CERTIFICATION OF A CARBURETED AIRCRAFT ENGINE ON ETHANOL FUEL

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ABSTRACT

Aircraft used in commercial operations must be licensed by the Federal Aviation Administration (FAA) in a certified category. In order to certify a new fuel, the engine and the airframe must both satisfy FAA requirements. The technical feasibility of ethanol as an aviation fuel was established over a 13 year period of research, development, flight test and demonstrations. A previous program obtained FAA certification for a fuel injected aircraft engine to use denatured 200 proof ethanol. It was determined that the use of ethanol in flight training operations would best establish the economic viability of ethanol while avoiding distribution problems. The most common flight trainer, the Cessna 152, was chosen to be certified. This aircraft is powered by a carbureted Lycoming engine, the O-235. This engine was modified to use ethanol and a test plan for certification was submitted to the FAA. The plan was accepted and the test conditions successfully met. After airframe certification, this aircraft will be placed in the flight training program at Baylor University and Texas State Technical College.

INTRODUCTION

The development of ethanol as an aviation fuel was initiated because of a threat to the supply of aviation gasoline as a result of the Arab oil embargo in 1973. While supply was never curtailed as a result of the embargo, US dependence on imported oil has increased over the years and the development of a domestic fuel supply has become critically important. In the course of a 13 year program of research, development, flight testing and certification at Baylor University, ethanol has proven to be a high performance, reliable and economically competitive replacement for 100 octane aviation gasoline. The passage of the Clean Air Act and the mandate to remove all lead from fuel has provided an additional reason to seriously consider the replacement of aviation gasoline by this renewable, clean burning, domestically produced fuel.

The use of ethanol in flight training operations offered the best arena to demonstrate that ethanol is an economically competitive, reliable and high performance fuel. Accordingly, the Cessna 152, the most common flight trainer was chosen to be certified.

The first step in the certification of a new fuel is to certify the engine. The engine in the Cessna 152, is the Lycoming O-235.

CERTIFICATION PROCEDURE

Reciprocating engine test procedures are established by the FAA. The certification of the IO-540 Lycoming series engine on ethanol was completed by the Baylor project and described in a previous publication. After a test plan submitted by the applicant was approved by the FAA, the engine was disassembled and all components subject to wear induced by use of the fuel were measured. The engine was then placed on a test stand calibrated and approved by the FAA. A dynamometer run established the development of power . Detonation testing was performed at this time. The engine was then run according to a schedule of power settings, cylinder head and oil temperatures prescribed by the FAA. The total time established by the FAA for the endurance test is 150 hours. At the end of the endurance test, the engine was again tested to determine if it developed rated power and then disassembled. The components measured at the beginning of the test were measured again to determine the amount of wear induced during the run.

LYCOMING O-235 ETHANOL CERTIFICATION TEST

The test engine was installed on the torque measuring test cell and operated on gasoline prior to conversion to ethanol. The accuracy of the torque measuring cell was verified during this testing and general operating parameters were reviewed for comparison to the ethanol testing. This test showed that the engine produced 125 HP at 2800 RPM, which is the rated power for this engine with the high compression pistons (9.7:1).

The carburetion was modified to permit the engine to operate on ethanol. The adjustments were made to permit what was considered to be adequate fuel flow for the testing. Initial tests revealed the engine produced more power on ethanol than had been anticipated. The engine produced very close to 150 HP at 2800 RPM and 28.3" HG. Additionally, the engine would overspeed using the same propeller that was used with gasoline.

During this test period the propeller was repitched numerous times in an attempt to lower the horsepower output of the engine. Finally, another propeller was obtained and was pitched to limit the engine speed to approximately 2700 RPM. However the power output remained at approximately 143 HP. It was decided to conduct the endurance test using 2700 RPM as the takeoff power and 2600 (126 HP) as the maximum continuous value, which is almost the same as the O-235F series engines use as both takeoff and maximum continuous power.

The official power and detonation test for the certification run was conducted on November 24, 1992. The test showed the engine produced 143 HP at 2725 RPM and 126 HP at 2600 RPM. The detonation test phase demonstrated that, as in the case of the IO-540 test, ethanol expands the limits of detonation over avgas. It was not possible to produce detonation within the operating envelope of the engine.

A problem was encountered during this phase of the test which has also been experienced using avgas. Rapid leaning of the fuel mixture to stoichiometric increases the amount of heat in the combustion chamber so fast that the piston cannot reject the heat fast enough to prevent loss of side clearance with the cylinder bore. The interference between the piston and cylinder wall produces a condition that has been noted for some time. The problem results in scuffed, glazed and sometimes rippled cylinder walls. The piston shows evidence of high heat and scuff marks that extend completely around the piston rather than just on the thrust surfaces. This phenomenon will be discussed in the operating manual. The damage that was produced in this incident required the rework of the cylinder barrels.

The endurance test was started on December 11, 1992, according to the test plan. Toward the end of the first block of testing, there was a noticeable loss in exhaust valve seating, and investigation revealed severe recession of the exhaust valve seat on the hottest running cylinder. The valve seat was replaced, but additional valve seat problems were experienced in short order. An evaluation of the problem resulted in finding that the mixture was extremely lean at full power. The decision was made to modify the carburetor further to increase fuel flow at the maximum power condition. The altered carburetor permitted the fuel flow to be increased from slightly more than 13 gallons per hour to more than 15 gallons per hour at 2700 RPM (140+ HP). Seven hours of additional maximum temperature operation were extended in the later blocks of operation, and the engine was subsequently operated until all blocks were completed without incident.

The engine was performance tested in the same manner as the pre-endurance performance test. The engine power recorded was approximately 5 HP more at the end of the test at the same engine speed as at the start of the test. This phenomenon was noted at the end of the IO-540 certification tests as well. Environmental conditions at the test cell will create some differences, but all indications are that the engine was producing slightly more power at the completion of the test.

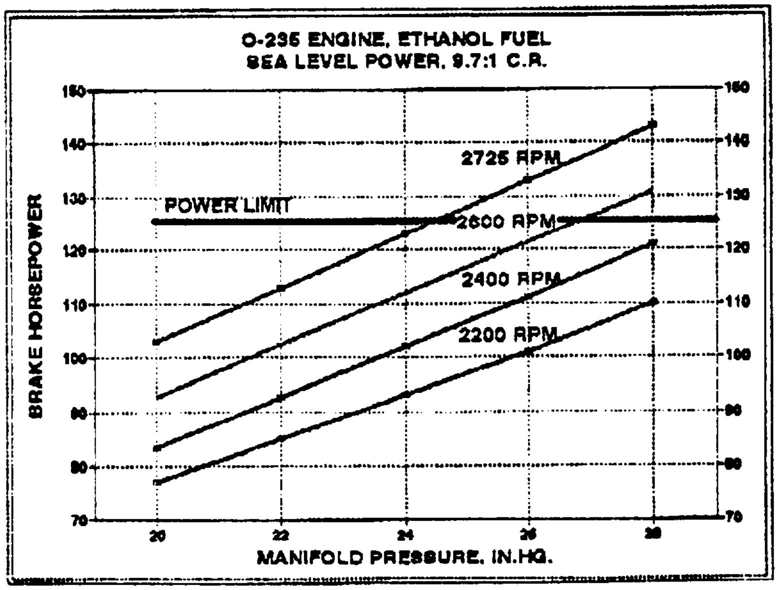
TEST DATA SUMMARY:							
BLOCK NO	1	2	3	4	5	6	7
START DATE	12/29/92	01/5/92	01/13/93	01/28/93	2/08/93	2/11/93	2/15/93
FINISH DATE	02/11/93	01/7/93	01/28/93	02/07/93	2/11/93	2/13/93	2/17/93
TOTAL HOURS							
TEST TIME	30HRS	20HRS	20HRS	20HRS	20HRS	20HRS	20HRS
HOT TIME	15HRS	15HRS	12HRS	15HRS	15HRS	0	0
HIGH RPM	2700	2600	2600	2600	2600	2600	2600
HIGH MP	28.6	27.8	27.5	26.5	26.5	25.5	26.1
LOW RPM	2425	2480	2425	2370	2303	2166	2200
LOW MP	23.4	24.8	23.5	23.8	22.0	19.8	19.9
TOTAL TIME							
ENDURANCE							
TEST	177.3 HRS						
TOTAL HOT							
TIME							
ENDURANCE							
TEST	57.0 HRS						

NOTE: As the engine operated throughout the test program, the friction horsepower was apparently reduced. Accordingly, the engine was able to hold the target speeds (RPM) at lower and lower manifold pressures. The environmental conditions also created some differences in engine operation, and probably influenced the increase in power obtained at the completion of the test. Instrumentation calibration at the completion of the engine test verified the accuracy of the measuring system, so the slight increase in power indicated is probably correct.

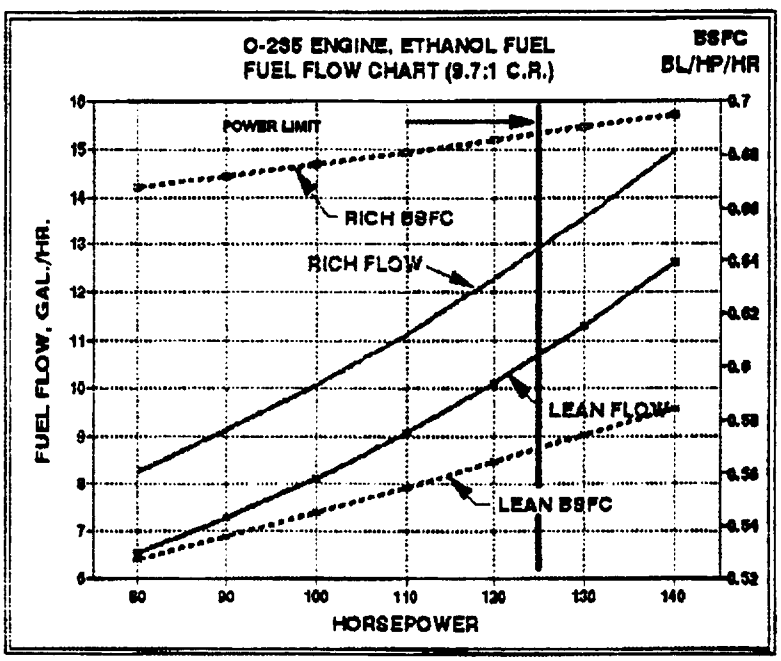
ENGINE OPERATING PARAMETERS

The test engine operating parameters have been validated through the performance, detonation and endurance certification testing. The nature of the test program included some research elements that have been investigated and resolved. These findings are to be included as part of the operating instructions. The performance data has been reduced to standard day conditions and is provided in the charts below.

Engine Operating Parameters



Fuel Flow Characteristics



ETHANOL OPERATING EVALUATION

The operation of the engine was evaluated during exploratory and FAA testing. The anomalies found during the test were primarily due to the limited experience with carburetor equipped engine on ethanol. However, these anomalies identified areas of concern that will be addressed in the engine operating manual and in flight testing of the engine installation.

1. Cold Starting.

The Reid Vapor Pressure (RVP) of denatured ethanol is 3.0 psi, compared with 5.5-7.5 for avgas. Low RVP is desirable from a safety standpoint as it means vapor lock is less likely, but it also means there is a cold start problem. This problem is easily resolved by a normal engine priming system drawing a small amount of gasoline from an auxiliary canister.

2. Detonation While Changing Fuels.

In the course of the testing, detonation was induced when ethanol was introduced into the fuel system when the engine was running under a high power setting on gasoline. Apparently, a momentary lean condition in the engine was created and serious detonation occurred in a matter of seconds. Although the engine can function on any percentage mixture of ethanol and gasoline, the change from straight avgas to straight ethanol cannot safely be accomplished while under power.

3. Valve seat Recession and Fuel/air Mixture.

Incidents of exhaust valve seat recession occurred during the endurance test that required repair. Evaluation of test conditions showed that the engine was operating at a very lean condition during maximum power conditions. A larger float needle and seat were installed in the carburetor and additional hot penalty time was accomplished without incident.

4. Power Increases.

The use of ethanol fuel resulted in significant increases in power. The maximum power obtained during the program was in excess of 150 HP at 2800 RPM. The endurance testing was conducted at 143 HP Take Off and 126 HP Maximum Continuous. Ethanol appears to produce greater average pressures without the severe peak pressures obtained using gasoline. Preliminary testing revealed some movement between crankcase halves resulting from operation at the high power setting. However, the torque of the thru-bolt and cylinder studs was slightly low, and after reassembling the engine using proper torque values, the endurance test was completed without further evidence of fretting. The possibility of fretting when using the entire power capability of the engine makes it incumbent to warn operators to recheck cylinder torque values after a period of operation.

5. Detonation.

The use of ethanol fuel precludes the possibility of detonation throughout the operation range of the engine. During the testing, a case where temperatures increased rapidly was encountered as a result of leaning the mixture too rapidly. This caused the loss of piston to barrel clearance resulting in damage to the cylinder.

TEAR DOWN INSPECTION

The test engine was visually inspected and compression tested at the completion of the endurance test and then disassembled for evaluation. The results of the evaluation are shown in the following table.

ITEM	NEW	SERVICE	CYL#1	CYL#2	CYL#3	CYL#4
TOP RING GAP	.045/.055	.067	.054	.035	.050	.061
2ND RING GAP	.015/.030	.047	.035	.035	NOTE 1	.040
OIL RING GAP	.015/.030	.047	.037	.036	NOTE 2	.034
CYL. BORE	4.3745/ 4.3765	4.380	4.375- 4.375	4.376- 4.375	4.3735- 4.377	4.370- 4.370
CYL. HEAD	N/A	N/A	GOOD	NOTE 3	GOOD	GOOD
INTAKE VALVE STEM	.4022/ .4030	.4010	.4023	.4025	.4026	.4020
INTAKE GUIDE ID.	.4040- .4050	NOT LISTED	.4047- .4088	.4047- .4056	.4047- .4050	.4046- .4062
INTAKE VALVE& GUIDE CLEAR.	.0010/ .0028	.006 NOTE 4	.0022/ .0065	.0022/ .0031	.0021/ .0024	.0026/ .0042
EX. VALVE STEM	.0010/ .0028	NOT LISTED	.4329	.4322	.4322	.4321
EX. GUIDE I.D.	4370/ .4380	NOT LISTED	.4382- .4403	.4378- .4464	.4378- .4450	.4378- .4432
EX. VALVE& GUIDE CLEAR.	.004/.006	NOTE 5	.0053/ .0074	.0056/ .0142	.0056/ .0128	.0057/ .0111
PRESS. TEST LEAK.	20 LB. IN 5 SEC.		2 LB. IN 5 SEC.	13 LB IN 5 SEC.	0 LB	0 LB
COM. TEST	60/80		75/80	64/80	75/80	75/80
PISTON PIN DIA.	1.1241/ 1.1246	NOTE 6	1.124	1.125	1.124	1.124
PISTON DIA.	4.329/ 4.3605	NOTE 7	4.365	4.363	4.3645	4.362

NOTE 1: The Number 3 cylinder 2nd compression ring was .001 over service limits on end gap. However, review of the build up data showed the ring was within service limits at installation so the actual wear was insignificant.

NOTE 2: The Number 3 cylinder oil ring was broken when the cylinder was removed at the completion of the test. This happens occasionally, and since the ring had an otherwise normal appearance, this was considered incidental.

NOTE 3: The Number 2 cylinder was found to have a small crack in one spark plug boss. Additionally, this cylinder had a crack between the fins under the exhaust port and another small crack across a fin around the exhaust port. The cracks between and across the fins did not extend through to the inside of the cylinder and could have existed in smaller form at the time of engine build-up.

NOTE 4: The Number 1 cylinder intake guide and valve clearance was slightly above the listed service limits. However, the build up clearance was close to the maximum new limits, and the average clearance was well within the service limits. The value of the clearance was therefore considered incidental and inconsequential.

NOTE 5: Lycoming Service Bulletin 338B establishes a procedure for checking and continuing operation with up to .030 valve movement in the exhaust guide. Lycoming has experienced exhaust valve and guide wear, and the clearances found at the completion of the test were considered normal.

NOTE 6: There is no listed service limit for the piston pin, but there is a service limit for the fit between the pin and piston. The difficulty in measuring .0001 tolerance and the uncertainty regarding the original diameter resulted in the belief the wear was nil.

NOTE 7: There is no current listing for the skirt diameter for the new Lycoming piston used in the test. This is a new type that has a different mass than the original piston, and Lycoming may have to increase the skirt diameter to help alleviate cylinder barrel cracking problems. The piston wear is judged to be minimal, and the new part tolerances are probably not correct for this piston.

CONCLUSION

This certification test demonstrated that the Lycoming O-235 series of engines operate on ethanol fuel within the provisions of the Federal Air Regulations when the engine is modified, installed and operated in accordance with the information supplied to the FAA in the application packet for the Supplemental Type Certificate.

Despite the high compression (9.7:1) of the test engine, detonation could not be induced during the testing while using just the ethanol fuel. Wear of components during the test was generally found to be minor. The somewhat high valve, valve guide and valve seat wear is attributed to the excessively lean mixture coupled with the extreme cylinder temperatures. Additionally, there is a general high exhaust valve and guide wear in the Lycoming engine series, and high guide wear exacerbates valve seat wear.

The relatively low wear and general engine cleanliness indicates that the engine can operate on ethanol fuel for longer time periods than on 100LL avgas. An additional test is planned in which the engine will run according to the schedule met in this test, except for 300 hours rather that 150 hours, to justify an increase in recommended TBO for the engine operating on ethanol fuel. The wear should be considerably lower when operated at normal temperatures and limited to the original power of the C, F, L and N series engines.

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