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CERTIFICATION OF THE CESSNA 152 ON 100% ETHANOL

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Abstract

In June 1996, the Renewable Aviation Fuels Development Center (RAFDC) at Baylor University in Waco, Texas, received a Supplemental Type Certificate (STC) for the use of 100% ethanol as a fuel for the Cessna 152, the most popular training aircraft in the world. This is the first certification granted by the Federal Aviation Administration (FAA) for a non-petroleum fuel.

Certification of an aircraft on a new fuel requires a certification of the engine followed by a certification of the airframe/engine combination.

This paper will describe the FAA airframe certification procedure, the tests required and their outcome using ethanol as an aviation fuel in a Cessna 152.

Introduction

RAFDC began testing ethanol as an aviation fuel 16 years ago in order to develop a high performance, reliable, domestically produced alternative to 100 Low Lead aviation gasoline (Avgas). During these years of research, testing, and demonstrations, RAFDC has proved that pure ethanol is a viable, reliable, and safe high octane alternative to 100 octane, low lead aviation gasoline. Two series of Lycoming engines, one injected and one carburated, were successfully certified on ethanol. The recent certification of the engine/airframe combination of a Cessna 152 granted by the Federal Aviation Administration is the foremost endorsement of the reliability of this fuel and the one with far more reaching consequences. The full FAA certification (airframe and engine) of an aircraft allows the use of the aircraft in commercial operations. This certification represents the first granted by the FAA for a series of aircraft using non-petroleum fuel.

With the implementation of the Clean Air Act Amendments (CAAA) in the U.S. and the mandatory phase-out of lead in transportation fuels, the only remaining contributor of lead in the atmosphere is Avgas. In the absence of a clean, technically and economically acceptable petroleum alternative, ethanol must be considered as a credible and viable contender as the next fuel for the general aviation piston engine fleet.

Ethanol is extremely well suited as an aviation fuel. It is a high octane fuel which does not require any additives to perform in existing aircraft engines. The reason a training aircraft, the Cessna 152, was chosen to be the first certified on ethanol, was to avoid an initial fuel distribution problem.

The most critical factor from the pilot's perspective is the ability of a fuel to produce power. Ethanol produces more power than Avgas, the amount of power increase depending on the compression ratio of the engine. In the case of the engine of the Cessna 152, a Lycoming O-235, dynamometer tests performed by Engine Components Inc.(ECI) showed that it produced 20% more power on ethanol, than on Avgas. The improved performance is a considerable safety advantage, especially for aircraft operating at high altitudes and/or high temperatures.

Ethanol burns cooler and cleaner and has a lower Reid Vapor Pressure (RVP) when compared to Avgas, thereby lessening the likelihood of vapor lock. The only drawback of ethanol is a slight reduction in range, the magnitude of which is directly related to the compression ratio of the engine. Research to improve the range of reciprocating engines on ethanol is ongoing.

Aircraft Modifications

The lower energy density and lower Reid Vapor Pressure of ethanol compared to Avgas, require some modifications to the engine and the airframe being certified on ethanol fuel. It is necessary to slightly modify the carburetor to allow for a higher flow rate. The higher flow rate requires the installation of an engine driven pump and an emergency boost pump. The 152 operated on Avgas, because of the lower fuel rate, does not require these pumps.

The lower Reid Vapor Pressure causes difficulty in starting in temperatures below 65 degrees F. A small canister containing Avgas is installed on the firewall and in cold weather, the engine is primed with a small amount of Avgas to start it. Additionally, because of the increased flow rate, an electronic fuel flow indicator with a totalizer is installed as a safeguard against running out of fuel.

Certification Program

In order to begin an airframe certification, a Type Inspection Authorization (TIA) must be applied for and issued by the FAA. A certification basis must be identified and stated. In the case of the ethanol fuel certification of the Cessna 152, the certification basis was Part 3 of the Civil Air Regulations and the Federal Air Regulations part 23 (FAR 23). The specific regulations for this certification are contained in FAR 23 subparts A through G. The requirements for the certification process are outlined in parts 1 and 2 of the Type Inspection Report.

A brief description of the tests that were designed to satisfy these requirements and the results obtained in this certification follows.

Part I. The Manufacturing Inspector was required to perform the following:

1. Obtain a statement of conformity from the applicant stating the aircraft is in compliance with FAR 21.33(a).

This requires that the propeller speed and pitch be limited to values that will assure safe operation under normal operating conditions. This was an issue in this certification process because of the additional power developed when operating the engine on ethanol. Since the propeller on the C-152 is not controllable, problems could have occurred during take-off and initial climb. To address this issue, the relevant part of FAR 23.33 states that, " at V(y) the propeller must limit the engine at full throttle to a speed not greater than the maximum allowable RPM". In all other flight situations, the problem of exceeding the redline RPM is handled simply by reducing power to stay within operating limitations. Flight tests demonstrated that, while close to redline on climb-out at V(y), the limit in the Cessna 152 was not exceeded.

2. Verify the following equipment is calibrated within 90 days.

a. Airspeed
b. Altimeter
c. CHT/EGT indicators
d. Fuel pressure gage
e. Optical Tachometer
f. 1 Gallon Liquid Test Measure
g. Digital Protractor.

RAFDC used three FAA certified companies to perform these calibration tests. The measurement devices used in these calibration tests are themselves calibrated in compliance with established procedures and must be traceable to the National Institute of Standards & Technology (NIST) in accordance with NIST test 731/243844. The aircraft used for the certification process was equipped with CHT and EGT on all 4 cylinders and a manifold pressure gauge. The manifold pressure gauge was also calibrated to the same standards, even though this was not required.

3. Perform the following tests to be witnessed by the FAA Project Engineer.

A. Minimum fuel pressure test.

This test demonstrates compliance with the requirements of FAR 33.7(b)(5)(1) which establishes rate and operating limitations for fuel pressure at the fuel inlet. Additionally, FAR 23.955(a) requires the fuel system to be capable of providing fuel at a rate and pressure sufficient for proper engine operation in the most critical attitude with respect to fuel feed and quantity of unusable fuel. This FAR further states that these conditions may be simulated in a suitable mockup.

Accordingly, an adjustable fuel pressure test rig was connected to the engine and the data recorded at full throttle and full rich mixture setting. Fuel pressure was regulated from the test rig and pressure was recorded from the airframe mounted fuel pressure gauge. The minimum safe fuel pressure was determined to be 0.8 PSI.

The fuel pressure limit is established as 110% of the measured minimum pressure. In this case, it is 0.8 X 1.10 = .88 PSI or rounded to 1.0 PSI.

B. Maximum fuel pressure test.

FAR 33.7(b)(5)(1) and 23.955(a) are again the relevant regulations.

An adjustable fuel pressure rig was connected to the engine and the data recorded at full throttle and full rich mixture setting. Fuel pressure was regulated from the test rig and pressure was recorded from the carburetor inlet.

During testing, fuel pressure was increased to 16 PSI in 1.0 PSI fuel increments. There were no RPM or power variations detected throughout the pressures measured. Testing was terminated at 16.0 PSI since the maximum fuel pressure developed by the two fuel pumps in combination would not exceed 8.0 PSI.

The maximum fuel pressure limit is established at 90% of the measured maximum pressure. In this case, it is 16.0 X .90 = 14.4 PSI

C. Engine driven fuel pump and emergency fuel pump flow test.

In addition to FAR 23.955(a), this test is governed by 23.955(4)(c) which states that, "the flow rate for each pump system (main and reserve supply) for each reciprocating engine must be 125 % of the fuel flow required by the engine at the maximum approved take-off power.

This test requires that the flow rate be measured at the minimum fuel level plus one gallon of fuel and at the best angle of climb attitude (minimum weight). This climb attitude was measured at 17.2 degrees nose-up. For this test, the aircraft was positioned at 18.0 degrees nose up.

During the engine certification of the Lycoming O-235 engine on ethanol, it was determined that the engine developed 126 HP and required 12.9 gallons of ethanol per hour(GPH). Since a 5% increase in HP is the maximum allowable by the FAR's, the engine installation has to be limited to 113 HP as the rated HP of this engine is 108(108 X 1.05 = 113). In order to be conservative, for the design of the fuel system test, a power rating of 126 HP was used to establish the fuel flow rates.

Using the foregoing criteria, it was determined that the minimum required fuel flow was 16.2 GPH. The engine driven pump delivered a flow of 30.5 GPH and the emergency fuel pump delivered 22.08 GPH. Thus, both pumps exceeded the test requirements by a substantial amount.

Part II. The flight test pilot was required to perform the following tests:

A. Conduct an induction system icing protection test in accordance with FAR 23.1093. This FAR requires that an airplane with sea level engines using conventional venturi carburetors have a preheater that can provide a heat rise of 90 degrees F. while using 75% of maximum continuous power. The actual heat rise during the Cessna 152 flight test was 112 degrees F., thus exceeding the requirement.

B. Conduct an engine cooling test as per FAR 23.1041 which states that, "the powerplant must maintain the temperatures of powerplant components and engine fluids within the limits established for those components and fluids under the most adverse ground and flight operations to the maximum altitude for which approval is requested".

The flight test in this case consisted of a maximum performance climb from Texas State Technical College (TSTC) airport (elevation 780 Ft. MSL) to 10010 Ft. MSL. The limit established for the cylinder head temperature for this test is 475 degrees F. The maximum CHT recorded during this test was 449.94 degrees F. The maximum allowable oil inlet temperature for this test is 245 degrees F. The maximum oil temperature recorded in the Cessna 152 was 217.94 degrees F.

C. Conduct a hot fuel test in accordance with FAR 23.961 which requires that the fuel system remain free from vapor lock when using fuel at a temperature of 100 degrees F. This test was performed with no indications of vapor lock.

D. Conduct engine re-start inflight and document a restart envelope in accordance with FAR 23.903. Since no airframe modifications were made which affected the glide characteristics of the airplane, the only issue addressed here was the ability to restart the engine. This was demonstrated satisfactorily in the course of the flight test program. Due to the addition of a boost pump on the modified airplane, turning the boost pump on was added to the engine failure restart procedures.

Conclusion

The Cessna 152 has been flying on ethanol since the FAA certification was granted. It was flown to be displayed at airshows in Idaho and in Wisconsin. It performed excellently at high altitudes and high temperatures. Data has been recorded and analyzed during cross country and local flights. The aircraft is now ready to be used in the flight training portion of the Aviation Sciences program at Baylor University/TSTC.

The use of ethanol as a transportation fuel has been proven successful. All of the initial technical problems have been solved. Performance is enhanced in all aspects while the only drawback, range loss, can be considerably ameliorated by further modifications to the engine.

The withdrawal of low lead aviation gasoline is impending. Ethanol can be the alternative. Besides the economic and political benefits derived from the domestic production of the fuel, the most important aspects of ethanol are that it is a clean burning, renewable fuel.

The result of its adoption as an aviation and general transportation fuel would be an improvement in air quality and a greater independence from foreign oil supplies.

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