

**ETHANOL AS AN AVIATION FUEL:
AN OVERVIEW OF THE PROGRAM AT BAYLOR UNIVERSITY**

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Abstract

Research and development of ethanol as an aviation fuel has been conducted at Baylor University for the past 13 years. Initially, the motivation was the possibility of fuel supply interruptions as a result of political instability in the Middle East. Modifications were developed to enable aircraft powered by reciprocating engines to use pure ethanol as fuel. Six different aircraft have been modified and flown on alcohol. Two series of aircraft engines have received Federal Aviation Administration (FAA) certification to use ethanol. Three aircraft are in the process of obtaining FAA certification to use ethanol as a fuel in commercial operations.

This paper will describe the Center's three areas of concentration: (1) certification of aircraft engines and airframes, (2) research and development to improve efficiency, performance and reliability of aircraft engines on alternative fuels, and, (3) educational programs to increase public awareness of alternative fuels in aviation.

Introduction

The removal of lead from fuel, as mandated by the Clean Air Act, is a cause for great concern in the aviation industry. The industry standard, 100 octane, low-lead aviation gasoline will have to be replaced by an unleaded fuel with a minimum motor octane of 98 as recommended by the General Aviation Manufacturers Association. Different approaches have been taken in an attempt to manufacture a suitable fuel. As of now, none of the proposed solutions are acceptable due to inadequate octane, excessive emissions, or high cost.

The 13 year Baylor University project proved that 100% denatured ethanol is the ideal fuel to replace 100 octane, low-lead aviation gasoline.

Project Background

When this project began in 1980, all of the activities engaged in by the project initiator were related to aviation. He was conducting air pollution research at Baylor University using an instrumented aircraft and flying aerobatic competition and airshows. The motivation for the research was the threat of fuel supply interruptions due to the unstable political climate of the Middle East. After considering a variety of fuels as possible candidates to replace aviation gasoline, ethanol was chosen because of its characteristics and availability. The Environmental Studies Institute at Baylor University was producing ethanol, using the waste stream from a local chocolate manufacturing company. A Texas oil man and environmentalist provided airplane and funds to initiate the project.

A Bellanca Decathlon, powered by a Lycoming

IO-320, was converted to ethanol. Once the necessary engine modifications were determined and implemented, performance on ethanol was carefully recorded and analyzed. The immediately evident results were cooler engine temperatures and increased engine power. This aircraft flew over 600 hours on ethanol fuel. After the flight test phase, aerobatic demonstrations and airshows were flown including the EAA airshow in Oskosh. In 1982, this Decathlon made the first transcontinental flight on ethanol. Three additional Aeronautic Association records were established with this ethanol powered aircraft. The Decathlon was sold to an association of ethanol producers in Brazil and aerobatic demonstrations were performed in Sao Paulo and Rio de Janeiro.

Encouraged by the success of this aircraft, a second airplane was modified to run on ethanol. This was a Pitts Special S1S, a single engine, single seat aerobatic airplane used in competition flying and airshows. The compression ratio of the Lycoming IO-360 A4A power plant was increased from 8.5:1 to 10:1. Various fuel combinations were tested; among them, different percentages of ethanol and gasoline, and of ethanol and methanol. The resulting data was published in technical papers. All fuel wetted aircraft components were tested for compatibility with ethanol and those affected were either changed or treated. As a result of the higher compression, efficiency was improved. A considerable increase in available power was also recorded when flying on ethanol. This Pitts was flown in numerous airshows in the United States and Italy. A Pitts Special S1S was also modified in Paris, France, and flown to demonstrate ethanol performance.

Three more aircraft were converted to run on ethanol: a twin engine Piper Aztec, a Siae Marchetti SF 260, and a Velocity. The latter was purchased and modified for the sole purpose of crossing the Atlantic ocean on ethanol

fuel in order to make an irrefutable public demonstration of the reliability of the fuel. This experimental category airplane, a canard type, was chosen because of its efficiency combined with a big cabin which accommodated large auxiliary fuel tanks. In the fall of 1989, the Velocity flew from Waco, Texas, to Paris, France, with refueling stops in the Azores Islands and Lisbon, Portugal. The flight was successful and proved the point.

The first ten years of research on ethanol as an aviation fuel and the record setting flights was carried out with very little financial support.

An important accomplishment of these years of activity has been the granting of a Supplemental Type Certificate by the FAA for the use of ethanol in a series of Lycoming engines. This certificate represented a significant achievement since it was the first official FAA recognition of the viability of ethanol as an airworthy alternative fuel.

As the mandates from the Clean Air Act stimulated the search for an alternative to leaded aviation gasoline, the project at Baylor University expanded its activities to respond more efficiently to the evolving situation and to assert the validity of ethanol as an aviation fuel.

At the beginning of 1991, the Center for the Research and Development of Ethanol as an Aviation Fuel was founded within the Aviation Sciences Department.

Center Activities

The Center for the Research and Development of Ethanol as an Aviation Fuel was instituted to conduct research and development, engine and airframe certification, and reliability demonstrations related to the use of ethanol fuel for

general aviation reciprocating engine aircraft. A program to be administered by the Department of Aviation Sciences in cooperation with Texas State Technical College was established with the following goals:

- Certify a range of reciprocating aircraft engines using ethanol.
- Certify a range of airplanes using the engines certified on ethanol fuel.
- Develop research and certification test facilities that meet current and projected FAA and environmental parameters.
- Conduct research and development testing to maximize efficiency, performance and economy.
- Conduct research and development testing to maximize the usable power potential with ethanol fuel and evaluate engine component wear, lubrication characteristics, etc.
- Develop public awareness for the use of ethanol as a renewable fuel by establishing seminars on the characteristics and use of ethanol and demonstrations using ethanol fuel in airplanes.
- Develop curriculum and training for teachers and instructors related to research and development and certification programs.
- Develop curriculum and initiate training of university and technical school students on research and development objectives and relevant FAA policy and certification procedures.
- Develop Advisory Circular documentation for FAA publication and disseminate information and procedures for certification of engines and airplanes using ethanol fuel.

This documentation should establish the minimum certification requirements based on results of the programs described above.

Research and testing proved that the efficiency of gasoline engines modified to run on ethanol could be considerably improved by such additional modifications as increasing the compression ratio or changing ignition timing. Additional research and development to implement these changes, or to manufacture a new engine ideal to run on ethanol, is needed. At the same time, to establish ethanol as a fuel, aircraft on ethanol must be proved in the market place as soon as possible and certification is a requisite for an aircraft to engage in commercial operations. Additionally, in order to insure acceptance of the new fuel, educational programs and demonstrations of the reliability of ethanol as an aviation fuel have to be conducted. These three main directions, research and development, certification of engines and airframes, and public education on the subject of ethanol as an aviation fuel, are to be pursued in parallel.

Current Programs

Following establishment of the Center and determination of the desired goals, an active search for the necessary funds began.

In order to proceed, both short and long term goals of the program had to be identified. The need to integrate new modifications into existing engines to increase the efficiency, or to manufacture a complete new engine to take advantage of the characteristics of ethanol, had to be measured against the urgency to certify existing engines on ethanol fuel to prove its effectiveness in the market place. New concepts and major alterations always require extensive documentation prior to the

official certification program.

A proposal to conduct research on the effects of increased compression on various cam geometries and changes in ignition timing was presented to the Federal Aviation Administration Technical Research Center. Additionally, different types of oxygenated fuels other than ethanol were proposed for testing. The proposal was accepted and the project is under way.

To proceed with the certification of existing aircraft engines where most of the research had been conducted, a strategy had to be devised to assure implementation of the certified engines in the market place. Introductory problems, such as distribution of the fuel, had to be overcome. In order to minimize these initial difficulties, two important areas in aviation, flight training and agricultural aviation, were identified. In both areas, most of the flying is local; requiring only single fuel storage.

A grant from the Texas Higher Education Coordinating Board was obtained to certify a Cessna 152: the most common flight trainer in the United States. The aircraft was provided by Texas State Technical College. The engine of the Cessna 152, a Lycoming O-235, has successfully completed the certification tests. This was the first carbureted engine to be certified on ethanol. The airframe certification is currently underway. Upon certification, this aircraft will be placed in the flight training portion of the aviation sciences program, thus insuring utilization in a commercial operation.

A contract to certify an agricultural spray aircraft, a Piper Pawnee, was entered into between the Center at Baylor University and a consortium of organizations of corn producing states. The engine, a Lycoming IO-540, is already certified. The Piper Pawnee is currently flying on ethanol in order to satisfy the

airframe certification requirements.

The airframe of a Pitts Special S2B is also being certified. This aircraft, utilizing ethanol, is used in airshows and demonstration flights. Once certification is obtained, this aircraft will also be used in the flight training portion of the Aviation Sciences program.

The certification tests on these engines has proved that ethanol burns cleaner and cooler and the engines run smoother because the limits of detonation are extended. These facts imply that the time between overhaul of ethanol powered engines can be safely extended; probably doubled.

A demonstration project funded by the Texas Governors' Energy Office was already successfully underway before the Center was established. Two ethanol powered airplanes, the Pitts Special and the Velocity, were taken to airshows and other aviation events for demonstration flights. Concurrently, talks with question & answer sessions were given, and informational material was distributed. This type of educational tour needed to be expanded from a state-wide to a nation-wide demonstration program. Proposals to raise funds were made to federal agencies and agricultural organizations.

During the summer of 1992, the South Dakota Corn Utilization Board sponsored a series of shows with the ethanol powered Pitts Special in the state of South Dakota. The Board contributed significantly to the success of the tour by organizing the publicity and notifying the media prior to the shows. Local radios, television stations, and newspapers carried stories about the ethanol program. Meetings were arranged and talks given to local pilots and organizations. As a result of a talk delivered to an Experimental Aircraft Association chapter in Sioux Falls, six airplanes were converted to

ethanol. These aircraft are part of a team called the Vanguard which performs in shows and aviation events. Currently, the team, sponsored by the local Corn Growers Association, is involved in demonstration programs around the country.

A nation-wide demonstration program was proposed to the Governors' Ethanol Coalition, an organization comprised of 19 ethanol producing states. The proposal was accepted and the project is under way. A Pitts Special S2B, a two seat aerobatic aircraft powered by ethanol, will perform demonstration flights in the coalition states. The engine of this aircraft has already received FAA certification on ethanol. This aircraft can also be used to take members of the media for demonstration rides. The Baylor University Communications Department has installed a miniature video camera on the wing interplane strut which produces spectacular images of aerobatic maneuvers. This video will be available to local television stations to encourage them to carry stories about ethanol powered aircraft.

An ethanol powered van will be used in this program as a support vehicle: to carry the fuel and as a demonstration booth to exhibit and distribute the information about the program. During the lectures and demonstrations given over the past few years, people always ask if ethanol could be used as an automotive as well as an aviation fuel. This van will serve the dual purpose of support vehicle and as educational display in its own right. Seminars on ethanol as an aviation fuel will be given along the way, and a video will be shown. During this demonstration project, specific instructions on conversion of aircraft to ethanol and technical support will be provided. Many recent developments have contributed to make such conversions more attractive. Among them are the current precarious situation regarding aviation gasoline, the threat of a considerable increase

in price, and a product that prevents the oxidation of aluminum parts, solving the main material compatibility problem.

During June 1993, the ethanol powered Pitts Special was shipped to Paris, France, to participate in the Paris airshow, the biggest aviation event in the world. The aircraft flew every day of the show in front of thousands of people. A lot of interest was generated in the audience and the media. National radio, television and newspapers carried the story of the event. The cover of the July issue of one of the most popular aviation magazines in France, *Aviation et Pilote*, was dedicated to the ethanol powered aircraft. This aviation magazine, in response to the success of the ethanol show and the interest generated, would like to take the lead in the promotion of ethanol as an aviation fuel in the European countries.

Future Projects

Once certification of the three aircraft currently undergoing tests, the Cessna 152, the Piper Pawnee, and the Pitts Special, is completed, certification of different types of aircraft will begin. Performance of the certified aircraft during field operations will be recorded and analyzed on a regular basis. The economics of the use of ethanol versus aviation gasoline will be determined by taking into account not only the savings accrued from the lower cost per mile of ethanol versus aviation gasoline, but also the long range savings to be derived from the decreased wear and lack of detonation in the engines.

The long range objective of the Center is to certify a core of aviation engines and aircraft (including turbocharged engines) to establish common ranges of alterations that could apply to most engines and aircraft without a full

range of testing. This program is designed to prove the concepts and light the fuse for entrepreneurial certification by other parties. As testing and certification questions are resolved, documentation will be provided that will serve as guidelines for the FAA and entrepreneurs for continued certification of the fleets of engines and airplanes.

Any progress achieved in the research and development phase of the project will be incorporated in the ongoing certifications. For example, there is enough evidence from the previous certification experiences to show that the time between overhaul of an ethanol powered engine can be considerably extended. Certification tests will be designed to prove this hypothesis. Eventually, an engine designed to take complete advantage of the ethanol characteristics will be manufactured.

Other renewable and oxygenated fuels will be tested, including ETBE, in the search for the ideal fuel to replace jet fuel.

Conclusion

Since its beginning, the goals set by the Center have been achieved on schedule, test results have met or exceeded expectations, and response, particularly among the general public in the aviation and agricultural communities, has been excellent. Despite the fact that current modifications have proven safe, reliable, superior in performance, and economically competitive, much remains to be accomplished in this area. However, the bureaucratic work of FAA certification must continue in order to insure that ethanol is proved in the final testing ground, the marketplace. A successful program of education directed at the grassroots level, officials in state and federal governments, and executives in private industry is a

necessary component of this effort to gain acceptance for a domestically produced, high performance, economic fuel for general aviation.

