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ETBE AS AN AVIATION FUEL

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Abstract

This paper discusses the preliminary flight testing of an aircraft using neat burning ethyl-tertiary-butyl-ether (ETBE) as a fuel.

No additional changes were made to the fuel delivery systems which had previously been modified to provide the higher fuel flow rates required to operate the engine on neat ethanol. Air-fuel ratios were manually adjusted with the mixture control. This system allows the pilot to adjust the mixture to compensate for changes in air density caused by altitude, pressure and temperature. The engine was instrumented to measure exhaust gas temperatures (EGT), cylinder head temperatures (CHT) and fuel flows, while the standard aircraft instruments were used to collect aircraft performance data. Base-line engine data for ETBE and Avgas are compared.

Preliminary data indicates the technical and economic feasibility of using ETBE as an aviation fuel for the piston engine fleet. Furthermore, the energy density of ETBE qualifies it as a candidate for a turbine engine fuel of which 16.2 billion gallons are used in the U.S. each year.

ETBE AS AN AVIATION FUEL

Introduction

In an effort to clean up the air, programs such as the phase-out of leaded gasoline and the use of cleaner fuels are being required in the United States. Mandates in the Clean Air Act Amendments of 1990, banning leaded fuels and requiring reformulated oxygenated fuels, are a major cause of turmoil in the aviation industry since 100 Low Lead (100 LL) is the only high octane aviation gasoline currently available.

Although aviation fuel is only a small fraction of the gasoline sold in this country, as a result of reducing lead in other fuels, 100 LL aviation gasoline (Avgas), is now the single largest source of lead in the atmosphere. At the current consumption level of around 300 million gallons of aviation gasoline a year, 0.45 million grams of lead are released annually into the air (Nussbaum, 1991).

The U.S. requirements for oxygenated fuels for automobiles are providing the opportunity to introduce fuels that can replace leaded aviation gasoline, providing not only environmental benefits but technical advantages as well.

Avgas Situation

Due to the difficulty of producing an unleaded alternative to 100 LL, the Environmental Protection Agency (EPA) has granted aviation gasoline a temporary waiver to the ban on leaded fuels. However, it is expected that within two years there will be no more leaded fuels. The urgency for the oil industry to find an alternative fuel is going to be dictated by economic considerations because the requirements for handling leaded fuels are going to be more restrictive. Some of the companies producing or delivering 100 LL have already quit its production and/or distribution, while most of the companies still producing it have already switched to dedicated distribution systems. This means high costs, as the pipes and trucks used to deliver leaded fuels cannot be used for the delivery of unleaded gasolines. Under these conditions, the aviation fuel market, which is very small when compared to the auto-gasoline market, provides narrow profit margins for the petroleum industry.

Besides the economic consideration of the producing companies, there are other costs involved with the continued use of leaded fuel.

Environmental regulations are going to affect the disposal of the oil used in the engines burning leaded fuel. The oil will contain too much lead to be burned in incinerators and will probably have to be treated as a toxic waste at a great expense due to high disposal fees.

Also, increased use of alkylates in the new automotive reformulated fuel will cause the price to increase and could result in supply shortages for their use in Avgas production.

Additionally, the Montreal Protocol requires elimination of all use of Ethyl-Di-Bromide, a lead scavenger without which 100 LL cannot be used.

Search for Alternatives

For these reasons, the search for an alternative fuel to aviation gasoline is underway. The American Society for Testing Materials (ASTM) formed the Committee D.2 Section J, and Subcommittee J Section J.2 to consider the problems involved in the development of an alternative fuel for aviation and to examine the proposed alternatives. In response to demands advanced during ASTM meetings by various fuel producers, the General Aviation Manufacture Association (GAMA) distributed suggested guidelines to fuel producer organizations. This general description of the proposed fuel characteristics called for a lead free high octane gasoline suitable for use in powerplants approved for 100 LL/130 Avgas. According to GAMA, the fuel should require only minimum, or preferably no, engine modifications and have minimal impact on operational procedures (GAMA 1991).

Guidelines were created in an effort to somewhat ease the current standards for aviation gasolines, which were, in part, established fifty years ago to meet the needs of large displacement radial engines. Since few of these engines are currently operating, the suggested new standards should be able to meet the requirements of most of the horizontally opposed General Aviation engines in use today.

Fuel formulations complying with GAMA's suggestions have been produced in laboratories and results have been presented at ASTM meetings. However, as of today, few of the gasoline producing companies or engine manufactures are involved in actual field testing of the proposed fuel blends.

The Federal Aviation Administration (FAA) Technical Center in Atlantic City, New Jersey, has been testing different fuels containing variable concentrations of ethers and other additives intended to improve the octane rating of the fuel.

The Center is currently testing octane number requirements in certain commonly used engines in order to determine if a lower octane number would be technically acceptable. An octane number of 98 has been proposed for aviation gasoline. This lower octane would facilitate the production of the new fuel and lower its cost.

The decision to adopt a fuel with a lower octane number will negatively affect 30 percent of the current General Aviation flying fleet, which will not be able to fly with the new fuel. The problem is that this group of aircraft burns about 80 percent of the total fuel used today (Mac Nair, 1995).

The FAA Technical Center is currently testing blends of unleaded gasoline with 5 to 30 percent MTBE (methyl tertiary butyl ether). Blends of unleaded gasoline and ETBE (ethyl tertiary butyl ether) are also being tested.

The Renewable Aviation Fuels Development Center (RAFDC) at Baylor University in Waco, Texas, has been working on research and certification of renewable fuels for aviation for the past 15 years. The Center has been testing ethanol, methanol, and various blends of the two in reciprocating engines and has certified two series of Lycoming engines on pure ethanol. As part of the search for an alternative to 100LL, RAFDC has received a grant from the FAA Technical Center to test the non-petroleum alternatives to aviation fuel and improve the efficiencies of the engines using these fuels.

One of the most promising fuels to be tested under this research project is ETBE. In April of 1995, the first flight tests ever on pure ETBE were performed by RAFDC. The results of the preliminary testing were so satisfactory that RAFDC flew a Pitts Special S2B aerobatic biplane, on ETBE at the Paris airshow (the largest aviation event in the world), in June 1995.

ETBE Characteristics

The technical characteristics that make ETBE an attractive fuel for aviation are numerous.

ETBE is made from domestically produced materials: ethanol, a renewable liquid fuel (43 percent by volume); and Isobutylene, produced from domestic natural gas liquids or obtained as a co-product in domestic oil refining and petrochemical production. It is an oxygenated fuel with an oxygen content of 15.7 percent by weight.

ETBE has a neat Reid Vapor Pressure (RVP) of 4.0. Its energy density is 96,000 BTU /gallon.

ETBE's high octane number, 110 (R+M/2), allows the use of a higher compression ratio in the engine, improving fuel efficiency. It should be noted that a six octane number increase in gasoline can allow the increase of engine compression ratio by two numbers. This translates into a 10 percent increase in fuel efficiency.

Flight Test Data

All data was taken in a Pitts Special S2-B powered by an Avco-Lycoming AEIO-540-D4A5. This is an air-cooled, fuel injected engine rated at 260 horsepower at 2700 RPM. The aircraft was equipped with the following instrumentation:

Oil Temperature
Oil Pressure
Fuel Flow (turbine type)
Fuel Pressure
Manifold Pressure (MAP)
Tachometer
Exhaust Gas Temperatures (all cylinders)
Cylinder Head Temperatures (all cylinders)
Airspeed
Altimeter (set to 29.92 Inches Hg.)
Outside Air Temperature (OAT)

All testing was done at 2000 feet pressure altitude. This means the altimeter was set to 29.92 Inches Hg. As reference, the ICAO standard atmosphere at 2000 feet has a temperature of 51.87 degrees F..

Range and Power Comparison Between Avgas and ETBE

Figure 1 and 2 depict data collected at 24 In. MAP and 2400 RPM on Avgas and ETBE. The OAT for the data on ETBE was 61 degrees F. and for Avgas it was 60 degrees F., thus the conditions were essentially identical for the two tests.

The maximum specific range for ETBE was 9.75 miles per gallon (mpg) at 14 gallons per hour (gph) and 140 miles per hour (mph). (Fig. 1)

The maximum specific range for Avgas was 11.5 mpg at 13 gph and 140 mph. (Fig 2)

Energy density for Avgas is approximately 125,000 BTU's per gallon. It is 96,000 BTU's per gallon for ETBE. Thus, the energy density of ETBE is approximately 23 percent less than Avgas. However, the range reduction on ETBE compared to Avgas was only 15 percent according to the measurements taken on the two flights. On both flights the airplane was operating at very close to the same RPM and airspeed, so the propeller efficiency was essentially constant. This implies that the engine combustion efficiency is greater on ETBE.

The maximum airspeed, hence maximum power available, are essentially the same at the power setting tested.

Additional Flight Test Data on ETBE

Data was taken at 25 in. MAP and 2500 RPM. The OAT was 58 degrees F. (Fig. 3) The graph shows that a maximum of 165 mph at 19 gph was recorded at a specific range of 8.5 mpg. For this power setting, the maximum specific range was 9.2 mpg at 16.2 gph and 150 mph.

In figure 4, data collected at 23 inches MAP and 2300 RPM is shown. The OAT was 72 Degrees F. In this case a maximum specific range of 10.2 mpg at 140 gph and 145 mph was recorded.

Comments

This flight data maps only a small portion of the performance of ETBE as an aviation fuel. For example, the range comparisons between Avgas and ETBE are given for only one power setting. Note that the specific range of ETBE increases from 9.75 mpg to 10.2 mpg at 23 in. MAP and 2300 RPM, while the airspeed actually increases at the lower power setting. Clearly, a caveat is necessary at this point. This data is taken in real world conditions and as such is subject to errors induced by updrafts, downdrafts and/or pilot induced errors such as incorrect instrument interpretation and imprecise aircraft control.

The initial results on ETBE (43 percent ethanol) are consistent with the extensive experience of RAFDC on neat ethanol as an aviation fuel.

A recently completed test stand facility equipped with a dynamometer will enable more precise data to be obtained.

Economics and Market Potential

The cost of ETBE production is predicted to swing around $ 0.75/ gallon. This calculation is made by assuming natural gas price at $ 2.00/MCF; butanes at $ 0.35/gallon; ethanol at $ 1.04/gallon (before $0.54/gallon credit).

The size of the aviation gasoline market represents an ideal niche for pure ETBE fuel. It is estimated that annual consumption of aviation gasoline varies between 300 and 350 million gallons. The most conservative figure given by the Aircraft Owners and Pilots Association (AOPA) for the year 1993 is 305 million gallons. Over the last ten years the consumption of aviation gasoline decreased abruptly from about one billion gallons in the early 80's to today's 300 million gallons. The reasons for this decrease are to be attributed to problems related to a down turn in general aviation largely because of product liability issues. A regulation to limit this product liability has been recently passed and there are predictions of a resurgence in general aviation with a consequent increase in aviation fuel consumption.

At today's projected prices, ETBE is already economic competitive with aviation gasoline ($ 1.60 to $ 2.30 per gallon). It is all the more so when considering that the price of ethanol is decreasing as new production technologies are developing and the feedstock base is expanding. On the other hand, the price of Avgas can only increase in the future since, as a general trend, petroleum prices can only rise as reserves are depleted, extraction costs increase, and the demand for energy grows.

Environmental Benefits

The production and use of fossil fuels worldwide contribute 57 percent to all manmade greenhouse gas emissions. Fossil fuels constitute 85 percent of U.S. energy consumption. The transportation sector is responsible for almost one third of U.S. carbon dioxide emissions (NTIS, 1992) and it is 97 percent dependent on oil (Lynd, 1991).

Renewable fuels can decrease the net output of carbon dioxide by displacing fossil fuels. The use of biomass to produce ethanol and ETBE, will greatly reduce the nation's greenhouse gas emissions. Fossil fuels remove carbon that is stored underground and transfer it to the atmosphere. Biomass releases carbon dioxide as it burns but extracts it from the atmosphere as it grows, creating a closed carbon cycle. Indeed, substantial quantities of carbon can be captured in the soil through biomass root structure, creating a net carbon sink.

ETBE's high octane rating eliminates the need to use carcinogenic hydrocarbon based aromatic octane enhancers (such as benzene which is proven to cause cancer) and many of the environmentally less desirable gasoline components such as sulfur.

Since the ban on leaded fuels exists because of environmental concerns, emission testing of the new blends are an important aspect of this research. Emissions from new fuels need to be environmentally acceptable. Data collected on the engines tested by the FAA Technical Center shows a general trend: by increasing ether concentrations, emissions of hydrocarbons and carbon monoxide decrease while emissions of oxides of nitrogen and of carbon dioxide increase (Ferrara, 1994). RAFDC is in the process of acquiring all the equipment necessary to analyze the emissions of pure ETBE and other renewable fuels.

There are three basic issues involved in the debate over the formulation of the next generation of fuels; economics, energy independence, and environment. The environmental issue and the potential of the new fuels to reduce and possibly eliminate the adverse health effects of the current liquid transportation fuels is by far the most important of all these issues.

Conclusions

Besides the environmental benefits, the economic advantages, and the superior performance, the adoption of a domestic renewable fuel will reduce the dependence on foreign oil, reduce the federal budget deficit, improve the balance of trade and national energy security, boost rural economy, and create jobs together with a major new American industry.

Today, the United States imports more than 50 percent of its petroleum. This situation presents an energy security problem and it is responsible for approximately $ 45 billion of the U.S. trade deficit. Furthermore, the military expense of maintaining access to the Persian Gulf oil exceeds $ 35 billion a year (U.S. DOE Alternative Fuels Hotline, 1996).

ETBE satisfies all of the requirements as an aviation fuel. The potential for ETBE production is enormous. ETBE combines the nation's two most abundant domestic clean burning fuels, natural gas and ethanol. It can be used in a reciprocating aircraft engine with minor modifications to its fuel injection system. Additionally, it has a great potential as a turbine fuel to improve emissions.

It is time for the real cost of oil to be taken into account. The promotion of biofuel programs cannot be postponed just because their prices are not competitive with the present artificially low cost of oil. Liquid biofuels development has to become a national priority. They will decrease our energy dependence and trade deficit while providing benefits to air quality and employment.

Although the potential market for ETBE (or ethanol) as an aviation fuel is a small percentage (0.5 percent) of total transportation fuel consumption in the US., its adoption will be an important step in the right direction.

The use of these fuels in aviation, where high performance is essential, will demonstrate the technical and economic feasibility of renewable fuels as high quality liquid transportation fuels.

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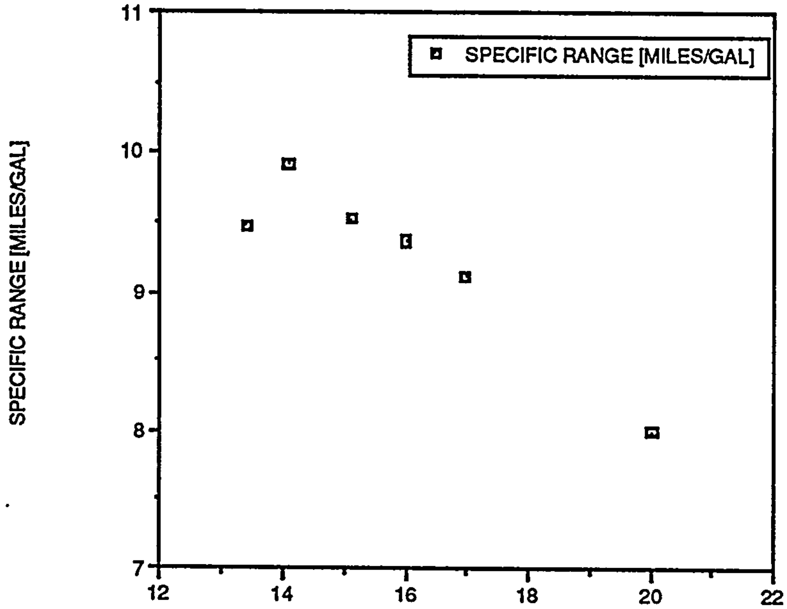
ETBE FLIGHT TEST DATA PITTS S-2B 1 MAY 1995
24"MAP, 2400 RPM, 2000 FT



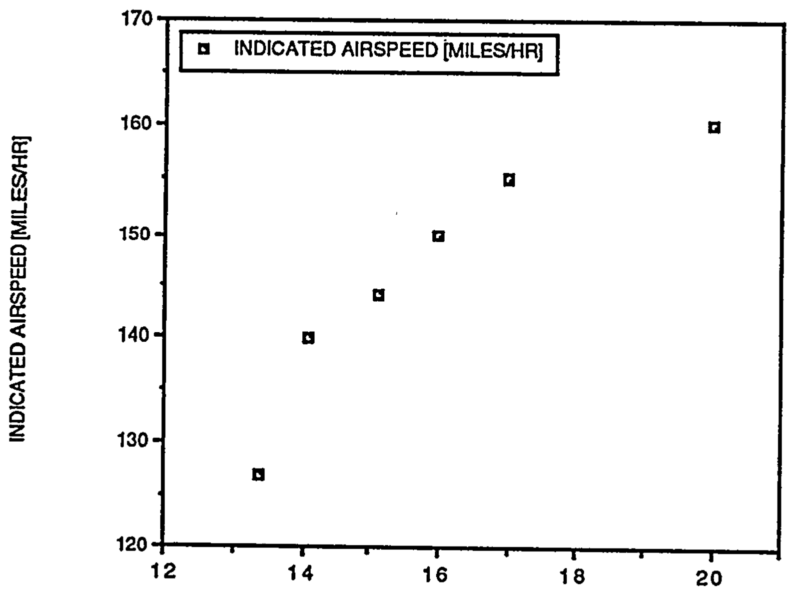
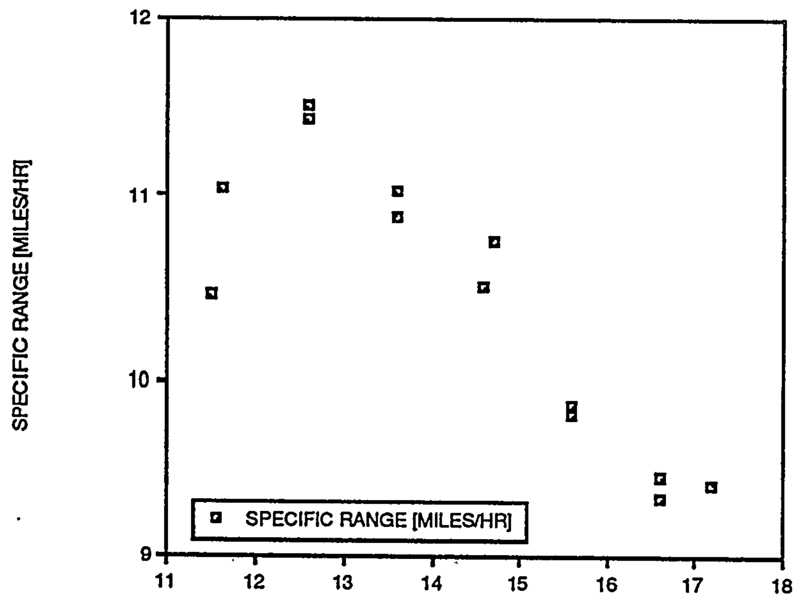


Figure 1

100LL FLIGHT TEST DATA
24"MAP, 2400 RPM, 2000 FT



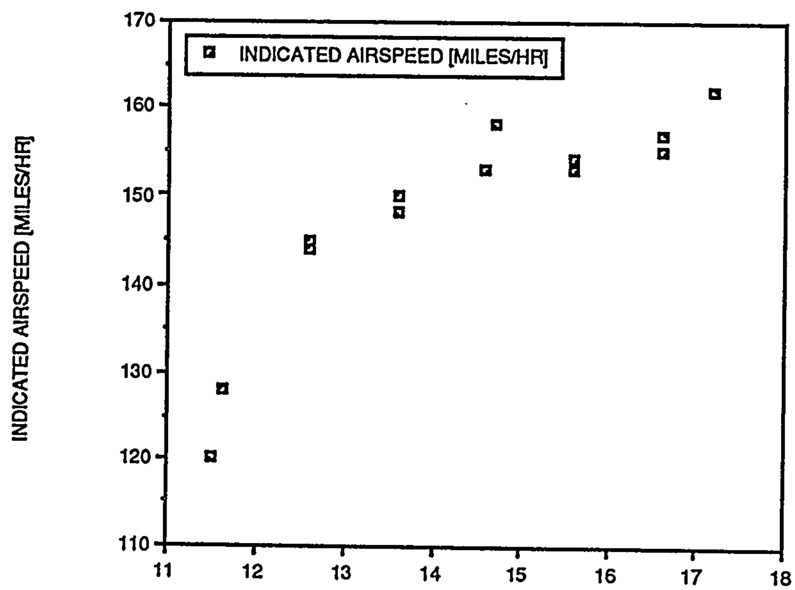


Figure 2

ETBE FLIGHT TEST DATA PITTS S-2B
25"MAP, 2500 RPM, 2000 FT

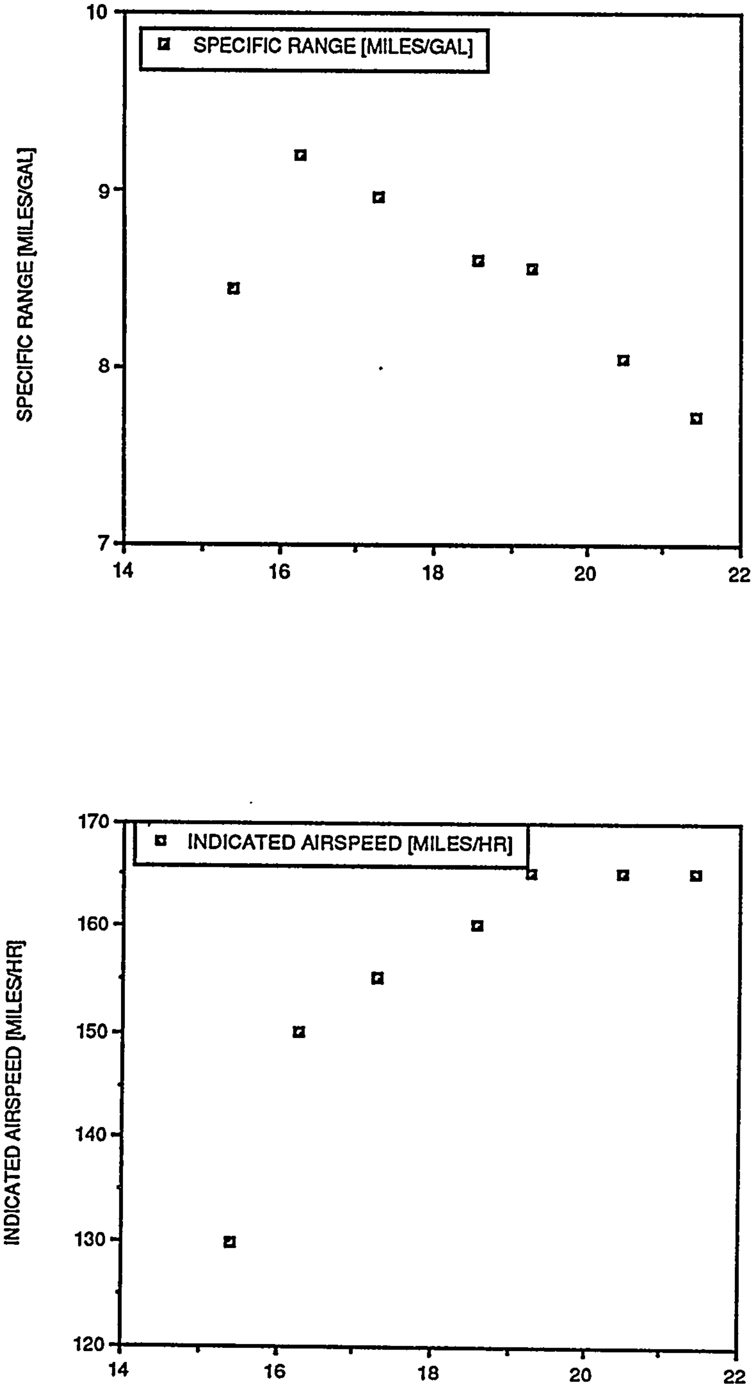
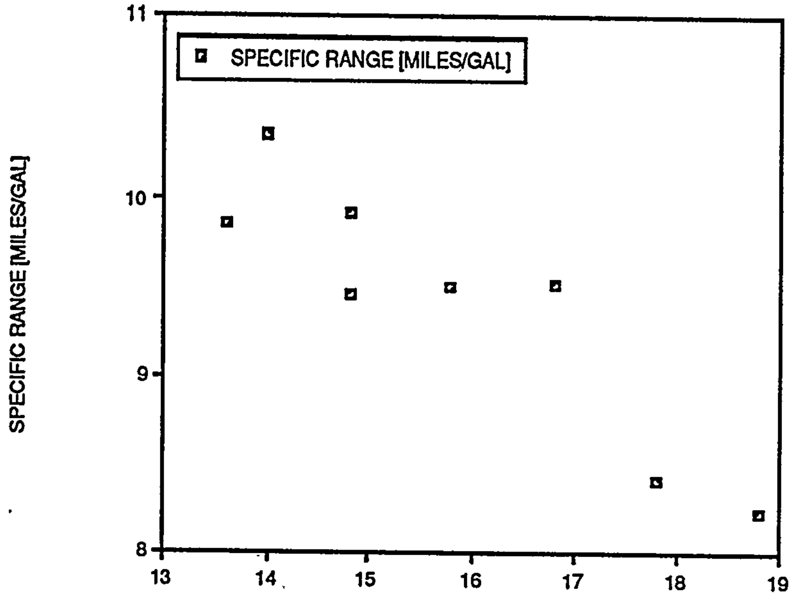


Figure 3

ETBE FLIGHT TEST DATA PITTS S-2B
23"MAP, 2300 RPM, 2000 FT



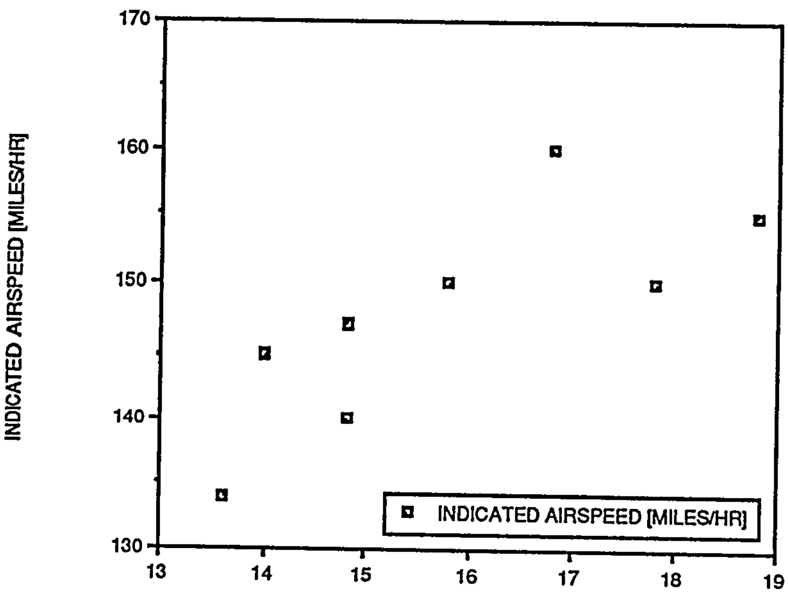


Figure 4

% HP	CORRECTED HORSEPOWER	AVGAS GPH	ETBE GPH	% FUEL CONSUMPTION CHANGE + = INC - = DEC	ETHANOL GPH	% FUEL CONSUMPTION CHANGE + = INC - = DEC
60	180	20.4	22.5	+ 10	22.5	+ 10
70	210	19.3	22.5	+ 17	25.2	+ 18
75	225	20.6	19.5	- 5	23.6	+ 15
80	238	21.8	21.8	0	24.2	+ 11
90	270	27.0	28.8	+ 7	31.5	+ 17
100	300	28.5	27.5	- 4	34.0	+ 19

1. ENGINE TESTED: MODIFIED LYCOMING IO-540 D4A5 WITH 10:1 COMPRESSION RATIOS
2. GPH: GALLONS PER HOUR
3. MAX POWER AVAILABLE ON AVGAS: 300 HP
4. MAX POWER AVAILABLE ON ETBE: 304 HP
5. MAX POWER AVAILABLE ON ETHANOL: 316 HP