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Spark Ignition Aircraft Engine Tests of Ethyl Tertiary Butyl Ether

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16. Abstract

Effective January 1, 1996, one of the 1990 Federal Clean Air Act Amendments banned the sale of leaded fuels for on-road vehicles. The Environmental Protection Agency exempted the general aviation, racing, farming, and marine communities from compliance. The general aviation community is now one of the largest domestic consumers of leaded fuel. The need for a safe, alternative, high-octane unleaded fuel is becoming more apparent.

The Federal Aviation Administration William J. Hughes Technical Center, working in conjunction with the Cessna Aircraft Company, performed endurance and detonation tests on ethyl tertiary butyl ether (ETBE) containing less than 1% butane. A Lycoming IO540-K piston aircraft engine was detonation-tested and the results were compared to those from a 100 low-lead (100 LL) piston aviation gasoline. The engine produced 3.3% more horsepower on ETBE than on 100LL but at a fuel mass flow rate that was 21.5% greater. The ETBE did not perform as well as the 100LL in the detonation test with the IO540-K engine. The detonation limited fuel mass flow for ETBE was 33% greater than for 100LL. Results from these detonation tests were used to determine the fuel mass flow adjustments for a 150-hour endurance test with a Lycoming IO360-C engine. The Lycoming IO360-C engine was purchased new and was torn down and measured at the completion of the test. The endurance test results indicated that the engine experienced normal levels of engine wear after the 150-hour test. There were minimal engine sludge and varnish deposits, combustion chamber deposits, and fuel system deposits. The engine lubrication oil analyses showed minimal fuel dilution, viscosity change, and acid content. There were no observations of difficulty with starting or material compatibility issues.

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LIST OF ACRONYMS AND SYMBOLS

AC	Advisory Circular
AFL	Air-to-fuel ratio spread for the left bank cylinder
AFR	Air-to-fuel ratio spread for the right bank cylinder
AMS	Aerospace Material Specification
ASTM	American Society for Testing and Materials
bhp	Brake horsepower
BSFC	Brake-specific fuel consumption
BTDC	Before top dead center
CEDI	Cessna Detonation Indication System
CFR	Code of Federal Regulations
CHT	Cylinder head temperature
CRC	Coordinated Research Council
EGT	Exhaust gas temperature
EPA	Environmental Protection Agency
ETBE	Ethyl tertiary butyl ether
FAA	Federal Aviation Administration
FR	Full rich
FT	Full throttle
hp	Horsepower
in. Hg	Inches of mercury
lb/bhp hr	Pounds per brake-horsepower hour
MAP	Manifold absolute pressure
MON	Motor octane number as determined by ASTM D 2700
NRP	Normal-rated power
psi	Pounds per square inch
psig	Pounds per square inch gauge
rpm	Revolutions per minute
R&D	Research and development
TO	Takeoff
100LL	Low-lead aviation gasoline
WOT	Wide open throttle

EXECUTIVE SUMMARY

The Environmental Protection Agency (EPA) has exempted the general aviation community from compliance with the Amendments to the 1990 Clean Air Act banning the sale of leaded fuels. The general aviation community is now a leading consumer of leaded fuels and it is uncertain how long the EPA will continue to exempt the aviation community.

The Unleaded Aviation Gasoline Project, under the Airport and Aircraft Safety Research and Development (R&D) Division Propulsion and Fuel Systems Branch located at the Federal Aviation Administration (FAA) William J. Hughes Technical Center has taken a leading role in testing spark ignition, piston aircraft engines on high-octane unleaded aviation gasolines.

In 2000, the FAA funded the Cessna Aircraft Company to evaluate ethyl tertiary butyl ether (ETBE) containing butane as a potential stopgap fuel in the event that there was a supply disruption of the current 100 low-lead (100LL) aviation gasoline for spark ignition, piston aircraft engines. In a parallel effort, the Unleaded Aviation Gasoline Project, under the Airport and Aircraft Safety R&D Division Propulsion and Fuel Systems Branch located at the FAA William J. Hughes Technical Center completed a 150-hour endurance test in a new four-cylinder Lycoming IO360-C model engine using ETBE with butane. The test procedures of Title 14 Code of Federal Regulations Parts 33-49 were used. The test evaluated engine performance at severe and controlled conditions addressing such issues as wear, performance, materials compatibility, oil dilution, deposit formation, and startability. The majority of this testing was performed at full-rated power and engine speed under maximum engine and oil temperatures.

Engine teardown and measurement showed that camshaft lobe 1 failed resulting in metal particle buildup on the piston skirts and the crankshaft front and rear main bearing shells showed slight delamination. These failures were not believed to be fuel related, as the engine oil analyses showed minimal fuel dilution, minimal oil viscosity change, and low acid content. All of the other high-contact, high-stress parts of the engine showed normal wear. Combustion chamber and fuel system deposit formation was negligible as were engine sludge and varnish buildup.

The ETBE was also detonation tested in a used six-cylinder Lycoming IO540-K engine and compared to the detonation results of a specially blended 100LL fuel.

The engine produced 3.3% more peak power when operating on the ETBE as it did when operating on the specially blended 100LL. However, the ETBE required an average of 21.5% more fuel mass flow, thus reducing the average peak-power efficiency from a brake-specific fuel consumption (BSFC) of 0.472 pound per brake-horsepower hour (lb/bhp hr) for 100LL to 0.554 lb/bhp hr for ETBE. On average, detonation-free operation slightly lean of best power was attainable with 100LL, but it was not with ETBE. For detonation-free operation on ETBE the engine had to be operated rich of best power. The ETBE detonation-limited fuel mixture setting resulted in 32.3% more fuel mass flow consumption than that for 100LL. The average detonation limited BSFC for ETBE was found to be 0.595 lb/bhp hr and for 100LL it was 0.465 lb/bhp hr.

Without further significant changes to engine ignition timing, valve timing, and cylinder compression ratio the consequence of the reduction in efficiency is to reduce operating duration and range with a reduction in distance traveled for each gallon of fuel of 18.7%. Furthermore, significant changes would be required to engine operating procedures, as operating at mixtures lean of best power or at best economy would be unsafe due to detonation when operating on ETBE.

1. INTRODUCTION.

1.1 PURPOSE.

This research evaluated the endurance performance of ethyl tertiary butyl ether (ETBE) containing butane in a new, four-cylinder Lycoming IO360-C engine and the detonation performance of the ETBE containing butane in a used, six-cylinder Lycoming IO540-K engine.

1.2 BACKGROUND.

The Environmental Protection Agency (EPA) has exempted the general aviation community from complying with a 1990 Clean Air Act Amendment that banned the sale of fuels containing lead additives. However, it is uncertain for how long the EPA will exempt the general aviation community since it has become a leading source of airborne lead. As scrutiny towards leaded fuels, lead scavengers such as ethylene dibromide, and lead-tainted lubricating oils continues, economic pressures to replace the current 100 low-lead (100LL) general aviation fuel with a high-octane, unleaded alternative will increase. The Airport and Aircraft Safety Research and Development (R&D) Division, Propulsion and Fuel Systems Branch located at the Federal Aviation Administration (FAA) William J. Hughes Technical Center, along with the Coordinated Research Council (CRC) Unleaded Avgas Development Subcommittee (which is comprised of aircraft manufacturers, engine manufacturers, petroleum producers, other regulatory agencies, and aircraft owner's and pilot's associations), has tested many blends of high-octane, unleaded aviation gasolines to provide data toward the development of an unleaded aviation gasoline.

In a parallel effort in 2000, the FAA funded the Cessna Aircraft Company to investigate the use of ETBE containing butane as a potential stopgap fuel to keep the general aviation fleet in the air should supply disruptions occur with the current 100LL aviation gasoline.

1.3 RELATED DOCUMENTS.

- Lycoming Service Instruction 1472, "Removal of Preservative Oil"
- Lycoming Service Instruction 1241C, "Pre-oiling of Engines Prior to Initial Start"
- Lycoming Service Instruction 1427B, "Textron Lycoming Reciprocating Engine Break-in and Oil Consumption Limits"
- Teledyne Contintental Motors Service Information Directive SID97-4C
- Teledyne Continental Motors Service Bulletin SB03-3
- ASTM D 445, "Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and the Calculation of Dynamic Viscosity)"

- ASTM D 664, “Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration”

- ASTM D 910, “Standard Specification for Aviation Gasoline”

- ASTM D 2700, “Standard Test Method for Detonation Characteristics of Motor and Aviation Fuels by the Motor Method”

- ASTM D 3524, “Standard Test Method for Diesel Fuel Diluent in Used Diesel Engine Oils by Gas Chromatography”

- ASTM D 6424, “Standard Practice for Octane Rating Naturally Aspirated Spark Ignition Aircraft Engines”

- ASM–489, Metals Concentration by Arc Spark Method

- FAA Advisory Circular (AC) 20-24B, “Qualification of Fuels, Lubricants, and Additives for Aircraft Engines”

- FAA AC 33-47, “Detonation Testing in Reciprocating Aircraft Engines”

- Title 14 Code of Federal Regulations (CFR) 33.49, “Endurance Tests”

2. TEST PROCEDURES.

The ETBE was supplied in two separate lots shown in table 1. The table lists the weight percent composition of the supplied blends. Light components are components such as butane that increase the fuel volatility, allowing for easier cold starting. Heavy components are components that require higher temperatures to boil, and may increase varnish and sludge engine deposits or fuel system deposits. In both lots, the ETBE concentration was approximately 95% with the heavy components comprising 3.5% of the fuel, and butane comprising from 0.5 to 0.95%.

TABLE 1. CHEMICAL COMPOSITION OF ETBE

First Lot	
Lot number	3BPETB01
Density	6.22 lb/gal
Composition	Weight %
Light components	0.95
ETBE	95.36
Heavy components	3.47
Total	99.78
Second Lot	
Lot number	4DPETB01
Density	6.22 lb/gal
Composition	Weight %
Light components	0.50
ETBE	95.60
Heavy components	3.41
Total	99.51

2.1 DETONATION TEST.

The detonation test of the ETBE in a Lycoming IO540-K 300-horsepower (hp)-rated engine was done first. The IO540-K engine was outfitted with individual cylinder pressure transducers to monitor for detonation. The fuel servo unit of the IO540-K had been previously modified to provide the engine with approximately 35% greater fuel mass flow, as measured on a flow bench. Due to the reduced energy density of ETBE as compared to 100LL, the engine fuel mass flow must be increased to operate on ETBE, both for proper power development and for detonation prevention. Since the four-cylinder Lycoming IO360-C engine and the six-cylinder Lycoming IO540-K engine have the same bore, stroke, valving, and specific rated power output, they will require, as a rough estimate, the same fuel mass flow per brake horsepower (bhp) to prevent detonation. The installation of the FAA detonation sensors is an invasive procedure and these sensors were not installed in the IO360-C engine used in the endurance test to prevent skewing the engine wear results. Operating the IO360-C engine throughout the endurance test in a detonation condition, reduced power condition, or overly lean condition, may skew the wear results. Therefore, the results from the detonation test with the IO540-K engine using ETBE were used to determine the approximate increase in fuel mass flow required for proper power development, proper mixture strength, and prevention of detonation for the IO360-C during the endurance test.

Table 2 lists the rated power and compression ratio of the Lycoming IO540-K and IO360-C model engines. The IO in the engine model description refers to fuel injection and opposed cylinder, and the numerical value of the model description refers to the cubic inch cylinder displacement.

TABLE 2. LYCOMING IO540- K AND IO360-C ENGINE MODEL SPECIFICATIONS

Engine Make and Model	Compression Ratio	Normal-Rated Power (bhp)	rpm	Ignition Timing (degree BTDC)	Cylinders	Bore (in.)	Stroke (in.)	ASTM D 910 Fuel
Lycoming IO540- K	8.7	300	2700	20	6	5.125	4.375	100/100LL
Lycoming IO360-C	8.7	200	2700	20	4	5.125	4.375	100/100LL

BTDC = Before top dead center
bhp = break horsepower

The engine was installed in a test stand and coupled to an eddy-current dynamometer. The engine was instrumented as listed in table 3, and the engine parameter data were recorded at a rate of one scan of all channels every 5 seconds.

TABLE 3. SENSORS AND INSTALLATION LOCATIONS

Parameter	Sensor Type	Sensor Location
Cylinder head temperatures 1-6	Bayonnet, J-type thermocouple	Manufacturer’s specified location
Exhaust gas temperatures 1-6	Band clamp, K-type thermocouple	Exhaust pipe within two inches of exhaust flange
Intake air temperature	T-type thermocouple	Intake duct just prior to throttle throat
Intake air pressure	Absolute pressure transducer	Intake duct just prior to throttle throat
Mass airflow rate	Kurz mass flow meter	Straight, smooth section of intake air duct. Six diameters downstream
Intake air humidity	Probe	Intake air duct
Manifold absolute pressure	Absolute pressure transducer	Intake manifold plenum after the fuel injection unit
Engine speed (rpm)	Magnetic pickup	Dynamometer shaft
Engine shaft torque	Load cell	Dynamometer
Fuel mass flow rate	Corliolis mass flow meter	After fuel control unit and prior to fuel manifold
Engine cowling air temperature	T-type thermocouple	Engine cowling plenum
Engine cowling air pressure	Gauge pressure transducer	Engine cowling plenum
Fuel temperature	Corliolis mass flow meter	After fuel control unit and prior to fuel manifold
Fuel mass density	Corliolis mass flow meter	After fuel control unit and prior to fuel manifold
Metered fuel pressure	Gauge pressure transducer	Output of fuel metering unit
Fuel pump pressure	Gauge pressure transducer	Output of engine driven pump
Oil temperature	J-type thermocouple	Return from oil cooler
Oil pressure	Gauge pressure transducer	Manufacturer’s location in accessory case
Air-to-fuel ratio, left bank	Lambda exhaust gas sensor	Left bank of cylinders common exhaust pipe
Air-to-fuel ratio, right bank	Lambda exhaust gas sensor	Right bank of cylinders common exhaust pipe

Sensors used to measure these parameters were installed at manufacturer recommended locations whenever possible and were calibrated prior to any engine testing. After the engine was installed and the instrumentation calibrated, a series of maintenance runs were performed to verify the engine systems integrity and instrumentation accuracy. Prior to any engine operation, the mixture cut-off and full-rich (FR) settings and the throttle stop and throw positions were checked.

The ETBE and 100LL fuels were tested at power settings ranging from takeoff (TO), 85%, 75%, and 65% power, as shown in table 4. TO is referred to as the condition of wide open throttle (WOT), and maximum-rated revolutions per minute (rpm). The hp and rpm combinations were chosen from the engine manufacturer's specifications. The dynamometer operated in the speed mode, which resulted in varying the engine load to maintain the desired rpm. Typically, the best power fuel mass flow, obtained from the engine manufacturer's detailed specifications, was adjusted at WOT and maximum-rated rpm. The resulting power was used to calculate the 85%, 75%, and 65% power. When adjusting the part throttle power settings, the engine rpm was set and the manifold absolute pressure (MAP) and mixture were adjusted until the desired power was attained at the best power fuel flow. The resulting MAP was then recorded and any mixture leaning or enrichening from this condition was performed while maintaining constant MAP. All analyses and figures presented in this report rely on fuel mass flow rates and not volume flow rates, unless specified otherwise, as is customary in reporting engine data.

TABLE 4. POWER SETTINGS FOR DETONATION TESTS

Power	MAP (in. Hg)	Engine speed (rpm)
TO - NRP	WOT	2700
85% of TO	Adjusted to attain power	2600
75% of TO	Adjusted to attain power	2450
65% of TO	Adjusted to attain power	2350

NRP = Normal-rated power

Each fuel flow setting was leaned from a richer, nondetonating, flow rate. Throughout the detonation tests the parameter settings listed in table 5 were maintained.

TABLE 5. PARAMETER SETTINGS FOR DETONATION TESTS

Parameter	Limit
Maximum cylinder head temperature	475° ±3°F (maximum as per engine manufacturer's detailed specifications)
All other cylinder head temperatures	Within 50°F of maximum cylinder head temperature
Induction air temperature	103° ±3°F
Induction air relative humidity	Less than 5%
Oil inlet temperature	245° –10°F (maximum as per engine manufacturer's detailed specifications)

2.2 ENDURANCE TEST.

A new Lycoming IO360-C, four-cylinder, naturally-aspirated, 200-hp engine was tested for 150 hours at severe and controlled conditions that addressed issues of wear, performance, materials compatibility, deposit formation, startability, and a host of other issues. Researchers in the Airport and Aircraft Safety R&D Division at the FAA William J. Hughes Technical Center requested that the Lycoming Engine Manufacturing Facility not perform the typical procedure of operating the new IO360-C engine on leaded fuel prior to shipment. This was done to prevent engine lead deposits from influencing the ETBE test.

The Precision RSA-5AD1 fuel injector servo unit for the new Lycoming IO360-C engine was sent to Precision Airmotive Corporation, Marysville, Washington, for rework. Precision increased the size of the main metering jet, and replaced the standard fuel injection nozzles with lower-pressure, higher-volume nozzles. This was done to allow for the greater fuel mass flows, needed to operate on ETBE at the same fuel pressures.

The Lycoming IO360-C engine was installed in a test stand and coupled to an eddy-current dynamometer via spacers, adaptors, an inertia flywheel and a drive shaft. The engine was instrumented with sensors as detailed in table 3.

Lycoming Service Instruction 1472 was followed to remove the preservative oil and replace it with Aeroshell 100, SAE 50 (SAE J1966) oil. The Aeroshell 100 was used during the break-in period only, after which the Aeroshell 15W50 oil was used. The engine was then pre-oiled as per the Lycoming Service Instruction 1241C.

Following the engine pre-oiling, the Lycoming Service Instruction 1427B for engine break-in and oil consumption tests were performed. The engine break-in, was performed at the FAA William J. Hughes Technical Center using unleaded fuels only. At the conclusion of the engine break-in period, when oil consumption had stabilized, the break-in oil was replaced with Aeroshell 15W50 (SAE J 1899) oil. This oil type was used throughout the 150-hour test.

Power baseline tests, which encompassed a combination of MAP settings and engine rpm settings over a practical operating envelope, were performed on the Lycoming IO360-C engine using isooctane. For these tests, the MAP was varied by 2.0 inches of mercury (in. Hg) increments, the rpm was varied by 100 increments, and the fuel mixture was varied. These tests were performed before and after the completion of the 150-hour endurance test. Relative differences in power output between pre- and posttest may indicate the occurrence of significant wear. For the power baseline test the inlet air temperature was maintained at 60° ±3°F and maximum cylinder head temperature (CHT) was maintained at 375° ±5°F.

Following the initial power baseline test, the 150-hour endurance test with the Lycoming IO360-C engine began. The majority of the testing was performed at full-rated power and rated engine speed under maximum engine and oil temperatures. Throughout the endurance test, the Cessna Engine Detonation Indication System (CEDI) was used. This system is nonintrusive and uses a quartz crystal washer under the spark plug to detect detonation. While the system has not been fully investigated, the referee method detailed in ASTM D 6424, developed by researchers in the Airport and Aircraft Safety R&D Division at the FAA William J. Hughes Technical Center of invasive piezoelectric pressure transducers could not be employed over concerns that installation may influence the endurance wear results. The CEDI system was relied upon as a guide to prevent operation in moderate to severe detonation levels.

The 150-hour endurance test was divided into seven phases. These phases listed below follow the requirements outlined in 14 CFR 33.49.

- 30 hours of alternating periods of 5 minutes at full throttle (FT) and 2700 rpm and 5 minutes at 150 bhp and 2450 rpm.

- 20 hours of alternating periods of 1.5 hours at FT and 2700 rpm and 0.5 hour at 150 bhp and 2450 rpm.

- 20 hours of alternating periods of 1.5 hours at FT and 2700 rpm and 0.5 hour at 140 bhp and 2400 rpm.

- 20 hours of alternating periods of 1.5 hours at FT and 2700 rpm and 0.5 hour at 130 bhp and 2350 rpm.

- 20 hours of alternating periods of 1.5 hours at FT and 2700 rpm and 0.5 hour at 120 bhp and 2300 rpm.

- 20 hours of alternating periods of 1.5 hours at FT and 2700 rpm and 0.5 hour at 100 bhp and 2150 rpm.

- 20 hours of alternating periods of 2.5 hours at FT and 2700 rpm and 2.5 hour at 150 bhp and 2450 rpm.

The mixture was adjusted to attain a fuel mass flow rate 35% greater than used for isooctane and then leaned until either the first indication of detonation occurred or peak power was reached. This detonation-free mixture setting was then used throughout the endurance tests.

The following test constraints were maintained throughout the tests: one of the cylinder head temperatures was maintained at the maximum allowable temperature of 475º ±3ºF, and all other cylinder head temperatures were maintained at not less than 50ºF of the maximum temperature. The engine oil inlet temperature was maintained at a maximum allowable of 245º ±10ºF. The engine air inlet temperature was maintained at the extreme hot-day standard of 103º ±3ºF. The fuel mixture was positioned for 35% more mass flow than the manufacturer best power mixture setting for 100LL. This is slightly rich of peak power when using ETBE to prevent engine detonation.

At the start of the endurance test and at 50-engine-hour intervals, maintenance was performed and a series of engine measurements were taken. Table 6 shows the maintenance schedule.

TABLE 6. IO360-C ENGINE MAINTENANCE SCHEDULE

Engine Cumulative Hours	Magneto Timing	Oil/Filter Service	Oil Analysis	Cylinder Compression Surveys	Rated Power Surveys	Valve Wear Surveys	Spark Plug Visual	Bore Scope Inspection
0	X	X	X	X	X	X	X	
Start of test	X	X	X	X		X	X	X
50	X	X	X	X		X	X	X
100	X	X	X	X		X	X	X
150	X	X	X	X		X	X	X
End of test	X	X	X	X	X	X	X	X

At each maintenance interval, the spark plugs were removed and the rings, valves, valve surfaces, cylinder dome and walls, and piston crown were inspected with a cylinder bore scope to ensure they were in visibly healthy condition. A compression test was performed with the engine warm using a differential pressure tester with a master orifice device. The differential test procedures followed those outlined in the Lycoming Service Instruction Number 1191A.

- The fuel inlet screen (finger screen) was removed, cleaned, reinstalled, and safety wired. The system was then pressure checked for evidence of leaks at the sealing gasket.

- The engine cylinder assembly was inspected for evidence of overheating, leakage between exhaust ports and pipes, and warped exhaust port flanges. The baffling was inspected for condition and security.

- The oil system was drained and the spin-on oil filter was changed. The oil pump scavenge screen was removed and inspected for metal particles and contamination. The screen was then thoroughly cleaned, reinstalled, and safety wired. New gaskets were installed. The system was then serviced to the proper level with Aeroshell 15W-50 multiviscosity oil. Aeroshell 15W-50 multiviscosity oil was used during the testing and any servicing of the engine with oil was recorded.

- All fluid-carrying lines were inspected for possible leaks or chafing. Electrical wiring was inspected for proper connections, security, and evidence of chafing as well.

- Cylinder differential pressure (compression) tests were performed per Teledyne Continental Aircraft Engine Service Bulletin M84-15.

- A series of valve recession measurements were taken using a Cessna ULA-017 gauge assembly and a depth micrometer. The installation of the gauge assembly and measurement method is shown in figures 1 through 4. Before measuring the exhaust valve recession, the valve rotor was removed to prevent errant measurements due to an extra layer of oil between the rotor and valve stem.

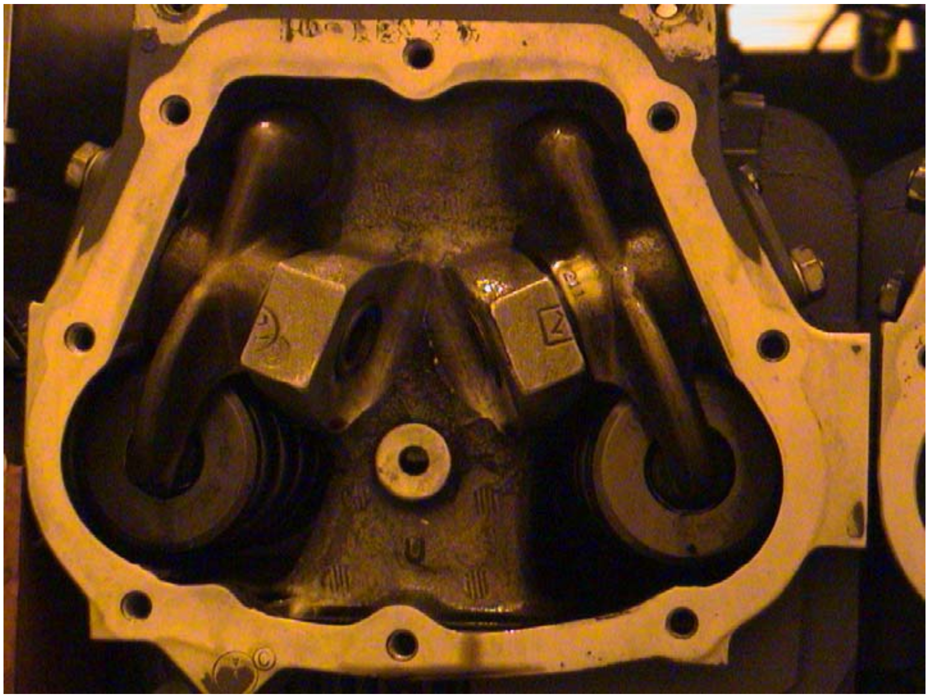

FIGURE 1. LYCOMING IO360-C CYLINDER WITH VALVE COVER AND GASKET MATERIAL REMOVED

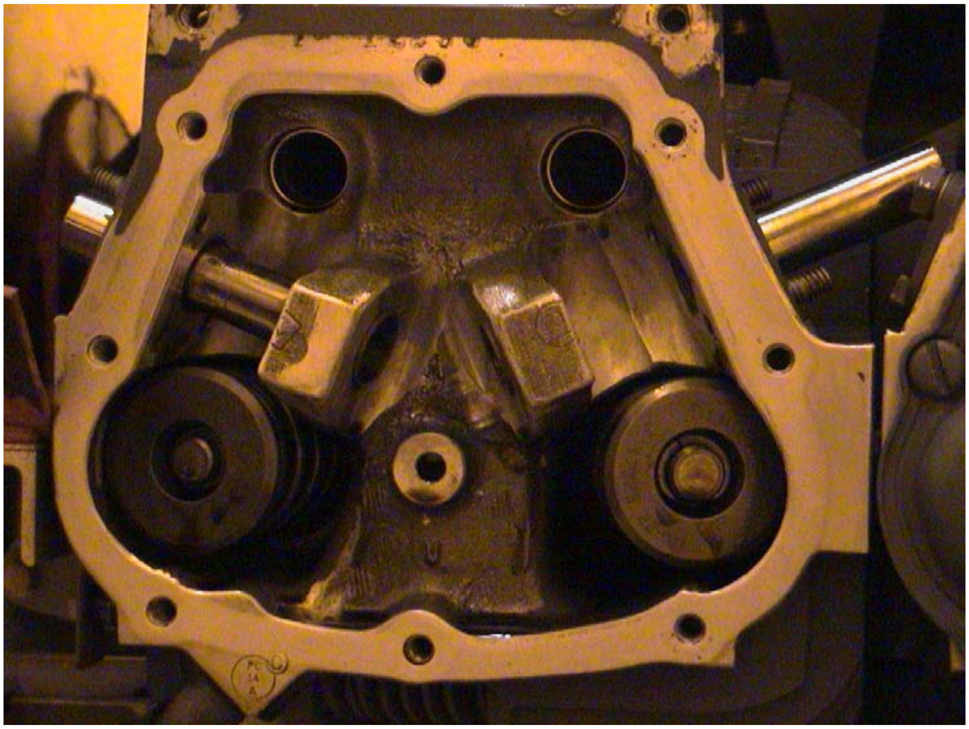

FIGURE 2. LYCOMING IO360-C CYLINDER WITH ROCKER ARMS REMOVED

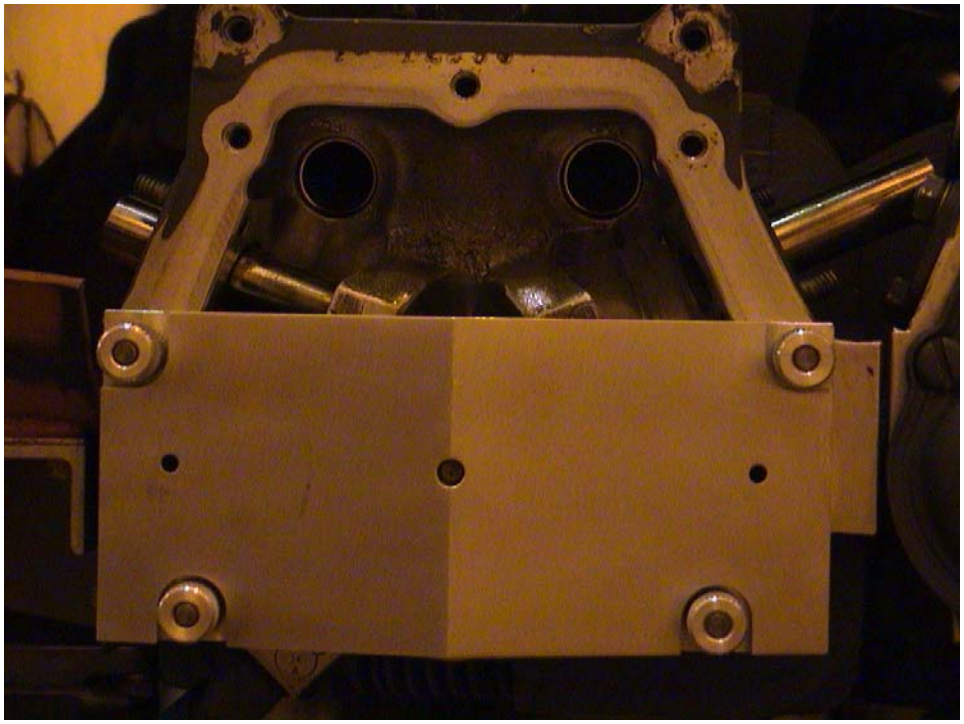

FIGURE 3. INSTALLATION OF CESSNA ULA-017 GAUGE ASSEMBLY

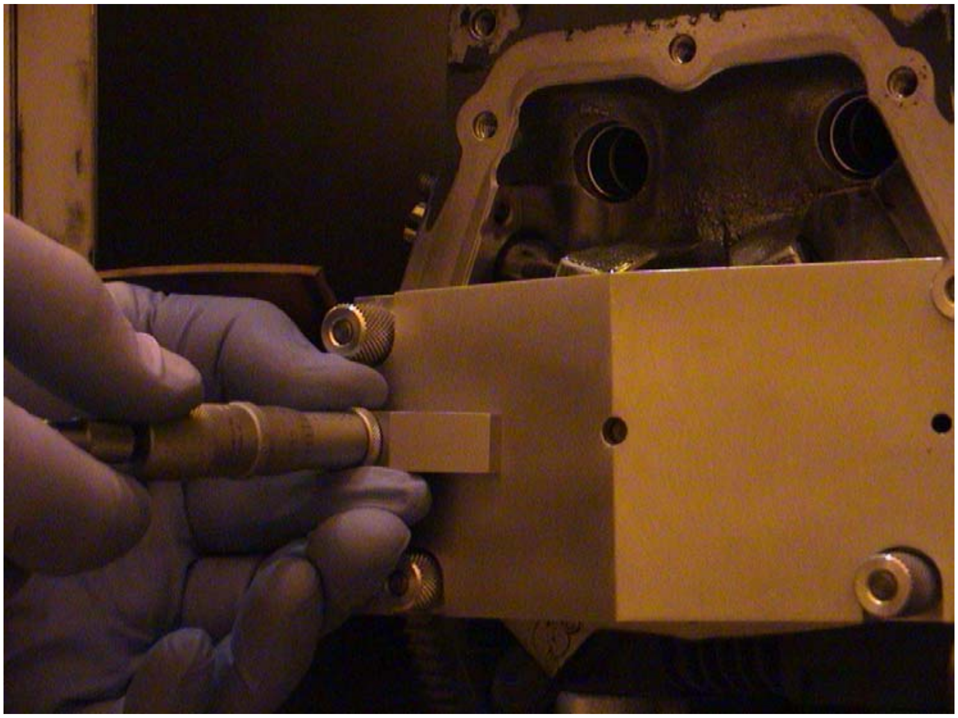

FIGURE 4. MEASURING VALVE STEM HEIGHT

After the inspection, the engine cowling was reinstalled and a performance engine run-up test was completed. At this time, the engine was inspected for evidence of oil leaks and proper operation.

At the completion of the test, the engine was sent to Teledyne Mattituck Services for teardown and inspection, and the critical high-stress areas of the engine were measured and compared against new and serviceable limits.

3. RESULTS.

3.1 DETONATION TEST.

The results of the detonation tests comparing the performance of ETBE to 100LL in the IO540-K engine are discussed in this section.

Figure 5 compares the detonation performance of the ETBE with the specially blended 100LL by plotting corrected hp versus fuel mass flow. The observed bhp is corrected to standard day conditions by adjusting for barometric pressure, inlet air temperature, and inlet air humidity differences. The linear lines drawn on the charts indicate the detonation-limited lines, or points of richest mixture setting where detonation was detected. These detonation onset points are shown as solid symbols in figure 5. Data to the left of the detonation-limited line indicates leaner fuel mixture operation and hence increasing detonation levels. Thus, the further to the left a detonation-limited line is in comparison to the power curve the better the detonation performance of the fuel.

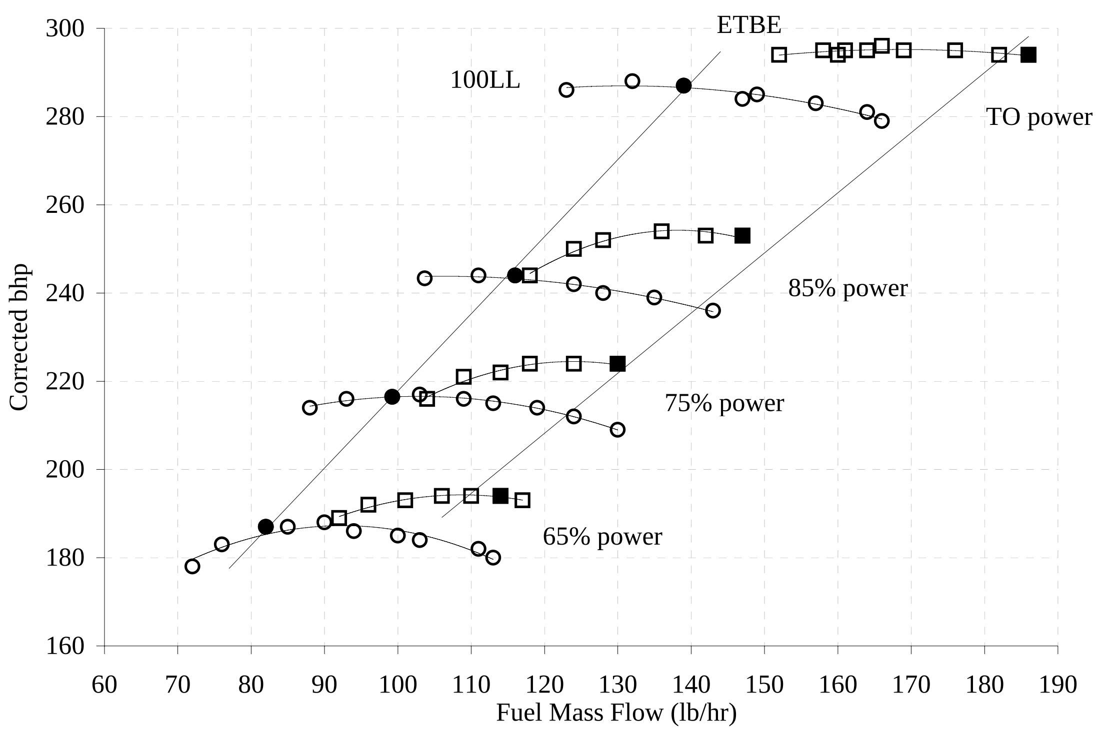

FIGURE 5. CORRECTED POWER CURVES FOR ETBE AND 100LL

Table 7 shows that the ETBE produced an average of 8 bhp more (3.3%) than 100LL. The peak power for ETBE occurred at a mixture setting, on average, of 23.8 lb/hr (21.5%) higher fuel mass flow than 100LL.

TABLE 7. PEAK POWER AND FUEL MASS FLOW COMPARISON BETWEEN ETBE AND 100LL

	Peak Power (Corrected bhp)				Fuel Mass Flow at Peak Power (lb/hr)			
Power Setting	100LL	ETBE	Power Difference (bhp)	Power Difference (%)	100LL	ETBE	Fuel Mass Flow Difference (lbs/hr)	Fuel Mass Flow Difference (%)
TO	288	296	10	4.1	132	166	34	25.8
85%, 2600 rpm	244	254	7	3.2	116	136	20	17.2
75%, 2450 rpm	217	224	6	3.2	103	124	21	20.4
65%, 2350 rpm	188	194	8	3.5	90	110	20	22.2
		Average:	8	3.3		Average:	23.8	21.5

The corrected brake specific fuel consumption (BSFC) is a measure of efficiency and is calculated by dividing the fuel mass flow by the corrected hp output. The lower the BSFC the greater the efficiency as less fuel is used to produce a unit of hp.

Dividing the fuel mass flow values by the peak power values for the TO condition in table 7, shows the increase in fuel mass flow at peak power for ETBE resulted in a corresponding decrease in efficiency from a BSFC of 0.46 pound per brake-horsepower hour (lb/bhp hr) for 100LL to 0.56 lb/bhp hr for ETBE.

The BSFC curves are shown in figure 6 with the solid symbols indicating the same detonation onset points shown in figure 5. The linear lines are the detonation-limited lines. Data below these lines for a given power setting indicate leaner mixtures and increased detonation values.

Typically, as fuel mass flow is reduced for a given power setting the BSFC will decrease and eventually form a cup where continued leaning results in an increase in BSFC. This inflection point is known as the best economy setting, where an engine has the best advantage of fuel consumption versus power output. The data in figure 6 does not show the best economy setting because unsafe levels of detonation were experienced at richer fuel mixtures. This shows that for operation on ETBE, best economy mixture setting would be an unsafe condition due to it being at a much leaner mixture than the onset detonation condition. The detonation-limited mass flow and BSFC values, corresponding to the solid symbols in figure 6 are shown in table 8.

Table 8 compares the detonation-limited fuel mass flow settings and the detonation-limited BSFCs for ETBE and 100LL. The ETBE required, on average, an increase of 35 lb/hr or 33% more fuel mass flow than 100LL to prevent detonation. At the maximum power condition the fuel mass flow for limiting detonation was 186 lb/hr for the ETBE versus 139 lb/hr for the

100LL. This resulted in a drop in efficiency as measured by the BSFC from 0.48 lb/bhp hr to 0.63 lb/bhp hr at the maximum power condition (TO).

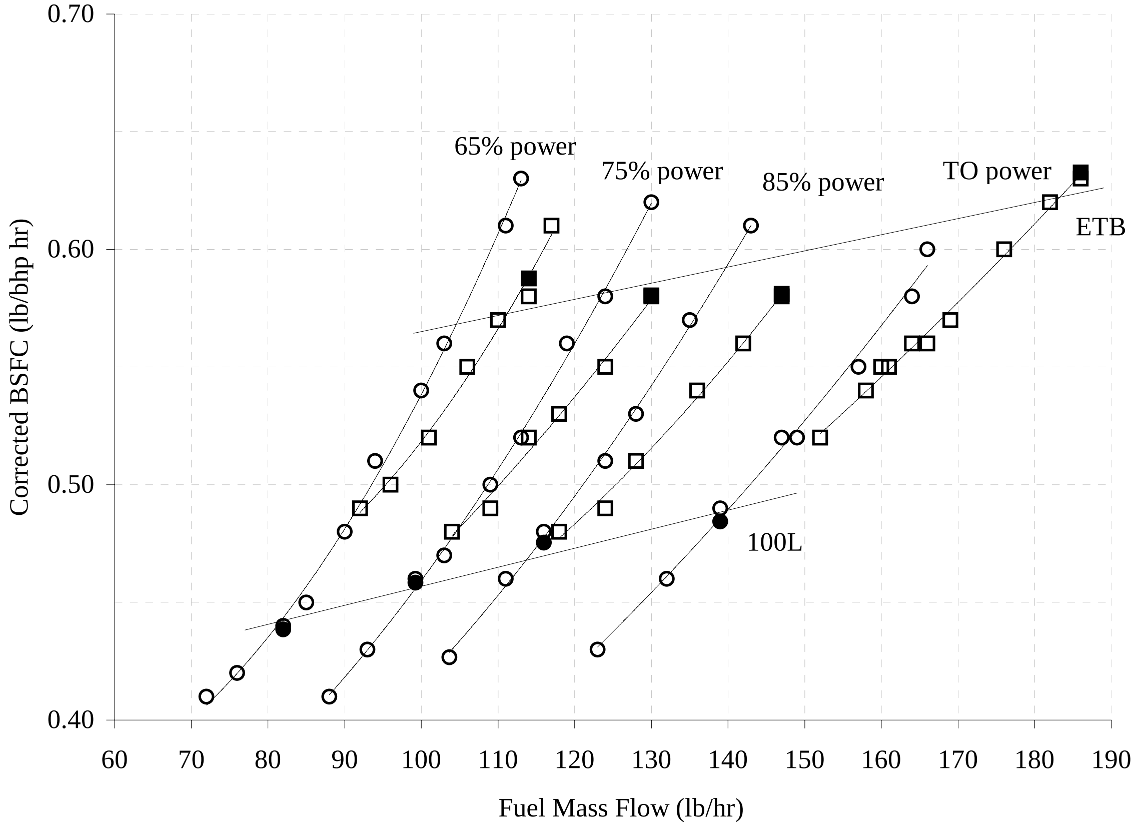

FIGURE 6. CORRECTED BSFC FOR ETBE AND 100LL

TABLE 8. DETONATION-LIMITED FUEL MASS FLOW AND BSFC COMPARISONS BETWEEN ETBE AND 100LL

	Detonation-Limited Fuel Mass Flow (lb/hr)				Detonation-Limited BSFC (lb/bhp hr)	
Power Setting	100LL	ETBE	Difference (lb/hr)	Difference (%)	100LL	ETBE
TO	139	186	47	33.8	0.48	0.63
85%, 2600 rpm	116	147	31	26.7	0.48	0.58
75%, 2450 rpm	99	130	31	31.0	0.46	0.58
65%, 2350 rpm	82	114	32	39.0	0.44	0.59
		Average:	35	32.3		

Comparing the average BSFC at peak power listed in table 7 with the average BSFC at detonation limited fuel mass flow from table 8 shows that, on average, the detonation onset for 100LL occurred at a BSFC of 0.465 lb/bhp hr and the peak power occurred at a BSFC of 0.472

and for the ETBE the detonation onset occurred at a BSFC of 0.595 lb/bhp hr and the peak power occurred at a BSFC of 0.554 lb/bhp hr. This shows that, on average, detonation occurs at mixtures lean of best power for 100LL and rich of best power for ETBE. Thus, best power operation at the elevated temperatures of this test is an unsafe condition when operating on ETBE.

Figure 7 shows the power performance of 100LL and ETBE for varying air-to-fuel ratios. The figure shows the power curves for the 100LL plotted at higher air-to-fuel ratios and leaner mixtures, than the ETBE curves. This shows the ability to operate at much leaner mixtures when operating on 100LL fuel as compared to ETBE. This is a consequence of much lower energy density of ETBE in comparison to 100LL and the existence of oxygen in the chemical structure of ETBE.

Figures 8 through 11 show the EGT and BHP output for ETBE and 100LL for the four power settings. Table 9 provides a summary of the exhaust gas data. Table 7 showed that the ETBE produced on average 3.3% greater peak power but at 21.5% greater fuel mass flow. This is also listed in columns 2 and 3 of table 9. However, the ETBE required on average 32.3% greater fuel mass flow to prevent detonation, which is shown in column 5 of table 9. The average EGT, shown in column 4 of table 9, was slightly higher at peak power for the ETBE than the 100LL, but this relationship reversed at limiting detonation (column 7 of the table) due to the sharp increase in fuel mass flow required for ETBE. Typically, for mixtures richer than peak EGT, higher fuel mass flows for a given MAP result in lower EGTs. Columns 9 and 10 illustrate the substantial drop in efficiency experienced, as measured by the BSFC, at both peak power and limiting detonation conditions with the largest drop occurring at the limiting detonation condition.

The figures also show that the relative location of limiting detonation to peak power differed substantially between the two fuels. On average, and shown in column 8 of table 9, the detonation-limited power occurred 25ºF lean of peak power for 100LL, whereas, for the ETBE, the location of detonation-limited power occurred 41ºF rich of peak power. The EGT data, along with the previous discussion of the BSFC data, show that leaning to best power or best economy would be a safety concern due to detonation.

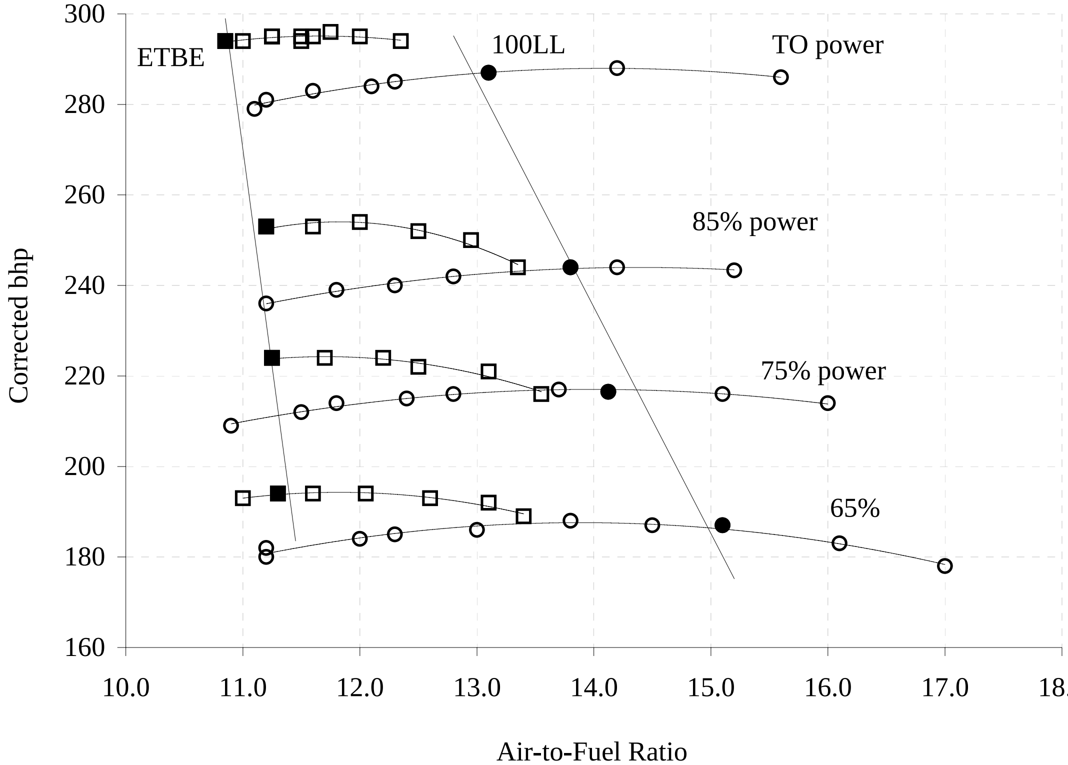

FIGURE 7. CORRECTED BHP VS AIR-TO-FUEL RATIO FOR ETBE AND 100LL

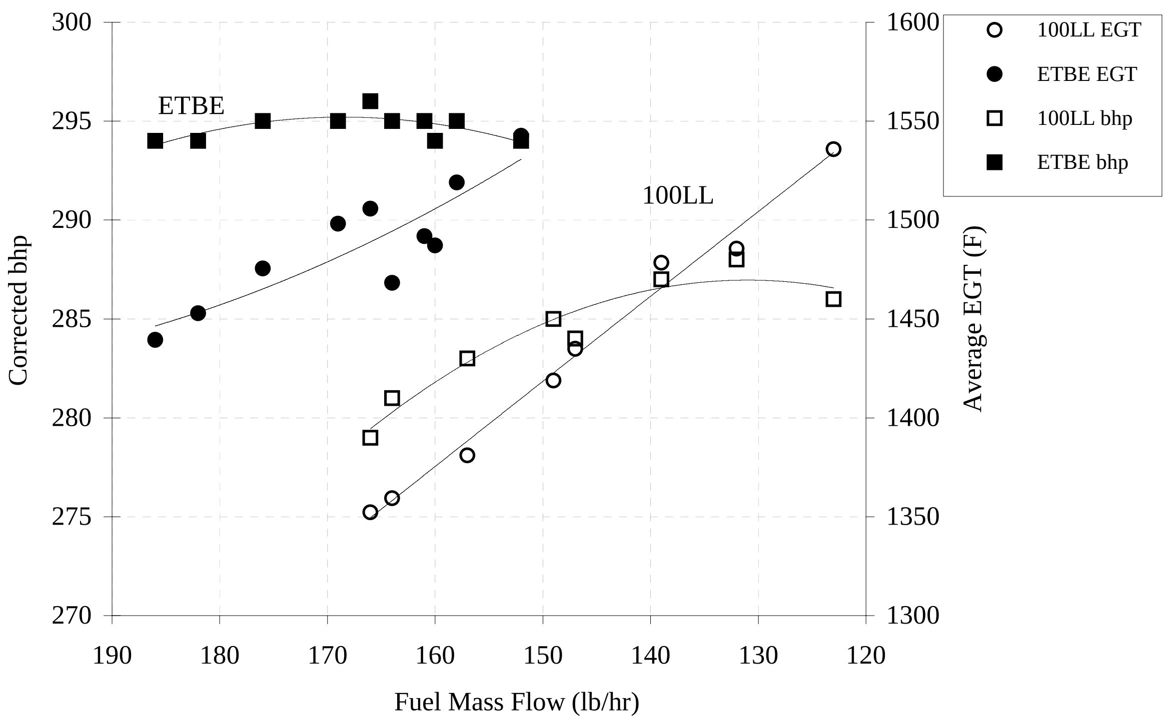

FIGURE 8. A BHP AND EGT COMPARISON BETWEEN ETBE AND 100LL AT TO POWER

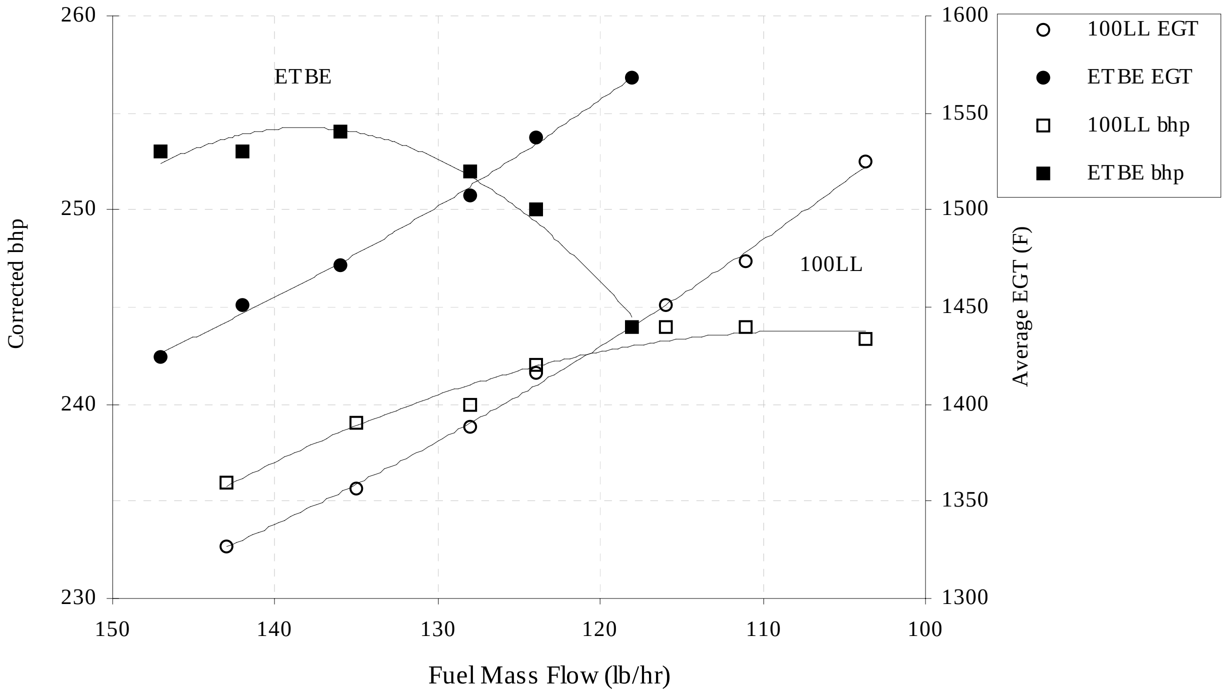

FIGURE 9. A BHP AND EGT COMPARISON BETWEEN ETBE AND 100LL AT 85% POWER

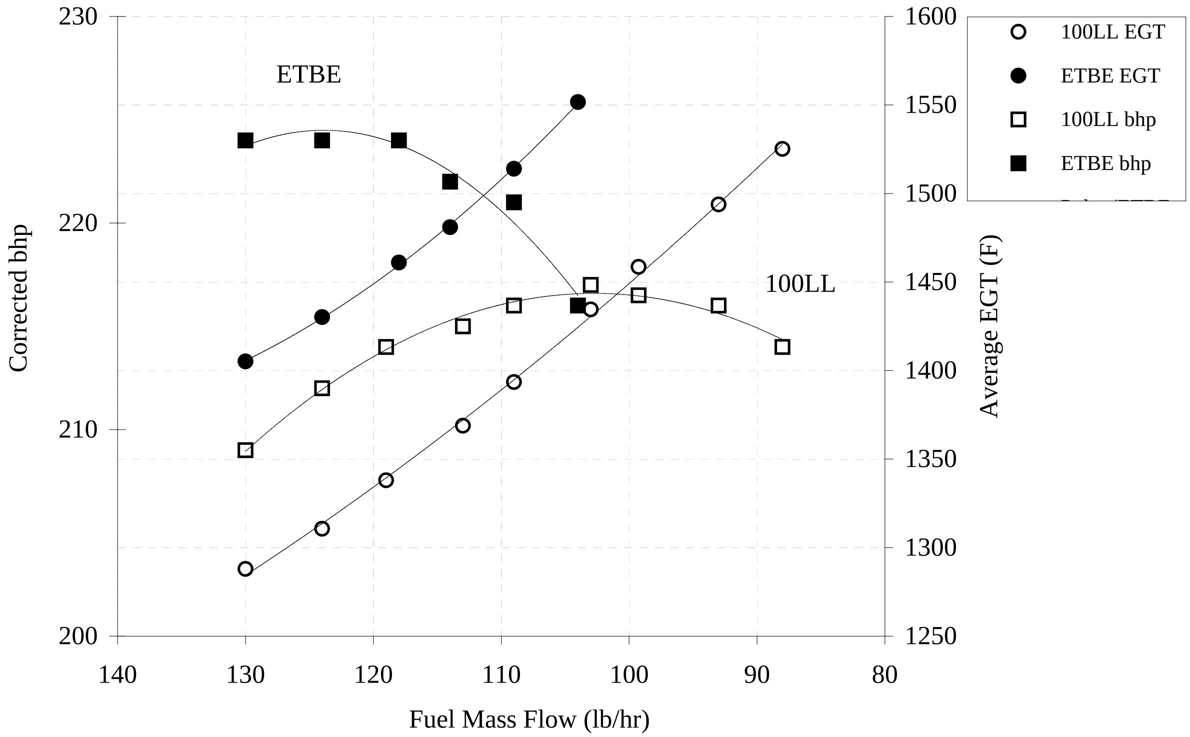

FIGURE 10. A BHP AND EGT COMPARISON BETWEEN ETBE AND 100LL AT 75% POWER

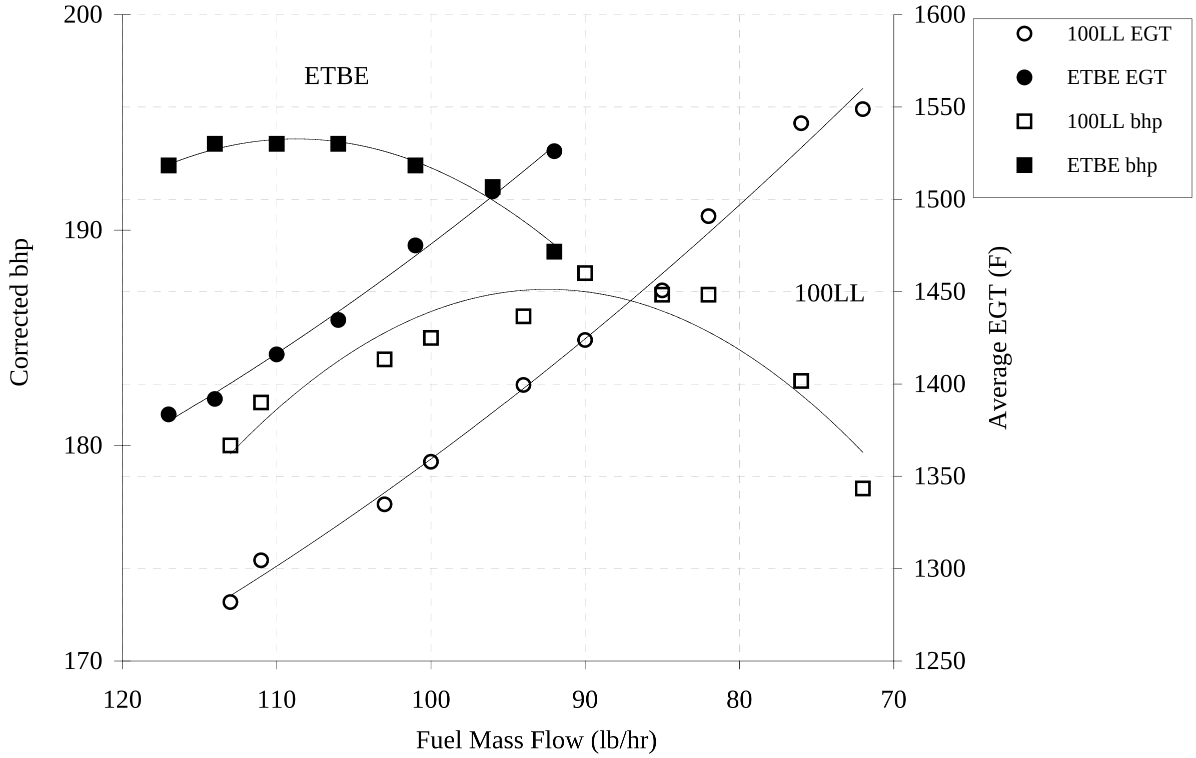

FIGURE 11. A BHP AND EGT COMPARISON BETWEEN ETBE AND 100LL AT 65% POWER

TABLE 9. EXHAUST GAS SUMMARY DATA

Fuel - % Power	Fuel Flow at Max bhp (lb/hr)	Max bhp	EGT at Max bhp (°F)	Detonation-Limited Fuel Flow (lb/hr)	bhp at Detonation-Limited Fuel Flow	EGT at Detonation-Limited Fuel Flow (°F)	EGT at Detonation-Limited Fuel Flow EGT at Max bhp (°F)	BSFC at Max bhp (lb/bhp hr)	BSFC at Limiting Detonation (lb/bhp hr)
100LL-TO	132	288	1486	139	287	1478	8	0.46	0.49
100LL-85	116	244	1451	116	244	1451	0	0.48	0.48
100LL-75	103	217	1435	99	217	1459	24	0.47	0.46
100LL-65	90	188	1424	82	187	1491	67	0.48	0.44
ETBE-TO	166	296	1506	186	294	1439	-67	0.56	0.63
ETBE-85	136	254	1472	147	253	1425	-47	0.54	0.58
ETBE-75	124	224	1430	130	224	1405	-25	0.55	0.58
ETBE-65	110	194	1416	114	194	1392	-24	0.55	0.58

Appendix A lists the engine parameter data for the ETBE detonation test with the Lycoming IO540-K engine. Appendix B lists the detonation intensity values for the ETBE test with the Lycoming IO540-K engine.

3.2 ENDURANCE TEST.

The Lycoming IO360-C engine oil consumption stabilized to 0.26 quarts per hour after 12.6 hours of break-in operations. This is well below the engine manufacturer's allowable oil consumption limits of 0.89 quarts per hour during engine break-in. After the engine was broken-in using isooctane, a differential compression test was performed and the valve heights were measured.

After the engine break-in period and the initial measurements were taken, the fuel controller was sent to Precision Airmotive Corporation, Marysville, Washington, for modification. The detonation test results of the Lycoming IO540-K engine suggest that detonation-free operation could also be attained with the Lycoming IO360-C engine with a 35% increase over the 100LL fuel schedule. Therefore, the fuel controller was modified by enlarging the fuel controller main-metering jet and the fuel injection nozzles increasing the fuel mass flow. Also, enlarged fuel injection nozzles were provided to allow a greater flow.

After the fuel controller had been modified and as detailed in section 2.2, a power baseline test was performed on the Lycoming IO360-C engine using isooctane. This power baseline was compared to another power baseline completed after the completion of the 150-hour test. Comparing the power development before and after the endurance test provides another measure of the health of the engine. Figure 12 details the comparison of the power baseline tests. On average, the engine produced 3.9 less bhp at the end of the test. This amount of power loss is nominal given the duration and severity of the endurance test.

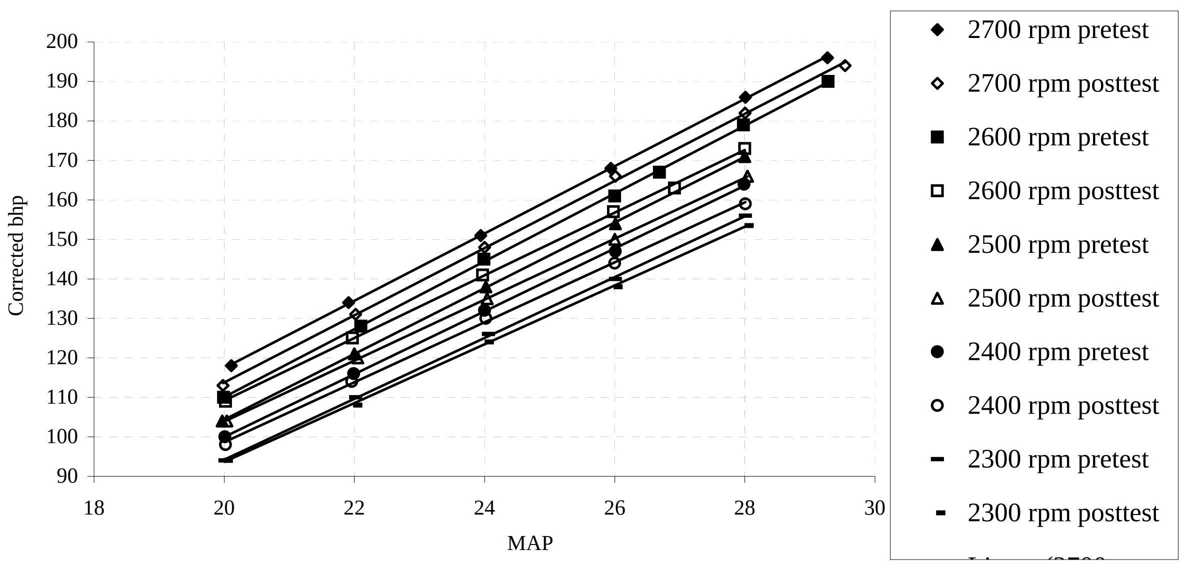

FIGURE 12. COMPARISON OF PRE- AND POSTTEST POWER BASELINES USING ISOOCTANE

At the beginning of the test and after every 50 hours of engine operation, an oil sample was taken and analyzed for viscosity changes, fuel dilution, acidity, and metals concentration. The results are shown in table 11.

TABLE 10. OIL ANALYSES

	Sample Date (2003)	3/11/04	4/1/04	4/26/04	5/10/04	5/18/04
	Engine Hours	Baseline	62.4	112.5	162.8	191.3
Test Method	Description					
ASTM D 664	Acid Number, mg KOH/g	0.17	1.4	1.5	1.4	1.1
ASTM D 445	Viscosity, mm^2/s					
	40°C	149.8	229.0	236.1	233.3	211.0
	100°C	20.23	25.33	26.41	26.05	24.55
ASTM D 3525	Fuel Dilution, mass %	<.01	0.09	0.05	0.07	0.09
JOAP	Metals by Arc Spark, ppm					
	Iron	1	24	22	32	27
	Lead	1	5	5	8	8
	Copper	0	58	45	42	29
	Chromium	0	2	2	2	1
	Aluminum	0	78	61	39	31
	Nickel	1	3	2	2	2
	Silver	0	0	0	0	0
	Tin	1	9	6	6	5
	Titanium	0	0	0	0	0
	Silicon	8	9	11	7	7
	Boron	1	1	1	1	1
	Sodium	0	4	2	1	1
	Zinc	1	12	7	4	5
	Calcium	1	5	3	2	3
	Barium	0	0	0	0	0
	Magnesium	0	5	2	1	1
	Molybdenum	1	0	0	0	0
	Antimony	0	0	0	0	0
	Potassium	0	0	0	1	0
	Phosphorous	1230	373	395	395	444

The oil analyses did not indicate that either fuel dilution nor oil degradation had occurred. The acid number of the oil was low and showed a level trend, and the same trend occurred with the oil viscosity. Fuel dilution was measured to be less than 0.1%. The metals analyses showed low values and declining trends, which is a normal wear pattern. The high levels of phosphorous were from phosphorous based oil additives.

The oil filter was cut open and the filter medium was inspected for metallic particles as shown in figure 13. No significant amounts of metallic particles were found at any of the inspection intervals.

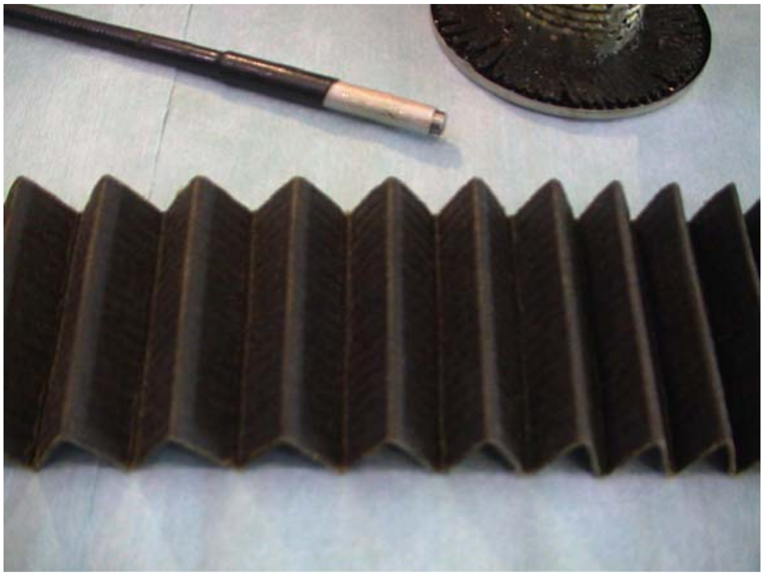

FIGURE 13. OIL FILTER INSPECTION

Table 12 lists the valve recession measurements. The first row of data in the table, for a given date is the depth of the valve stem as measured with a micrometer. The second row for a given date is the change in valve stem height from the previous measurement with the number of engine hours listed since the last measurement. The third row, for a given date, is for the change in valve depth (showing wear) from the original measurement with the number of engine hours listed since the initial measurement.

Figure 14 shows the exhaust valve recession. The change in valve recession was consistent over time and did not show accelerating wear. The total intake valve recession was less than 0.001 inches, whereas the average exhaust valve recession over the 150-hour test was found to be 0.0168 inch with a maximum value of 0.0178 inch in cylinder 1. These values are on the high side of the normal expected range for a test this severe and of this duration.

TABLE 11. VALVE RECESSION MEASUREMENTS

Date	Engine Hours	Test Hours	Intake Valves (inches)				Exhaust Valves (inches)			
			1	2	3	4	1	2	3	4
3/9/2004	12.6	0.0	1.5134	1.5125	1.5131	1.5088	1.5128	1.5123	1.5117	1.5100
4/1/2004	62.5	38.1	1.5135	1.5128	1.5122	1.5087	1.5078	1.5069	1.5071	1.5062
	wear/49.9		-0.0001	-0.0003	0.0009	0.0001	0.0050	0.0054	0.0046	0.0038
4/26/2004	112.5	80.1	1.5130	1.5135	1.5128	1.5087	1.5038	1.5020	1.5014	1.5029
	wear/50		0.0005	-0.0007	-0.0006	0.0000	0.0040	0.0049	0.0057	0.0033
	wear/99.9		0.0004	-0.0010	0.0003	0.0001	0.0090	0.0103	0.0103	0.0071
5/10/2004	162.8	127.0	1.5135	1.5135	1.5129	1.5092	1.4994	1.4985	1.4965	1.5014
	wear/50.3		-0.0005	0.0000	-0.0001	-0.0005	0.0044	0.0035	0.0049	0.0015
	wear/150.2		-0.0001	-0.0010	0.0002	-0.0004	0.0134	0.0138	0.0152	0.0086
5/20/2004	191.4	150.0	1.5139	1.5135	1.5123	1.5094	1.4950	1.4964	1.4947	1.4938
	wear/28.6		-0.0004	0.0000	0.0006	-0.0002	0.0044	0.0021	0.0018	0.0076
	wear/178.8		-0.0005	-0.0010	0.0008	-0.0006	0.0178	0.0159	0.0170	0.0162

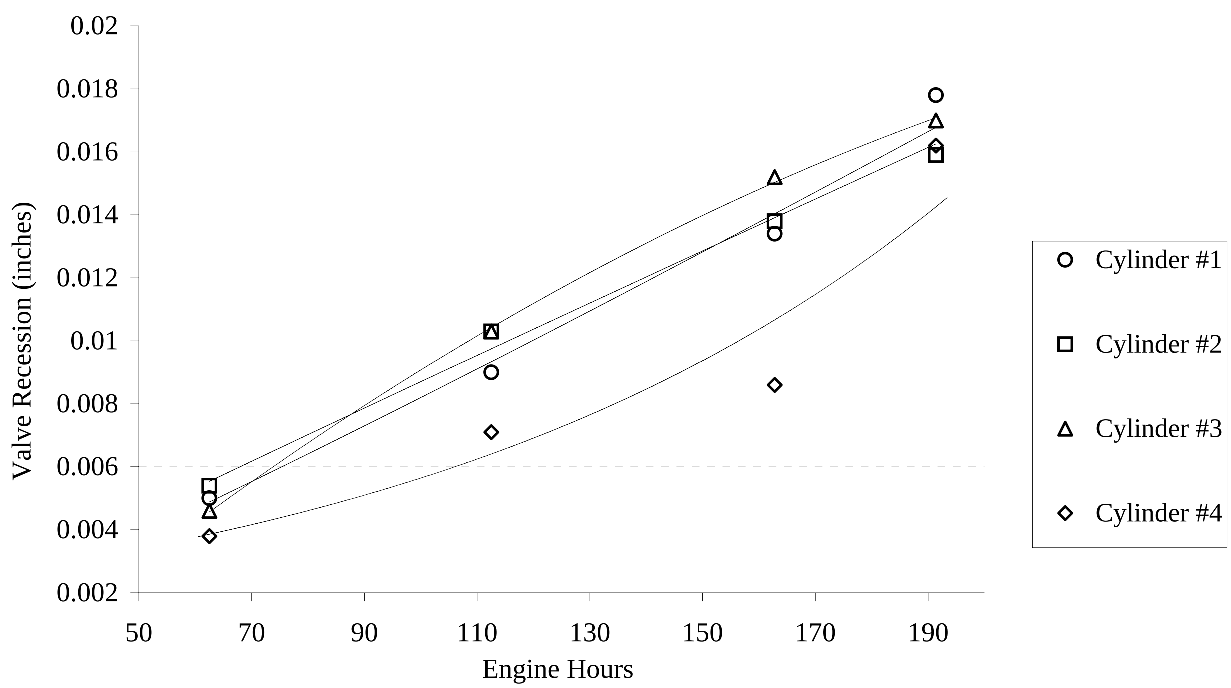

FIGURE 14. EXHAUST VALVE RECESSION

Table 13 shows the cylinder compression measurements. The engine was still showing pressures above 70 pounds per square inch gauge (psig) out of the psig applied at the end of the test. Typically, a value above 60 psig is considered acceptable.

TABLE 12. CYLINDER COMPRESSION MEASUREMENTS

Date	Engine Hours	Test Hours	Compression /80 psig			
			1	2	3	4
3/9/2004	12.6	0.0	71	72	68	70
4/1/2004	62.5	38.1	76	78	76	73
4/26/2004	112.5	80.1	76	72	77	74
5/10/2004	162.8	127.0	72	77	74	76
5/20/2004	191.4	150.0	70	71	74	70

Figures 15 through 17 show the combustion chamber of cylinder 3 after 50 engine hours of operation. There were no visible deposits on the spark plugs, piston faces, or valves. Also, the cylinder wall crosshatching, which is machined at the factory, is still visible. This was typical of what was seen in all of the cylinders at that time.

FIGURE 15. COMBUSTION CHAMBER OF CYLINDER 3 AFTER 50 ENGINE HOURS OF OPERATION

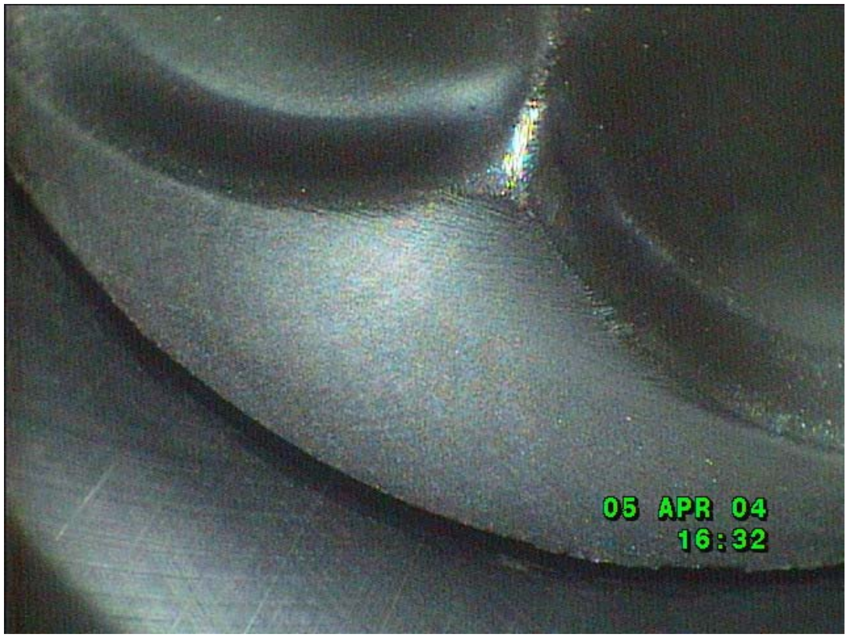

FIGURE 16. PISTON FACE AND CYLINDER WALL FOR CYLINDER 3 AFTER 50 ENGINE HOURS OF OPERATION

FIGURE 17. VALVE FACES FOR CYLINDER 3 AFTER 50 ENGINE HOURS

Figures 18 through 19 show cylinder 1 after 100 engine hours. Figure 18 shows a very clean spark plug and very slight cylinder wall scuffing. Figure 19 shows very little deposits on the piston face. The cylinder wall appears as a matted finish, as the crosshatching has worn.

FIGURE 18. COMBUSTION CHAMBER OF CYLINDER 1 AFTER 100 ENGINE HOURS

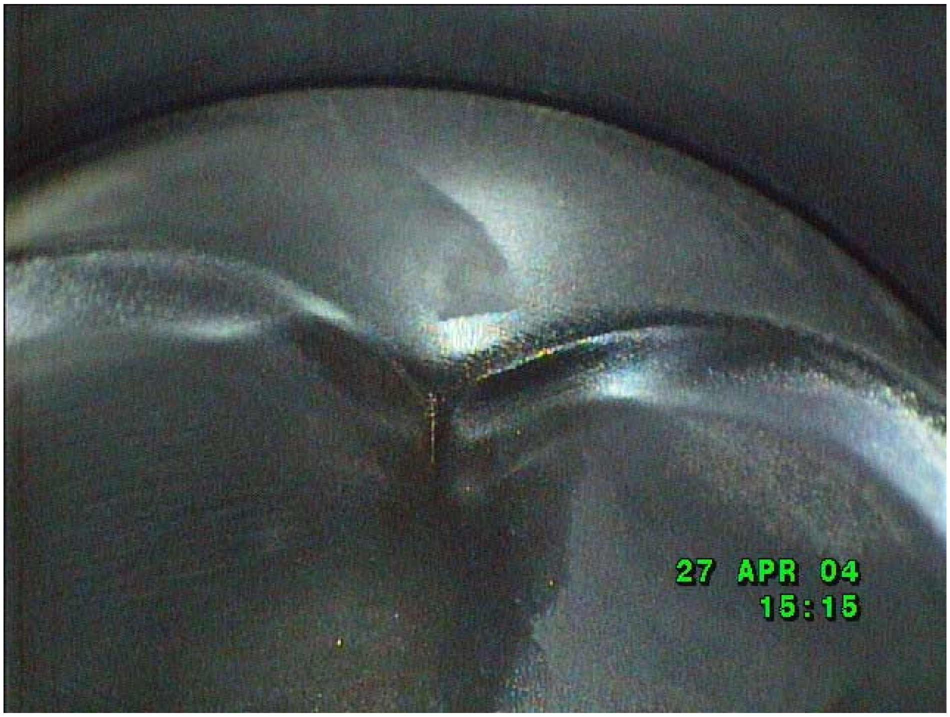

FIGURE 19. PISTON FACE OF CYLINDER 1 AFTER 100 ENGINE HOURS

Figure 20 shows the combustion chamber of cylinder 2 after 150 engine hours. The spark plug and combustion chamber of cylinder 2 are free of significant deposits.

FIGURE 20. COMBUSTION CHAMBER OF CYLINDER 2 AFTER 150 ENGINE HOURS

Figure 21 shows the piston face and cylinder wall of cylinder 4 after 150 engine hours. In this view the crosshatch is still visible on the cylinder wall. The piston face is very clean and there is only a slight deposit buildup on the edge of the piston face near the cylinder wall.

FIGURE 21. PISTON FACE AND CYLINDER WALL OF CYLINDER 4 AFTER 150 ENGINE HOURS

Figure 22 shows the combustion chamber and spark plug of cylinder 1 at the completion of the 150-hour test. The lack of deposits was noticeable and was typical of all of the cylinders.

FIGURE 22. SPARK PLUG OF CYLINDER 1 AT THE COMPLETION OF THE 150-HOUR TEST

Figure 23 shows the piston face of cylinder 3. The deposit formation is minimal. While the crosshatching is not visible, the cylinder wall shows no signs of scuffing. This was typical in all of the cylinders at the completion of the test.

FIGURE 23. PISTON FACE AND CYLINDER WALL OF CYLINDER 3 AT THE END OF THE 150-HOUR TEST

After the 150-hour endurance test and the power baseline were completed, the Lycoming IO360-C engine was sent to Teledyne Mattituck Services for teardown, inspection, measurement, and overhaul. The measurements showed that normal wear had occurred. The main crankcase bearing bores, the crankcase camshaft bearing bores, and the crankcase tappet bores showed normal wear. The crankcase front main bearing shells exhibited some delamination on the back end of the shells. There was also some delamination of the right and left rear bearing shells. It is not believed that this delamination was a consequence of the fuel since the oil analyses in table 11 showed minimal fuel dilution, minimal viscosity change, and low acid content. The crankshaft rod and main journals showed minimal wear, as did the camshaft journals. The crankshaft rod and cap bearings also showed minimal wear. The camshaft lobes and tappet diameters showed minimal wear except for the camshaft lobe of cylinder 1 and the face of tappet body of cylinder 1 where severe wear was found. This wear is not believed to be a consequence of the fuel, since the oil analyses showed that minimal oil dilution and viscosity changes had occurred and the acid content of the oil remained low. The piston skirts showed minimal wear and did have moderate to severe metal contamination caused by the camshaft lobe failure of cylinder 1. The connecting rod bearing surfaces and diameters were within new specifications, as were the wrist pin diameters. The piston ring side clearances were within new limit specifications.

Appendix C lists the ETBE endurance test data with the Lycoming IO360-C engine.

4. SUMMARY.

4.1 DETONATION TEST.

A used Lycoming IO540-K engine was used to compare the detonation performance of the ETBE fuel to 100LL. The test was performed at severe cylinder head and oil temperatures and with a standard hot-day intake air temperature. Significant changes to the fuel servo and distribution nozzles were required for safe operation on ETBE. The engine ignition timing of 20 degrees BTDC was not altered from the standard setting for 100LL. The cylinder compression ratio was not altered from its standard configuration.

ETBE produced, on average, 3.3% more peak hp than 100LL but required 21.5% more fuel mass flow. This is a consequence of both the ETBE having less energy density than 100LL and of the oxygen content of the ETBE. This increased fuel mass flow requirement resulted in a loss in efficiency at TO power from 0.48 lb/bhp hr for 100LL to 0.63 lb/bhp hr for ETBE. While 100LL has a mass density of 5.87 lb/gal, ETBE has a mass density measured to be 6.22 lb/gal. The consequence of the loss in efficiency and the increase in mass density is to reduce engine range, the distance traveled for each gallon of fuel by 18.7% when operating on ETBE.

Operation at peak power fuel mixture on ETBE resulted in 20ºF-higher-average EGT at maximum power than 100LL.

ETBE required 33% more fuel mass flow than required by 100LL at maximum power to prevent engine detonation.

On average, the detonation onset for 100LL occurred at a BSFC of 0.465 lb/bhp hr and the peak power occurred at a BSFC of 0.472 lb/bhp hr. The detonation onset for the ETBE occurred at a BSFC of 0.595 lb/bhp hr and the peak power occurred at a BSFC of 0.554 lb/bhp hr. This shows that detonation occurs at mixtures lean of best power for 100LL and rich of best power for ETBE. Thus best power operation, at the elevated temperatures of this test, is an unsafe condition due to detonation when operating on ETBE. Operation at best economy on ETBE would be an unsafe condition due to detonation.

Engine detonation occurred at an average EGT that was 41ºF rich of peak power on ETBE, whereas engine detonation occurred at an average EGT that was 25ºF lean of peak power on 100LL. The consequence of this is to change standard engine operating procedures for ETBE, because leaning to peak EGT, best power, or best economy power would produce unsafe conditions.

Detonation and power baseline performance curves could be repeated with the engine ignition timing retarded by 5º, to 15º BTDC from 20º BTDC. The probable result of retarding the ignition timing by 5º is significant detonation performance improvement with minimal power loss. There may be an added consequence from reducing the ignition timing of increased exhaust gas temperatures.

4.2 ENDURANCE TEST.

The Lycoming IO360-C engine was operated at maximum CHT and oil temperatures, and at maximum power for most of the 150-hour endurance test.

Engine teardown and measurement revealed that camshaft lobe 1 had failed resulting in metal buildup on the piston skirts and the front and rear main crankshaft bearing shells exhibited slight delamination. It is not believed that these failures were fuel-related because oil dilution with ETBE was minimal, oil viscosity change was minimal, and the oil acid content was low. The engine lubricating oil analyses, compression tests, and engine measurements indicated that normal wear had occurred. All other high-stress components of the engine experienced normal wear. The exhaust valve train showed an average recession of 16.8 thousandths of an inch. This is at the high end of the normal expected range for a test this severe.

There were minimal cylinder deposits, piston deposits, valve deposits, and nozzle deposits due to operation on ETBE. There were minimal engine varnish and sludge deposits.

The engine lost an average of 3.9 bhp after 150 hours of severe engine operations.

There were no observations of difficulty with engine starting nor observations of material compatibility issues.

APPENDIX A—LYCOMING IO540-K ETBE DETONATION TEST ENGINE PARAMETER DATA VALUES, Barometer 29.66 in. Hg

TABLE A-1. DATA FROM THE DETONATION TEST

Engine Parameter	Data Point								
	A	B	C	D	E	G	H	I	J
Detonation level	Ld	Ld	Hd	Hd	Hd	Hd	Ld	Md	Hd
Manifold absolute pressure (MAP) (in. Hg)	29.20	29.19	29.18	29.19	29.20	26.95	26.96	26.96	26.96
Engine speed (rpm)	2701	2701	2701	2701	2701	2602	2601	2601	2601
Produced Engine Torque (ft/lb)	550	548	547	549	548	472	490	490	490
Observed brake horsepower (bhp)	283	282	282	282	282	234	243	243	242
Temperature-corrected bhp (tcbhp)	294	294	294	295	294	244	253	253	254
Lycoming-corrected bhp (lcbhp)	296	296	296	296	295	246	254	255	255
Brake mean effective pressure (psig)	125.4	124.9	125.1	125.6	125.3	107.8	111.9	112	111.7
Fuel mass flow (lb/hr)	186	182	160	158	152	118	147	142	136
Fuel volume flow (gal/hr)	30.2	29.6	26	25.7	24.8	19.3	23.9	23.1	22.1
Percent relative fuel mass flow	35.0	32.1	16.1	14.7	10.3	0.3	24.9	20.6	15.5
BSFC (lb/bhp hr)	0.66	0.65	0.57	0.56	0.54	0.51	0.61	0.59	0.56
Temperature corrected brake fuel consumption (lb/tcbhp hr)	0.63	0.62	0.55	0.54	0.52	0.48	0.58	0.56	0.54
Lycoming corrected brake fuel consumption (lb/lcbhp hr)	0.63	0.61	0.54	0.54	0.52	0.48	0.58	0.56	0.53
Induction air temperature (°F)	101	102	106	104	100	104	101	102	104
Induction air pressure (in. Hg)	29.68	29.67	29.66	29.67	29.67	29.66	29.66	29.66	29.66
Cooling air temperature (°F)	102	98	100	99	100	106	105	103	104
Cooling air pressure (in. H_2O)	3.8	2.9	5.5	3.5	5.8	4.2	2.4	3	3.5
Fuel inlet temperature (°F)	74	72	71	71	71	75	73	73	73
Fuel density (lb/gal)	6.14	6.14	6.15	6.15	6.15	6.13	6.14	6.14	6.14
Metered fuel pressure (psi)	11.3	10.9	10	9.1	8.8	5.5	8	7.5	7
Unmetered fuel pressure (psi)	24.6	24.6	24.7	24.8	24.8	24.8	24.6	24.7	24.8
#1 Cylinder head temperature CHT (°F)	456	458	458	464	462	461	448	455	450
#2 CHT (°F)	428	428	430	427	433	441	431	435	428
#3 CHT (°F)	442	442	444	442	448	447	441	445	438
#4 CHT (°F)	426	426	428	430	438	438	428	430	425
#5 CHT (°F)	472	474	477	474	478	476	473	478	473
#6 CHT (°F)	455	454	456	456	460	452	450	452	446
#1 EGT (°F)	1424	1442	1470	1509	1530	1560	1409	1437	1460
#2 EGT (°F)	1424	1436	1469	1497	1522	1548	1407	1433	1454
#3 EGT (°F)	1452	1464	1500	1534	1558	1590	1440	1466	1490

TABLE A-1. DATA FROM THE DETONATION TEST (Continued)

Engine Parameter	Data Point								
	A	B	C	D	E	G	H	I	J
#4 EGT (°F)	1428	1440	1474	1502	1526	1549	1409	1436	1458
#5 EGT (°F)	1464	1476	1514	1546	1567	1586	1447	1472	1488
#6 EGT (°F)	1444	1459	1496	1526	1553	1577	1435	1462	1480
Oil inlet temperature (°F)	230	232	230	240	237	240	238	238	233
Oil pressure (psi)	66	66	66	66	66	64	64	64	64
Humidity temperature (°F)	105	105	106	107	104	104	103	103	103
Relative humidity (%)	1	1	1	0	0	0	1	1	1
Air-to-fuel ratio left bank (AFL)	10.7	10.9	11.4	11.9	12.2	13.3	11.1	11.5	11.9
Air-to-fuel ration right bank (AFR)	11.0	11.1	11.6	12.1	12.5	13.4	11.3	11.7	12.1

TABLE A-1. DATA FROM THE DETONATION TEST (Continued)

Engine Parameter	Data Point								
	K	L	M	N	O	P	Q	R	S
Detonation level	Md	Md	Hd	Ld	Md	Md	Hd	Md	Md
MAP (in. Hg)	26.94	26.96	25.86	25.88	25.87	25.87	25.87	25.87	24.05
Engine speed (rpm)	2601	2602	2452	2451	2451	2451	2451	2452	2352
Produced engine torque (ft/lb)	486	484	444	460	461	460	458	454	404
Observed brake horsepower (bhp)	241	240	208	215	215	215	214	212	182
Temperature-corrected bhp (tcbhp)	252	250	216	224	224	224	222	221	189
Lycoming-Corrected bhp (lcbhp)	253	252	218	225	225	225	224	222	190
Brake mean effective pressure (psig)	110.8	110.6	101	105.2	105.2	105.4	105	103.7	92.3
Fuel mass flow (lb/hr)	128	124	104	130	124	118	114	109	92
Fuel volume flow (gal/hr)	20.9	20.2	17	21.2	20.2	19.4	18.7	17.8	15.1
Percent relative fuel mass flow	8.8	5.4	0.1	25.1	19.3	13.6	9.7	4.9	0.8
Brake specific fuel consumption (BSFC) (lb/bhp hr)	0.53	0.52	0.5	0.6	0.58	0.55	0.54	0.51	0.51
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.51	0.49	0.48	0.58	0.55	0.53	0.52	0.49	0.49
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.51	0.49	0.48	0.58	0.55	0.53	0.51	0.49	0.49
Induction air temperature (°F)	105	103	102	102	101	101	101	100	102
Induction air pressure (in. Hg)	29.66	29.68	29.66	29.68	29.67	29.66	29.66	29.66	29.67
Cooling air temperature (°F)	100	100	102	105	106	107	106	107	104
Cooling air pressure (in. H_2O)	4	2.8	2.8	2.5	2.5	3.5	2	4.1	3
Fuel inlet temperature (°F)	74	74	76	76	76	76	76	77	78
Fuel density (lb/gal)	6.13	6.13	6.12	6.12	6.12	6.12	6.12	6.12	6.11

TABLE A-1. DATA FROM THE DETONATION TEST (Continued

Engine Parameter	Data Point								
	K	L	M	N	O	P	Q	R	S
Metered Fuel Pressure (psi)	6.5	6	4.5	6.5	6	5.5	5.2	4.9	3.8
Unmetered Fuel Pressure (psi)	24.7	24.8	24.6	24.5	24.5	24.5	24.5	24.6	24.6
#1 CHT (°F)	448	452	452	453	454	452	451	452	445
#2 CHT (°F)	430	429	437	438	439	434	432	431	438
#3 CHT (°F)	439	438	442	442	444	441	439	440	443
#4 CHT (°F)	428	426	434	432	436	432	430	430	432
#5 CHT (°F)	475	474	475	475	477	475	474	478	474
#6 CHT (°F)	447	448	446	452	451	448	445	444	444
#1 EGT (°F)	1494	1527	1541	1384	1410	1445	1464	1498	1510
#2 EGT (°F)	1494	1516	1540	1392	1417	1448	1468	1503	1512
#3 EGT (°F)	1525	1560	1568	1415	1440	1468	1492	1526	1537
#4 EGT (°F)	1496	1522	1546	1398	1423	1452	1472	1503	1516
#5 EGT (°F)	1522	1556	1554	1418	1442	1474	1488	1518	1537
#6 EGT (°F)	1516	1546	1561	1424	1449	1479	1502	1536	1544
Oil Inlet Temperature (°F)	233	230	236	232	234	232	236	234	237
Oil Pressure (psi)	64	64	62	63	63	63	62	62	62
Humidity Temperature (°F)	105	105	103	104	103	103	102	102	103
Relative Humidity (%)	1	1	1	1	1	1	1	1	1
AFL	12.4	12.9	13.5	11.1	11.6	12.1	12.4	13.1	13.4
AFR	12.6	13.0	13.6	11.4	11.8	12.3	12.6	13.1	13.4

TABLE A-1. DATA FROM THE DETONATION TEST (Continued)

Engine Parameter	Data Point					
	T	U	V	W	X	Y
Detonation level	Ld	Ld	Ld	Md	Md	No
MAP (in. Hg)	24.05	24.05	24.07	24.1	24.09	24.03
Engine speed (rpm)	2352	2352	2352	2351	2352	2351
Produced engine torque (ft/lb)	416	416	416	415	412	415
Observed brake horsepower (bhp)	186	186	186	186	184	186
Temperature-corrected bhp (tcbhp)	194	194	194	193	192	193
Lycoming-corrected bhp (lcbhp)	195	195	195	194	193	195
Brake mean effective pressure (psig)	94.9	94.9	95	94.9	93.9	94.8
Fuel mass flow (lb/hr)	114	110	106	101	96	117
Fuel volume flow (gal/hr)	18.6	18.1	17.3	16.5	15.6	19.2
Percent relative fuel mass flow	24.9	20.5	16.1	10.6	5.1	28.1
BSFC (lb/bhp hr)	0.61	0.59	0.57	0.54	0.52	0.63

TABLE A-1. DATA FROM THE DETONATION TEST (Continued)

Engine Parameter	Data Point					
	T	U	V	W	X	Y
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.58	0.57	0.55	0.52	0.5	0.61
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.58	0.56	0.54	0.52	0.49	0.6
Induction air temperature (°F)	101	102	102	101	101	100
Induction air pressure (in. Hg)	29.67	29.64	29.66	29.68	29.66	29.67
Cooling air temperature (°F)	102	100	98	100	101	100
Cooling air pressure (in. H_2O)	1.5	1.4	3	1.7	1.3	2.6
Fuel inlet temperature (°F)	78	78	78	78	78	78
Fuel density (lb/gal)	6.11	6.12	6.12	6.11	6.11	6.11
Metered fuel pressure (psi)	5.1	4.8	4.6	4.2	3.9	5.4
Unmetered fuel pressure (psi)	24.6	24.5	24.4	24.5	24.6	24.5
#1 CHT (°F)	446	446	448	445	444	449
#2 CHT (°F)	438	439	440	438	436	443
#3 CHT (°F)	444	443	444	442	441	447
#4 CHT (°F)	432	434	434	433	430	438
#5 CHT (°F)	474	474	476	475	474	478
#6 CHT (°F)	450	454	450	450	446	452
#1 EGT (°F)	1370	1398	1415	1457	1486	1361
#2 EGT (°F)	1378	1398	1422	1457	1488	1369
#3 EGT (°F)	1402	1427	1445	1481	1514	1395
#4 EGT (°F)	1384	1406	1426	1467	1496	1375
#5 EGT (°F)	1406	1427	1444	1481	1510	1391
#6 EGT (°F)	1411	1440	1456	1507	1532	1410
Oil inlet temperature (°F)	234	234	235	235	236	236
Oil pressure (psi)	62	62	62	62	62	62
Humidity temperature (°F)	103	102	102	102	102	102
Relative humidity (%)	1	1	1	1	1	1
AFL	11.2	11.5	12	12.6	13.1	10.9
AFR	11.4	11.7	12.1	12.6	13.1	11.1

LK = Light knock
HK = Heavy knock
MK = Moderate knock

APPENDIX B—LYCOMING IO540-K ETBE DETONATION TEST RESULTS

TABLE B-1. MAXIMUM FILTERED DETONATION DATA

Data Point	Maximum filtered detonation knock 1	Maximum filtered detonation knock 2	Maximum filtered detonation knock 3	Maximum filtered detonation knock 4	Maximum filtered detonation knock 5	Maximum filtered detonation knock 6	Detonation
A	14	-4	5	1	12	0	Ld
B	4	-1	23	17	0	-1	Ld
C	71	22	267	21	42	22	Hd
D	75	46	68	118	62	27	Hd
E	67	45	73	65	221	35	Hd
F	0	0	0	0	2	0	No Point
G	75	68	195	160	168	82	Hd
H	13	-2	15	-3	16	0	Ld
I	38	12	51	12	27	5	Md
J	76	43	69	8	104	15	Hd
K	61	56	61	67	77	46	Md
L	82	89	92	46	76	34	Md
M	38	29	72	54	142	29	Hd
N	14	1	4	2	22	-1	Ld
O	29	25	27	15	47	10	Md
P	72	19	70	32	46	27	Md
Q	39	17	50	64	239	67	Hd
R	64	48	50	98	95	37	Md
S	34	88	65	97	42	16	Md
T	0	5	21	0	4	4	Ld
U	14	6	34	0	36	2	Ld
V	26	24	36	25	33	14	Ld
W	89	34	61	23	29	16	Md
X	68	45	78	54	65	36	Md
Y	2	-3	3	-3	7	-2	No

Ld =Light density
Md =Moderate detonation
Hd =Heavy detonation

TABLE B-2. AVERAGE FILTERED DETONATION DATA

Data Point	Average filtered detonation knock 1	Average filtered detonation knock 2	Average filtered detonation knock 3	Average filtered detonation knock 4	Average filtered detonation knock 5	Average filtered detonation knock 6	Detonation
A	14	NaN	NaN	NaN	12	NaN	Ld
B	NaN	NaN	17	17	NaN	NaN	Ld
C	34	17	64	16	26	22	Hd
D	30	27	31	34	26	27	Hd
E	30	27	39	23	41	21	Hd
F	NaN	NaN	NaN	NaN	NaN	NaN	No Point
G	31	33	37	40	35	45	Hd
H	12	NaN	15	NaN	13	NaN	Ld
I	21	12	44	12	21	NaN	Md
J	26	29	27	NaN	34	15	Hd
K	32	24	25	26	32	22	Md
L	36	32	33	24	32	24	Md
M	24	21	26	26	33	23	Hd
N	14	NaN	NaN	NaN	17	NaN	Ld
O	20	25	19	15	28	NaN	Md
P	38	15	27	22	24	18	Md
Q	22	13	27	23	37	30	Hd
R	29	31	21	26	32	30	Md
S	22	28	30	30	29	16	Md
T	NaN	NaN	16	NaN	NaN	NaN	Ld
U	14	NaN	18	NaN	21	NaN	Ld
V	17	23	18	25	18	13	Ld
W	27	20	27	17	16	14	Md
X	23	21	30	22	27	23	Md
Y	NaN	NaN	NaN	NaN	NaN	NaN	No

Ld = Light detonation
Md – Moderate detonation
Hd = Heavy detonation

APPENDIX C—LYCOMING IO360-C POWER BASELINE PARAMETER DATA USING ISOOCTANE

TABLE C-1. PRE-ENDURANCE TEST POWER BASELINE AT 2700 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points					
	G	F	E	D	C	B
MAP (in. Hg)	20.11	21.91	23.94	25.94	28.01	29.27
Engine speed (rpm)	2700	2700	2700	2699	2699	2700
Produced engine torque (ft/lb)	229	259	294	328	363	382
Observed brake horsepower (bhp)	118	134	151	168	187	196
Temperature-corrected bhp (tcbhp)	118	134	151	168	186	196
Lycoming-corrected bhp (lcbhp)	117	134	151	168	187	197
Brake mean effective pressure (psig)	52.0	59.1	67.2	75.0	82.8	87.2
Fuel mass flow (lb/hr)	63.0	67.0	74.0	80.0	88.0	94.0
Fuel volume flow (gal/hr)	11.3	11.9	13.2	14.2	15.7	16.8
BSFC (lb/bhp hr)	0.54	0.51	0.49	0.47	0.47	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.54	0.51	0.49	0.47	0.47	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.54	0.51	0.49	0.47	0.47	0.48
Induction air temperature (°F)	59	59	58	58	58	58
Duct pressure (in Hg)	29.97	29.98	29.97	29.97	29.98	29.98
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	51	51	51
Cooling air pressure (in. H_2O)	7.0	5.0	8.0	6.0	11.0	8.0
Fuel inlet temperature (°F)	71	71	71	70	70	70
Fuel tank temperature (°F)	61	61	59	59	59	58
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	4.0	4.0	5.0	6.0
Unmetered fuel pressure (psi)	23.0	23.0	22.0	22.0	22.0	22.0
#1 CHT (°F)	350	349	350	350	350	350
#2 CHT (°F)	342	338	338	339	344	344
#3 CHT (°F)	345	344	344	344	342	339
#4 CHT (°F)	330	327	328	329	330	333
#1 EGT (°F)	1432	1434	1434	1449	1440	1416
#2 EGT (°F)	1424	1428	1424	1433	1416	1389
#3 EGT (°F)	1400	1404	1404	1418	1403	1399
#4 EGT (°F)	1422	1424	1416	1426	1419	1407

TABLE C-1. PRE-ENDURANCE TEST POWER BASELINE AT 2700 rpm (Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points					
	G	F	E	D	C	B
Oil inlet temperature (°F)	205	196	193	202	201	196
Oil pressure (psi)	85	86	86	85	85	84
Humidity temperature (°F)	54	54	54	54	54	54
Relative humidity (%)	49	49	49	49	48	48
Air-to-fuel ration right bank (AFR)	13.9	13.8	13.3	13.4	12.9	12.7
Air-t0-fuel ratio left bank (AFL)	13.1	13.1	13.1	13.5	13.1	12.7

TABLE C-2. PRE-ENDURANCE TEST POWER BASELINE AT 2600 rpm (Barometer = 30.12 in. Hg)

Engine Parameter	Data Points						
	N	M	L	K	H	I	J
MAP (in. Hg)	19.99	22.10	23.99	26.00	26.69	27.98	29.28
Engine speed (rpm)	2600	2600	2600	2600	2600	2600	2600
Produced engine torque (ft/lb)	223	259	293	326	337	362	385
Observed brake horsepower (bhp)	110	128	145	161	167	179	191
Temperature-corrected bhp (tcbhp)	110	128	145	161	167	179	190
Lycoming-corrected bhp (lcbhp)	110	128	145	161	167	180	192
Brake mean effective pressure (psig)	51.0	59.3	66.8	74.5	77.2	82.7	87.7
Fuel mass flow (lb/hr)	62	68	73	78	81	85	96
Fuel volume flow (gal/hr)	11.1	12.1	13	13.9	14.6	15.2	17.1
BSFC (lb/bhp hr)	0.56	0.53	0.5	0.48	0.49	0.47	0.5
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.56	0.53	0.5	0.48	0.49	0.47	0.5
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.56	0.53	0.5	0.48	0.49	0.47	0.5
Induction air temperature (°F)	58	59	59	58	58	58	58
Duct pressure (in. Hg)	29.97	29.97	29.97	29.97	29.97	29.97	29.98
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	52	52	52	52
Cooling air pressure (in. H_2O)	7.0	8.0	9.0	4.0	4.0	4.0	12.0
Fuel inlet temperature (°F)	72	72	71	71	71	71	71
Fuel tank temperature (°F)	63	63	62	62	61	62	62
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	4.0	4.0	4.0	5.0	6.0

TABLE C-2. PRE-ENDURANCE TEST POWER BASELINE AT 2600 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points						
	N	M	L	K	H	I	J
Unmetered fuel pressure (psi)	23.0	23.0	22.0	22.0	22.0	22.0	22.0
#1 CHT (°F)	348	352	350	352	351	350	348
#2 CHT (°F)	340	338	338	339	344	340	340
#3 CHT (°F)	340	340	344	342	347	346	344
#4 CHT (°F)	327	332	325	330	330	324	326
#1 EGT (°F)	1378	1404	1391	1419	1409	1414	1361
#2 EGT (°F)	1373	1400	1387	1413	1398	1390	1347
#3 EGT (°F)	1348	1377	1368	1399	1384	1380	1339
#4 EGT (°F)	1384	1406	1389	1414	1407	1398	1357
Oil inlet temperature (°F)	194	190	195	195	193	191	200
Oil pressure (psi)	84	84	84	84	84	84	84
Humidity temperature (°F)	54	54	54	54	54	54	54
Relative humidity (%)	49	49	49	50	49	49	49
AFR	13.2	13.2	13.2	13	12.8	12.8	12.1
AFL	12.8	12.9	12.9	13.2	12.9	12.9	12.2

TABLE C-3. PRE-ENDURANCE TEST POWER BASELINE AT 2500 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	O	P	Q	R	S
MAP (in. Hg)	19.97	22.00	24.02	26.01	28.00
Engine speed (rpm)	2500	2500	2500	2500	2500
Produced engine torque (ft/lb)	220	255	290	323	360
Observed brake horsepower (bhp)	104	121	138	154	171
Temperature-corrected bhp (tcbhp)	104	121	138	154	171
Lycoming-corrected bhp (lcbhp)	104	121	138	154	172
Brake mean effective pressure (psig)	50.3	58.2	66.0	73.9	82.1
Fuel mass flow (lb/hr)	58.0	64.0	70.0	74.0	81.0
Fuel volume flow (gal/hr)	10.4	11.4	12.5	13.2	14.4
BSFC (lb/bhp hr)	0.56	0.53	0.51	0.48	0.47
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.56	0.53	0.51	0.48	0.47
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.56	0.53	0.51	0.48	0.47

TABLE C-3. PRE-ENDURANCE TEST POWER BASELINE AT 2500 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	O	P	Q	R	S
Induction air temperature (°F)	59	59	58	58	58
Duct pressure (in. Hg)	29.96	29.96	29.96	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	52	51.3
Cooling air pressure (in. H_2O)	2.0	4.0	6.0	4.0	6.0
Fuel inlet temperature (°F)	72	72	72	72	72
Fuel tank temperature (°F)	64	64	64	64	64
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	3.0	3.0	4.0	4.0
Unmetered fuel pressure (psi)	23.0	23.0	23.0	22.0	22.0
#1 CHT (°F)	352	352	351	351	348
#2 CHT (°F)	342	342	341	339	340
#3 CHT (°F)	339	341	342	340	342
#4 CHT (°F)	334	332	329	329	324
#1 EGT (°F)	1392	1384	1379	1401	1395
#2 EGT (°F)	1381	1379	1373	1392	1386
#3 EGT (°F)	1362	1360	1356	1375	1367
#4 EGT (°F)	1394	1395	1392	1407	1397
Oil inlet temperature (°F)	195	194	203	194	193
Oil pressure (psi)	83	83	83	82	83
Humidity temperature (°F)	54	54	54	54	54
Relative humidity (%)	49	49	49	49	49
AFR	13.1	13.1	13.4	13.2	12.9
AFL	13.2	12.7	13.3	12.9	13.2

TABLE C-4. PRE-ENDURANCE POWER BASELINE AT 2400 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	T	U	V	W	X
MAP (in. Hg)	20.01	21.99	24.00	26.01	27.99
Engine speed (rpm)	2400	2400	2400	2400	2400
Produced engine torque (ft/lb)	218	255	288	323	358

TABLE C-4. PRE-ENDURANCE POWER BASELINE AT 2400 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	T	U	V	W	X
Observed brake horsepower (bhp)	100	116	132	147	164
Temperature-corrected bhp (tcbhp)	100	116	132	147	164
Lycoming-corrected bhp (lcbhp)	100	116	132	148	164
Brake mean effective pressure (psig)	49.8	58.2	65.7	73.8	81.8
Fuel mass flow (lb/hr)	56.0	62.0	66.0	72.0	76.0
Fuel volume flow (gal/hr)	10.1	11	11.8	12.9	13.7
BSFC (lb/bhp hr)	0.56	0.53	0.5	0.49	0.46
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.56	0.53	0.5	0.49	0.47
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.56	0.53	0.5	0.49	0.46
Induction air temperature (°F)	59	59	59	58	59
Duct pressure (in. Hg)	29.95	29.95	29.95	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	51	52
Cooling air pressure (in. H_2O)	6.0	5.0	2.0	5.0	5.0
Fuel inlet temperature (°F)	72	72	73	73	73
Fuel tank temperature (°F)	64	64	64	64.3	64
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	3.0	4.0	4.0
Unmetered fuel pressure (psi)	23.0	23.0	23.0	23.0	22.0
#1 CHT (°F)	350	346	353	351	350
#2 CHT (°F)	338	332	338	341	340
#3 CHT (°F)	338	334	337	341	340
#4 CHT (°F)	324	319	328	326	324
#1 EGT (°F)	1356	1357	1376	1368	1380
#2 EGT (°F)	1339	1347	1363	1357	1366
#3 EGT (°F)	1318	1334	1353	1341	1352
#4 EGT (°F)	1358	1372	1390	1379	1390
Oil inlet temperature (°F)	212	206	218	212	212
Oil pressure (psi)	81	81	80	80	80
Humidity temperature (°F)	54	54	54	54	54
Relative humidity (%)	48	49	49	49	49
AFR	13.2	13.3	13	13.1	13.1
AFL	12.8	13.1	13.4	13.1	13.2

TABLE C-5. PRE-ENDURANCE POWER BASELINE AT 2300 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	Y	Z	AA	AB	AC
MAP (in. Hg)	20.01	22.02	24.06	26.01	28.01
Engine speed (rpm)	2300	2300	2300	2299	2300
Produced engine torque (ft/lb)	216	252	288	322	358
Observed brake horsepower (bhp)	94	110	126	141	157
Temperature-corrected bhp (tcbhp)	94	110	126	140	156
Lycoming-corrected bhp (lcbhp)	94	110	126	141	157
Brake mean effective pressure (psig)	49.2	57.5	65.8	73.5	81.7
Fuel mass flow (lb/hr)	54.0	59.0	64.0	69.0	72.0
Fuel volume flow (gal/hr)	9.7	10.6	11.4	12.3	13.0
BSFC (lb/bhp hr)	0.57	0.53	0.51	0.49	0.46
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.57	0.53	0.51	0.49	0.46
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.57	0.53	0.51	0.49	0.46
Induction air temperature (°F)	59	58	58	58	58
Duct pressure (in .Hg)	29.95	29.95	29.95	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52.5	52	52	52	52
Cooling air pressure (in. H_2O)	5.0	5.0	4.0	3.0	2.0
Fuel inlet temperature (°F)	73	73	73	73	73
Fuel tank temperature (°F)	65	65	64	64.5	64
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	3.0	3.0	3.0	4.0
Unmetered fuel pressure (psi)	23.0	23.0	23.0	22.0	22.0
#1 CHT (°F)	351	350	352	354	351
#2 CHT (°F)	337	338	340	344	342
#3 CHT (°F)	334	336	336	340	341
#4 CHT (°F)	327	323	327	330	327
#1 EGT (°F)	1346	1338	1362	1365	1384
#2 EGT (°F)	1330	1325	1350	1361	1378
#3 EGT (°F)	1314	1316	1340	1341	1356
#4 EGT (°F)	1351	1351	1381	1378	1393
Oil inlet temperature (°F)	216	216	212	209	206

TABLE C-5. PRE-ENDURANCE POWER BASELINE AT 2300 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	Y	Z	AA	AB	AC
Oil pressure (psi)	78	78	78	78	78
Humidity temperature (°F)	54	54	54	54	54
Relative humidity (%)	49	49	49	49	49
AFR	13.2	13.2	13.4	13.2	13.2
AFL	12.8	12.9	13.2	13.2	13.3

TABLE C-6. PRE-ENDURANCE POWER BASELINE AT 2200 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	AD	AE	AF	AG	AH
MAP (in. Hg)	20.07	22.15	23.98	25.99	27.99
Engine speed (rpm)	2200	2200	2200	2200	2200
Produced engine torque (ft/lb)	208	244	277	313	348
Observed brake horsepower (bhp)	88	102	116	131	146
Temperature-corrected bhp (tcbhp)	88	102	116	131	146
Lycoming-corrected bhp (lcbhp)	86	102	116	131	146
Brake mean effective pressure (psig)	47.3	55.7	63.4	71.5	79.7
Fuel mass flow (lb/hr)	51.0	55.0	60.0	65.0	68.0
Fuel volume flow (gal/hr)	9.1	9.9	10.7	11.6	12.2
BSFC (lb/bhp hr)	0.58	0.54	0.52	0.5	0.47
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.58	0.54	0.52	0.5	0.47
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.58	0.54	0.52	0.5	0.47
Induction air temperature (°F)	59	59	58	58	58
Duct pressure (in. Hg)	29.95	29.95	29.95	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	53	52.7	52	52	52
Cooling air pressure (in. H_2O)	4.0	3.0	6.0	4.0	2.0
Fuel inlet temperature (°F)	73	73.33	74	74	74
Fuel tank temperature (°F)	64	64	64	64	65
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	3.0	3.0	3.0
Unmetered fuel pressure (psi)	23.0	23.0	23.0	23.0	22.0

TABLE C-6. PRE-ENDURANCE POWER BASELINE AT 2200 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	AD	AE	AF	AG	AH
#1 CHT (°F)	352	352	350	350	351
#2 CHT (°F)	342	343	344	344	340
#3 CHT (°F)	339	340	340	342	343
#4 CHT (°F)	330	331	331	332	329
#1 EGT (°F)	1338	1334	1326	1335	1362
#2 EGT (°F)	1320	1324	1321	1332	1356
#3 EGT (°F)	1318	1305	1303	1313	1336
#4 EGT (°F)	1352	1353	1344	1348	1380
Oil inlet temperature (°F)	212	217	211	201	209
Oil pressure (psi)	77	77	77	77	77
Humidity temperature (°F)	54	54	54	53	53
Relative humidity (%)	49	49	49	50	50
AFR	13.2	13	13.1	13.2	13.4
AFL	12.7	12.6	12.7	13.1	13.0

TABLE C-7. PRE-ENDURANCE POWER BASELINE AT 2100 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	AI	AJ	AK	AL	AM
MAP (in. Hg)	19.97	22.03	24.02	26.01	28.00
Engine speed (rpm)	2100	2100	2100	2100	2100
Produced engine torque (ft/lb)	194	229	264	299	336
Observed brake horsepower (bhp)	78	92	106	119	134
Temperature-corrected bhp (tcbhp)	78	92	106	119	134
Lycoming-corrected bhp (lcbhp)	78	91	106	119	134
Brake mean effective pressure (psig)	44.6	52.2	60.4	68.5	76.7
Fuel mass flow (lb/hr)	47.0	51.0	56.0	60.0	64.0
Fuel volume flow (gal/hr)	8.4	9.1	10.0	10.7	11.5
BSFC (lb/bhp hr)	0.60	0.56	0.53	0.50	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.61	0.56	0.53	0.50	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.61	0.56	0.53	0.50	0.48

TABLE C-7. PRE-ENDURANCE POWER BASELINE AT 2100 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	AI	AJ	AK	AL	AM
Induction air temperature (°F)	58	58	58	58	57
Duct pressure (in. Hg)	29.95	29.95	29.95	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	52	52
Cooling air pressure (in. H_2O)	2.0	2.0	4.0	2.0	2.0
Fuel inlet temperature (°F)	74	74	74	74	74
Fuel tank temperature (°F)	64	64	64	64.3	65
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	2.0	3.0	3.0
Unmetered fuel pressure (psi)	23.0	23.0	23.0	23.0	23.0
#1 CHT (°F)	348	350	350	351	352
#2 CHT (°F)	339	344	346	345	344
#3 CHT (° F)	338	342	344	344	344
#4 CHT (°F)	330	336	337	336	336
#1 EGT (°F)	1306	1316	1313	1325	1344
#2 EGT (°F)	1280	1296	1299	1313	1340
#3 EGT (°F)	1296	1302	1288	1308	1328
#4 EGT (°F)	1315	1336	1330	1340	1357
Oil inlet temperature (°F)	217	208	210	208	214
Oil pressure (psi)	76	75	76	75	75
Humidity temperature (°F)	53	53	53	53	53
Relative humidity (%)	50	50	50	51	51
AFR	13.3	12.9	12.9	13.3	13.4
AFL	12.7	12.4	12.6	13.1	13.1

TABLE C-8. PRE-ENDURANCE POWER BASELINE AT 2000 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points					
	AN	AO	AP	AQ	AR	AS
MAP (in. Hg)	20.03	22.11	23.98	25.99	27.99	29.02
Engine speed (rpm)	2000	2000	2000	2000	2000	2000
Produced engine torque (ft/lb)	186	220	252	288	325	343
Observed brake horsepower (bhp)	71	84	96	110	124	131
Temperature-corrected bhp (tcbhp)	71	84	96	110	124	131
Lycoming-corrected bhp (lcbhp)	70	84	96	110	124	131
Brake mean effective pressure (psig)	42.3	50.5	57.4	65.9	74.2	78.4
Fuel mass flow (lb/hr)	44.0	48.0	53.0	57.0	60.0	63.0
Fuel volume flow (gal/hr)	7.8	8.7	9.4	10.1	10.8	11.3
BSFC (lb/bhp hr)	0.61	0.57	0.55	0.52	0.48	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.61	0.58	0.55	0.52	0.49	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.61	0.58	0.55	0.52	0.49	0.48
Induction air temperature (°F)	58	58	58	58	57	58
Duct pressure (in. Hg)	29.95	29.95	29.95	29.95	29.95	29.95
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	52	52	52	52	52	52
Cooling air pressure (in. H_2O)	1.0	3.0	4.0	2.0	1.0	6.0
Fuel inlet temperature (°F)	74	74	74	74	74	74
Fuel tank temperature (°F)	64	64	65	64	65	64
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	2.0	2.0	3.0	3.0
Unmetered fuel pressure (psi)	24.0	23.0	23.0	23.0	23.0	22.0
#1 CHT (°F)	349	350	352	351	350	353
#2 CHT (°F)	342	347	348	348	346	342
#3 CHT (°F)	342	346	346	347	346	346
#4 CHT (°F)	336	338	343	339	337	340
#1 EGT (°F)	1294	1278	1298	1305	1312	1328
#2 EGT (°F)	1274	1259	1281	1290	1302	1312
#3 EGT (°F)	1276	1262	1283	1281	1292	1306
#4 EGT (°F)	1303	1292	1319	1316	1326	1335
Oil inlet temperature (°F)	210	214	215	213	210	211
Oil pressure (psi)	74	74	74	74	74	73

TABLE C-8. PRE-ENDURANCE POWER BASELINE AT 2000 rpm (Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points					
	AN	AO	AP	AQ	AR	AS
Humidity temperature (°F)	53	53	53	53	53	53
Relative humidity (%)	50	50	50	50	50	51
AFR	13.1	12.7	12.9	12.9	13.1	13.1
AFL	11.8	11.8	12	12.3	12.8	12.6

TABLE C-9. POSTENDURANCE POWER BASELINE AT 2700 rpm (Barometer = 30.12 in. Hg)

Engine Parameter	Data Points					
	F	E	D	C	B	A
MAP (in. Hg)	19.98	22.02	24.00	26.01	28.01	29.54
Engine speed (rpm)	2702	2702	2702	2701	2702	2702
Produced engine torque (ft/lb)	218	254	287	321	352	376
Observed brake horsepower (bhp)	112	131	148	165	181	193
Temperature-corrected bhp (tcbhp)	113	131	148	166	182	194
Lycoming-corrected bhp (lcbhp)	112	130	147	165	181	194
Brake mean effective pressure (psig)	91.2	106.2	120.2	134.1	147.3	156.3
Fuel mass flow (lb/hr)	61.0	66.0	72.0	78.0	85.5	94.0
Fuel volume flow (gal/hr)	10.9	11.9	13.0	14.1	15.3	16.8
BSFC (lb/bhp hr)	0.54	0.51	0.49	0.47	0.48	0.49
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.54	0.51	0.49	0.47	0.47	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.55	0.51	0.49	0.47	0.48	0.49
Induction air temperature (°F)	62	59	60	61	63	64
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16	30.15
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	74	74	74	74	75	74
Cooling air pressure (in. H_2O)	6.0	6.0	8.0	10.0	10.0	10.0
Fuel inlet temperature (°F)	76	76	75	75	75	75
Fuel tank temperature (°F)	77	77	77	77	77	77
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	4.0	4.0	5.0	6.0
Unmetered fuel pressure (psi)	20.0	19.0	19.0	19.0	19.0	20.0
#1 CHT (°F)	345	344	346	348	353	358

TABLE C-9. POSTENDURANCE POWER BASELINE AT 2700 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points					
	F	E	D	C	B	A
#2 CHT (°F)	330	329	330	332	338	346
#3 CHT (°F)	346	348	351	352	355	359
#4 CHT (°F)	322	324	327	330	335	342
#1 EGT (°F)	1454	1465	1465	1468	1479	1439
#2 EGT (°F)	1436	1448	1452	1455	1448	1419
#3 EGT (°F)	1402	1414	1411	1404	1403	1385
#4 EGT (°F)	1424	1428	1428	1423	1429	1401
Oil inlet temperature (°F)	204	201	206	204	204	202
Oil pressure (psi)	82	82	82	82	82	82
Humidity temperature (°F)	52	53	54	55	56	55
Relative humidity (%)	37	36	36	36	36	37
AFR	14.1	14.2	13.9	13.7	13.7	13.3
AFL	13.8	13.8	13.6	13.8	13.8	13.4

TABLE C-10. POSTENDURANCE POWER BASELINE AT 2600 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points					
	L	K	J	I	G	H
MAP (in. Hg)	20.02	21.97	23.97	25.98	26.92	28.00
Engine speed (rpm)	2603	2602	2601	2602	2603	2602
Produced engine torque (ft/lb)	218	252	284	317	328	349
Observed brake horsepower (bhp)	108	125	141	157	162	173
Temperature-corrected bhp (tcbhp)	109	125	141	157	163	173
Lycoming-corrected bhp (lcbhp)	108	124	140	156	162	172
Brake mean effective pressure (psig)	90.8	105.4	119.1	132.4	137.2	145.9
Fuel mass flow (lbs/hr)	62.0	67.0	73.0	79.0	84.0	85.0
Fuel volume flow (gal/hr)	11.1	12.0	13.0	14.2	15.1	15.2
BSFC (lb/bhp hr)	0.57	0.54	0.52	0.50	0.52	0.49
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.57	0.54	0.52	0.50	0.52	0.49
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.57	0.54	0.52	0.51	0.52	0.49
Induction air temperature (°F)	63	63	60	58	62	60
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.15	30.15

TABLE C-10. POSTENDURANCE POWER BASELINE AT 2600 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points					
	L	K	J	I	G	H
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	75	75	74	74	74	75
Cooling air pressure (in. H_2O)	4.0	10.0	10.0	10.0	6.0	6.0
Fuel inlet temperature (°F)	77	77	77	77	77	77
Fuel tank temperature (°F)	79	79	78	78	78	78
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	4.0	4.0	5.0	5.0
Unmetered fuel pressure (psi)	20.0	19.0	19.0	18.0	19.0	18.0
#1 CHT (°F)	332	338	352	367	352	364
#2 CHT (°F)	316	321	334	351	338	349
#3 CHT (°F)	337	349	363	376	356	370
#4 CHT (°F)	312	319	332	343	328	339
#1 EGT (°F)	1384	1381	1392	1411	1398	1425
#2 EGT (°F)	1372	1375	1391	1410	1396	1418
#3 EGT (°F)	1348	1346	1352	1367	1352	1369
#4 EGT (°F)	1373	1368	1376	1387	1375	1392
Oil inlet temperature (°F)	204	201	203	203	206	205
Oil pressure (psi)	81	81	81	80	81	80
Humidity temperature (°F)	53	52	51	52	54	53
Relative humidity (%)	38	39	39	38	38	38
AFR	13.5	13.6	13.6	13.5	13.1	13.2
AFL	13.2	13.5	13.5	13.5	13.2	13.4

TABLE C-11. POSTENDURANCE POWER BASELINE AT 2500 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	M	N	O	P	Q
MAP (in. Hg)	20.04	22.05	24.04	26.00	28.04
Engine speed (rpm)	2502	2502	2502	2502	2502
Produced engine torque (ft/lb)	217	250	284	314	347
Observed brake horsepower (bhp)	103	119	135	150	165
Temperature-corrected bhp (tcbhp)	104	120	135	150	166

TABLE C-11. POSTENDURANCE POWER BASELINE AT 2500 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	M	N	O	P	Q
Lycoming-corrected bhp (lcbhp)	103	119	134	149	165
Brake mean effective pressure (psig)	90.6	105	118.3	131.6	145.2
Fuel mass flow (lb/hr)	59.0	64.0	69.0	74.0	80.0
Fuel volume flow (gal/hr)	10.6	11.5	12.4	13.4	14.4
BSFC (lb/bhp hr)	0.57	0.54	0.51	0.49	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.57	0.54	0.51	0.49	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.57	0.54	0.51	0.50	0.49
Induction air temperature (°F)	62	61	60	59	60
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	75	75	75	75	75
Cooling air pressure (in. H_2O)	4.0	3.0	4.0	4.0	4.0
Fuel inlet temperature (°F)	78	78	78	78	78
Fuel tank temperature (°F)	79	79	79	79	79
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	3.0	3.0	3.0	4.0	4.0
Unmetered fuel pressure (psi)	19.0	19.0	19.0	18.0	18.0
#1 CHT (°F)	338	344	352	362	373
#2 CHT (°F)	325	331	340	348	358
#3 CHT (°F)	343	348	356	366	377
#4 CHT (°F)	318	322	330	338	348
#1 EGT (°F)	1370	1384	1390	1402	1416
#2 EGT (°F)	1360	1372	1380	1398	1416
#3 EGT (°F)	1332	1348	1352	1362	1375
#4 EGT (°F)	1354	1377	1386	1390	1402
Oil inlet temperature (°F)	203	204	206	206	206
Oil pressure (psi)	80	80	80	80	79
Humidity temperature (°F)	53	53	52	52	51
Relative Humidity (%)	38	38	38	38	39
AFR	13.4	13.4	13.4	13.5	13.4
AFL	13.5	13.3	13.5	13.4	13.6

TABLE C-12. POSTENDURANCE POWER BASELINE AT 2400 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	V	U	T	S	R
MAP (in. Hg)	20.02	21.96	24.02	26.00	28.01
Engine speed (rpm)	2402	2402	2401	2401	2402
Produced engine torque (ft/lb)	216	248	284	316	346
Observed brake horsepower (bhp)	98	114	130	144	158
Temperature-corrected bhp (tcbhp)	98	114	130	144	159
Lycoming-corrected bhp (lcbhp)	98	113	129	144	158
Brake mean effective pressure (psig)	89.8	104.2	118.8	132.2	144.1
Fuel mass flow (lb/hr)	56.0	62.0	68.0	72.0	77.0
Fuel volume flow (gal/hr)	10.1	11.1	12.1	12.9	13.9
BSFC (lb/bhp hr)	0.57	0.55	0.53	0.50	0.49
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.57	0.55	0.52	0.50	0.49
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.57	0.55	0.53	0.50	0.49
Induction air temperature (°F)	60	60	62	63	63
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	75	75	75	75	75
Cooling air pressure (in. H_2O)	3.0	3.0	5.0	10.0	10.0
Fuel inlet temperature (°F)	78	78	78	78	78
Fuel tank temperature (°F)	79	79	79	79	79
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	3.0	3.0	4.0	4.0
Unmetered fuel pressure (psi)	20.0	19.0	18.0	18.0	18.0
#1 CHT (°F)	353	346	340	346	368
#2 CHT (°F)	338	328	320	324	349
#3 CHT (°F)	356	350	346	357	379
#4 CHT (°F)	332	326	322	329	348
#1 EGT (°F)	1357	1361	1362	1361	1382
#2 EGT (°F)	1352	1370	1365	1378	1403
#3 EGT (°F)	1320	1330	1330	1322	1337
#4 EGT (°F)	1350	1362	1362	1354	1370
Oil inlet temperature (°F)	205	205	202	200	204
Oil pressure (psi)	78	79	79	78	78

TABLE C-12. POSTENDURANCE POWER BASELINE AT 2400 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter			Data Points		
	V	U	T	S	R
Humidity temperature (°F)	51	52	54	54	52
Relative humidity (%)	40	40	40	40	39
AFR	13.4	13.5	13.6	13.5	13.5
AFL	13.2	13.6	13.4	13.5	13.6

TABLE C-13. POSTENDURANCE POWER BASELINE AT 2300 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	W	X	Y	Z	AA
MAP (in Hg)	20.01	22.00	24.02	26.00	28.02
Engine speed (rpm)	2302	2301	2301	2301	2302
Produced engine torque (ft/lb)	212	245	280	313	349
Observed brake horsepower (bhp)	93	107	123	138	153
Temperature-corrected bhp (tcbhp)	94	108	124	138	154
Lycoming-corrected bhp (lcbhp)	93	107	122	136	153
Brake mean effective pressure (psig)	88.8	102.8	117.2	131.2	146.0
Fuel mass flow (lb/hr)	54.0	59.0	64.0	70.0	74.0
Fuel volume flow (gal/hr)	9.7	10.6	11.5	12.5	13.3
BSFC (lb/bhp hr)	0.58	0.55	0.52	0.51	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.58	0.55	0.52	0.51	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.58	0.55	0.52	0.51	0.49
Induction air temperature (°F)	62	64	64	63	61
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	75	75	75	75	74
Cooling air pressure (in. H_2O)	3.0	3.0	4.0	6.0	10.0
Fuel inlet temperature (°F)	78	79	79	79	79
Fuel tank temperature (°F)	79	79	79	79	79
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	3.0	3.0	3.0	4.0
Unmetered fuel pressure (psi)	20.0	20.0	19.0	19.0	19.5
#1 CHT (°F)	353	357	360	358	348
#2 CHT (°F)	340	345	348	344	329

TABLE C-13. POSTENDURANCE POWER BASELINE AT 2300 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	W	X	Y	Z	AA
#3 CHT (° F)	356	359	363	363	357
#4 CHT (°F)	333	336	339	339	332
#1 EGT (°F)	1335	1345	1350	1351	1362
#2 EGT (°F)	1326	1340	1346	1371	1388
#3 EGT (°F)	1300	1312	1318	1322	1325
#4 EGT (°F)	1330	1344	1352	1350	1358
Oil inlet temperature (°F)	204	206	204	206	203
Oil pressure (psi)	78	78	78	78	78
Humidity temperature (°F)	51	53	54	54	53
Relative humidity (%)	41	41	41	41	42
AFR	13.4	13.3	13.5	13.6	13.6
AFL	13.4	13.3	13.3	13.4	13.6

TABLE C-14. POSTENDURANCE POWER BASELINE AT 2200 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	AF	AE	AD	AC	AB
MAP (in. Hg)	19.96	22.02	24.00	25.99	28.00
Engine speed (rpm)	2201	2201	2201	2202	2202
Produced engine torque (ft/lb)	206	239	273	304	342
Observed brake horsepower (bhp)	86	100	114	128	144
Temperature-corrected bhp (tcbhp)	86	100	115	128	144
Lycoming-corrected bhp (lcbhp)	86	100	114	127	143
Brake mean effective pressure (psig)	85.9	99.9	113.8	127.2	143
Fuel mass flow (lb/hr)	52.0	56.0	61.0	65.0	70.0
Fuel volume flow (gal/hr)	9.4	10.1	10.9	11.7	12.6
BSFC (lb/bhp hr)	0.60	0.56	0.53	0.51	0.48
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.60	0.56	0.53	0.51	0.48
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.61	0.56	0.53	0.51	0.49
Induction air temperature (°F)	62	62	63	63	60
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00

TABLE C-14. POSTENDURANCE POWER BASELINE AT 2200 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter			Data Points		
	AF	AE	AD	AC	AB
Cooling air temperature (°F)	75	74	74	75	75
Cooling air pressure (in. H_2O)	4.0	4.0	4.0	4.0	4.0
Fuel inlet temperature (°F)	80	79	79	79	78
Fuel tank temperature (°F)	80	80	80	80	80
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	3.0	3.0	3.0
Unmetered fuel pressure (psi)	19.0	19.0	19.0	19.0	19.0
#1 CHT (°F)	338	346	361	360	341
#2 CHT (°F)	324	331	341	338	318
#3 CHT (°F)	339	348	360	356	340
#4 CHT (°F)	324	330	342	338	322
#1 EGT (°F)	1301	1312	1328	1342	1361
#2 EGT (°F)	1292	1306	1329	1362	1388
#3 EGT (°F)	1274	1284	1299	1307	1315
#4 EGT (°F)	1322	1324	1329	1341	1350
Oil inlet temperature (°F)	202	203	204	204	203
Oil pressure (psi)	77	77	76	76	77
Humidity temperature (°F)	52	53	53	52	52
Relative humidity (%)	44	44	44	43	42
AFR	13.6	13.4	13.4	13.4	13.4
AFL	13.1	13.1	13.3	13.3	13.4

TABLE C-15. POSTENDURANCE POWER BASELINE AT 2100 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	AG	AH	AI	AJ	AK
MAP (in. Hg)	20.05	22.02	24.02	26.05	28.01
Engine speed (rpm)	2102	2102	2102	2101	2101
Produced engine torque (ft/lb)	197	228	261	296	329
Observed brake horsepower (bhp)	79	91	105	118	132
Temperature-corrected bhp (tcbhp)	79	92	105	119	132
Lycoming-corrected bhp (lcbhp)	78	91	104	118	131

TABLE C-15. POSTENDURANCE POWER BASELINE AT 2100 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	AG	AH	AI	AJ	AK
Brake mean effective pressure (psig)	81.9	95.1	109.1	123.5	137.2
Fuel mass flow (lb/hr)	48.0	52.0	57.0	62.0	66.0
Fuel volume flow (gal/hr)	8.6	9.4	10.3	11.1	11.8
BSFC (lb/bhp hr)	0.61	0.57	0.55	0.53	0.50
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.61	0.57	0.54	0.52	0.50
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.61	0.57	0.55	0.53	0.50
Induction air temperature (°F)	62	63	65	65	64
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	75	75	75	75	75
Cooling air pressure (in. H_2O)	2.0	2.0	3.0	3.0	5.0
Fuel inlet temperature (°F)	80	80	80	80	80
Fuel tank temperature (°F)	80	80	80	80	80
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	2.0	3.0	3.0
Unmetered fuel pressure (psi)	19.0	20.0	19.0	19.0	19.0
#1 CHT (°F)	332	335	340	348	354
#2 CHT (°F)	320	326	330	337	341
#3 CHT (°F)	330	330	336	343	350
#4 CHT (°F)	317	320	325	330	337
#1 EGT (°F)	1277	1286	1303	1314	1325
#2 EGT (°F)	1273	1282	1295	1320	1341
#3 EGT (°F)	1268	1270	1278	1284	1291
#4 EGT (°F)	1294	1313	1308	1318	1325
Oil inlet temperature (°F)	196	198	200	200	199
Oil pressure (psi)	76	76	76	76	75
Humidity temperature (°F)	52	51	52	53	54
Relative humidity (%)	44	44	45	45	46
AFR	13.4	13.3	13.3	13.2	13.4
AFL	12.9	13.1	13.1	13.1	13.3

TABLE C-16. POSTENDURANCE POWER BASELINE AT 2000 rpm
(Barometer = 30.12 in. Hg)

Engine Parameter	Data Points				
	AP	AO	AN	AM	AL
MAP (in. Hg)	20.02	21.96	24.03	26.02	28.00
Engine speed (rpm)	2002	2001	2002	2000	2002
Produced engine torque (ft/lb)	183	216	251	288	320
Observed brake horsepower (bhp)	70	82	96	110	122
Temperature-corrected bhp (tcbhp)	70	83	96	110	122
Lycoming-corrected bhp (lcbhp)	70	82	95	110	122
Brake mean effective pressure (psig)	76.3	90.3	105.1	120.2	133.9
Fuel mass flow (lb/hr)	44.0	49.0	54.0	58.0	62.0
Fuel volume flow (gal/hr)	8.0	8.8	9.6	10.4	11.2
BSFC (lb/bhp hr)	0.64	0.59	0.56	0.53	0.51
Temperature-corrected brake fuel consumption (lb/tcbhp hr)	0.64	0.59	0.56	0.53	0.51
Lycoming-corrected brake fuel consumption (lb/lcbhp hr)	0.64	0.60	0.57	0.53	0.51
Induction air temperature (°F)	64	62	62	63	63
Duct pressure (in. Hg)	30.16	30.16	30.16	30.16	30.16
Induction air pressure (in. Hg)	30.00	30.00	30.00	30.00	30.00
Cooling air temperature (°F)	76	76	75	75	74
Cooling air pressure (in. H_2O)	2.0	2.0	2.0	4.0	5.0
Fuel inlet temperature (°F)	80	80	80	80	80
Fuel tank temperature (°F)	80	80	80	80	81
Fuel density (lb/gal)	5.60	5.60	5.60	5.60	5.60
Metered fuel pressure (psi)	2.0	2.0	2.0	3.0	3.0
Unmetered fuel pressure (psi)	19.0	20.0	19.0	18.0	19.0
#1 CHT (°F)	350	352	344	336	346
#2 CHT (°F)	342	342	329	320	330
#3 CHT (°F)	348	348	340	340	346
#4 CHT (°F)	337	336	328	324	332
#1 EGT (°F)	1268	1278	1293	1288	1302
#2 EGT (°F)	1261	1268	1284	1292	1316
#3 EGT (°F)	1248	1252	1254	1250	1264
#4 EGT (°F)	1285	1288	1296	1288	1299
Oil inlet temperature (°F)	196	200	197	200	197
Oil pressure (psi)	74	74	74	74	74
Humidity temperature (°F)	52	52	53	53	54

TABLE C-16. POSTENDURANCE POWER BASELINE AT 2000 rpm
(Barometer = 30.12 in. Hg) (Continued)

Engine Parameter	Data Points				
	AP	AO	AN	AM	AL
Relative humidity (%)	48	48	47	46	46
AFR	13.2	13.1	13.1	13.2	13.3
AFL	12.7	12.8	12.9	13.1	13.2