty Weight 1607.4

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
start	stop										
6:51:00		2500	101	93	116	5.9	22.5	24.80	1755.9	104.5	
6:54:00		2500	101	93	118	5.8	22.3	24.80	1754.6	105.5	105.0
6:57:00		2500	102	94	116	5.9	22.0	24.80	1752.6	105.0	
7:09:00		2400	98	89	111	5.1	20.8	23.75	1744.7	100.0	
7:12:00		2400	96	87	109	5.1	20.6	23.75	1743.4	98.0	99.3
7:14:00		2400	98	91	109	5.1	20.3	23.75	1741.4	100.0	
7:27:00		2300	94	87	106	4.7	19.3	22.90	1734.8	96.5	
7:30:00		2300	95	86	107	4.7	19.0	22.90	1732.8	96.5	96.0
7:33:00		2300	95	85	105	4.7	18.9	22.90	1732.1	95.0	
7:40:00		2100	80	82	90	3.9	18.2	20.10	1727.5	86.0	
7:43:00		2100	76	81	85	3.7	18.1	20.10	1726.9	83.0	85.3
7:45:00		2100	76	84	90	3.9	18.0	20.10	1726.2	87.0	
7:54:00		Full Throttle	102	101	114	5.9	17.3	24.80	1721.6	107.5	
							12.6				
						Total Fuel Used	11.9				

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Comments

Full Throttle RPM: 2500

RPM	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
2550	1307	1252	1246	1199	365	349	317	330
2550	1310	1255	1245	1205	364	348	320	332
2550	1312	1259	1252	1205	364	350	323	334
2400	1294	1237	1268	1222	360	345	310	334
2400	1293	1234	1277	1222	361	347	310	334
2400	1288	1228	1268	1221	359	345	308	334
2300	1286	1243	1245	1228	352	345	303	333
2300	1287	1240	1243	1225	353	346	302	332
2300	1285	1237	1240	1231	351	345	248	331
2100	1279	1202	1191	1188	350	343	296	324
2100	1280	1200	1188	1184	350	342	297	328
2100	1276	1203	1192	1191	353	350	300	331
Full Throttle	1316	1257	1242	1196	361	349	322	329

Fuel Flow Power Curve	
105	5.9
100	5.0
90	4.4
80	3.2
70	2.8
60	2.5
55	2.4
50	3.1
45	3.4
40	4.0
35	---

Figure B.4. Peak EGT – E60

Ethanol (E95) **80%**
Avgas **20%**
Mixture Setting **Peak EGT**

Date	25-Mar-2006		
Flight (a, b, or c)	A		
Aircraft	N152BU	1212.4	lbs
Pilot	T. Compton	195	lbs
Observer	No Observer	0	lbs

Engine On	9:30	Tach Time	
Engine Off	11:30	stop	4527.5
PA	4000	start	4525.5
OAT	4.5°C	total	2.0

Basic Empty Weight 1407.4

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
start	stop										
9:55:00		2500	105	101	111	6.3	22.9	24.75	1558.5	106.0	
9:58:00		2500	104	102	112	6.3	22.7	24.75	1557.2	107.0	106.5
10:01:00		2500	104	102	111	6.3	22.5	24.75	1555.9	106.5	
10:08:00		2400	98	104	98	5.4	21.7	23.25	1550.6	101.0	
10:11:00		2400	98	105	97	5.4	21.5	23.25	1549.3	101.0	101.2
10:14:00		2400	98	105	98	5.4	21.2	23.25	1547.3	101.5	
10:22:00		2300	94	100	92	4.9	20.4	22.00	1542.0	96.0	
10:25:00		2300	94	100	91	4.8	20.1	22.00	1540.1	95.5	95.8
10:28:00		2300	94	100	92	4.9	19.9	22.00	1538.7	96.0	
10:39:00		2100	85	82	89	4.0	19.1	20.50	1533.5	85.5	
10:42:00		2100	86	83	90	4.1	18.9	20.50	1532.1	86.5	86.3
10:45:00		2100	86	83	91	4.1	18.7	20.50	1530.8	87.0	
10:53:00		Full Throttle	105	111	103	6.3	18.1	24.75	1526.9	107.0	
							14.3				
						Total Fuel Used	10.2				

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Comments Perfect flight conditions.

Full Throttle RPM: 2500

RPM	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
2550	1317	1245	1227	1200	351	347	315	328
2550	1314	1248	1227	1205	354	347	315	327
2550	1311	1247	1225	1200	349	345	312	322
2400	1304	1227	1269	1217	350	344	305	326
2400	1303	1229	1273	1216	353	344	307	327
2400	1306	1230	1270	1214	352	344	305	326
2300	1292	1211	1233	1208	342	340	293	323
2300	1294	1213	1235	1202	345	345	295	324
2300	1293	1209	1236	1218	342	338	294	327
2100	1258	1175	1190	1171	343	341	293	316
2100	1260	1171	1200	1174	339	338	292	314
2100	1261	1177	1194	1174	340	337	290	314
Full Throttle	1317	1247	1217	1195	354	352	313	325

Fuel Flow Power Curve	
105	6.3
100	5.5
90	4.4
80	4.0
70	3.0
60	2.6
55	2.8
50	3.8
45	4.0
40	4.3
35	4.5

Figure B.5. Peak EGT – E80

Ethanol (E95) **90%**
Avgas **10%**
Mixture Setting **Peak EGT**

Date	26-Sep-2006	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	L. Kaufman	165 lbs
Observer	T. Compton	210 lbs

		Tach Time	
Engine On	9:03		
Engine Off	10:47	stop	4437.7
PA	4000	start	4436.2
OAT	15.5°C	total	1.5

Basic Empty Weight 1587.4

Time start	stop	RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
9:25:00		2500	100	113	98	6.6	22.5	24.25	1735.9	105.5	
9:26:00		2500	98	111	94	6.7	22.3	24.25	1734.6	102.5	104.5
9:28:00		2500	99	113	98	6.6	22.2	24.25	1733.9	105.5	
9:37:00		2400	94	109	89	5.7	21.2	23.25	1727.3	99.0	
9:39:00		2400	95	109	89	5.6	21.0	23.25	1726.0	99.0	99.0
9:41:00		2400	94	109	89	5.6	20.7	23.25	1724.0	99.0	
9:51:00		2300	89	104	85	5.6	19.8	22.00	1718.1	94.5	
9:53:00		2300	91	105	85	5.7	19.6	22.00	1716.8	95.0	94.5
9:55:00		2300	90	104	84	5.5	19.3	22.00	1714.8	94.0	
10:14:00		2100	80	93	72	4.6	17.5	19.50	1702.9	82.5	
10:16:00		2100	80	93	74	4.6	17.4	19.50	1702.2	83.5	83.0
10:18:00		2100	78	92	74	4.5	17.2	19.50	1700.9	83.0	
10:10:00		Full Throttle	102	97	116	6.7	17.9	24.25	1705.5	106.5	
					Total Fuel Used		6.6				

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Comments

Full Throttle RPM: 2525

RPM	EGT #1	#2	#3	#4	CHT #1	#2	#3	#4
2550	1302	1239	1213	1180	392	383	332	3336
2550	1299	1238	1210	1176	395	382	333	337
2550	1298	1237	1217	1179	396	386	335	336
2400	1293	1218	1281	1227	385	378	332	345
2400	1289	1213	1267	1241	381	374	329	344
2400	1288	1216	1267	1230	385	382	330	347
2300	1221	1124	1242	1167	381	373	329	343
2300	1216	1120	1239	1169	379	367	333	337
2300	1214	1107	1225	1158	376	362	333	336
2100	1173	1079	1186	1120	372	357	328	320
2100	1165	1081	1177	1105	364	350	329	320
2100	1168	1081	1180	1106	365	350	331	318
Full Throttle	1301	1232	1223	1182	387	376	330	331

Fuel Flow Power Curve	
105	
100	8.3
90	7.1
80	5.0
70	4.7
60	4.1
55	4.0
50	4.1
45	4.2
40	4.3
35	5.3

Figure B.6. Peak EGT – E90

Ethanol (E95) **100%**
Avgas **0%**
Mixture Setting **Peak EGT**

Date	27-Sep-2007	
Flight (a, b, or c)	A	
Aircraft	N152BU	1212.4 lbs
Pilot	T. Compton	195 lbs
Observer		0 lbs

Engine On	14:45	Tach Time	
Engine Off	17:00	stop	4413.0
PA	4000	start	4411.1
OAT	24°C	total	1.9

Time		RPM	IAS	GS(1)	GS(2)	Fuel Flow	Fuel Remaining	Manifold Pressure	Weight	KTAS	
									1407.4		
start	stop										
15:05:00		2500	104	102	109	7.1	23.2	24.75	1560.5	105.5	
15:07:00		2500	101	102	107	7.1	23.0	24.75	1559.2	104.5	104.7
15:09:00		2500	101	101	107	7.1	22.8	24.75	1557.9	104.0	
15:19:00		2400	97	94	104	6.1	21.9	23.00	1551.9	99.0	
15:21:00		2400	96	98	103	6.1	21.8	23.00	1551.3	100.5	99.5
15:23:00		2400	96	96	102	6.2	21.6	23.00	1550.0	99.0	
15:36:00		2300	92	95	97	5.6	20.6	22.75	1543.4	96.0	
15:38:00		2300	94	95	97	5.6	20.4	22.75	1542.0	96.0	95.8
15:40:00		2300	92	96	95	5.6	20.3	22.75	1541.4	95.5	
15:56:00		2100	81	85	82	4.6	19.3	20.50	1534.8	83.5	
15:59:00		2100	82	87	82	4.7	19.1	20.50	1533.5	84.5	84.5
16:01:00		2100	84	87	84	4.6	18.9	20.50	1532.1	85.5	
16:13:00		Full Throttle	102	107	101	7.1	17.9	24.75	1525.5	104.0	
							15.3				
						Total Fuel Used	9.2				

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Comments Discrepency in data recording found on previuous flight. Re-investigation flight.

Full Throttle RPM: 2590

RPM	EGT				CHT			
	#1	#2	#3	#4	#1	#2	#3	#4
2550	1294	1229	1213	1163	359	351	305	304
2550	1294	1232	1211	1164	357	351	304	304
2550	1294	1227	1214	1165	358	351	304	305
2400	1241	1190	1245	1205	352	337	300	308
2400	1249	1192	1248	1211	353	339	296	307
2400	1244	1192	1248	1206	352	335	297	306
2300	1237	1191	1219	1248	339	329	284	311
2300	1237	1196	1215	1243	336	327	281	308
2300	1235	1195	1217	1233	337	334	282	305
2100	1230	1157	1174	1199	316	317	282	301
2100	1223	1159	1179	1202	315	316	280	298
2100	1224	1156	1174	1197	314	315	280	297
Full Throttle	1259	1203	1240	1215	347	349	321	339

Fuel Flow Power Curve	
105	
100	5.3
90	4.3
80	3.7
70	3.3
60	2.7
55	2.5
50	3.7
45	5.0
40	
35	

Figure B.7. Peak EGT – E95

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