

POWERED BY ETHANOL IS NOW INSTRUMENTATION. IN ADDITION, IT IS CURRENTLY USED BY BARTON UNIVERSITY TO CONDUCT AIR POLLUTION STUDY FUNDAMENTAL TO TEXAS NATURAL RESOURCES CONSERVATION COMMISSION.

2000
2000

880

1000

1000
1000

FAA CERTIFIED ETHANOL POWERED
AIRCRAFT

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

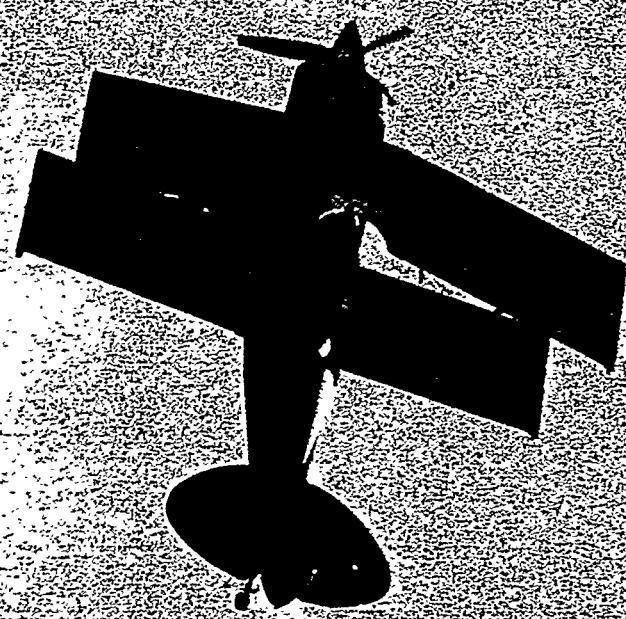


TABLE OF CONTENTS

DEFG310-95GO10088

EXECUTIVE SUMMARY

Background	1
Work Accomplished	2
Related Activities	3
Conclusion	7

PISTON ENGINE TEST STAND REPORT

1.	Introduction	9
1.1	Statement of Purpose	9
1.2	Objectives and Approach	9
1.3	Related Background and Experience	10
2.	Facility and Equipment Descriptions	10
2.1	Dynamometer and Engine	10
2.2	Test Cell Water, Air, and Fuel	12
2.3	Data Acquisition as Originally Configured	13
2.4	Test Personnel and Qualifications	14
2.5	Relocation of the Emissions Equipment	15
3.	Initial Efforts	15
3.1	Description of Electramotive Inc. Advanced Digital Electronic Control (ADEC)	15
3.2	ADEC installation Shakedown Problems	16
3.3	Testing Capabilities in the All-Mechanical Configuration	17
4.	First-Round Comparative Testing	19
4.1	Fuels and Properties Comparison	19
4.1.1	Detonation Resistance	19
4.1.2	Volatility: Vapor Lock and Cold Start	22
4.1.3	Materials Compatibility	24
4.1.4	Mixture Metering	24
4.1.5	A Comparison of Selected Basic Properties for the Test Fuels	26
4.2	First-Round Testing Procedures	27
4.3	First Round Results Obtained	28

4.4	First-Round Conclusions Drawn	30
5.	Second-Round Testing	36
5.1	Revised Testing Procedures	36
5.2	Checkout and Initial Testing - Ethanol	37
5.3	Discussion of Results Obtained	39
6.	Perceived Objectives and Near-Term Plans	40
6.2	Addressing the Boost Pump / Fuel Flow Gage Interaction	40
6.3	Addressing the Testing Problems Encountered	41
6.4	Repeat Testing with Precision Procedures	41
6.5	Effects of Timing Setpoint vs Fuel as a Mean to Improve Alt Fuel Efficiency	42
6.6	ADEC as a Solution	42
	Conclusion	43
	References	44
App. A	First-Round Hand-Plotted Full Data Set	
App. B	Second-Round Hand-Plotted Data Set	
App. C	Relative Fuel Efficiencies at 8.5:1, 10:1, 10.5:1 Compression Ratios	
	Selected Data from Mankato State Automotive Study	
	Selected Results from the 300 BHP IO-540 Dyno Testing	
	Selected Results from the Pitts S2B Flight Testing on ETBE	
App. D	Pictures	
App. E	RAFDC's Pamphlets	

ADDENDUM A: REPORT ON THE TURBINE ENGINE TEST STAND

App. A-1: Emission Testing Graphs

ADDENDUM B: REPORT ON THE SECOND INTERNATIONAL CONFERENCE ON ALTERNATIVE AVIATION FUELS

App. B-1: Pictures and Conference Program

App. B-2: Articles

ADDENDUM C: PAPERS PUBLISHED DURING THE STUDY

EXECUTIVE SUMMARY

Background

The Renewable Aviation Fuels Development Center (RAFDC) at Baylor University was granted U. S. Department of Energy (US DOE) and Federal Aviation Administration (FAA) funds for research and development to improve the efficiency in ethanol powered aircraft, measure performance and compare emissions of ethanol, Ethyl Tertiary Butyl Ether (ETBE) and 100 LL aviation gasoline.

The premise of the initial proposal was to use a test stand owned by Engine Components Inc. (ECI) based in San Antonio, Texas. After the grant was awarded, ECI decided to close down its test stand facility. Since there were no other test stands available at that time, RAFDC was forced to find additional support to build its own test stand. Baylor University provided initial funds for the test stand building.

Other obstacles had to be overcome in order to initiate the program. The price of the emission testing equipment had increased substantially beyond the initial quote. Rosemount Analytical Inc. gave RAFDC an estimate of \$120,000.00 for a basic emission testing package. RAFDC had to find additional funding to purchase this equipment. The electronic ignition unit also presented a series of time consuming problems. Since at that time there were no off-the-shelf units of this type available, one had to be specially ordered and developed. FAA funds were used to purchase a Super Flow dynamometer.

Due to the many unforeseen obstacles, much more time and effort than originally anticipated had to be dedicated to the project, with much of the work done on a volunteer basis. Many people contributed their time to the program. One person, mainly responsible for the initial

design of the test stand, was a retired engineer from Allison with extensive aircraft engine test stand experience. Also, many Baylor students volunteered to assemble the test stand and continue to be involved in the current test program.

Although the program presented many challenges, which resulted in delays, the RAFDC's test stand is an asset which provides an ongoing research capability dedicated to the testing of alternative fuels for aircraft engines.

The test stand is now entirely functional with the exception of the electronic ignition unit which still needs adjustments.

Work Accomplished

Data has been collected on performance and emissions of three different fuels: Avgas, ethanol and ETBE. Data has been validated, reduced and summarized. The data constituted the basis for papers presented at the XI and the XII International Symposium of Alcohol Fuels (ISAF) that were held respectively in Sun City, South Africa, and in Beijing, China (papers included in report). Additionally, students at various universities in the USA and abroad used the material for research projects and thesis.

The driving force for the development of cleaner burning fuels for the general aviation piston engine fleet is the eventual phase-out of lead from 100 LL aviation gasoline. Emissions testing of ethanol and ETBE have shown overall decreased emissions when compared to aviation gasoline. Additionally, both test stand and flight test results have shown an increase in available power when using ethanol and ETBE.

The research and data collection at the RAFDC's test stand on various fuels is ongoing. Flight testing with an engine on various compression ratios were also performed. Additional data was collected using the three fuels at an independent test stand on an IO-540 Lycoming engine with a 10:1 compression ratio. Research funds to complete this type of work at the RAFDC's test stand using various compression ratios and ignition timing will be sought as soon as the ignition timing unit is operational.

FAA funds were also granted to RAFDC to support the Second International Conference on Alternative Aviation Fuels. A report on the results of the conference is included. The proceedings of the conference are being published by the FAA.

Additionally, the FAA Technical Center provided RAFDC with a Pratt & Whitney PT6-6 turboprop engine for the newly completed RAFDC's turbine engine test stand equipped with emission testing equipment. This research is prompted by environmental concerns over the emissions of commercial aircraft. The test stand is currently fully operational and a report on this work is included.

Related Activities

Activities closely related to the alternative fuels research ongoing at RAFDC, have augmented and expanded the scope of the program. These include:

Air pollution investigations with instrumented aircraft powered by alternative fuels.

RAFDC has been involved for quite some time in air pollution studies using instrumented aircraft. Extensive experience in this field includes studies conducted in North, Central and South America.

RAFDC's Beechcraft King Air has been used since 1996 to collect air pollution data in the state of Texas. RAFDC's work is helping the Texas Natural Resources Conservation Commission (TNRCC) develop a State Implementation Plan for the state of Texas. One engine of this aircraft will soon be flying on a renewable fuel blend. This will be accomplished as soon as the ground tests -- performed on the turbine engine provided by the FAA -- are completed.

Because of the increased need for this type of air pollution investigation and the opportunity to power these aircraft by renewable fuels, RAFDC has developed a low-cost air pollution instrumented aircraft powered by ethanol. A Cessna 152 has been equipped with an Ozone analyzer, a Sulfur Dioxide analyzer, and a Nephelometer. During the summer of 1998 this aircraft was also used to monitor air quality in Texas under a contract with the TNRCC.

These sampling flights have proved the concept that a low cost air quality sampling aircraft, fueled by a clean burning renewable fuel is a feasible and environmentally desirable operation. The goal of RAFDC is to pursue widespread replication of this aircraft. This concept is incorporated into the scope of the International Clean Airports Program.

The International Clean Airports Program (ICAP)

There is now recognition by the aviation industry for the need to proceed on a voluntary and cooperative basis in order to improve the overall environment in regions involved with aircraft operations. RAFDC's initial work with the US Department of Energy (DOE) in promoting the Clean Airport Program verified this recognition. Five airports were designated as Clean Airports during the program and seven more aircraft were converted to use ethanol. The Clean Airports Program, originally initiated by the DOE, has transitioned into the International Clean Airport Program (ICAP) as a result of

enthusiastic support by the international attendees of The Second International Conference on Alternative Aviation Fuels. The conference, held at Baylor University in November 1997, developed innovative concepts, original ideas and international support to launch the newly expanded program. The Palm Springs International Airport in California, was the first airport to be designated under this program on Earth Day 1998.

There is currently a great concern in regard to the pollution caused by large commercial airports, particularly those in the non-attainment areas. Recent studies have reported that the pollution from aircraft engines is having a greater effect on pollution levels than had been previously thought. The primary reason is the unprecedented growth of airline traffic.

Although aircraft engine manufacturers have made great strides in cleaning up emissions from large turbine engines, this has not been sufficient to prevent significant increases in pollution caused by commercial airliners in extremely sensitive urban areas. The situation in aviation is similar to that confronting the automobile industry in the early 1980's. The automobile manufacturers had made great advances in cleaning up tailpipe emissions, but the increase in the number of miles driven had offset most of the gains. The solution was reformulated gasolines.

An additional concern to today's global environmental action priority is the need to reduce the impact of fossil fuels on global warming. One of the world's most advanced industries, aviation, can provide leadership in stabilizing greenhouse gas emissions. Biofuels, together with other renewable sources of energy, present an elegant and economical solution to this problem.

RAFDC, in coordination with other national and international organizations and agencies, is promoting the ICAP (pamphlet included in the report) to devise strategies to

voluntarily initiate programs to lessen the environmental impact of aviation. There is a growing awareness that, considering the current and anticipated growth of air traffic, ignoring the issue will only exacerbate the problem. The ICAP's contention is to take action before the aviation industry is forced to deal with crippling regulations.

RAFDC's background is unique in the areas of aviation, education, clean alternative aircraft fuels and air pollution research. RAFDC, by providing its experience in these issues will be able to make a significant contribution to the problems facing the aviation industry and highly polluted urban areas. This program will also offer an opportunity to effect implementation of renewable fuels in aviation.

In conclusion, it is important that serious consideration be given to the adoption of renewable fuels in aviation for the following reasons:

- There is growing public support for renewable ethanol as an aviation fuel and as a replacement for imported fossil-based fuels. Ethanol is a viable alternative now. The biofuel proponents, who presented their case at the "Second International Conference on Alternative Aviation Fuels", demonstrated by means of collected data, successful completion of certification programs and extensive field experience, that ethanol meets and exceeds all objective criteria for the next fuel for general aviation.
- There are commitments by the United States to reduce greenhouse gas emissions. The use of biomass fuels can help achieve this goal. According to the Argonne National Laboratory, each gallon of gasoline replaced by corn-based ethanol will cut CO₂ emissions by 35 to 46 percent. Those percentages will only improve as cellulosic biomass joins feed grains as key feedstocks for the production of ethanol and other biofuels.

- Already available is FAA certification of two popular series of aircraft engines to operate on ethanol, and a full certification on ethanol of a series of aircraft . This certification was a considerable achievement since it was the first to be granted by the Federal Aviation Administration to a non-petroleum fuel to be used in aircraft. A second full certification for a series of popular agricultural spray aircraft is expected to be granted in the next few months
- A flight school using ethanol in its training aircraft is being organized.

There are a number of compelling reasons for the introduction of clean burning, renewable and domestically produced biofuels in aviation. Energy security is rapidly becoming a critical issue with the United States currently importing over 50% of its oil. The crisis caused by the Arab Oil Embargo in 1973 occurred at a time when the US was importing approximately 37% of its oil. Furthermore, the rapid growth of commercial aviation is having an increasing impact on the greenhouse gases as well as the standard pollutants burden. The U.S. aviation industry has the opportunity to provide leadership in the areas of energy security and environmental responsibility by a gradual adoption of environmentally friendly practices.

Conclusion

RAFDC is appreciative of the opportunity provided by the US DOE to research and develop alternative fuels for aviation. Tests were successfully performed with the initial test engine and the data collected has already been widely circulated through national and international conferences, shows, INTERNET and mailing.

RAFDC is fully committed to make the best use of its research facilities, and to make sure that the results of this work will have extensive, widespread circulation among the aviation community.

Initially, the work of RAFDC was motivated by a concern for the survival of general aviation as a result of the 1973 oil embargo. Today, that threat still exists along with the other concerns of energy security and environmental impact.

RAFDC has proved that the capability to develop reliable, high-performance, clean burning, renewable fuels for aircraft engines is a reality today. The continuation and expansion of research and development of alternative aviation fuels is a natural sequel to the work accomplished under the current program, particularly now that the major technical and financial hurdles related to the test stand assembly are resolved.

The continuation of RAFDC's activities in this field will be a productive investment in the future and the image of general aviation as a responsible member of the environmental community.

1. INTRODUCTION

1.1 Statement of Purpose

RAFDC conducts research on the performance and emissions characteristics, and the fuel management needs, of alternate fuels for aviation engines. This includes both piston and turbine types. The focus of this report is the air-cooled spark ignition engine typical of general aviation, as typified by a Lycoming IO-360.

1.2 Objectives and Approach

The objective of the Lycoming IO-360 test project was to define the relative performance and emissions impacts of ethanol and Ethyl Tertiary Butyl Ether (ETBE) vs aviation gasoline (Avgas). Based on prior work, the initial configuration of interest was an IO-360 with modified mixture ratio settings, but no changes to the ignition settings or to the type of injection (continuous). This corresponds to the minimum necessary flexible-fuel conversion modification, and has proven effective in related aircraft certification projects.

In order to take full advantage of the unique technical characteristics of each fuel, optimal ignition timing settings and fuel injection settings need determination. Investigation of optimal timing settings would include both revised magneto settings, and the possibility of substituting an electronic ignition control capable of providing a map of settings vs the appropriate engine condition measurements. Similarly, continuous mechanical fuel injection could be replaced by electronic pulse injection, up to and including injection co-timed with the opening of each individual intake valve. These correspond to a more extensive alternate fuel modification. It is anticipated that different settings would be required for each alternate fuel, especially the timing settings.

Compression ratio modifications offer a means to take advantage of the higher octane ratings of the alternate fuels, with resulting performance and emissions benefits.

Compression changes represent the most extensive and least flexible modification to the engine. Such changes would also affect the optimal timing and injection settings, requiring recharacterization of each. Accordingly, compression changes were to be investigated after the initial timing and ignition work.

1.3 Related Background and Experience

RAFDC has obtained two Supplemental Type Certificates (STC's) for ethanol flex-fuel conversions of a series of Lycoming O- and IO-540 engines, and for a series of Lycoming O-235 engines. These projects required extensive endurance testing and power calibration testing.

RAFDC has obtained one STC for the ethanol flex-fuel conversion of a Cessna 152 aircraft, with another project in progress on a Piper Pawnee ethanol conversion.

Certification of the aircraft (as opposed to the engine) provides considerable practical experience in fuel management, materials compatibility, and safety-of-flight issues.

2. FACILITY AND EQUIPMENT DESCRIPTION

2.1 Dynamometer and Engine

The test engine is a slightly-modified Lycoming IO-360 aircraft engine currently equipped with Precision Airmotive RSA-5 continuous mechanical fuel injection and dual magneto ignition. The modifications lie within the fuel injection system, and were selected and

calibrated by the manufacturer to enable appropriate metering of lower-stoichiometry fuels (including 50-50 ethanol-methanol mixtures). The modifications comprise enlarged passages in the mixture plates and idle valves within the servo unit, and slightly larger fuel injector orifices. System pressures and operation are otherwise identical to the unmodified fuel injection system operating on aviation gasoline. To operate the modified unit successfully on gasolines, or on other fuels of intermediate stoichiometry, one simply leans the mixture appropriately with the manual leaning control.

By means of a short drive shaft and a propeller flange-mounted flywheel, this engine drives the absorber unit of a SuperFlow 901 dynamometer system. This system consists of the basic engine stand, dyno water tank, absorber unit with servo-control, and a control console with readouts and data acquisition capability. Because the engine is air-cooled, no cooling tower was included in the mechanical setup. The engine oil cooler was hooked up to a separate line from the dyno water supply to provide extra oil cooling capability. The absorber itself has an extra water input valve that increases torque capacity at low RPM, necessary with this aircraft engine design. Water supply is open-loop from the local city supply. The absorber is a standard SuperFlow centrifugal water brake of the water level-modulation servo-control approach. The stand itself required a slight modification to accommodate the aircraft-type engine mounting geometry.

The basic dynamometer control console is augmented with a PC and SuperFlow software that affords real-time data observation, post-test data storage, view, and printout. It has also the capability to run the test in an all-manual mode, servo-control to constant input RPM mode, or a fully automated transient RPM sweep mode. This last is incompatible with the time constant of the emissions data system, and with the time constant of aircraft-type fuel metering, so the transient test mode is not an option with this engine. Raw test data, data corrected to standard temperature and pressure, and

corrected to SAE-standard, data reporting formats are automatically generated real-time by the software for the printout.

The normal dyno console remote hydraulic throttle control was not used. Instead, an aircraft-type vernier throttle push-pull cable was installed, plus another for the mixture control. Analogue intake manifold vacuum and absolute-pressure gages, and an analogue oil pressure gage, were also installed directly on the console just below the cell observation window. Also within direct view of the observation window are console analog torque and RPM readouts, and the capability to display digitally air / fuel ratio information (or a variety of other data channels). These contribute greatly to the safe and precise control of a test.

2.2 Test Cell Water, Air, and Fuel

The dyno water supply is open-loop from the city. Cleanliness is adequate, and the supply rate sufficient for the absorber, as long as no cooling tower flow is needed (air-cooled only), and as long as the oil-cooler flow is very low. Dyno servo-control has proven unreliable if too much oil cooler flow is drawn, but the low oil cooler flow setting has proven more than adequate for this type of testing.

The cell is equipped with three air handling fans: engine cooling air, engine exhaust, and cell ventilation. The cell ventilation causes a slight negative pressure in the cell when it is active, on the order of 4 to 5 pounds per square foot (or 0.002 atm). This is sufficient to effectively prevent entry when the ventilation is running. Because the engine draws combustion air from outside the cell, there is no effect on incoming charge pressures due to cell ventilation, but it does affect exhaust back-pressures very slightly.

The engine combustion air is drawn through a turbine-type air flow transducer at the cell wall, and through a few feet of flex hose to a custom-made injection servo air box. Test data clearly show that the drag of the long flex hose more than offsets any benefits of low cell back-pressure on the exhaust. However, the effect must be very small, since the test engine develops very nearly its rated power when operated on aviation gasoline.

Having a very slight negative cell pressure when the ventilation fan is running has proven very convenient for detecting leaks in the combustion air line and airbox. The airflow will read too high whenever the fan is on and there is a leak. Thus, with engine off and ventilation on, airflow will read zero only if there is no leak.

There are two sources of test fuel for the dyno stand. The test cell has a small (approximately 10 gallon) tank installed in one corner of the building, and accessible through an outside door. It has a feed line with ball valve cutoff, and a return line, also with ball valve cutoff. By rearranging two connections, the stand can be connected directly to a 3000 gallon aboveground storage tank outside, adjacent to the test cell building. This tank contains ASTM D-4806 Fuel Grade Ethanol. The small (10 gal) tank is easily filled with other fuels or blends as desired, and has sufficient capacity to support most types of test runs that might be of interest.

2.3 Data Acquisition as Originally Configured

Data files are stored on the associated PC hard drive in the test cell, in a custom format that only the dyno software reads. Currently, dyno performance data is printed out and either hand-plotted or manually keyed into other software located on other computers located off the test site. As long as the performance data files are not too voluminous, this setup has proven adequate.

The Rosemount emissions equipment was originally located within the cell control room, outputting directly to a separate PC. Data could be recorded digitally on disks for plotting at other locations, or manually read directly from the analog gages on the bench front panel (which inherently provides an averaging function). The original emission hookup used a 10-foot heated (300 F) sampling line, with a residence time under one second. The engine/dyno operator was close to the emissions bench operator, thus, control and coordination was convenient. The five original data channels included carbon dioxide (CO₂), carbon monoxide (CO), unburned hydrocarbons (UBHC), oxides of nitrogen (NO_x), and oxygen (O₂). A sixth channel for sulfur dioxide (SO₂) has recently been installed and has been used in the complementary turbine program.

Considering the manual recovery of dyno performance data, and the convenient averaging function of manually reading the emissions gages, manual data acquisition has been the preferred procedure in this facility to date.

2.4 Test Personnel and Qualifications

The tests are conducted under the supervision of a faculty member who is also an experienced professional engineer with 20 years' industrial service in aerospace / defense engineering before joining the faculty at Baylor. His work history included a variety of field test and development activities with propulsion items, fuels, explosives, and hazardous materials.

...

The engine / dyno operating crew consists of a minimum of two persons: the supervising faculty and one of the mechanics available at the test site, which is at Baylor's flight operations hangar at the TSTC airport. These mechanics are fully-qualified and certified A&P's. Using at least two persons in the cell insures maximal safety.

The emissions equipment is maintained and operated by a qualified student worker. This person is fully trained in the calibration, data validation, and instrument maintenance procedures. Only one person is required at a time to operate this equipment.

2.5 Relocation of the Emissions Equipment

On a related project, a mobile turboprop test stand facility has been constructed on the rear of a medium truck. This installation includes a larger control cabin, with better space for the emissions equipment. The emissions bench was moved to this self-contained unit, and re-equipped with a long (100 ft) heated sampling hose. The latest testing in the dyno facility utilized this new arrangement. The 100 ft sampling hose has a longer residence time (about 3 seconds max) than the original 10 ft line, but this has not proven to be a problem with the non-transient tests. A data-logger based, PC-compatible emissions data acquisition option has been added to the new truck installation on the turbine program.

3. INITIAL EFFORTS

3.1 Description of Electramotive Inc. Advanced Digital Electronic Control (ADEC)

It was initially intended to outfit the test engine with an ADEC system from Electramotive, Inc., of California. This system has the capability to simulate the fixed timing / starting retard characteristics of the original magneto ignition system, then easily add custom timing curves for each fuel from that baseline by simple software changes. The ADEC included electronic (solenoid-type) multi-port, individually-timed fuel injection. It allows approximation of the characteristics of continuous mechanical servo injection by timing the pulses slightly ahead of intake valve opening, so as to produce the

puddling characteristic continuous systems inherently produce. From this baseline, pulse train shaping and timing improvements could be customized for each fuel in this particular engine.

The ADEC was installed on the test engine and underwent considerable shakedown activity. The system featured dual ignition capability with four double-ended coils each feeding two cylinders simultaneously (at ignition on one and during exhaust on the other). Timing control utilized both crankshaft and cam position sensors. The crank sensor featured a dual Hall effect sensor rigged to provide extreme precision angular sensing. The cam sensor was a standard single Hall unit used to differentiate the number-one cylinder firing event from among the other crank sensor pulses. Of two possible injector mount locations on the intake manifold pipes, the one closer to the intake valve was chosen to enhance spray breakup and atomization at the expense of a little settling time for the vapor mixing process.

3.2 ADEC Installation Shakedown Problems

Persistent problems with the ADEC system were encountered during shakedown activities, some of which have not yet been resolved. The first serious problem encountered was a failure of the crankshaft position sensor to respond as specified in bench response tests. Results on the same sensor differed between tests conducted at the manufacturer's facility, and similar tests conducted in the RAFDC's test cell. Part of the trouble was traced to the diagnostic tool used in the bench tests. Although built as specified by the manufacturer's drawings, the results differed until the manufacturer revised this device at his facility. The operation of a second plain Hall sensor was adopted as a backup to the more precise dual latchup sensor provided by Electramotive.

One problem never resolved relates to the fuel injection timing. It proved reasonable to suspect that the injectors and wiring, as supplied and installed, were delivering fuel co-timed with the ignition event rather than the intake valve opening event one stroke earlier. Resolving this issue was postponed when it was decided, for the time being, to revert to the backup all-mechanical (original-equipment) servo injection configuration. Solution of the problem may require a new injector wiring harness, and possible rerouting of the fuel lines as well. Some diagnostic instrumentation not currently installed will also be required to conduct this effort.

One problem positively identified was a spark plug wiring installation not in accord with the actual engine firing order. The cause for this may, or may not, relate to engine hardware items from a left hand engine supplied to Electramotive as backup information for the design customization effort. The actual test cell engine is right-hand, and the manufacturer was advised of this. All documents and design drawings supplied by Electramotive reflect a right hand design except the physical firing order of the actual harness, which seems to be left hand. The solution requires a re-work of the entire ignition harness. This was not done since it was decided to revert to the original engine controls in the interest of time.

3.3 Testing Capabilities in the All-Mechanical Configuration

At this point in the project, it was more important to acquire timely baseline data in the modified mechanical configuration than it was to solve the ADEC problems. Furthermore, the first-level control improvements contemplated were simple fixed-point timing adjustments easily investigated with the stock magnetos. Accordingly, the original equipment was restored.

Baseline configuration data with all three neat fuels (aviation gasoline, ethanol, and ETBE) including emissions was considered to be top priority. Such testing would require no deviations from the stock timing and the modified servo adjustments. Following this test phase, the next most important potential improvement was thought to be timing adjustments to take advantage of the higher octane ratings of the ethanol and the ETBE relative to the baseline 100-octane grade aviation gasoline.

The nominal spark timing of the magneto-equipped engine is +25 degrees before top dead center (BTDC). It features a starting retard to about 0 degrees BTDC to prevent kickback, which then jumps to the full advance setting as soon as the engine picks up to idle RPM. Advancing this setting experimentally for a test fuel will affect the starting retard, but not enough to render it dysfunctional for that purpose. It was this baseline setting that was used in the first- and second-round comparative testing. Therefore, for these tests, the only deviation from the all-stock IO-360 configuration was the modified injection servo and injectors.

Later tests will investigate other changes intended to improve performance of the alternate fuels. The first will be timing advance. The concept for defining timing adjustments calls for determining the margin between stock timing and the onset of detonation, while operating on gasoline at a suitable single-point test condition. The timing settings for onset of detonation with ethanol and ETBE would then most likely be further advanced, reflecting the higher octane ratings of these fuels. These settings would be reduced by the margin previously obtained with aviation gasoline, to determine recommended timing settings for the neat alternate fuels. Compromise timing settings for blends would be a future research subject dependent on which blends might be considered suitable.

4. FIRST-ROUND COMPARATIVE TESTING

4.1 Fuels and Properties Comparison

The three fuels tested in the first round (all-mechanical engine control) were grade 100LL aviation gasoline (per ASTM D-910), Fuel Grade Ethanol (ASTM D-4806), and commercial ethyl tertiary butyl ether (ETBE). All three are liquids at ordinary temperatures, and each has unique properties to recommend it as a neat fuel. For purposes of use as piston engine fuels, technical issues in several areas must be addressed: detonation resistance, vapor lock, cold starting, materials compatibility, and mixture metering.

Aviation gasoline is a well-characterized mixture of petroleum compounds that must meet specifications for a number of properties (see ref.1). ETBE is a “pure” commercial chemical. Fuel Grade Ethanol is a single compound, C₂H₅OH, denatured by the addition of unleaded gasoline or a gasoline precursor, at about 5% by volume. It is commonly used as a blending feedstock for gasoline at the refinery. In some ways it behaves like the pure chemical ethyl alcohol, and in other ways shows the effects of the blended denaturant. Most notably, the gasoline component affects the Reid vapor pressure test (a slight increase), and the shape of the distillation curve. This curve is essentially flat at the normal boiling point, as would be expected for a pure substance.

4.1.1 Detonation Resistance

Octane number is used to gauge detonation resistance. To determine octane rating four standard tests are used: motor octane number (MON, see ref. 2), research octane number (RON, see ref. 3), aviation lean rating (AvLean), and aviation rich supercharge rating (AvRich, see ref. 4). The pump grade (PON) or antiknock index (AKI) of

automotive gasolines (ASTM D-439) is computed as 0.5 (MON+RON). The AvLean test is no longer actually used. Instead, AvLean rating is obtained from the MON rating using ASTM D-2700 Table 8. For MON between about 83 to 100, AvLean and MON differ by less than 0.5 octane number. Above 100, they diverge quite rapidly, with AvLean being reported in accordance with a performance number definition, not an octane number definition. The AvRich rating is a separate test. All use the same basic CFR test engine, but differ in procedures and test conditions, and the AvRich test uses a supercharger.

Some low-compression, unsupercharged aircraft are approved to burn automotive unleaded regular gasoline under a Supplemental Type Certificate (STC). Therefore, a complete understanding of all four octane tests and both sets of gasoline properties is important.

Aviation and automotive gasoline octane data are widely available in their respective test definitions. They share MON in common by the Table 8 correlation. Since for most automotive gasolines, MON and RON differ by 8 to 10 octane points, MON can easily be approximated by subtracting about 4 to 5 points from the PON (or AKI). The civil grade number (or the first number in a two-number military grade designation) for aviation gasolines is the AvLean rating. This correlates directly to MON.

The aviation gasoline used in our tests was civil grade 100LL, which meets or slightly exceeds an AvLean rating of 100, and an AvRich rating of 130. It has a slightly lower lead content than the grade 100 it replaced, which is in turn equivalent to the military 100 / 130 grade. The corresponding MON is very close to 100.

ETBE data are available from the manufacturer in automotive format (MON and RON). The manufacturer of the material used in these tests reports MON as 98-104, and RON as 116-120. The MON would correspond to an AvLean rating of at least 98, using the Table 8 scaling procedure.

A range of octane data can be found in the literature for ethanol. Most of them are MON and / or RON. Often, the values quoted seem to represent the views of whichever interest funded the test, and the issue can be very partisan. The data reported here are from work done by Southwest Research Institute (SWRI) of San Antonio, Texas, for the U.S. Department of Energy (DOE), and seem consistent with Baylor's ground and flight test experience, and with field test experiences reported by others investigating alternative fuels in ground vehicles. SWRI reported ethanol MON as 111.7, and RON as 115.9. Using the Table 8 correlation for AvLean from MON, we estimate AvLean as just off top-of-scale at 131. However, this scaling of ethanol (or ETBE) MON to AvLean with Table 8 may be an improper procedure, since the correlation was originally defined only for gasolines.

The predecessor to the current ASTM specification for the AvRich test was an Army-Navy (AN) specification: AN-F-18a. They share the same definitions, procedures, and equipment, and the very same scaling table for rating test fuels against reference blends of iso-octane and tetraethyl lead (TEL). The top of the defined scale for the AvRich test is performance number 161 at some 6 cc of TEL per gallon of iso-octane. In March of 1944, tests of neat ethanol to this specification, performed by Allison, revealed non-detonability while some 10 cc TEL per gallon of iso-octane would detonate at the same conditions. Therefore, ethanol appears to be non-detonable in the AvRich test to conditions far above top-of-scale for the test.

4.1.2 Volatility: Vapor Lock and Cold Start

Vapor lock and cold-starting are not only related to vapor pressure but are also closely related to liquid specific heat, latent heat of evaporation, liquid thermal conductivity, and boiling point (or boiling range). Of the latter, boiling point and latent heat of evaporation may be the most important. All are measures of volatility. Decreasing vapor pressure decreases the likelihood of vapor lock but increases the difficulty of starting, particularly in cold weather.

Reid vapor pressure refers to a specific test at a specific temperature (100F). Gasolines with different distillation curves will respond to this test slightly differently, so that vapor lock comparisons in real installations sometimes do not correlate exactly with Reid vapor pressure. However, if the distillation curves are similar enough, the Reid test will indeed work as a predictor of vapor lock susceptibility.

Pure substances such as neat ethanol, or ETBE, have a true vapor pressure, and a single boiling point, not a distillation curve. However, they will respond and produce a reading in a suitable version of the Reid test, which may not correspond exactly to the results for a distillate mixture like a gasoline.

True vapor pressure can be defined as the initial vapor pressure at start of boiling, whatever that temperature might be, and not 100 F, as in the Reid test. Such data have been published for a variety of piston and turbine aviation fuels. With gasolines, there is no specification, however; only controls on the variation in distillation curves, and on the Reid vapor pressure results.

Blends of these fuels can produce even more complicated results. For example, the Reid test result obtained for a blend of automotive gasoline with ethanol is not linear: there is a

peak RVP at about 10% ethanol, which actually does correspond to the field observations of vapor lock susceptibility in ground engines. Conversely, those same field observations indicate that the low-RVP blends are not necessarily substantially more immune to vapor lock (although the neat alcohol fuels appear to be very resistant to vapor-lock). Clearly, one must examine all the relevant properties (not just a vapor pressure measure), and combine this with some experimental data, before successfully predicting vapor lock tendencies.

The specification of vapor pressure for the customary gasoline-based fuel actually depends on a complex tradeoff among the several volatility properties, typical engine installation designs, and typical operational requirements, as well as economics and availability of the fuel. Without the altitude vapor-lock volatility constraint, automotive gasolines have a substantially higher Reid vapor pressure specification than aviation gasolines, and a different (wider-cut) distillation curve. They also have a reputation for easier cold starting and poorer long term storage stability.

Vapor pressure is also related to the concentration of the fuel vapors in the air, which has to lie in a flammable range for ignition ever to occur. In the case of both ethanol and ETBE, vapor pressures are simply too low to provide practical unaided cold start capability. Rerouting the primer pump of an aircraft engine to a separate start fuel canister containing gasoline has proven to be the most practical way to address this difficulty, since the engines were originally designed to start and run on such gasolines. The benefit of the start canister approach is that there is no longer a tradeoff to be made between vapor lock and cold start with these fuels.

4.1.3 Materials Compatibility

Materials compatibility refers to the prevention or alleviation of fuel-induced corrosion or solvent-attack effects upon fuel system and engine materials, and related or adjacent exposed structures. The gasolines and ETBE are both non-polar solvents. There is very little data available on neat ETBE, but experience and testing at Baylor indicate it can generally be tolerated by anything already rated for exposure to gasoline. Ethanol is a polar solvent of harsher characteristics, although not nearly as corrosive as methanol. The two most noticeable effects (ref. 5) on modern civil aircraft systems are (1) rapid oxidation corrosion of unprotected aluminum items exposed to ethanol, and (2) the formation of aluminum hydroxide by exposure of (even coating-protected) aluminum items to ethanol vapor. This second effect occurs only in narrow passages after fuel has evaporated, which occurs only after sitting idle for a very long time. (Long disuse would be bad practice even with gasolines.)

Bare or clad aluminum components can be protected from the liquid-phase oxidation effect by a corrosion inhibiting additive in the fuel known as DCI-11, or by a simple coating on the parts. Most ethanol producers now add DCI 11 to their product to prevent corrosion to the aluminum floating roofs in storage tank.

4.1.4 Mixture Metering

Mixture metering calibration depends upon several engine characteristics, and most directly on the fuel stoichiometry. Stoichiometry is usually expressed in terms of the theoretical air fuel ratio, which is the ratio by mass of air to fuel for which there is neither excess fuel nor excess air. This would assume all carbon in the fuel is burned to CO₂, and all hydrogen to H₂O. For nearly all petroleum distillates without any blended oxygenates

this averages quite close to 14.7. The stoichiometric ratios are lower for ethanol (9.00) and ETBE (12.2).

There is a range of air / fuel ratios with a given fuel in engines that are flammable; outside this range the engine will not run. Many perceive that metering is done in proportion to heating value, but this is incorrect. Since for most popular fuels and alternative fuels, heating value and stoichiometry are nearly proportional, the misperception persists. In fact, metering must be done to maintain a flammable mixture ratio that is most closely related to the air / fuel stoichiometry. The specifics of that relationship to stoichiometry depend most strongly on the design of the in-cylinder combustion pattern. It is throttle setting that must be adjusted to achieve a given level of power output in response to metering, to heating value, and to the efficiency of the engine-fuel combination. It is range that would be in proportion to heating value if all these other variables were equal, which they are not (as the data herein quite clearly show).

The modified RSA-5 injection system is set up from the factory to handle mixture ratios as low as 6.0 air / fuel (by mass), with the air at normal density. With gasolines, this is more than twice the ideal fuel needed for a given mass of air, and is actually too rich to burn (about 30% excess fuel is the rich limit with gasolines, depending upon the individual engine design). With ethanol at 9.0 stoichiometry, the design 6:1 mixture is about as rich as one should attempt, at about 50% excess fuel. (Ethanol will burn with more excess fuel than will gasolines.) The servo unit was set up to accommodate a 50-50 mixture of ethanol and methanol (7.5 stoichiometry), for which 6:1 is about 20% excess fuel, enough to compensate for cold air density effects and still be slightly rich in order to produce a power mixture, but not risking that the rich flammability limit be exceeded.

ETBE has a stoichiometric air/fuel ratio of 12.2, intermediate between ethanol and the gasolines. Determining experimental mixture flammability limits is one obvious objective. Another would be to determine whether the servo mixture modifications are really necessary with ETBE, since its stoichiometry is not far from the gasoline baseline. (Such modifications are already known to be necessary with ethanol.)

4.1.5 A Comparison of Selected Basic Properties for the Test Fuels

fuel:				
property	units of measure	aviation gasoline (100 LL)	ethanol (fuel grade)	ETBE (pure)
specific gravity	--	.69-.79 .7893	.7456	
Reid vapor pressure	psig	5.5 to 7	2.3	4.3
heating value (lower)	BTU/lbm	18,700	11,700	15,500
stoich. air / fuel	--	14.7	9.0	12.2
latent heat of evap. (at boiling)	BTU/lbm	148 +/-	378	134
boiling point (range)	deg F	106-316 +/-	173 +/-	163
10% recovery point	deg F	150	--	--
MON	--	100 (min)	111.7	98-104
RON	--	N.A.	115.9	116-120
AvLean	--	100 (min)	>131 (est.)	98 min
AvRich	--	130 (min)	nondetonable	N.A
ability to absorb water	vol %	nil	0-100	0.5

Notes:

1. N.A. means not available
2. Data obtained for neat ethanol in March 1944 showed nondetonability at conditions beyond top-of-scale (AvRich 161) in the military version of the rich supercharge test

4.2 First-Round Testing Procedures

The initial round of tests was conducted before it was determined that the oil cooler could draw too much water away from the dyno absorber servo-control. Consequently, these tests were conducted in the all-manual mode, similar to the way such testing was done earlier this century with the Prony friction brake setup. Load was manually adjusted to match RPM and throttle setting, which is a slow and difficult process. The engine was mapped in the sense that a considerable spread of RPM's and manifold pressures (throttle settings) were investigated, at two appropriate mixture settings.

The control variables associated with an aircraft engine include: RPM, throttle setting and mixture setting. The latter is set manually in flight for different flight conditions. Mixture settings are determined by observing maximum RPM or by an empirical decrement of exhaust gas temperature below peak.

A typical first round test profile began and ended with engine-off reference points recorded from the dyno. This ensured that calibrations were not lost during the run. Points were taken at cold and warm idle, the difference being that warm corresponded to cylinderhead temperatures above 240 F. Once 240 F was achieved, testing could proceed.

The low-MAP sweep encompassed 1700, 2100, 2500, and 2700 RPM settings, all at 12 inches of mercury (in Hg) manifold vacuum (about 17 in Hg MAP at the test cell elevation). Dyno and emissions performance were recorded at every point.

There were two mid-MAP sweeps; one leaned, and one peaked to power mixture. These encompassed 2100, 2500, and 2700 RPM, but not 1700. (Higher MAP at lower RPM is not advisable.)

The high-MAP sweep was only run peaked to power mixture. This encompassed only the 2500 and 2700 RPM speeds, for the same reasons that the mid-MAP sweeps were truncated. This was followed by a cooldown at rich idle.

The final investigation included in the run looked at the range of feasible mixtures at a typical maximum cruise condition. 2400 RPM would be set at a nominal 25 in Hg MAP (4 in Hg vacuum), and data would be taken at peak-RPM power mixture, at as rich a mixture as possible consistent with smooth performance, and at as lean a mixture as possible.

Following this, the engine would be allowed to cool at rich idle, and then shut down.

At each test point, 3 dyno performance points were obtained. This allowed repeatability to be assessed before manually averaging the data. The emissions-gage readings are already inherently time averaged.

4.3 First-Round Results Obtained

A practice run was made for dyno performance only using neat fuel-grade ethanol from the large external fuel tank. This was followed the same day by an ethanol run complete with emissions data acquisition. Since dyno performance for the two runs was very similar, techniques and test settings appeared to be repeatable enough to proceed, so that the emissions results obtained in this way would be valid.

Complete runs (with emissions data) were made with aviation gasoline (specifically grade 100LL), and with neat ETBE. On aviation gasoline the feasible-mixture test at the cruise setting showed a narrower usable range of mixtures. ETBE provided the narrowest (but perfectly adequate) range of feasible cruise mixtures of the three fuels.

The most sensitive of the emissions channels (NOx) was lost during the ETBE run due to a dirty filter. This necessitated a retest later. A comparison of all the behavior and data obtained during this round of testing indicated some instrumentation and equipment problems. Of most concern was an apparent interaction between the fuel flow transducer and the boost pump power. There were also some secondary instruments that did not read correctly. These problems, being noncritical, went unresolved at that time.

In a subsequent run, the engine was retested with the (modified) servo and stock-size fuel injectors (at the cylinderheads). Both aviation gasoline and ETBE were tested, in that order. The intent was to approximate a "stock" (unmodified) system to determine whether aviation gasoline performance was preserved under the ethanol modification. Based on previous experience, the criteria for a sufficiently warm engine for test purposes was revised downward to 200 F CHT. The data with aviation gasoline indicate that the same performance was indeed obtained.

During this run, when ETBE was tested, performance levels were poorer than expected, indicating that very rich mixtures had to set in order to run at all. It was not positively determined why this was so. The interaction of the modified servo with the "stock" injectors may have been unfavorable for lower-stoichiometry fuels, or (more likely) there may have been an unrecognized engine malfunction.

It was concluded from these data that (1) ETBE needed to be re-tested in the modified engine to obtain the lost NOx data, and (2) the unmodified servo / ETBE attempt was a no-test, and needs to be tested again with a true stock servo and injectors.

The dyno performance data from this first round of testing was hand-averaged and hand-plotted. The emissions data were averaged by manually reading the gages, and hand-plotted as bar graphs. The entire package of these hand-plotted results was first put together and presented at the FAA Designee's Conference in Arlington, Texas, on June 4th, 1998. That package is included in its entirety as Appendix A.

Selections from the data were incorporated into a paper (ref. 6) presented at ISAF XII, Beijing, China, September 1998, which focused more on the final assessment of relative performance and emissions of the three fuels, than on the details and actual history of the testing.

4.4 First-Round Conclusions Drawn

The power performance of the engine on each of the three fuels proved repeatable, in spite of the mixture setting uncertainties, as fig. 4.1 shows. Dyno-measured brake power is plotted vs RPM at full throttle, for the rich power mixture conditions. The three fuels correlate quite well. The power readings as plotted have been corrected to standard air density conditions. In this way, a direct comparison can be made to the published rating for this engine (180 BHP, or 134 KW, at 2700 RPM, full throttle, rich power mixture, sea level standard). The effects of the inlet air flex hose friction losses can be seen as a 4 BHP (3 KW) loss in the Avgas data. The two alternate fuels actually significantly improve power production at otherwise identical conditions. This same effect was observed at about the same magnitude (5-10% improvement in mid power band) in a ground vehicle road test trial between ethanol and autogas done at Mankato State

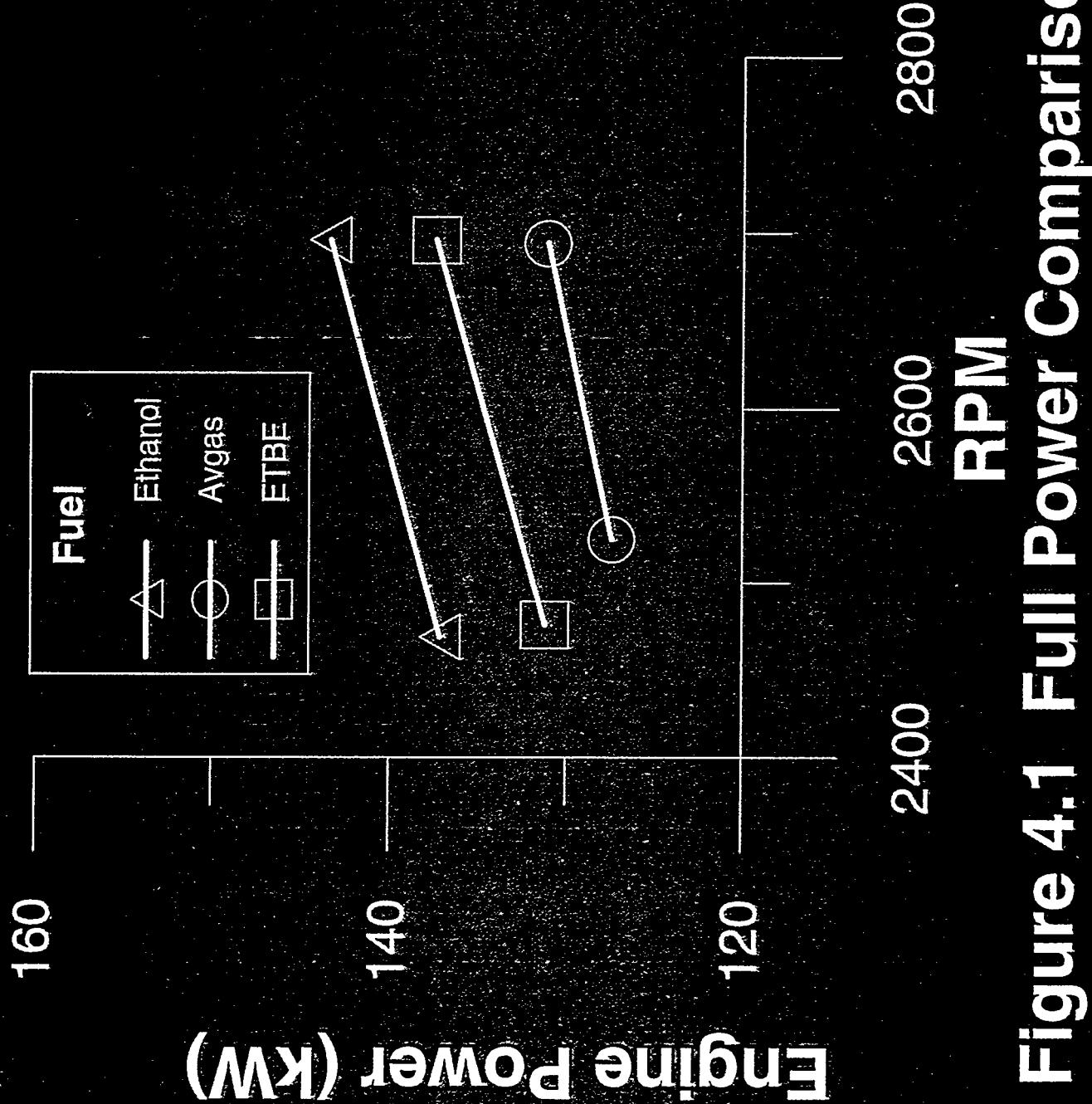


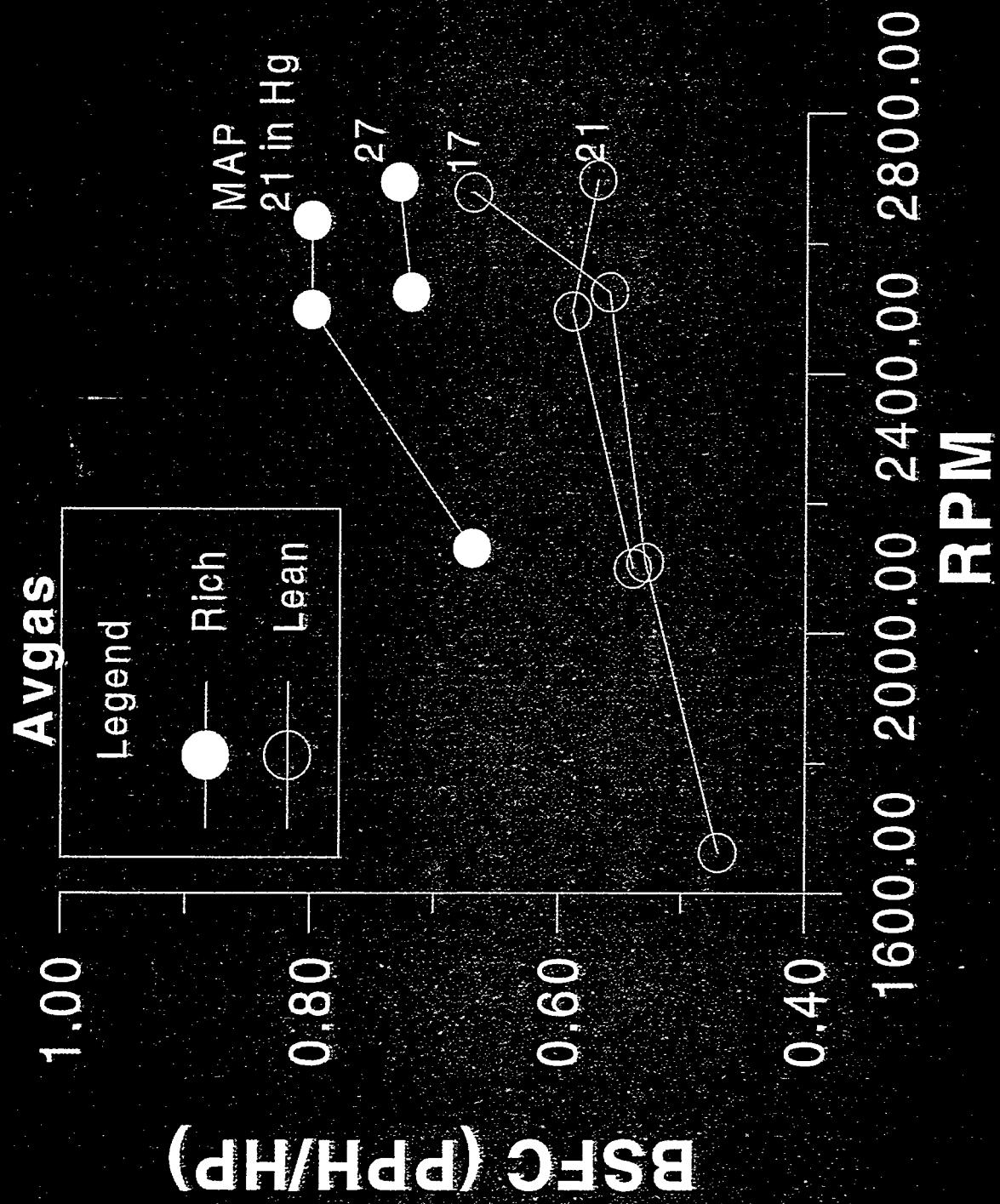
Figure 4.1 Full Power Comparison

University (ref. 7). Selected data from a 1995 paper are included in Appendix C. A similar power increase was also found in the static thrust testing of an ethanol IO-540-equipped Piper Pawnee aircraft.

As fig. 4.2 shows, fuel consumption figures have been affected by the difficulties with repeatable mixture control. The effect is less with Avgas and ethanol, since a semblance of self-correlated curves is apparent, although the trends are not linear. The ETBE curves are all “knotted” together, except for the lean low-MAP sweep, reflecting the narrower feasible mixture range. The fact that these rich-mixture curves “knotted up” at about the same value of fuel consumption is fortunate: reasonably accurate conclusions can still be drawn from the data quite effectively. Precision mixture-setting procedures are necessary for very high quality.

As the power curves in fig. 4.1 show, data were successfully obtained for each fuel near enough to the power ratepoint (2700 RPM full throttle) to use those emissions data directly. These are shown in fig. 4.3 - 4.6 (along with cruise point data). Unfortunately, the NOx gage failed due to filter clogging during the ETBE run that acquired these data. This was later rectified in second-round testing. Figs 4.3-4.6 do include the second-round NOx data for ETBE.

The formation of CO₂ and NOx are directly related to higher flame temperatures, which in turn reflect higher efficiencies, if mixture and entering air temperature do not vary. Consequently, one would expect more of these emissions from the fuels that generated more power (more energy conversion efficiency). That is exactly what the full power CO₂ and NOx emissions show.



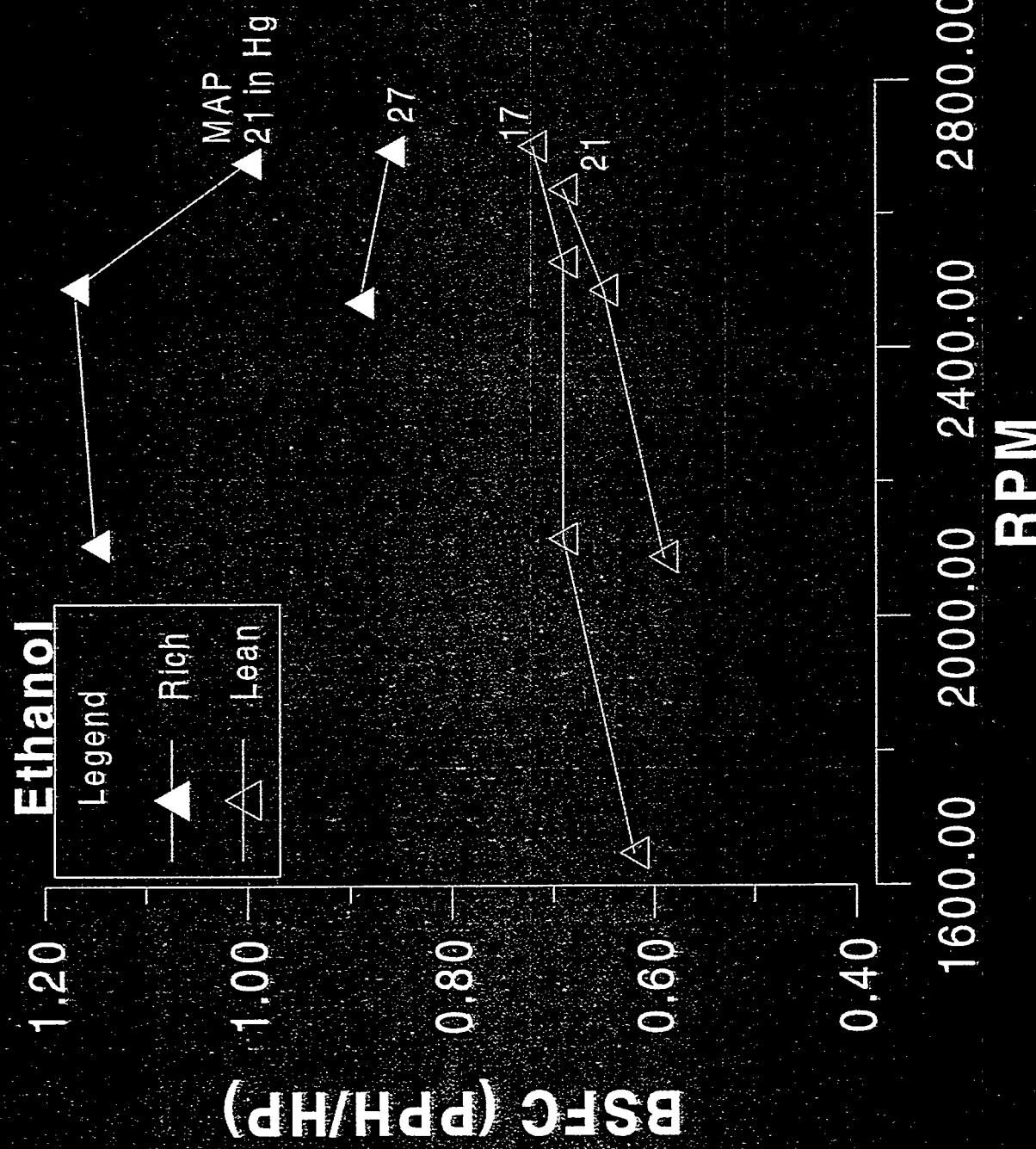
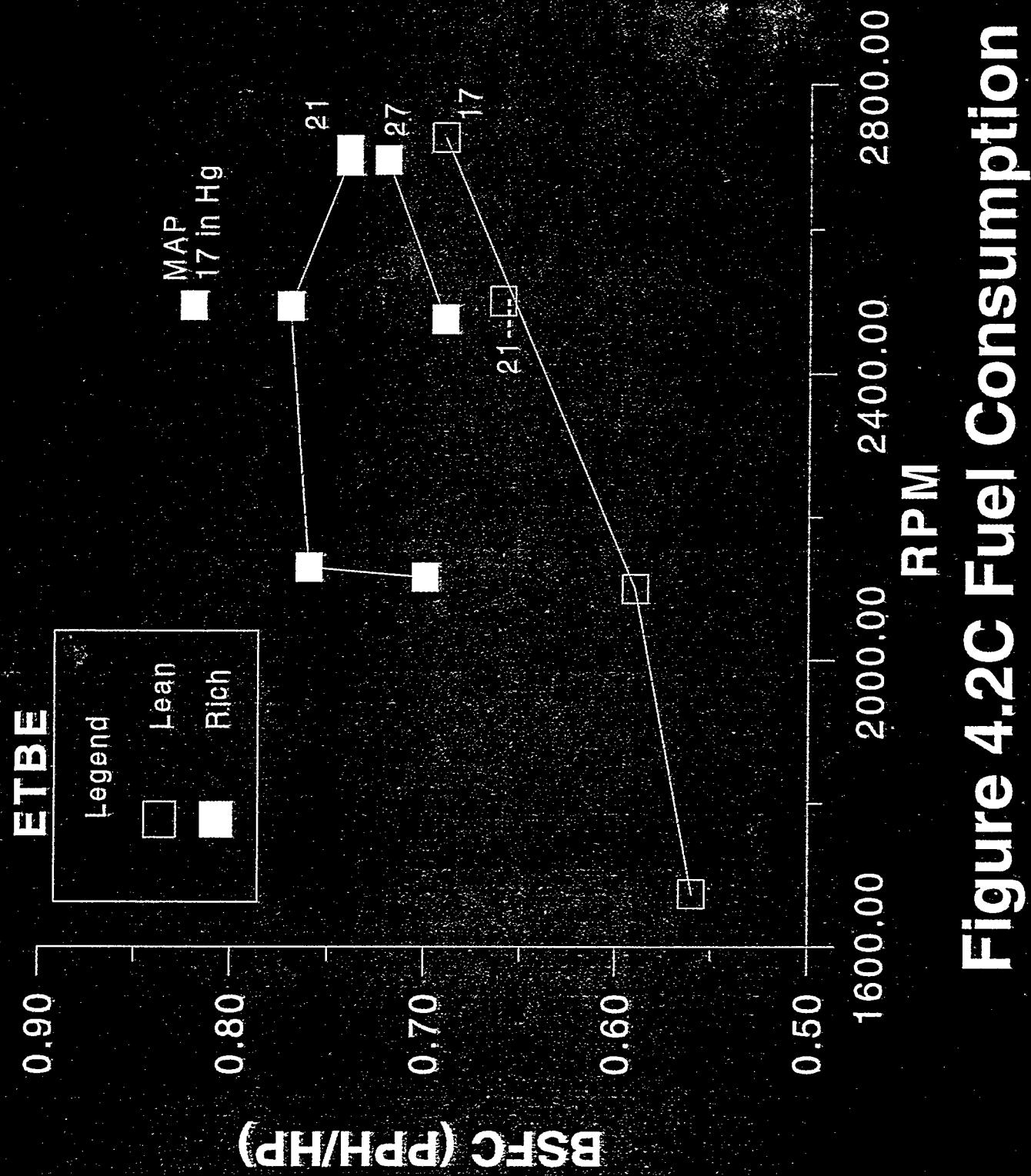


Figure 4.2B Fuel Consumption



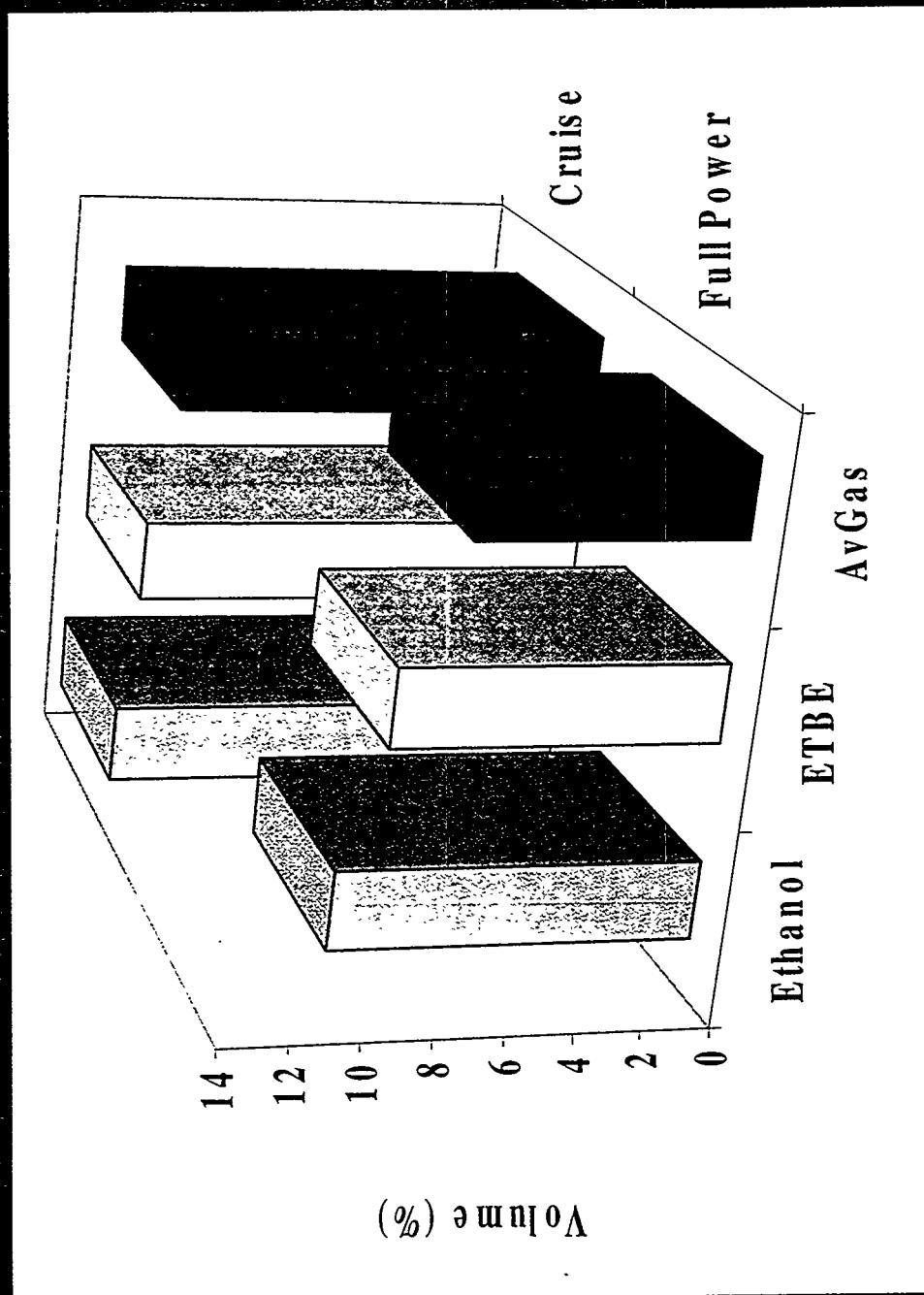


Figure 4.3 CO₂ Emissions

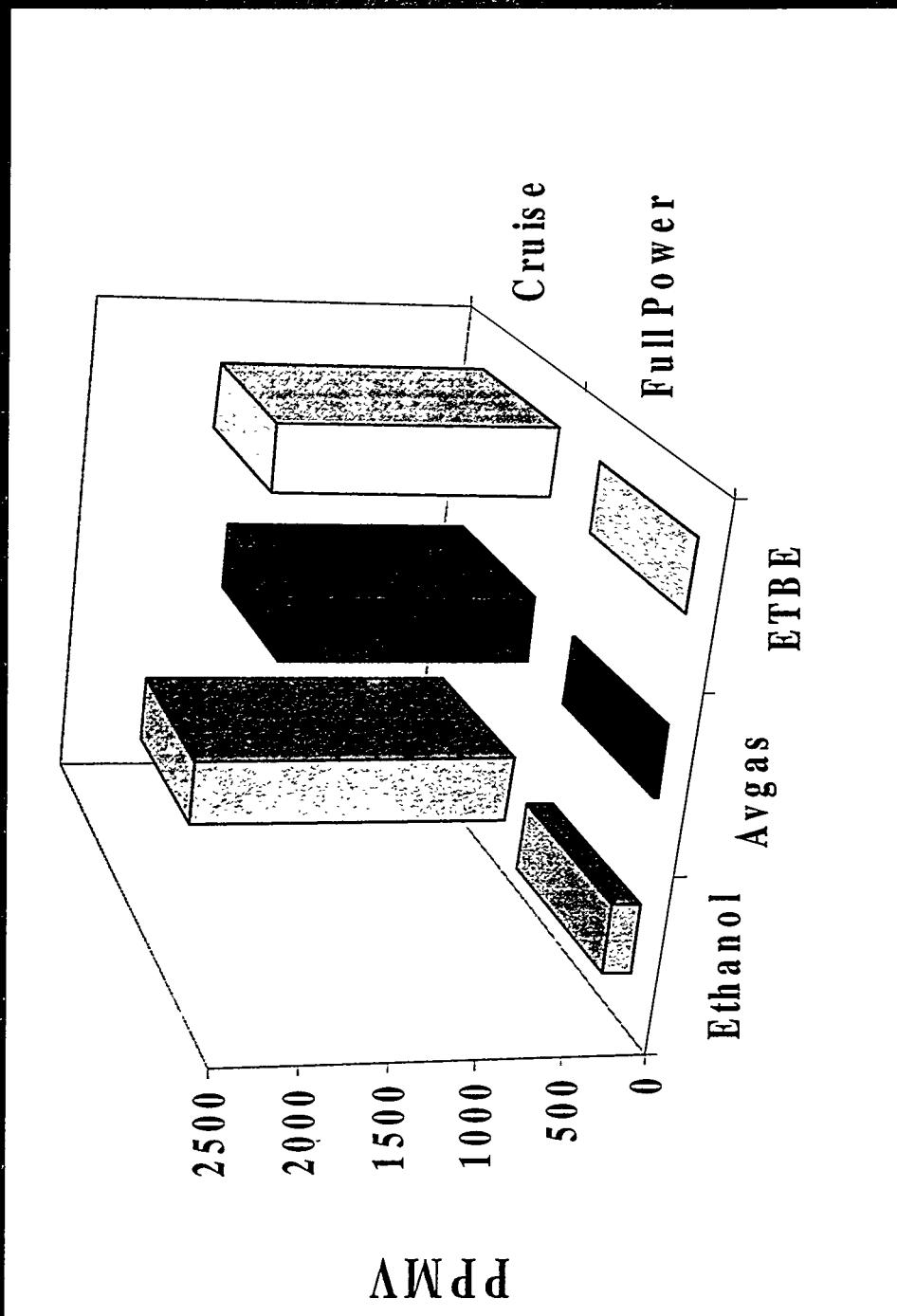


Figure 4.4 NO_x Emissions

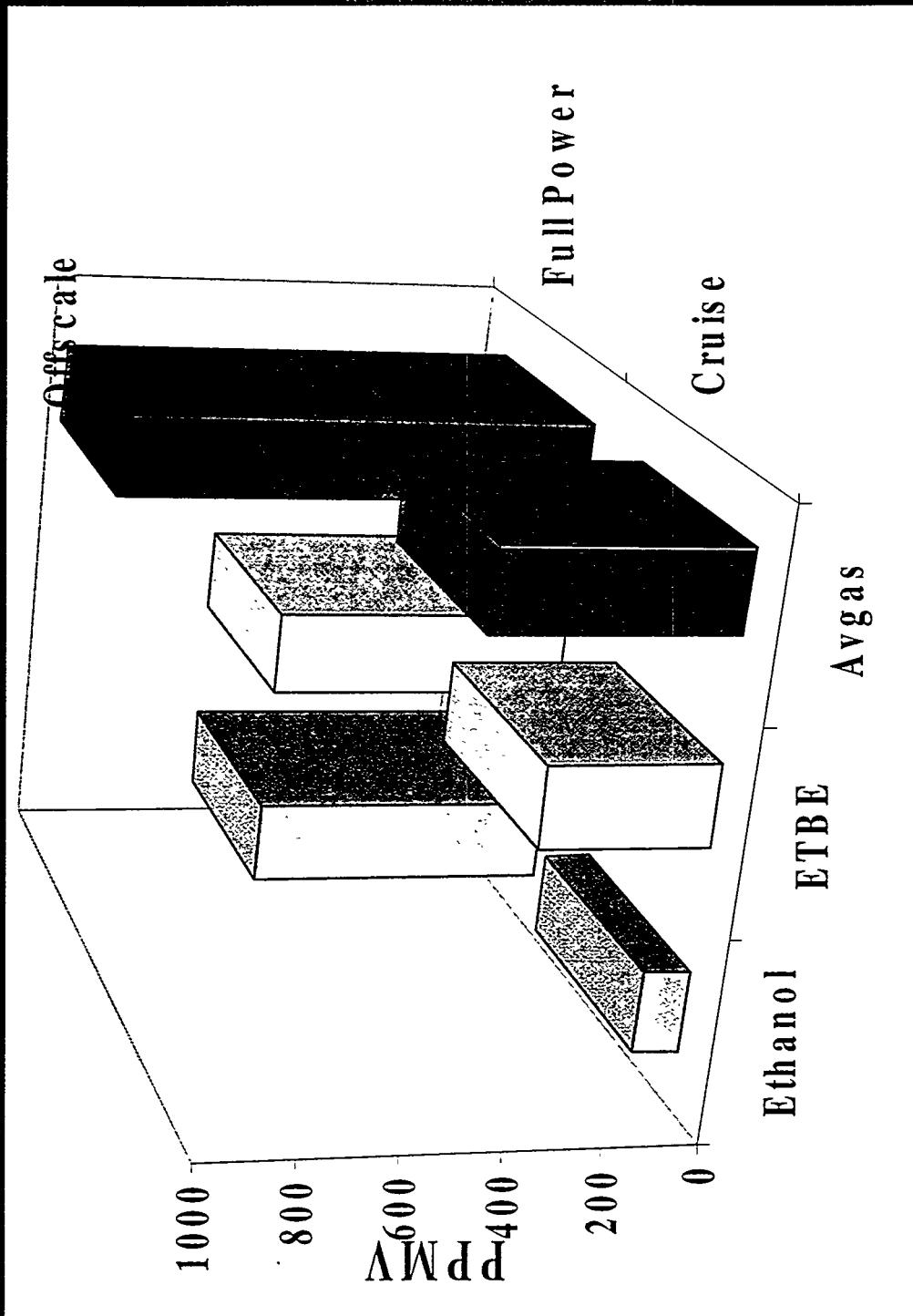


Figure 4.5 Unburned Hydrocarbons

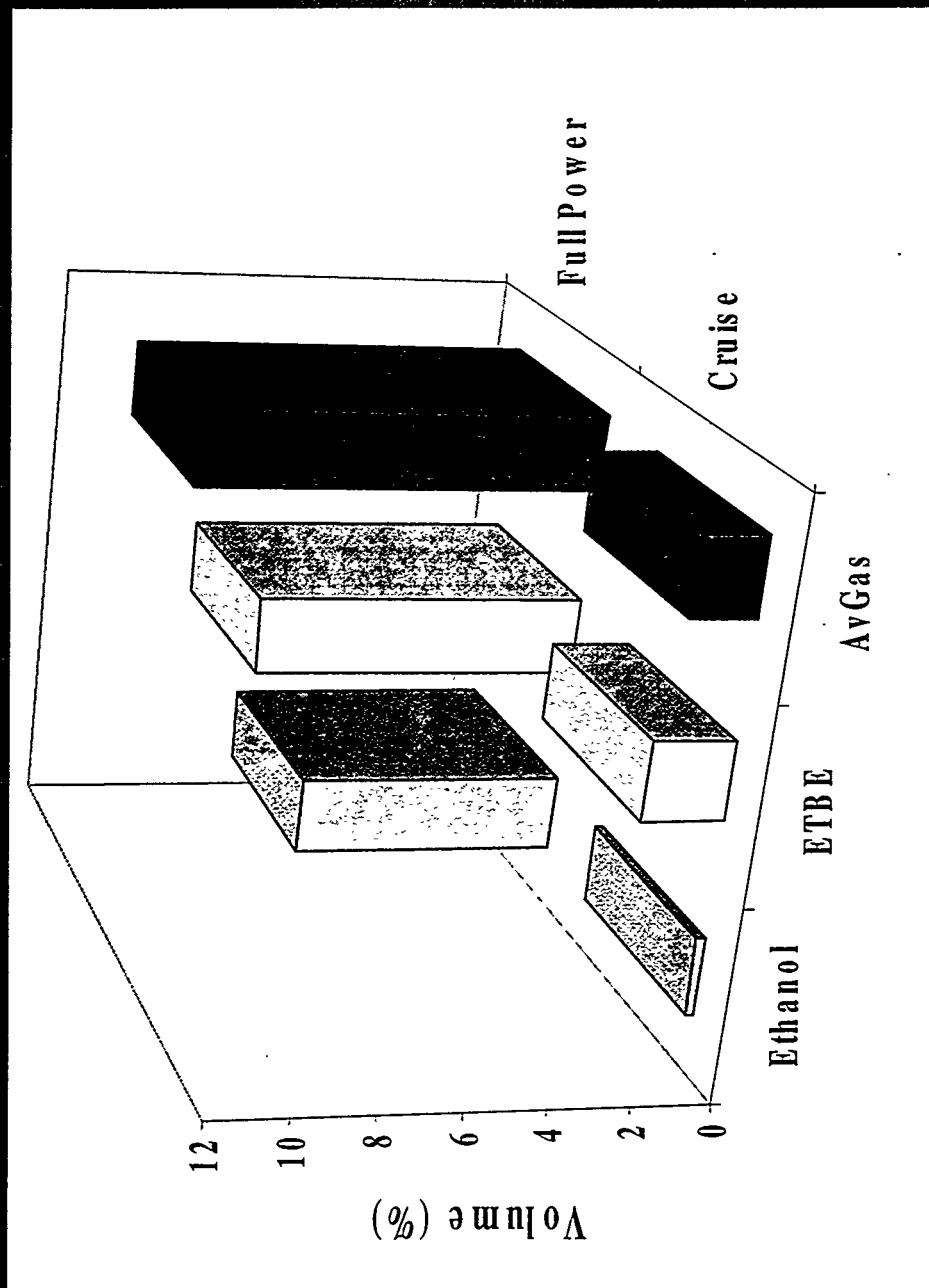


Figure 4.6 CO Emissions

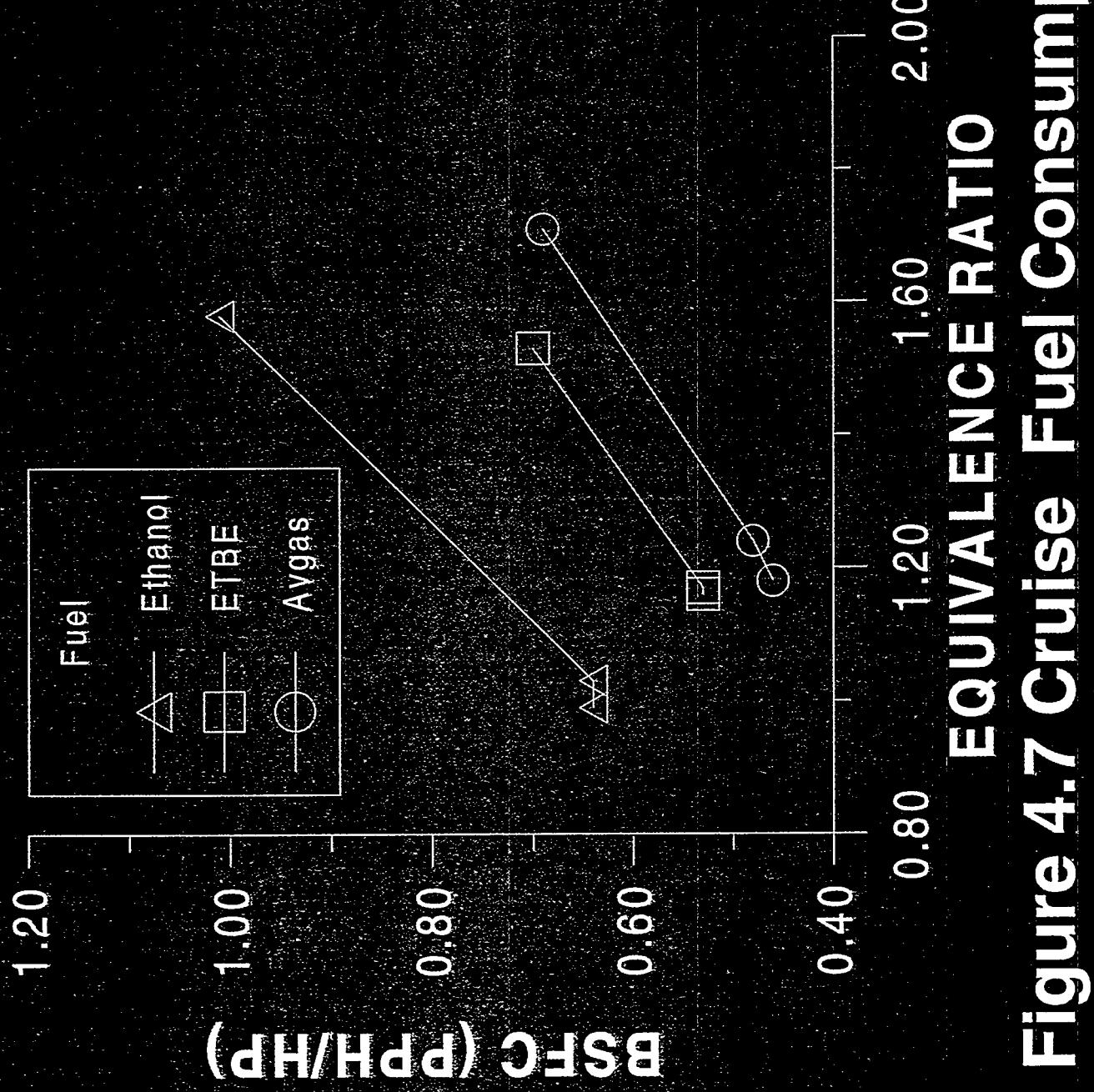


Figure 4.7 Cruise Fuel Consumption

UBHC and CO emissions are associated with lower efficiencies and consequent cooler flames. Ethanol and ETBE are more efficient and consequently produce lower emission of UBHC and CO.

The cruise test point featured a single common RPM and MAP condition, so that the remaining significant engine control variable is mixture setting. Power and fuel consumption performance for the three fuels are depicted vs mixture in fig. 4.7. Mixtures range from a rich value near rich stumble (engine almost dies) through a best lean point, to a leaned point near lean stumble. The only fuel that could actually be leaned to stoichiometric was ethanol. The other two were still rich of stoichiometry even at the lean stumble. This particular data presentation clearly shows this.

This same figure shows very similar brake specific fuel consumption performance (0.5 pph/BHP) for Avgas and ETBE at leaned cruise conditions. Ethanol BSFC is about 15-20 % higher at 0.65 to 0.70 pph/BHP. Similar ethanol performance levels were also reported in the Mankato State paper for road vehicles (Appendix C). The IO-540 data in particular average almost exactly the same BSFC values as the IO-360 data herein, for all three of these fuels.

Actual flight test data provides the most dramatic confirmation of all. Selected data from a paper (ref. 8), obtained in a Pitts S2B tested by Baylor, are included in Appendix C. This aircraft had a compression ratio of 8.5:1. The same as the IO-360. The cruise flight condition of 2400 RPM, 24 in Hg MAP corresponds very well to the lean cruise point for the IO-360 dyno tests reported herein. The flight data show optimum fuel consumption rate about 17 % higher on ETBE relative to Avgas performance. The corresponding IO-360 cruise data show BSFC 15 % higher. (Note that the heating value of Avgas is 1.23 times that of ETBE.)

As stated earlier, the flight test data on the Pitts S2B was obtained utilizing an IO-540 Lycoming with the standard 8.5:1 compression ratio. Subsequently, the engine was modified to a 10:1 compression ratio.

Testing of the modified engine was performed at Barrett Performance Inc. in Tulsa, Oklahoma. This test stand is calibrated, thus the data obtained is reliable and from an independent source. As shown in the table (Appendix C, reference 8) HP and fuel flow was recorded for various percentages of available power for Avgas, ETBE and ethanol.

While the efficiency and available power on Avgas increased with increased compression, greater gains were seen for ethanol and ETBE. Most striking was the fuel consumption comparison between ETBE and Avgas at 75% power. Here ETBE was recorded at 5% less consumption than Avgas. At 80%, ETBE and Avgas had exactly the same consumption while ethanol consumed only 11 % more fuel than Avgas. Maximum available power on Avgas, ETBE and ethanol was respectively: 300 HP, 304 HP and 316 HP.

Figs 4.3-4.6 also show the corresponding emissions data for the best-lean cruise point. Again, the second-round NOx data for the ETBE have been included for completeness. Leaned operation produces hotter flames and higher efficiencies in general, so that CO₂ and NOx are higher, and UBHC and CO are lower, across the board at cruise. Within this trend, the same trend across the fuels is evident as at full power: the two alternative fuels tend to increase NOx and CO₂ while reducing CO and UBHC, relative to Avgas. The cruise UBHC and CO emissions with ethanol are actually unexpectedly low, reflecting its unique leaned-to-stoichiometry condition during this test.

Calculated thermal efficiencies are little more speculative, considering how sensitive they are to mixture settings. Yet a comparison at full power was still possible, as shown in

fig. 4.8. In this figure, air flow rate is plotted vs calculated thermal efficiency for the three fuels, all at the full ratepoint power, rich mixture condition. As might be expected from the power levels already presented, efficiency also improves as the oxygen content increases (ethanol contains the most oxygen, and has the least heating value).

As is well-known among auto racers using alcohol fuels, there is an evaporative cooling effect that improves incoming air density for more air consumption and more power.

This

is reflected in the plot as higher air flow rate with the ethanol. The cooling effect can be correlated to fuel flow rate multiplied by the fuel's latent heat of evaporation. For ethanol, fuel flow rates are higher, and the latent heat is much higher than that for Avgas. Higher air consumption and power are naturally to be expected.

However, fuel flow rates and latent heat with ETBE are almost identical to those with Avgas, so enhanced intake cooling should not be expected relative to Avgas. Indeed, the ETBE and Avgas air flow rates are identical, and yet ETBE shows significant improvement in power and thermal efficiency over the Avgas.

The effect cannot be incoming charge cooling, so there must be a physical-chemical effect at work which also improves efficiency. It is possible that the ethanol and the ETBE are both simpler molecules without carbon chains, consequently they would burn easier and more completely when available residence times are short. (This would also result in lower soot production and a less-visible flame.) If this is true, then a part of the ethanol improvement should also be traced to this effect, and the remainder to incoming charge densification.

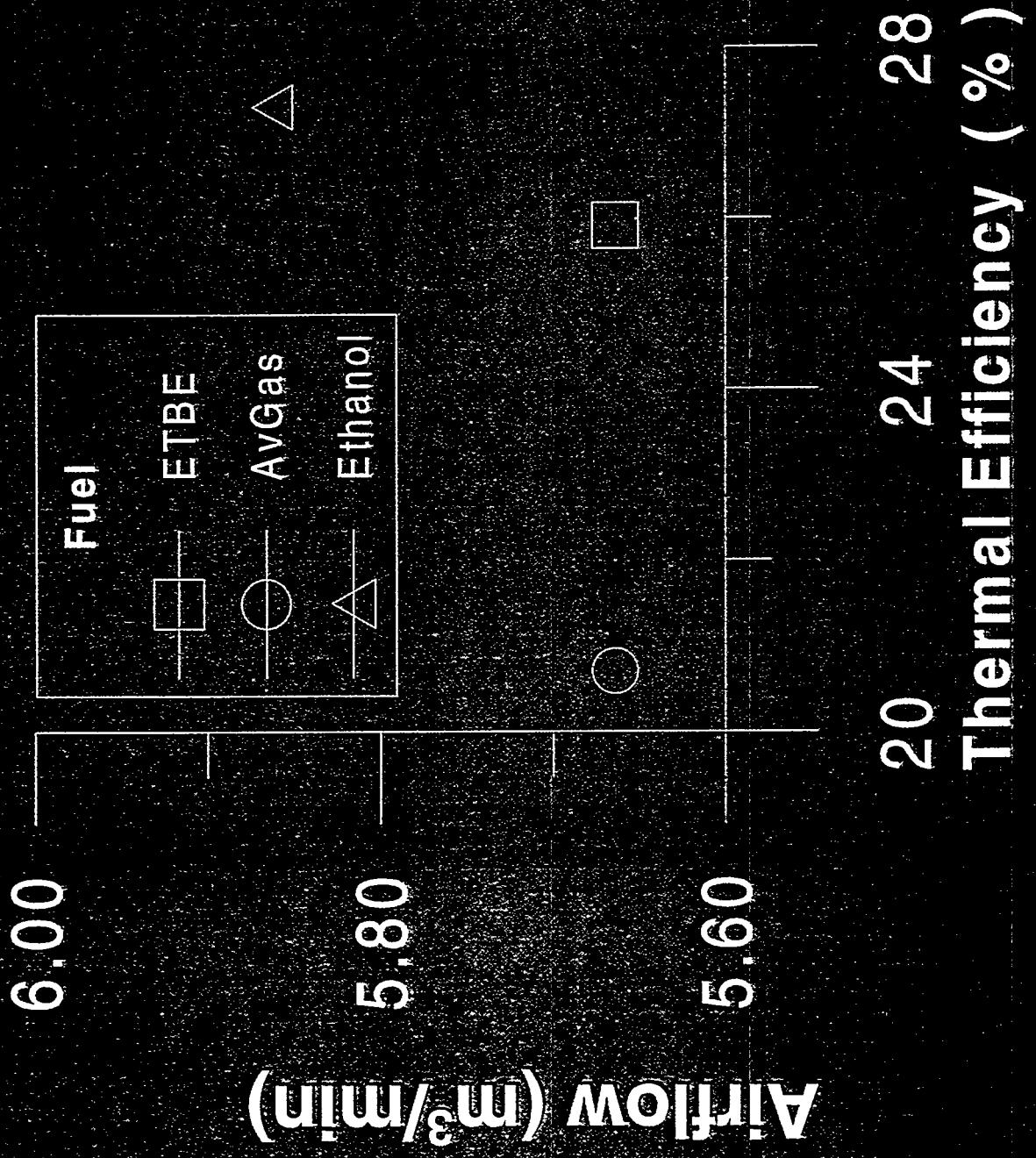


Figure 4.8 Full Power Thermal Efficiency

Provided this effect can be repeated and confirmed, it is a new result. Uncovering it required the unique combination of fuels actually tested: one (ETBE) with the relative cooling effect zeroed by equal evaporative cooling rates as compared to the Avgas.

One should be very cautious about quoting percentage changes or improvements to be expected, based on these data. There are uncertainties associated with the mixture procedures used in the testing. These results need to be tested for repeatability. However, this effect does appear to be real, based on the data available to date.

Efficiencies are higher with ETBE and ethanol than with Avgas. This shows in the fuel flow rates and specific fuel consumption data at both cruise and at full power: fuel flows are not higher with the alternative fuels in proportion to the lower heating value. The fuel flow increase (and expected range reductions) are less than energy content would indicate. This effect is stronger at full power than at cruise, and that outcome may relate as much to the power mixture ER's and part-load throttle losses as to anything else.

Support for the physical-chemical explanation of the higher efficiencies with ethanol and ETBE can also be found in the exhaust gas temperatures recorded during the tests. While these are naturally quite scattered, with all three fuels (operating generally rich of stoichiometric) the lean data tended to be hotter, as expected. Yet the only fuel able to lean close to stoichiometry, ethanol, generally looks cooler than either Avgas or ETBE, as shown in the raw data hand-plots of Appendix A.

It is already well known that ethanol flames do not soot. This lack of sooting reduces the radiation heat loads inside the engine cylinders, allowing cooler hardware and exhaust temperatures. ETBE also looks generally cooler than Avgas, although not as much as the ethanol (it has a higher carbon content than ethanol). This issue certainly deserves further

investigation, for it could considerably shorten the search for efficient, clean alternative fuels.

5. SECOND-ROUND TESTING

The lack of NOx data with ETBE obtained during the first round testing provided an opportunity to refine procedures and test again for repeatability. The first change was testing under dyno servo-control with the oil cooler water set at a much reduced flow. This afforded a much more stable engine / dyno system, and allowed attaining specific test conditions with much improved speed and accuracy. However, testing with dyno servo-control to constant RPM precludes setting power mixtures as the peak-RPM point. This forces consideration of an algorithm to set mixtures repeatably, the second big change in the second round tests.

One of the outputs (either analog or digital on the console, and digital on the PC readout) available to the test operator is measured torque. At constant RPM as loaded by the dyno, throttle position is proportional to intake manifold pressure, which is proportional to cylinder pressures, which is in turn proportional to torque. As mixture is reset, these variables also respond. A power mixture is actually a maximum-torque mixture under these conditions, and can easily be set by maximizing the torque readout with the mixture control once the specified RPM and manifold pressure have been reached.

5.1 Revised Testing Procedures

For the second round, it was decided to test only at the engine full-power and maximum-cruise points, as the power test curves had been so repeatable previously. There was no

need to re-document behavior already known to be repeatable. Further, the emissions comparisons were made only at these two test conditions during the first round tests. It was decided to use a test profile consisting of idle warmup (to 200 F CHT), full power at 2700 RPM, full throttle conditions, and max cruise power at 2400 RPM, intake vacuum of 4 in Hg (about 25 in Hg MAP at cell conditions). The large injectors were reinstalled.

At each of the two points, the mixture was set to maximum torque as a measure of “power mixture”, and the operating air / fuel ratio recorded manually as the test point stabilized and emissions data were taken. This was followed by enrichment to just short of stumble as a measure of full rich mixture and data taken. (Again, in this context, stumble means the point where the engine wants to die from mixture maladjustment.) Similarly, the point just short of lean stumble was determined and data taken including operating air / fuel.

The lean stumble and power mixture air / fuel ratios were manually averaged with 2/3 weight to the lean stumble point and 1/3 to the power mixture point, done with a hand calculator in real time during the test. The resulting weighted average air / fuel ratio was then taken as best lean for that fuel in the engine at that condition. The mixture control was reset to obtain it, and data acquired at that point. Thus four mixture points would be obtained at each of the two power settings (best torque, rich stumble, lean stumble, and best lean). Afterward, the engine would be idled rich to cool off before shutdown.

5.2 Checkout and Initial Testing - Ethanol

A test was run with these procedures, using ethanol fuel because of its availability and prior history of benign behavior in testing. The engine-dyno system proved controllable as expected, and the power mixture point proved to be repeatable as long as the servo-controlled RPM was steady (requiring good ignition and combustion behavior). The

servo air box developed a leak, and the NOx gage quit (dirty filter), necessitating an in-test shutdown. Dyno performance data from this checkout attempt were lost due to a computer problem later resolved. A full ethanol run was also successfully completed with full data acquisition. During that run, it was determined that engine misfire transients during the search for the lean stumble point were causing the filter problems with the NOx gage. This instrument has proven very sensitive to such effects. During the run, the rich stumble point was dropped as an unnecessary risk to the NOx filter. Engine performance appeared very similar to that obtained in the first round tests (both produced about 192 BHP, as corrected to standard, on ethanol at full power, best torque mixture).

It was decided to re-sequence the procedures to minimize the exposure of the NOx gage to transients by dry-running the test without emissions to define the best lean point, and then re-testing with emissions at only the best torque and best lean points.

Selected Second-Round Data

test pt.	RPM	(corr) BHP	ER	BSFC pph/BHP	EGT deg F	
full, rich	2661	191	1.19	.75	1528	ethanol
full, lean	2673	153	0.89	.70	1553	ethanol
cruise, rich	2402	149	1.25	.75	1447	ethanol
cruise, lean	2402	129	0.93	0.63	1529	ethanol
full, rich	2683	182	1.34	0.65	1526	ETBE
full, lean	2685	182	1.34	0.64	1634	ETBE
cruise, rich	2373	143	1.46	0.67	1397	ETBE
cruise, lean	no data obtained -----					ETBE

5.3 Discussion of Results Obtained

The full power comparison between the first second-round results was mixed. Equal power levels were demonstrated (191 vs 192 BHP ethanol and 182 vs 184 BHP ETBE, as corrected to standard). However, equal fuel consumptions were not obtained, so mixture ratios and efficiency factors are different. This shows up in the full power emissions data: ethanol and ETBE emissions do not agree that well between the first and second runs. See also the raw data plots in Appendices A and B.

Note in the data table just above, that the ETBE full power lean point in fact wandered richer to match the ETBE full power rich point as described in the selected data table. This happened after the operator had manually set the mixture lean before trying to record data. This mixture setpoint instability may in fact point to a defect or problem in the servo, and may be all or part of the general problems experienced running in this test cell. The question is certainly deserving of further investigation.

For the ethanol cruise point, the dyno-measured power and fuel consumption data agree better between the two runs, and so the cruise emissions also agree much better, as can be seen in the raw data plots of Appendices A and B.

Unfortunately, there are no reliable second-round performance data for the ETBE at lean cruise. However, the CO₂, UBHC, and CO emissions agree very well, just as did the ethanol (see Appendices A and B again). Therefore, it is very likely that the missing first round NOx data on ETBE strongly resemble the second round NOx data, providing the justification for including it on figs 4.3-4.6. It is also likely that the missing performance data on ETBE strongly resemble the first round performance data. However, for numerical or predictive purposes, the tests need to be repeated with improved procedures (especially mixture, as already discussed).

6. PERCEIVED OBJECTIVES AND NEAR-TERM PLANS

6.1 Addressing the Instrumentation Uncertainties

There are two categories (1) hardware problems, and (2) data presentation and correlation. The main hardware problems are finding a solution to the boost pump - flow transducer interaction, and repairing the damage to the air metering turbine. Minor problems include resolving questions about the calibrations of two minor auxiliary gages. All of these are straightforward, but may require nontrivial effort and some diagnostic tools to resolve.

The data correlation and presentation problem is less defined. A similar procedure was worked out for the turbine test program, but the differences between the two types of engines are considerable. It is anticipated that analogous procedures will work for the IO-360, but that details will be substantially different. Considerable effort may be needed in trial correlations of data already obtained.

6.2 Addressing the Boost Pump / Fuel Flow Gage Interaction

A part of this interaction is understood: there should be a transiently-high erroneous indication of flow right after the boost pump is turned on. This indication reflects the fuel required to compress the air in the fuel pump surge chamber. Experiments show it is about 5 to 10 seconds in duration. This error should revert back to zero error after that time has elapsed. Observations in test indicate that it does not: in fact, flow rates appear to double, and remain doubled, indefinitely after the boost pump is turned on. This cannot be physically real, as that much enrichment would kill the engine, and that does not happen. Another possibility is that not all the fuel delivered to the servo goes into the engine: massive flooding may be simply draining or accumulating in the air box,

unseen. The conclusions are that there is either (1) a mechanical interaction of unknown character, (2) there may be unobserved accumulation in the airbox, or (3) there is electrical crosstalk between the transducer data circuit and the boost pump power circuit.

6.3 Addressing the Testing Problems Encountered

A servo inlet pressure gage and a section of clear line viewable (or filmable) during the test would serve to rule out any questions concerning vapor lock.

The servo and injectors need to be inspected internally for wear or damage. In particular, minute scoring on the mixture plates has been known to cause mixture settings to behave erratically.

The fuel can be checked by testing in an airplane already known to perform well on ETBE (the Pitts S2B is one candidate).

6.4 Repeat Testing with Precision Procedures

Experience to date indicates that the full power lean test condition is neither safe nor practical. This reduces the test profile to full power at power mixture, and cruise power at power mixture and at the best lean mixture. Power mixture can be set using the torque gage in the RPM servo-control mode. However, the air turbine meter is required to obtain the best lean setting. Results do indicate that both ethanol and ETBE (and presumably Avgas) lean best at air/fuel ratios unique to each fuel, identical at both power settings. Once defined, this air/fuel can be set in subsequent tests without re-defining. These air/fuel ratios do not correspond to identical equivalence ratios among the fuels, however. The engine responds to each fuel in a noticeably different manner regarding the range of combustible mixtures.

6.5 Effects of Timing Setpoint vs Fuel as a Means to Improve Alt Fuel Efficiency

Except for starting retard, aircraft magneto ignitions are single-setpoint spark timing systems, similar to road and farm equipment earlier in the century. The setpoint timing is chosen to minimize the chance of detonation in the heavily-loaded climbout condition, and is consequently too-retarded at the much less heavily-loaded cruise condition. This leads to cruise inefficiency and excess fuel consumption.

As discussed earlier, ethanol and ETBE apparently provide substantially more detonation protection than 100/130 grade Avgas, and quite probably more protection than the old 115/145 grade that is no longer available. Therefore the timing could be advanced further toward a true best-torque setting with these fuels. This might provide enough benefit to be worth the effort required to reset the magneto timing when switching from one fuel to the other, as long as that is not too frequent. In frequent switching, or when using blends, this option might not be so attractive.

6.6 ADEC as a Solution

A better solution to the timing problem lies in a system with true speed and load compensation built-in, as in modern road equipment. Such systems provide as much specific power output at substantially-improved specific fuel consumption, and with flexible operation over a much wider range of speeds and loads. This can be done with mechanical controls. However, the flexibility of an electronic spark control can best provide this option, and it is tailorabile from fuel-to-fuel or blend-to-blend simply by changing a few software items. This could even be done with a blend sensor as is now available in the latest road equipment, although this particular ADEC is not so equipped.

Such electronic engine controls also offer the opportunity to replace continuous fuel injection with properly timed pulse injection delivered to the appropriate intake valve. As in road equipment, this also offers substantial efficiency and economy improvements.

The ADEC system removed in favor of the current mechanical configuration (as discussed above) is fully capable of providing these benefits. (The current mechanical configuration is not.) Our particular ADEC unit suffers from a crossed-wire spark timing problem, and possibly-mistimed fuel injection events. Substantial effort is required to resolve these issues. Once that is done, the potential control benefits can be explored.

CONCLUSION

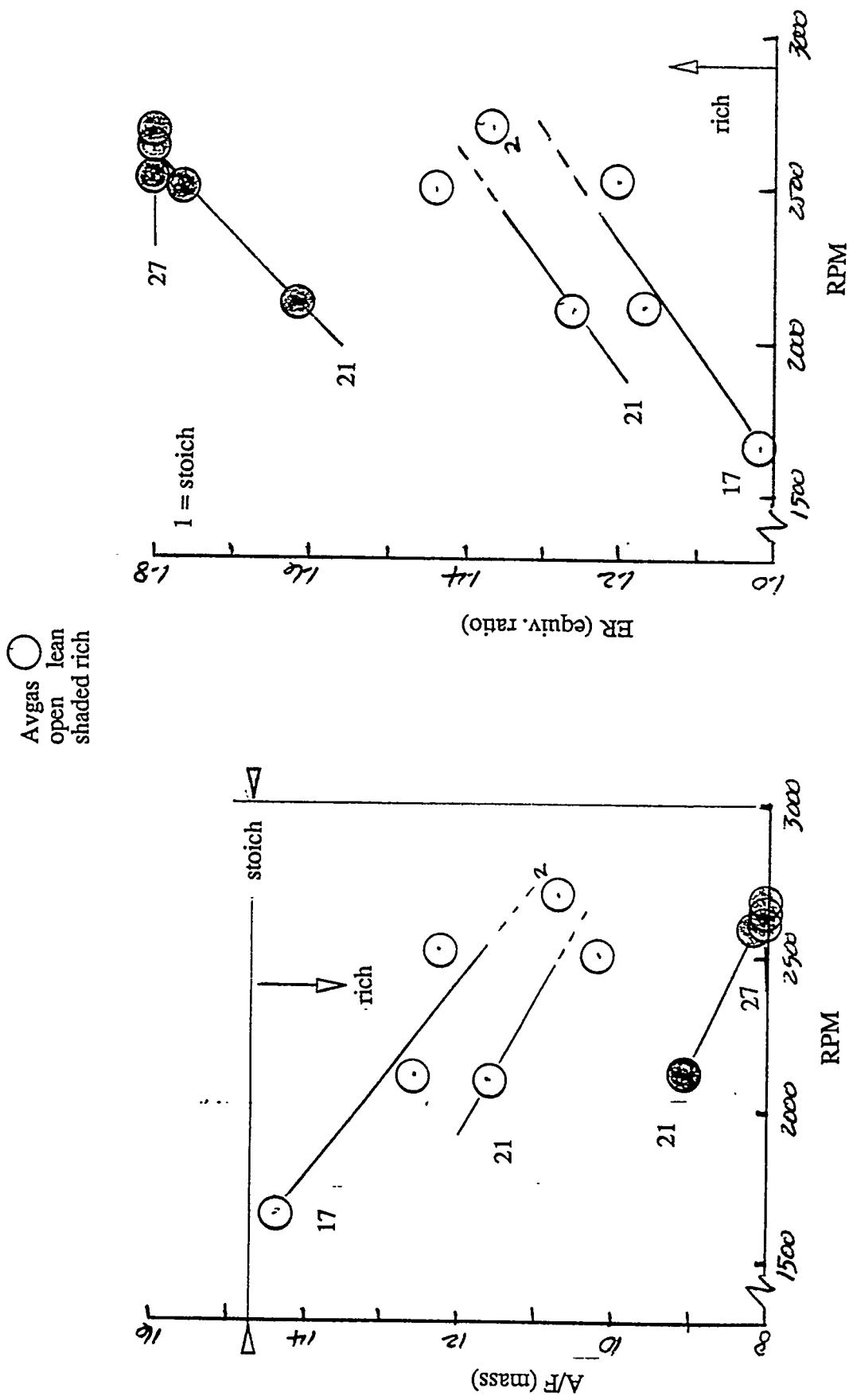
While not all of the stated goals of the project were achieved, others were realized which have the potential to benefit aviation. RAFDC now has an engine test stand for piston engines and one for turboprop engines.

The test stand and flight test data obtained during the project will be invaluable in assessing future decisions concerning the adoption of clean burning renewable biomass fuels. More specifically, the data indicates that modification of piston engines to take advantage of the high octane of ethanol and ETBE holds great promise. Impressive increases in fuel efficiency were indicated in the data. It is important at this point to determine repeatability of this data and test more extensive modifications.

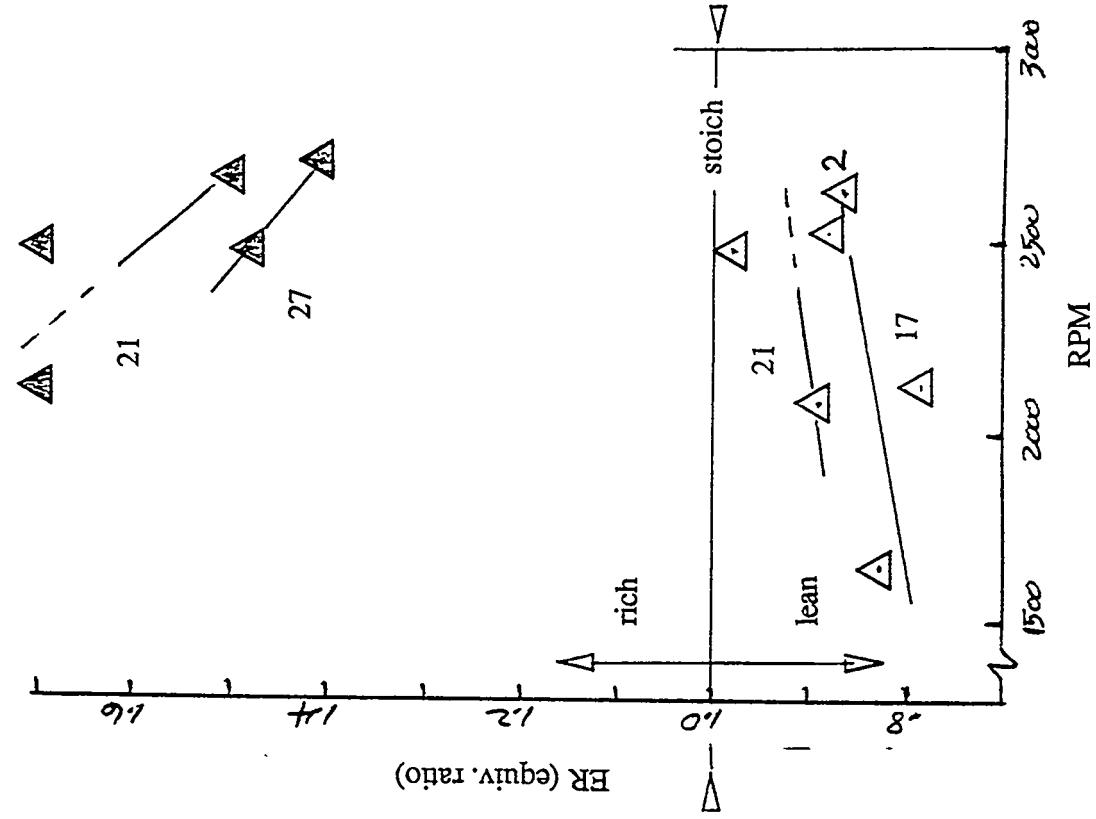
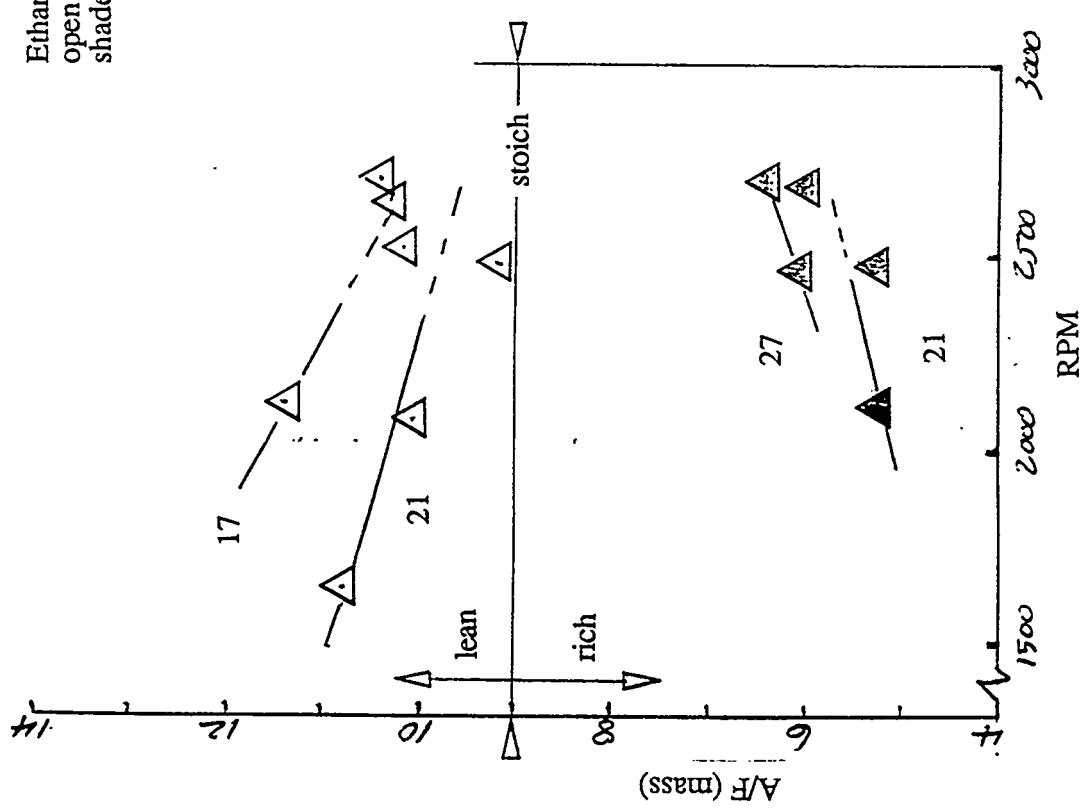
REFERENCES:

1. Coordinating Research Council, Inc., CRC Report No. 530 "Handbook of Aviation Fuel Properties", third printing 1988, available from SAE.
2. ASTM specification D-2700 "Standard Test for Knock Characteristics of Motor and Aviation Fuels by the Motor Method", available from ASTM, also covers Aviation Lean.
3. ASTM specification D-2699 "Standard Test for Knock Characteristics of Motor Fuels by the Research Method", available from ASTM.
4. ASTM specification D-909 "Standard Test for Knock Characteristics of Aviation Gasolines by the Supercharge Method", available from ASTM.
5. Richard L. Bechtold, Alternative Fuels Guidebook, published by SAE, Warrendale, PA, 1997. ISBN 0-7680-0052-1
6. G. W. Johnson, M. E. Shauck, M. G. Zanin, Performance and Emissions Comparison between Avgas, Ethanol, and ETBE in an Aircraft Engine, presented at the Twelfth International Symposium on Alcohol Fuels, Beijing, China, September 1998.
7. Bruce Jones, et al, Mankato State University, A Comparative Analysis of Ethanol Versus Gasoline as a Fuel in Production Four-Stroke Cycle Automotive Engines, SAE paper 952749.
8. G. D. Maben, M. E. Shauck, and M. G. Zanin, ETBE as an Aviation Fuel, presented at the Eleventh International Symposium on Alcohol Fuels, Sun City, South Africa, April 1996.

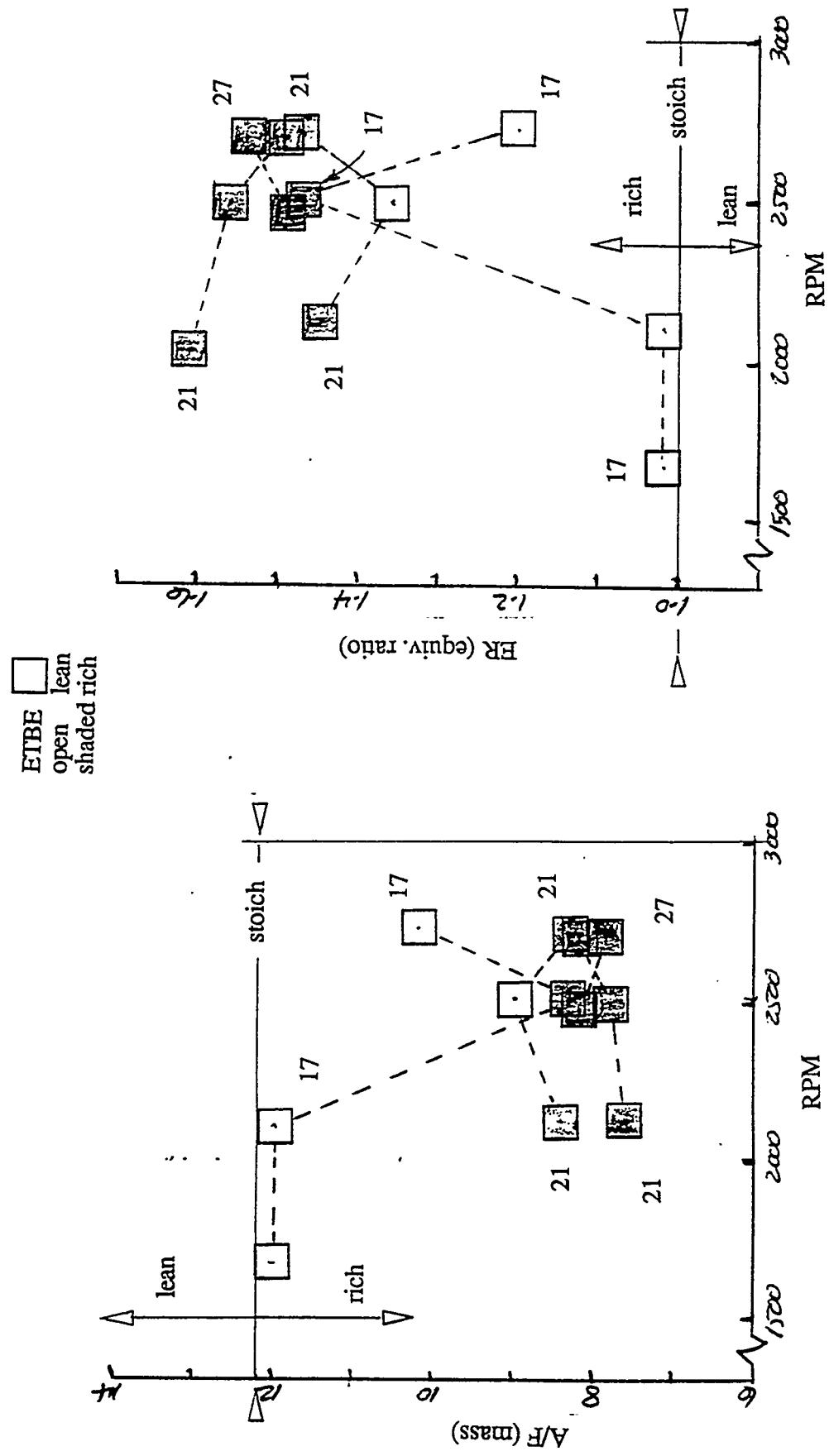
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr; mags @ 25 BTDC, manual rpm leaning



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

AvGas 

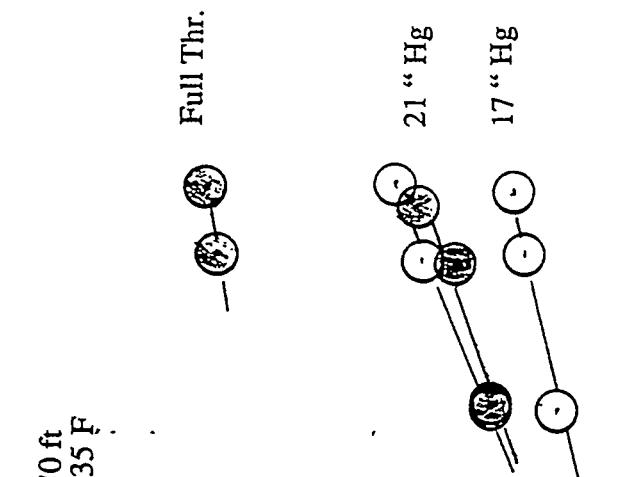
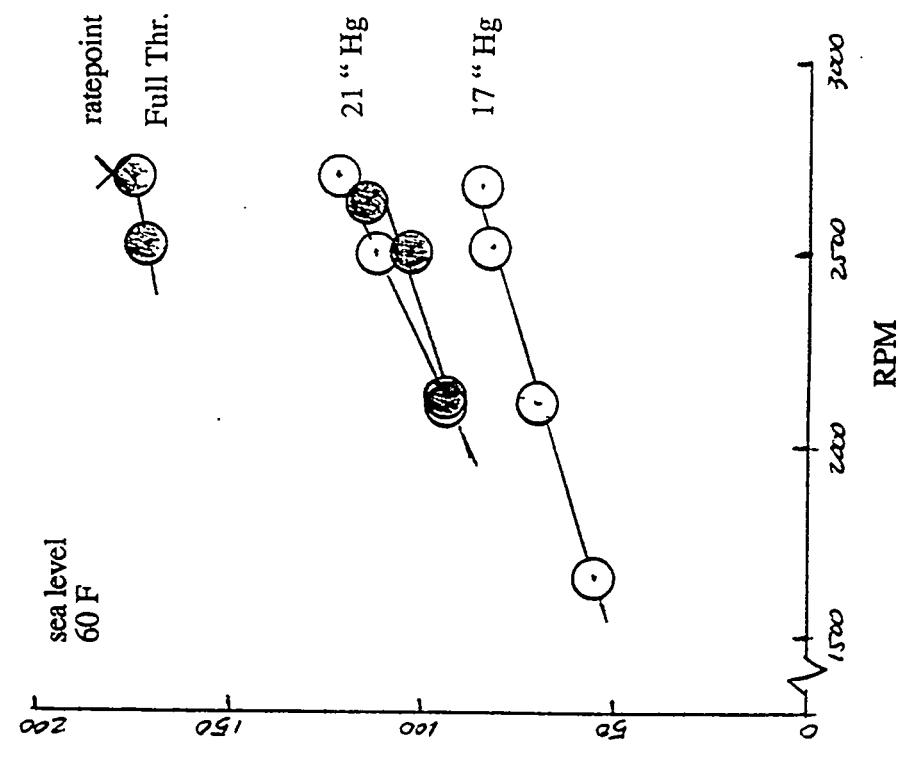
unshaded:
shaded:
 leaned
full rich

Field Elev. 470 ft
C.A.T. 129-135 F

raw BHP

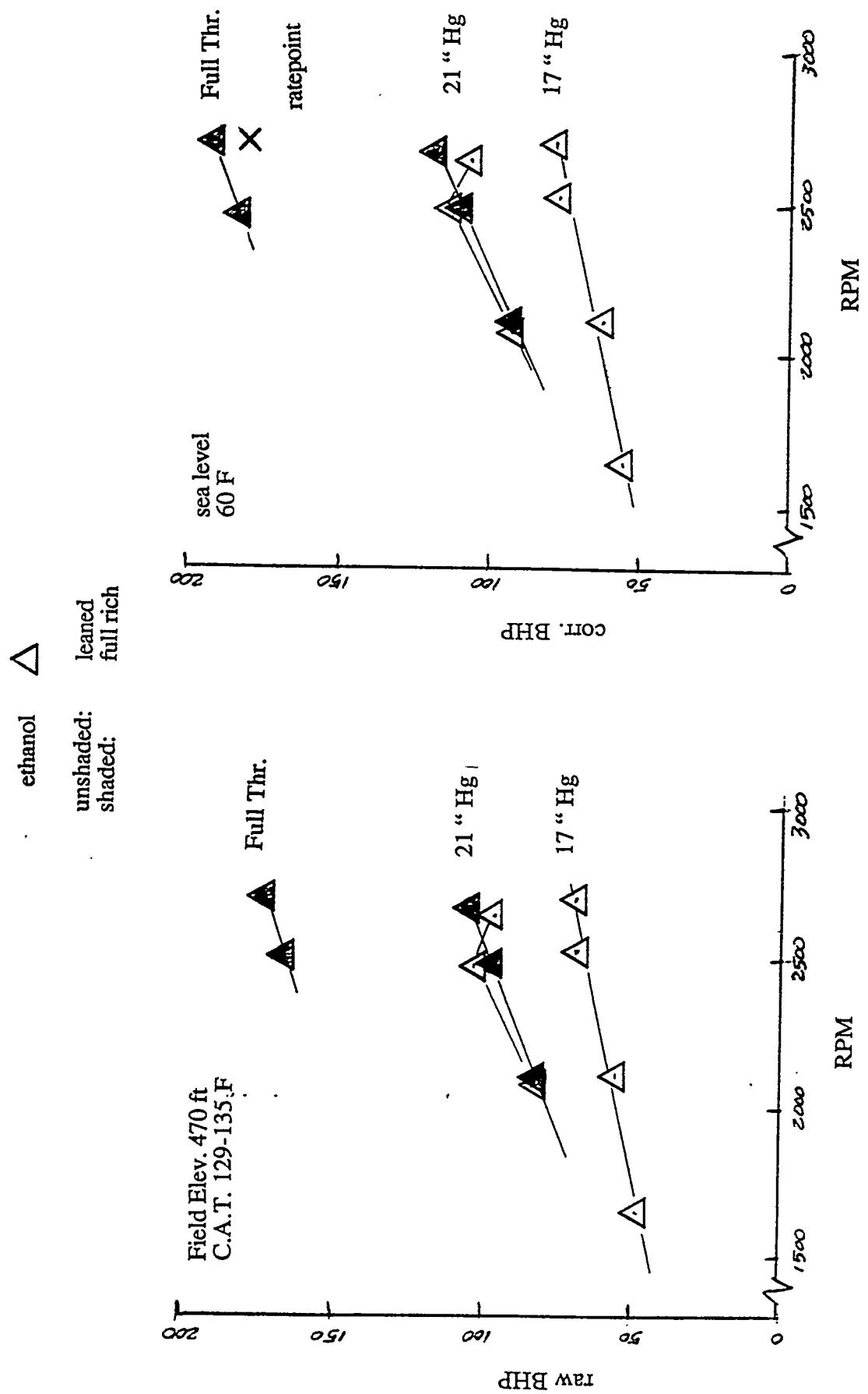
Field Elev. 470 ft
C.A.T. 129-135 F

raw BHP



$$P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) * \sqrt{(\text{C.A.T.}, \text{deg R} / 520.)}$$

IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



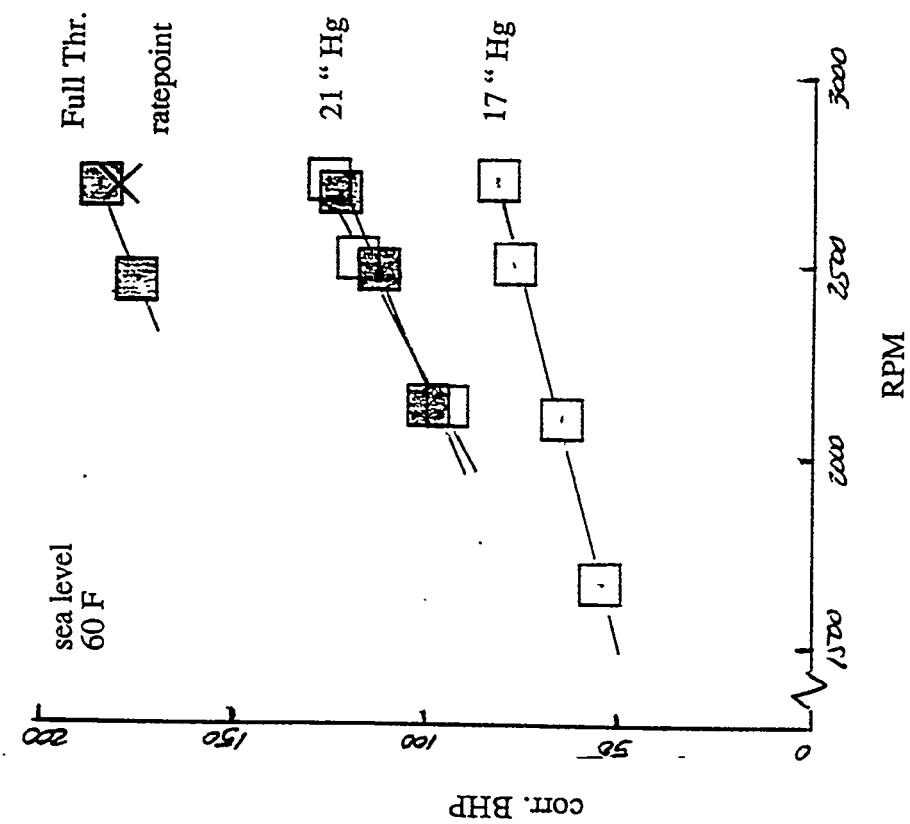
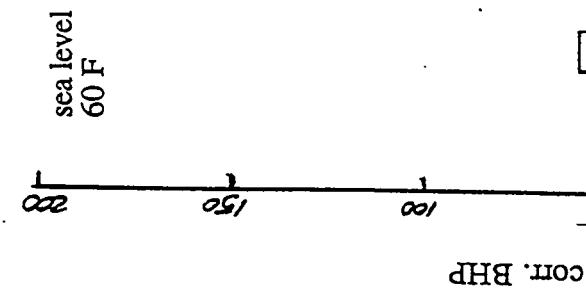
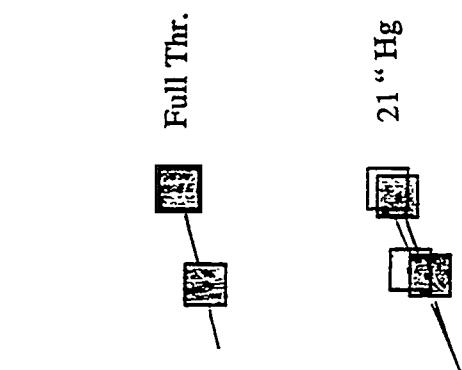
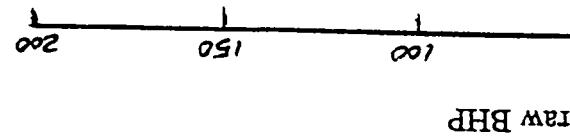
$$P_{\text{corr}} = \text{Praw} * (29.92 / \text{uncorr. baro.}) * \sqrt{(\text{C.A.T.}, \deg \text{R} / 520.)}$$

IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

ETBE

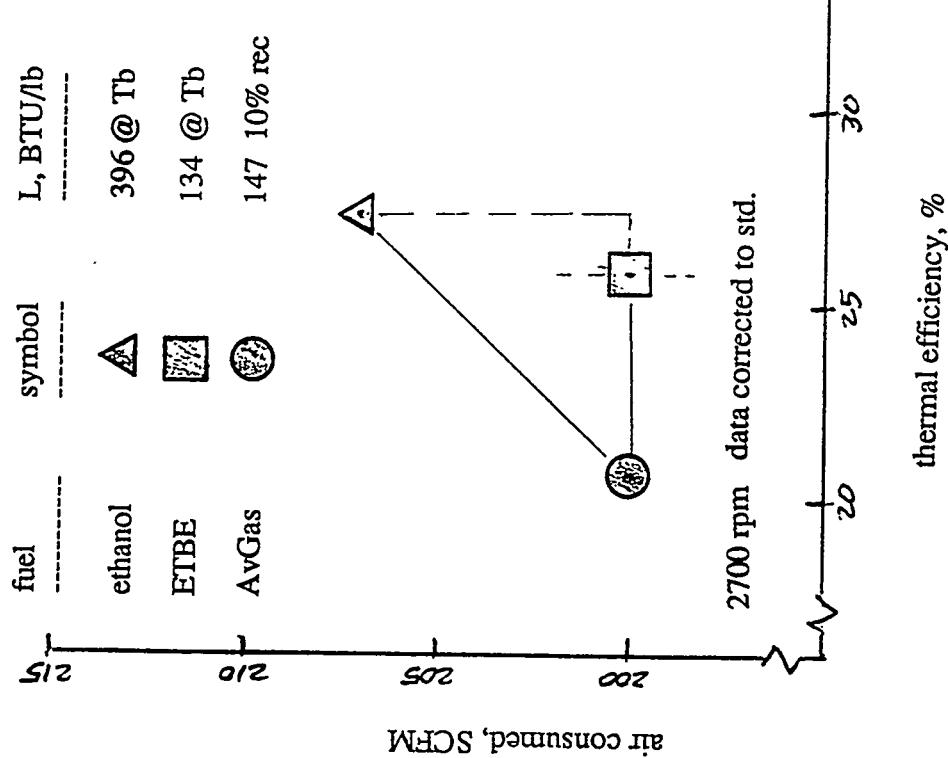
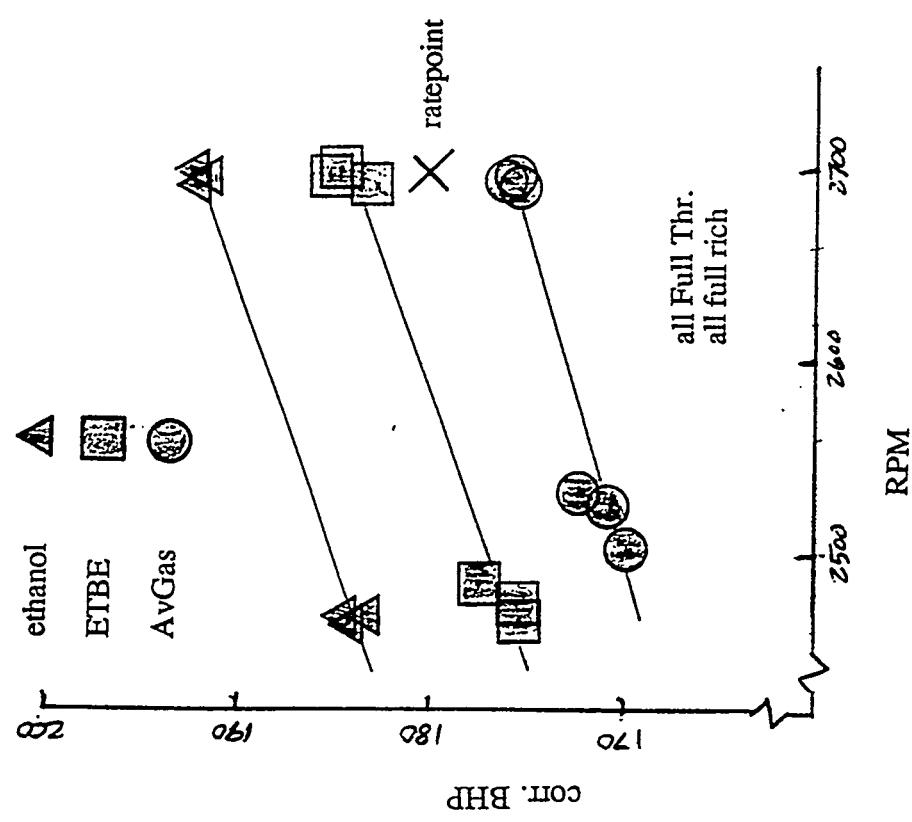
unshaded: leaned
shaded: full rich

Field Elev. 470 ft
C.A.T. 129-135 F



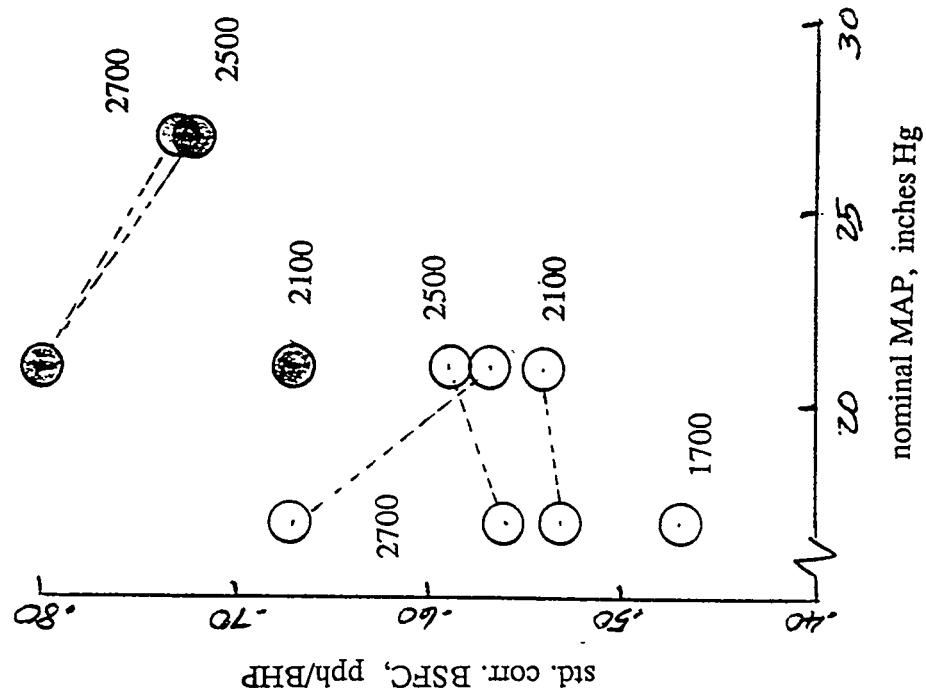
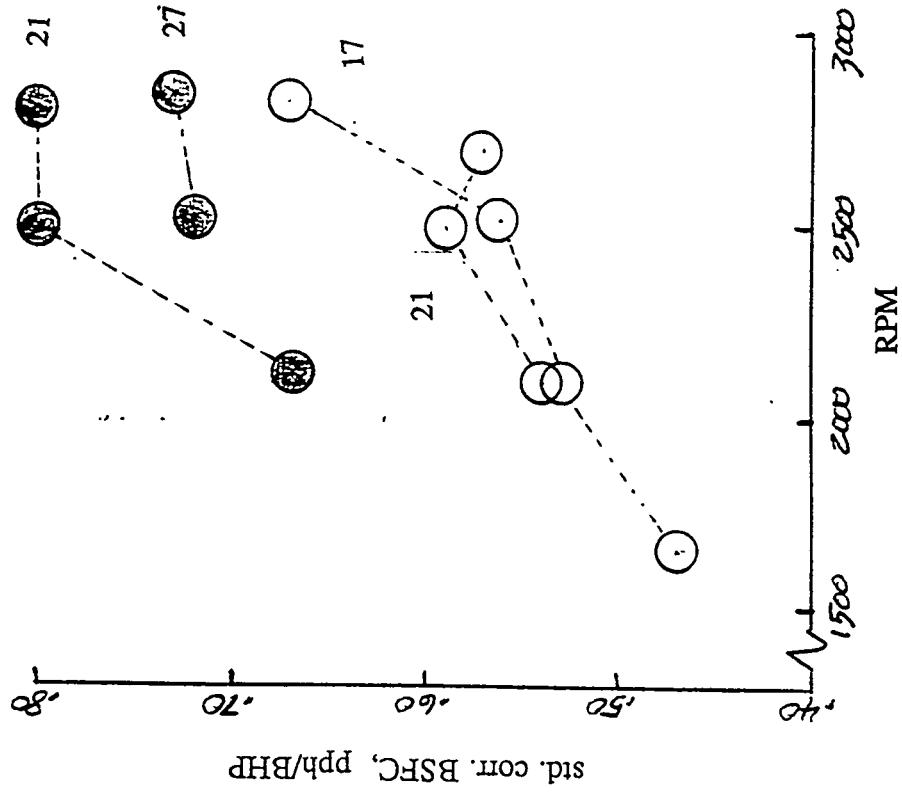
$$P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) * \sqrt{(\text{C.A.T.}, \text{deg R} / 520.)}$$

IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



AvGas ○
open lean
shaded rich

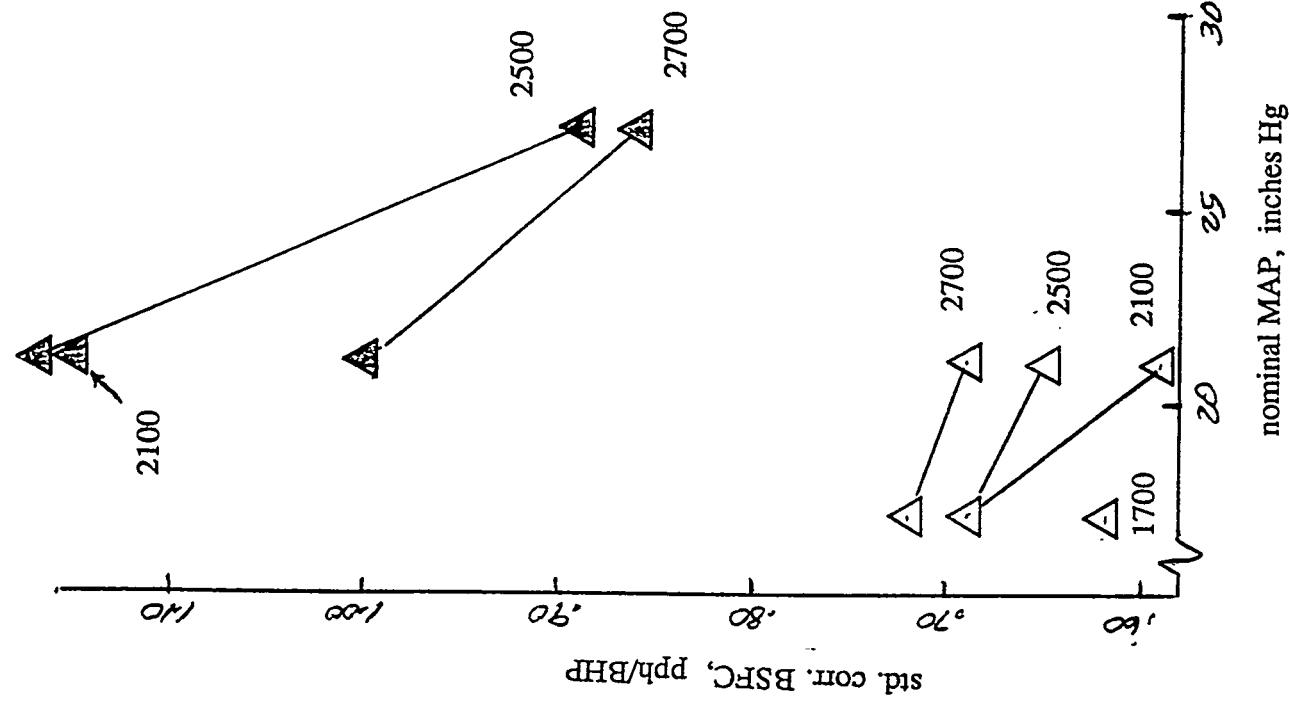
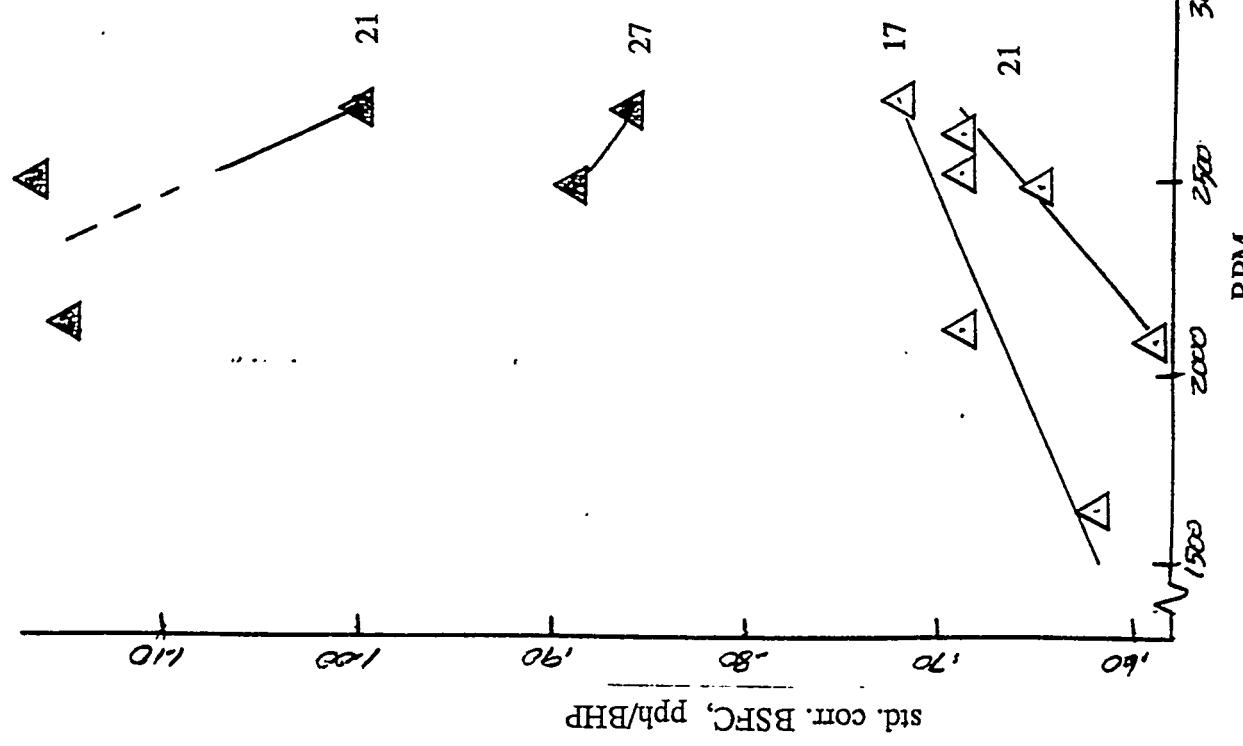
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning
 $P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) *$ (C.A.T., deg R / 520.)



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

$P_{corr} = P_{raw} * (29.92 / \text{uncor. baro.})^*$ (C.A.T., deg R / 520.)

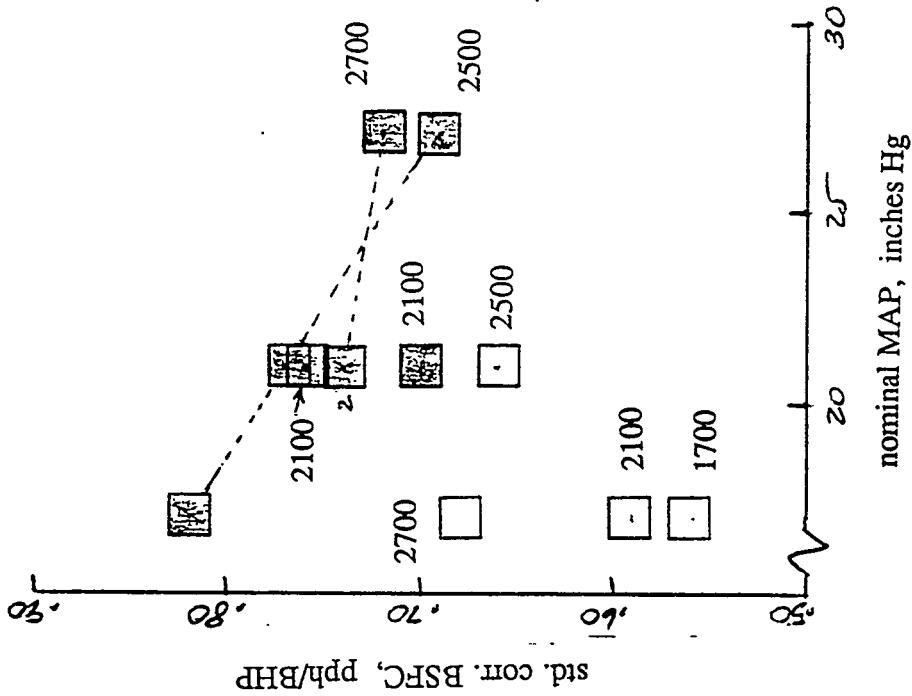
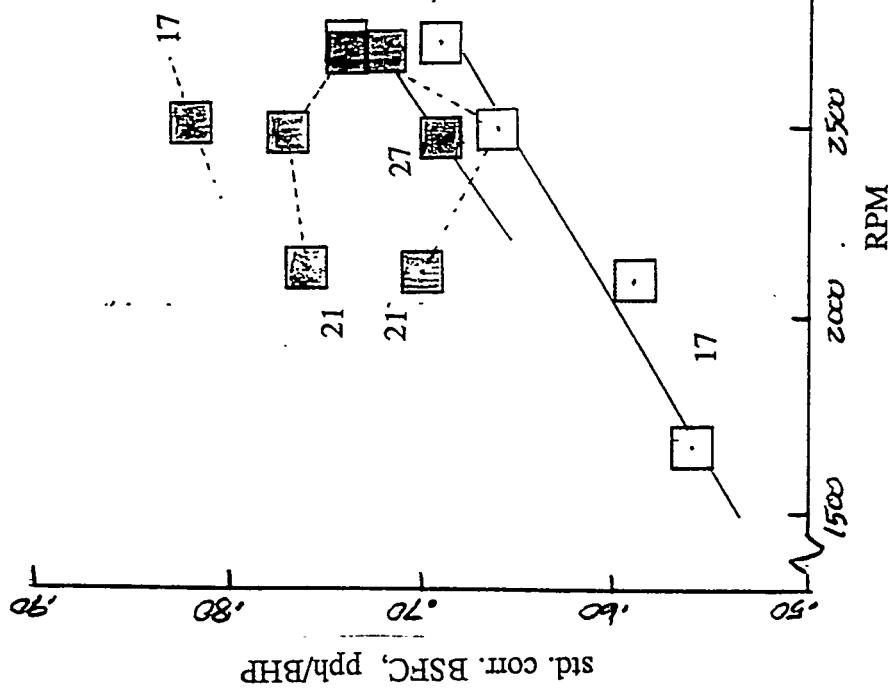
Ethanol \triangle
open lean
shaded rich



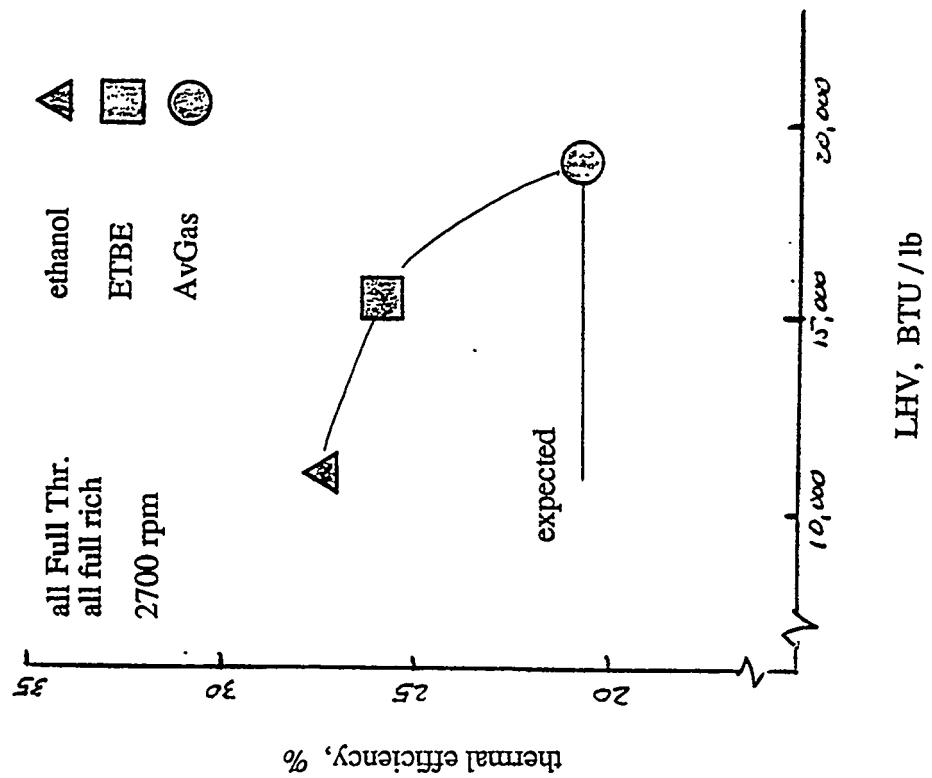
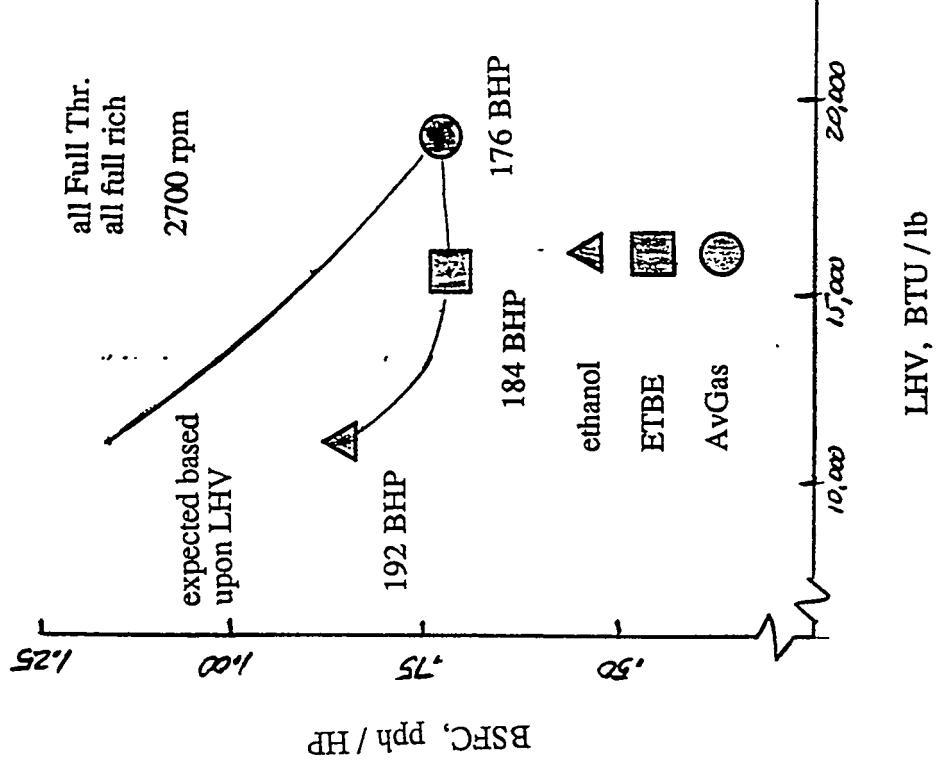
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

$P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) *$ (C.A.T. deg R / 520.)

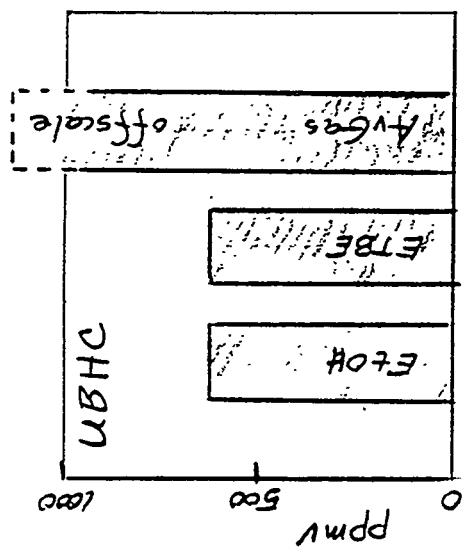
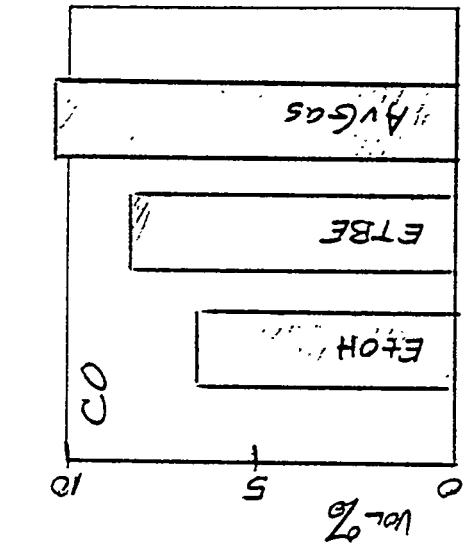
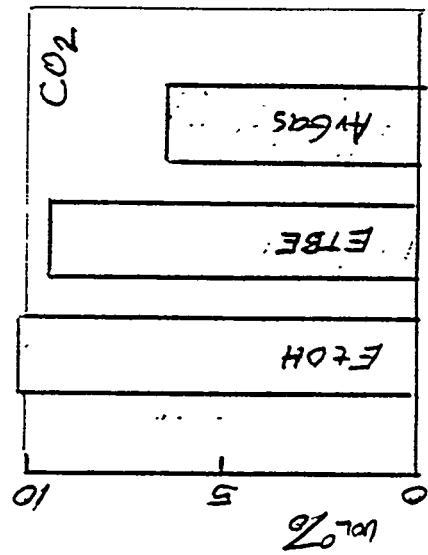
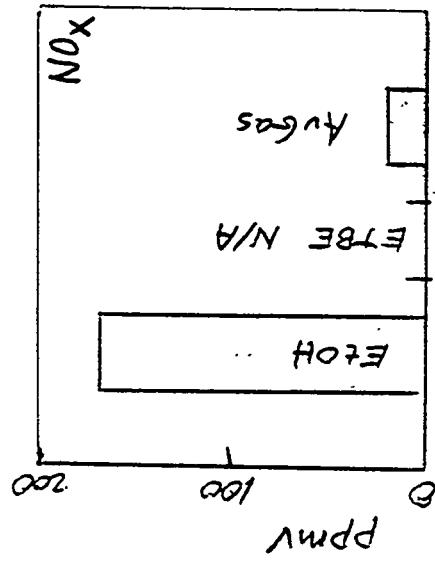
ETBE
open lean
shaded rich



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

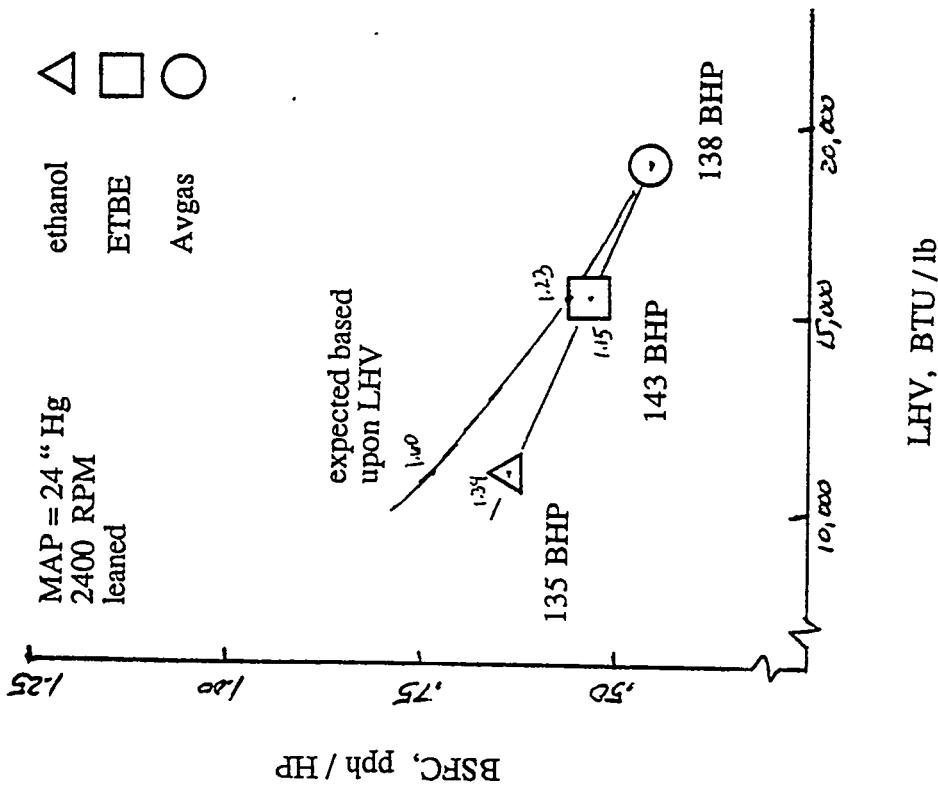
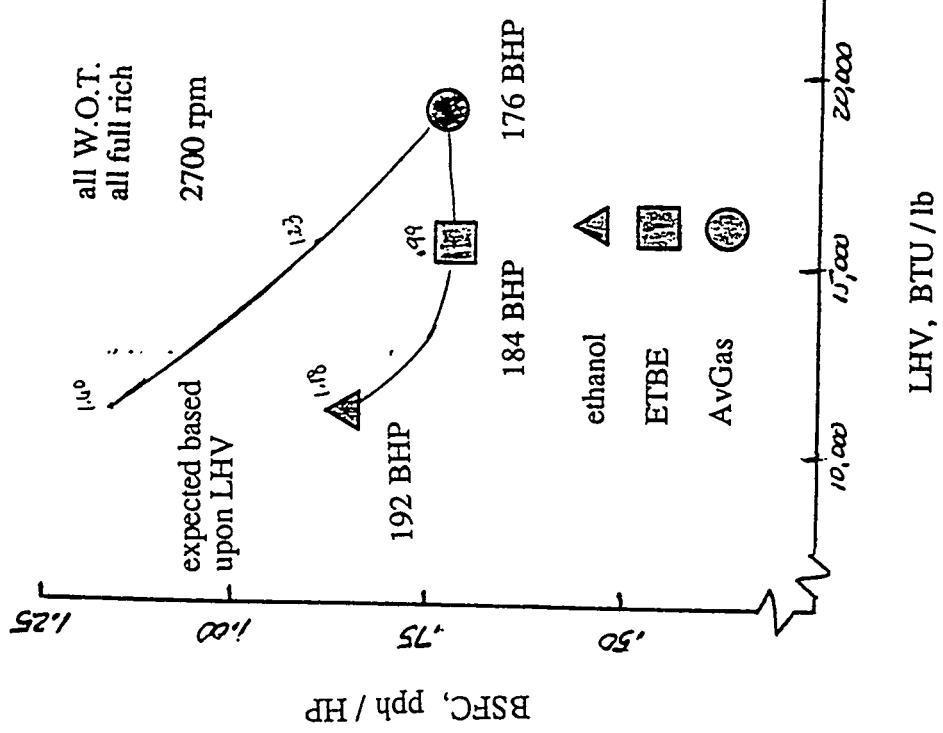


Full Power

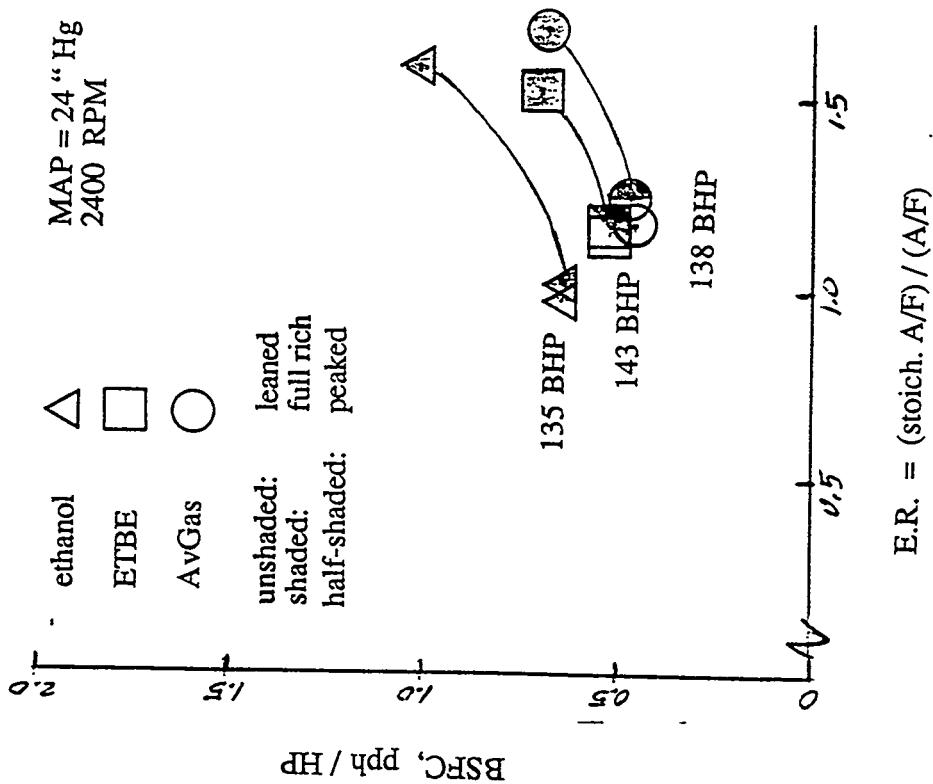
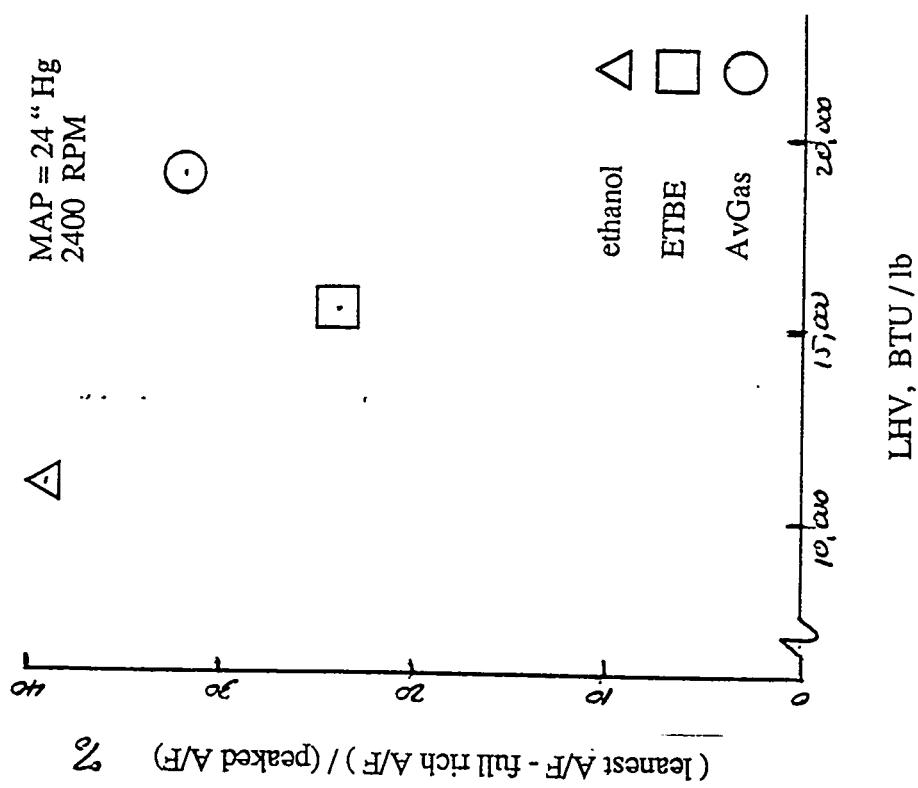


IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

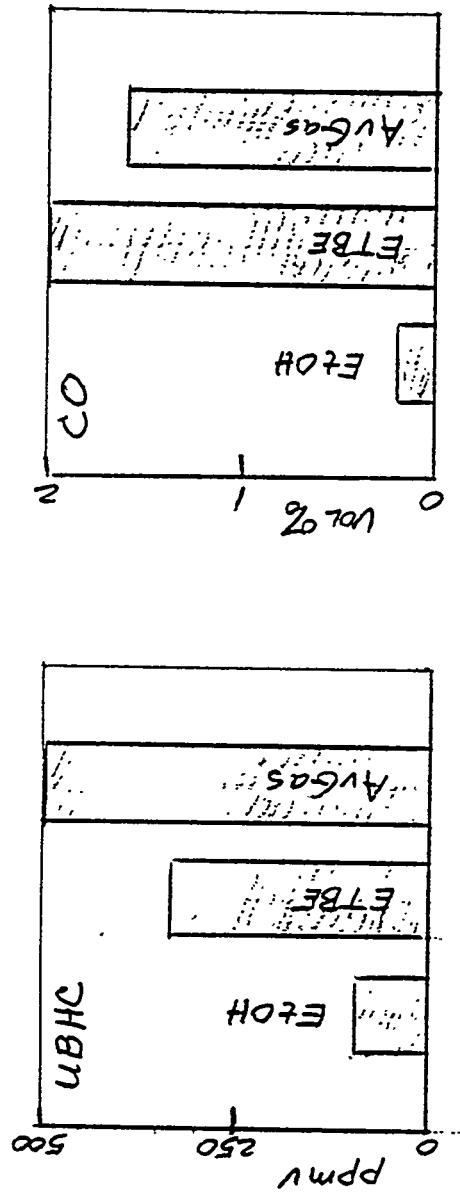
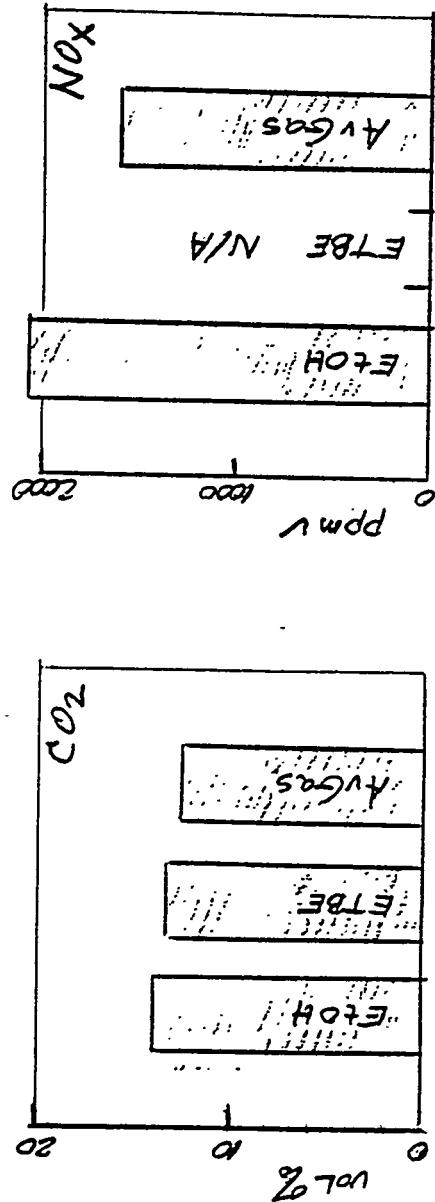
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



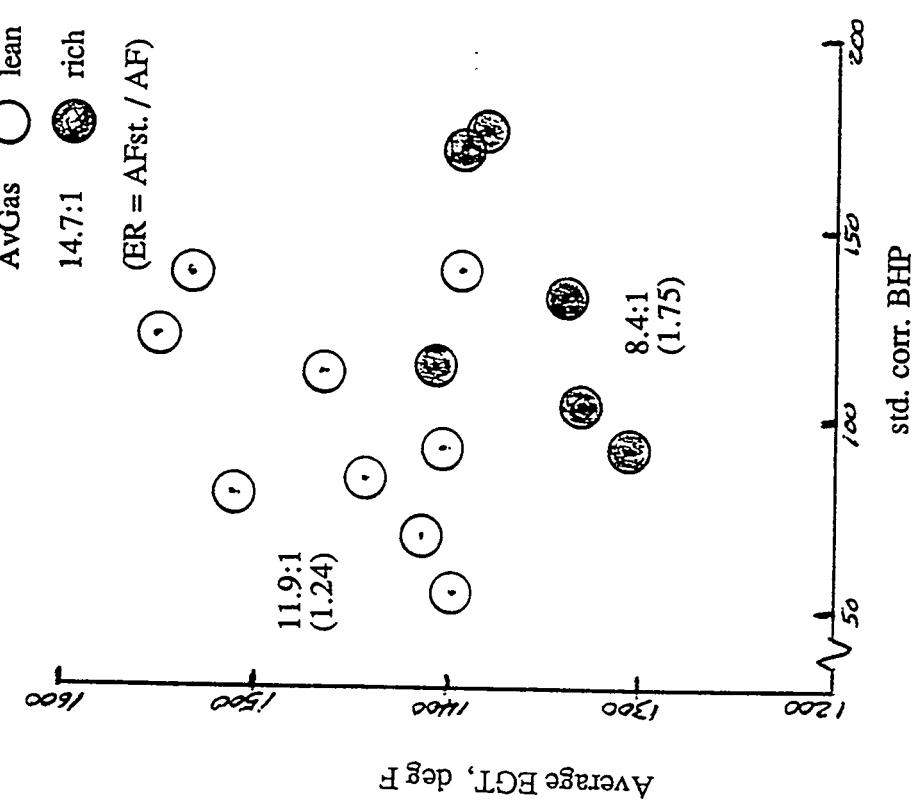
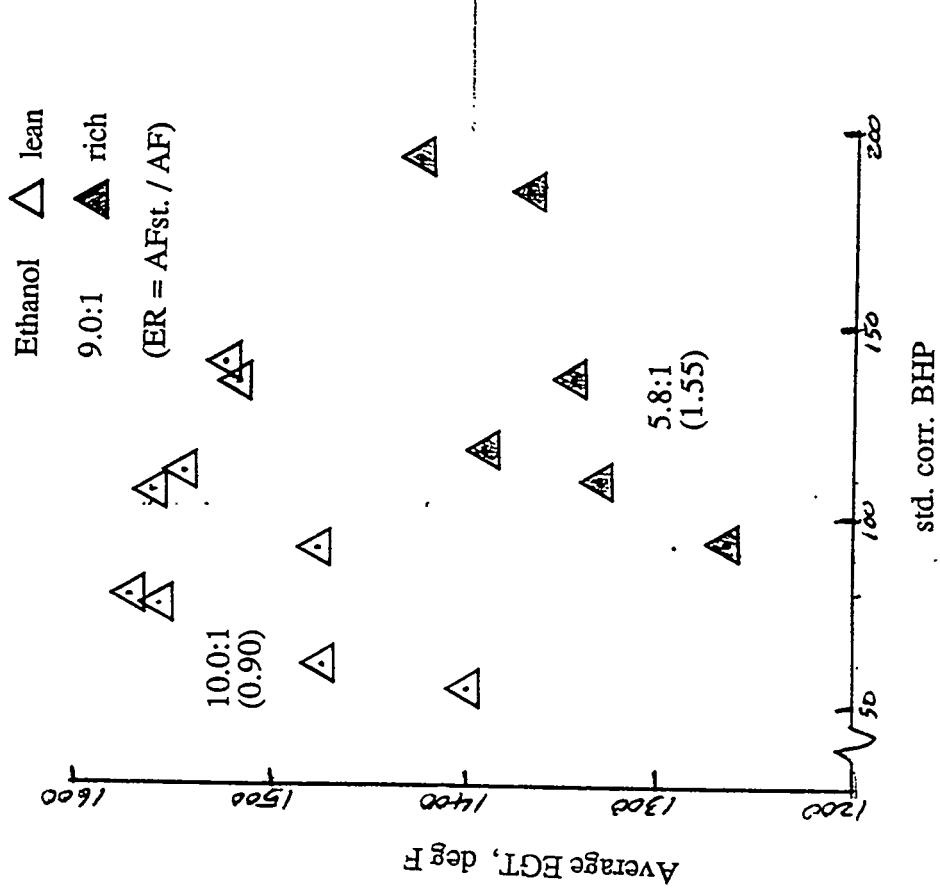
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



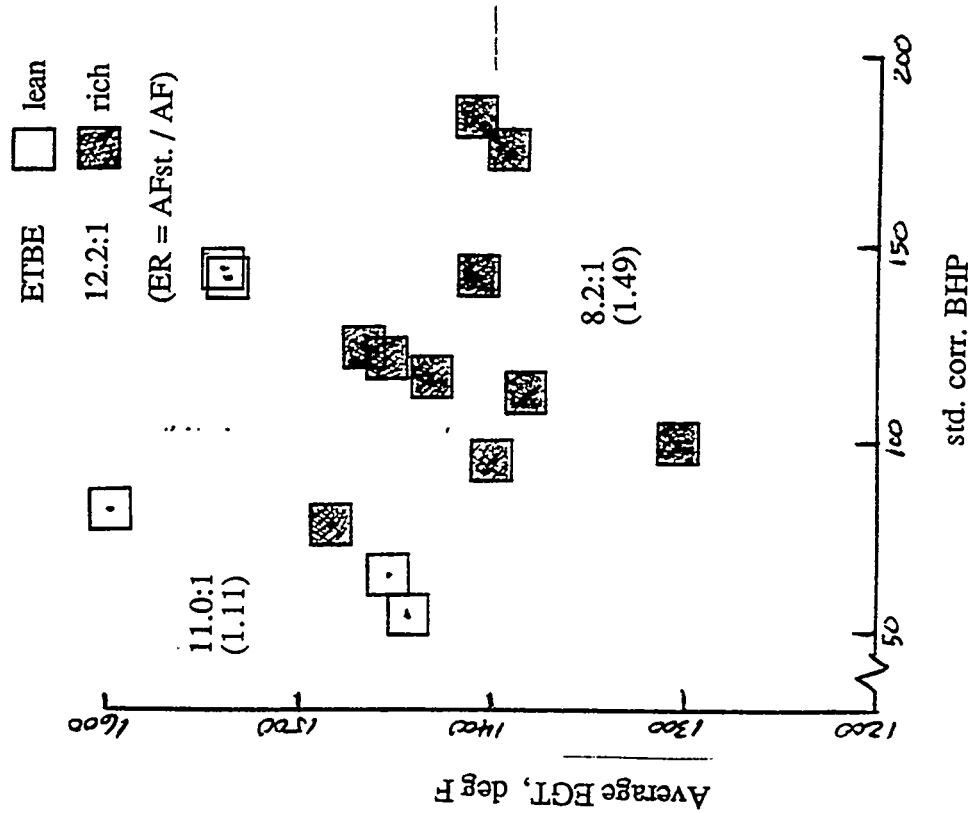
"CRUISE" (24" Hg MAP, 2400 RPM)



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

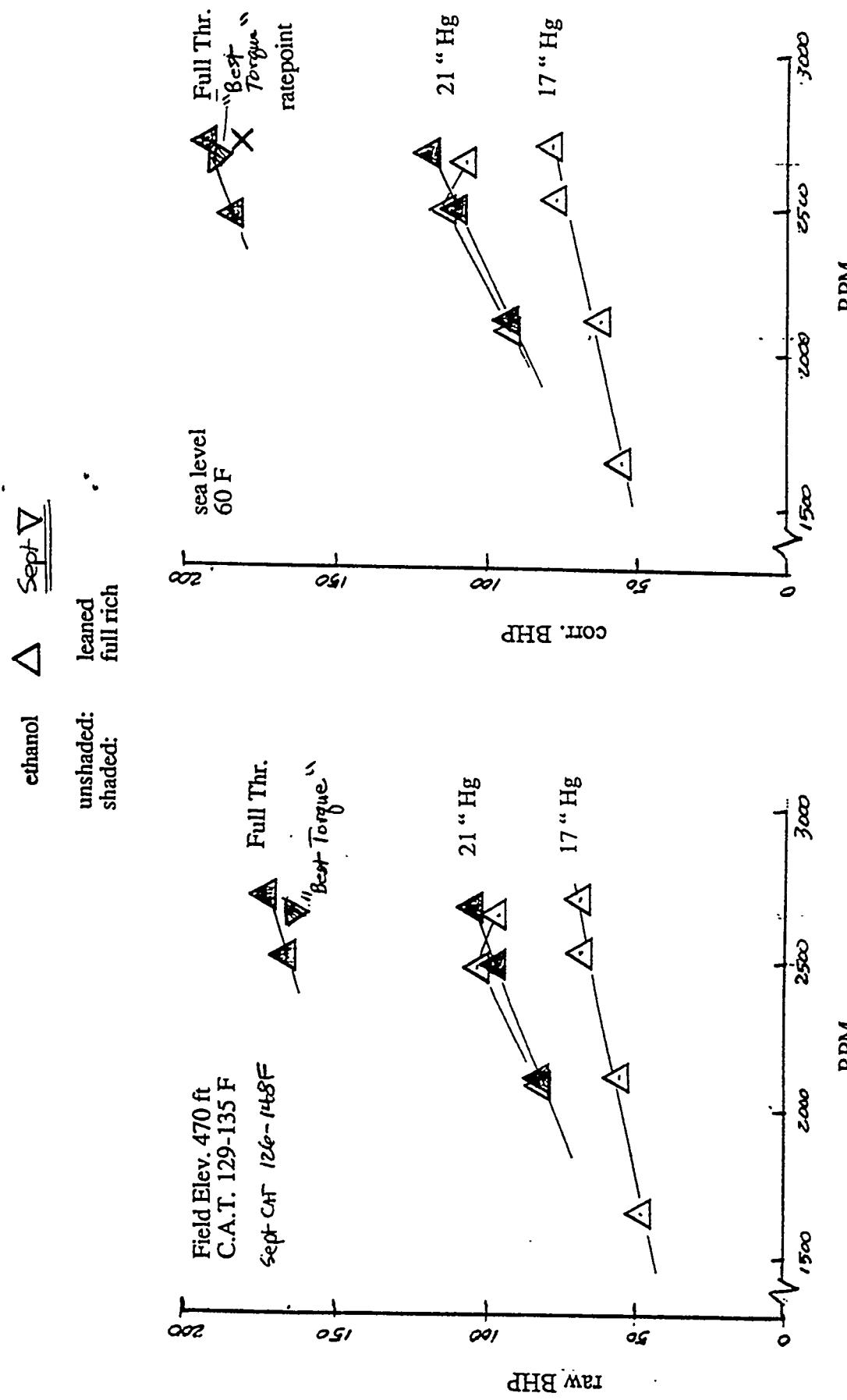


IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning

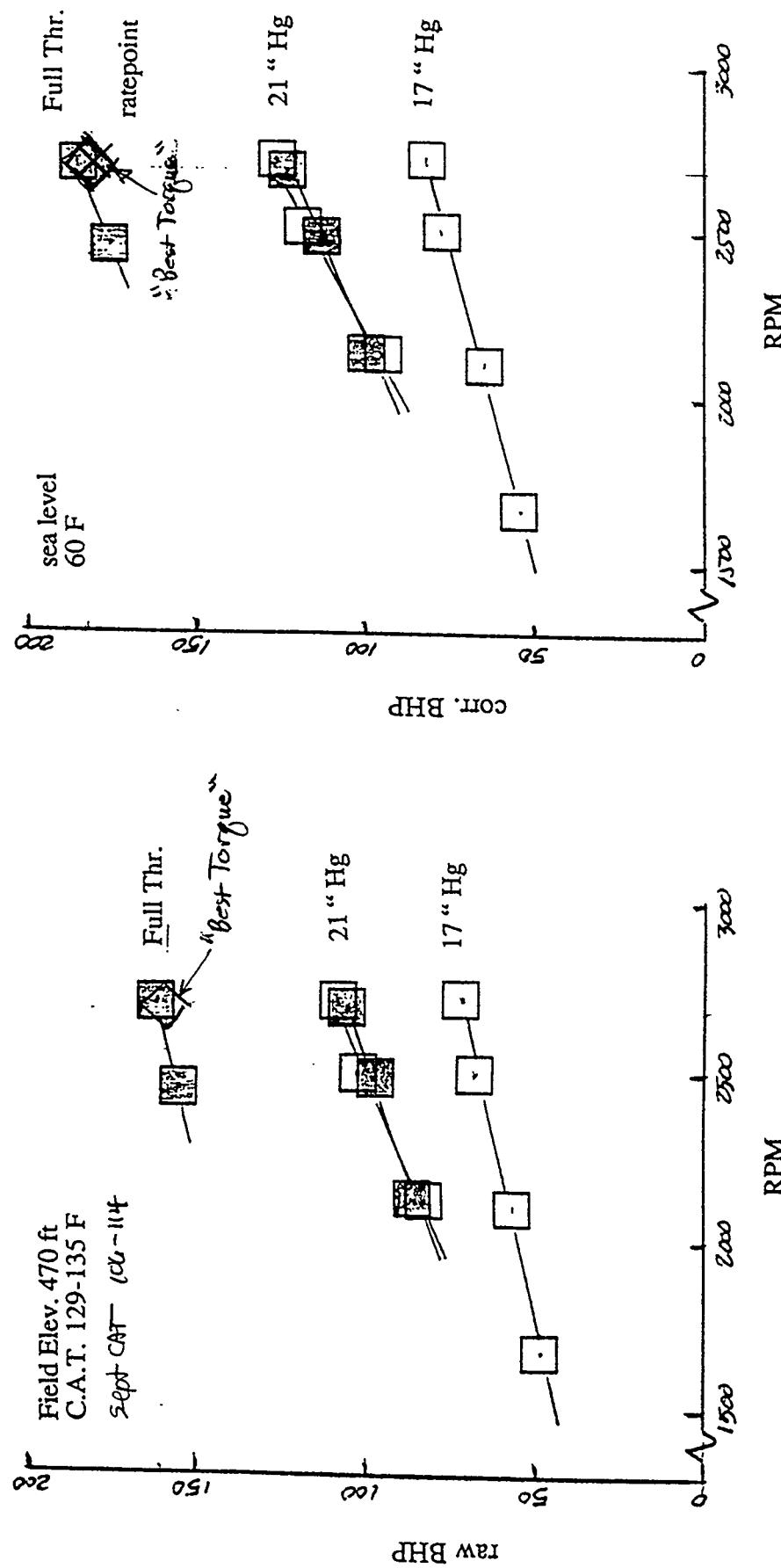


$$P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) * \sqrt{(\text{C.A.T.}, \text{deg R} / 520.)}$$

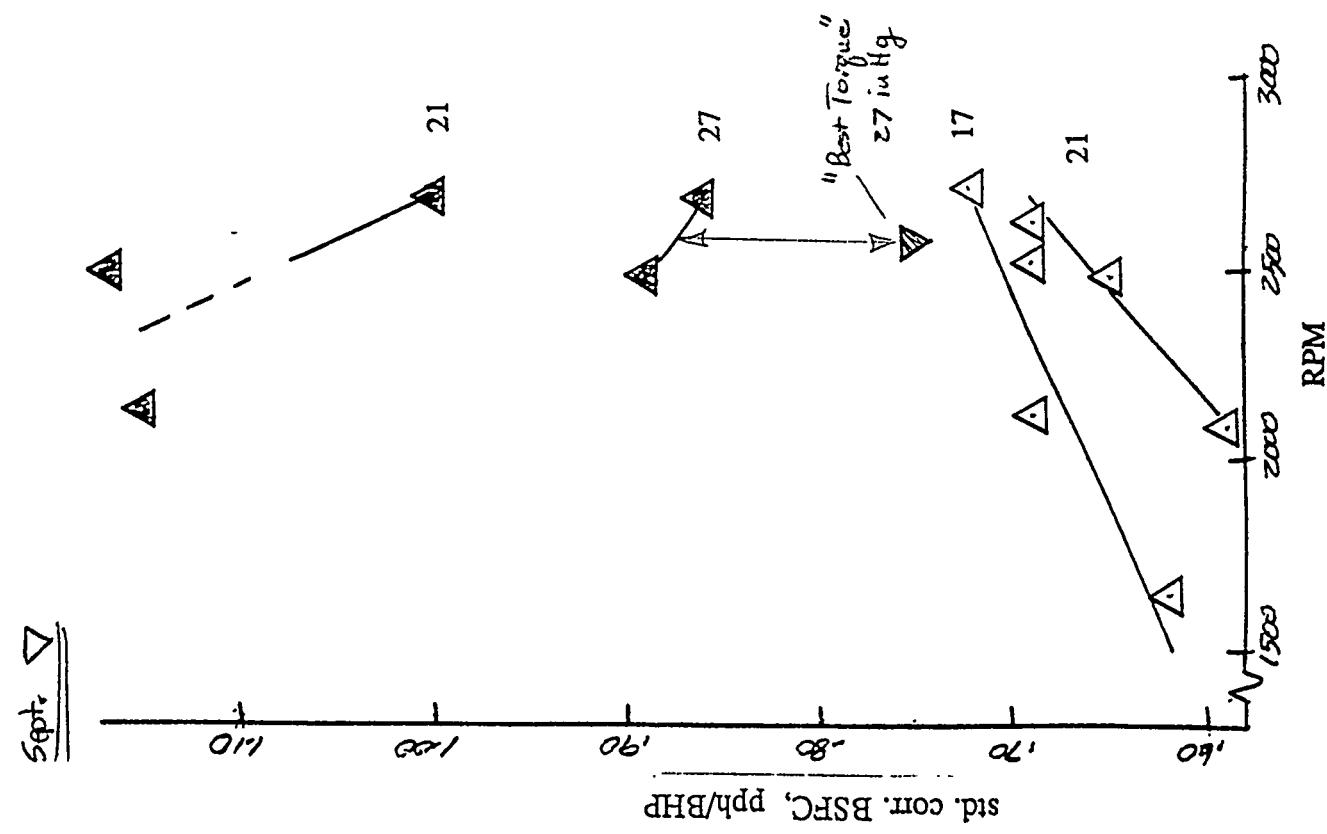
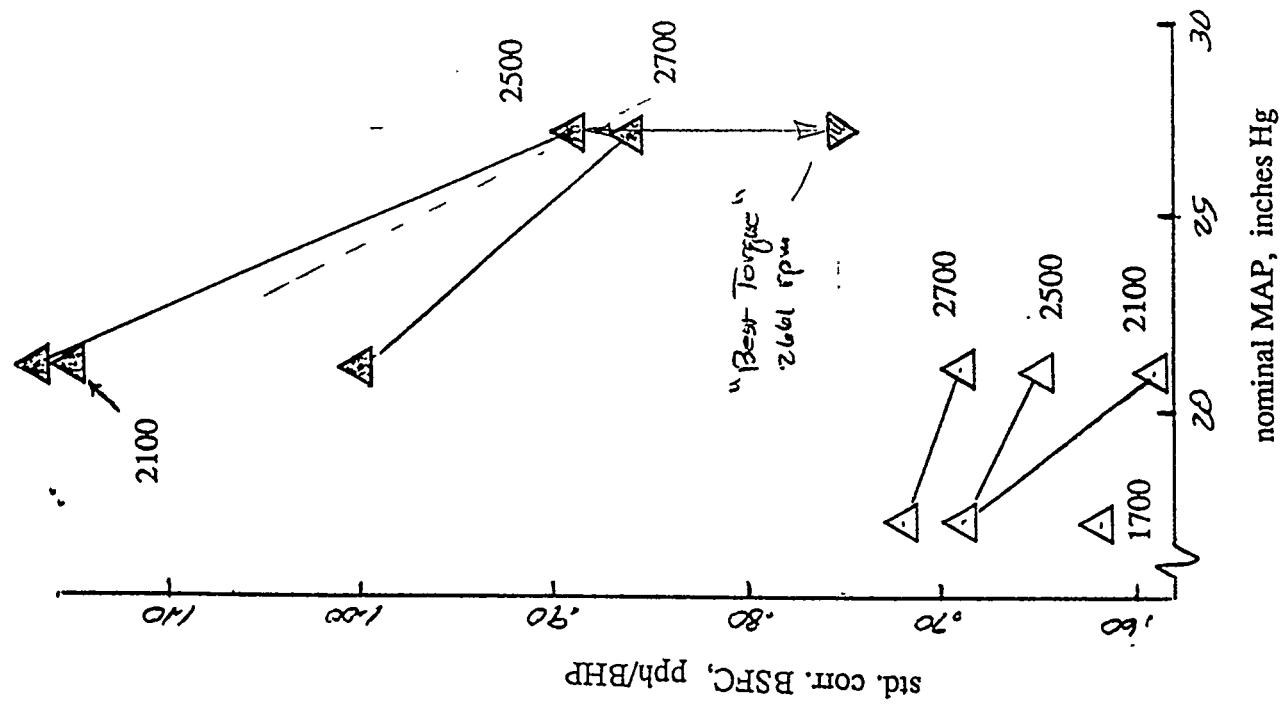
1U-36U/dyno: CR 8.5:1, servo w/EtOH ca., mags @ 25 BTDC, manual rpm leaning

ETBE Sept -

unshaded: leaned
shaded: full rich



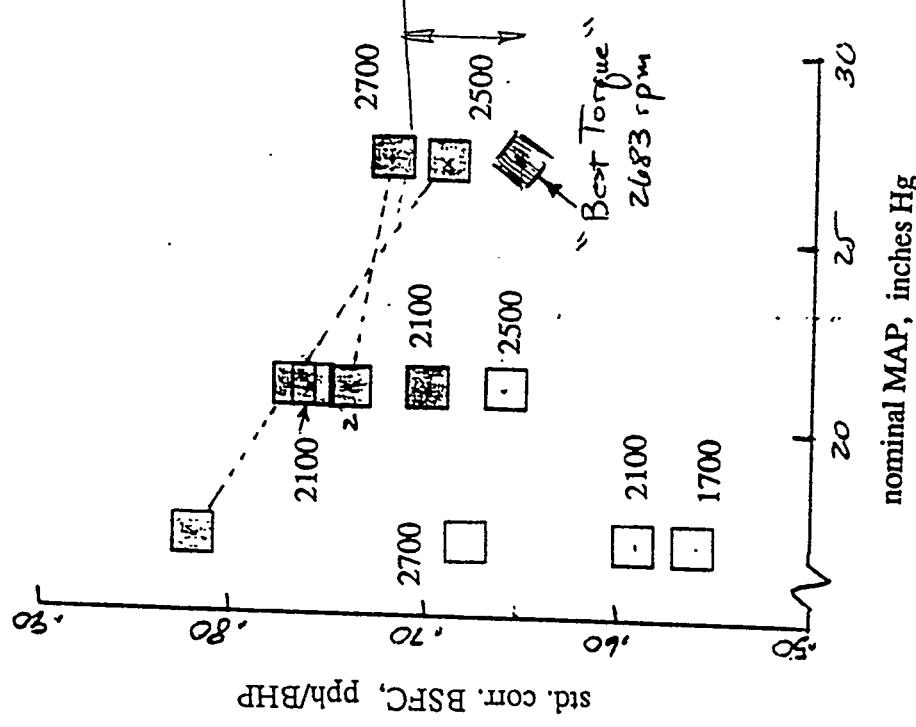
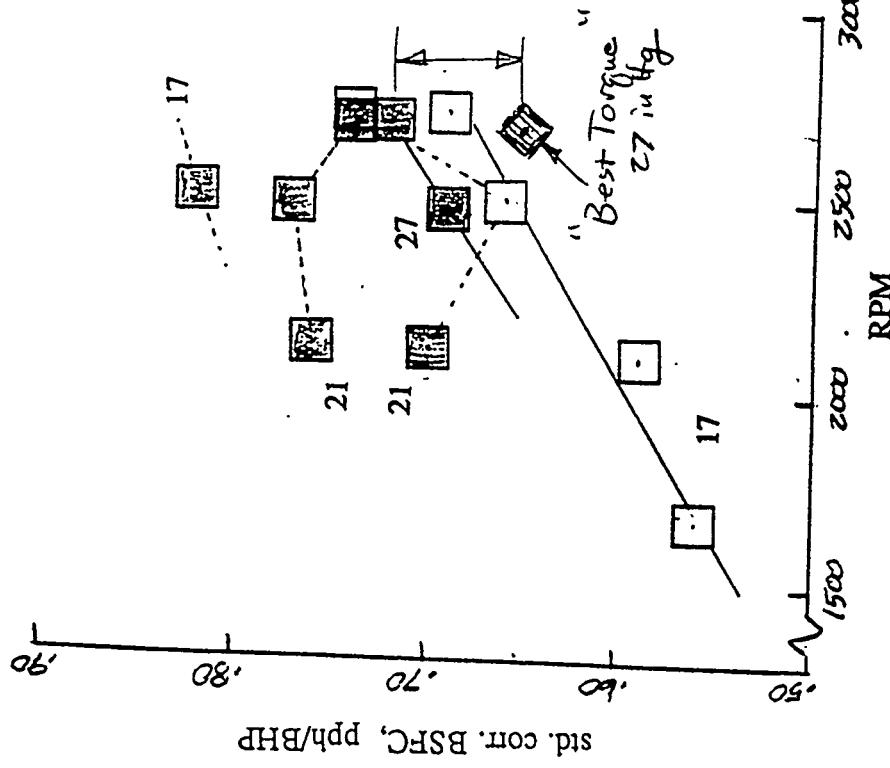
$$P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) * \sqrt{(\text{C.A.T.}, \text{deg R} / 520.)}$$



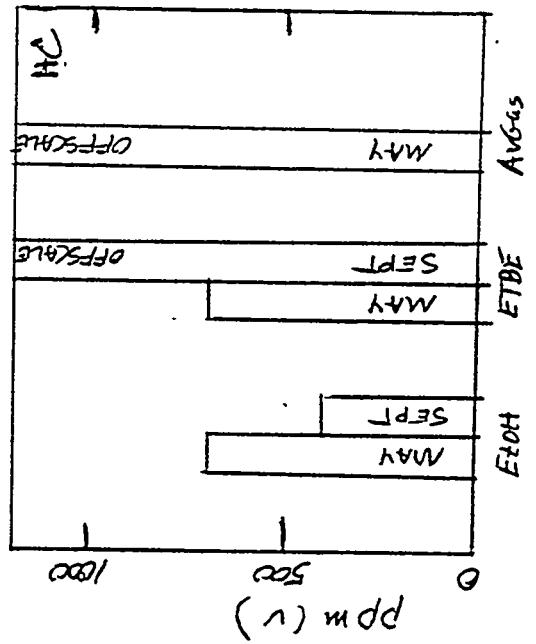
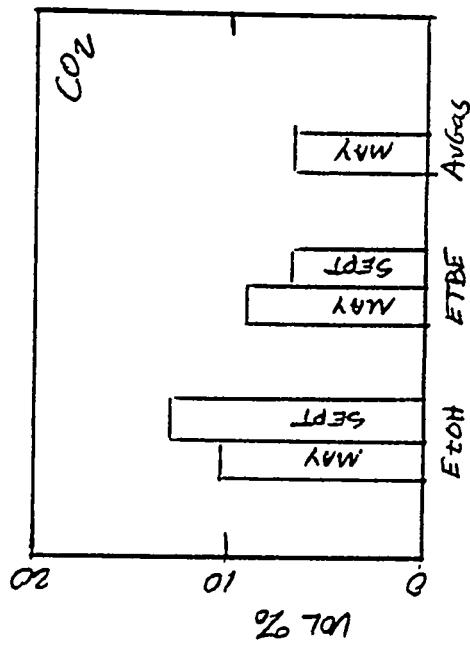
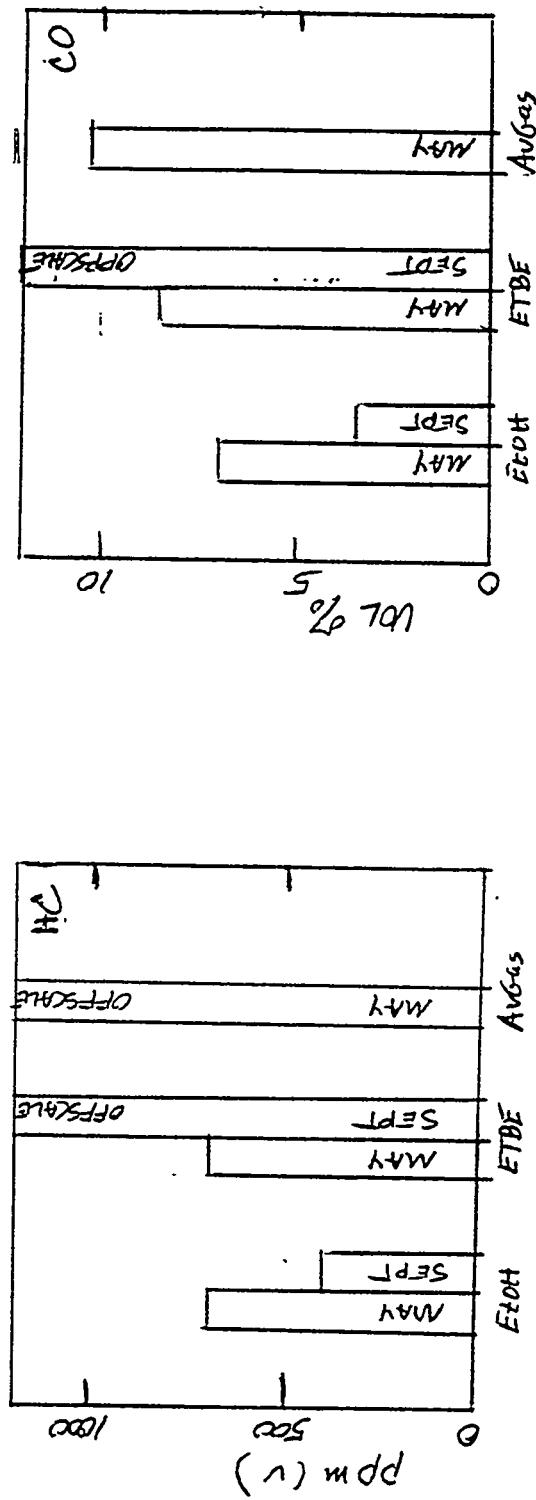
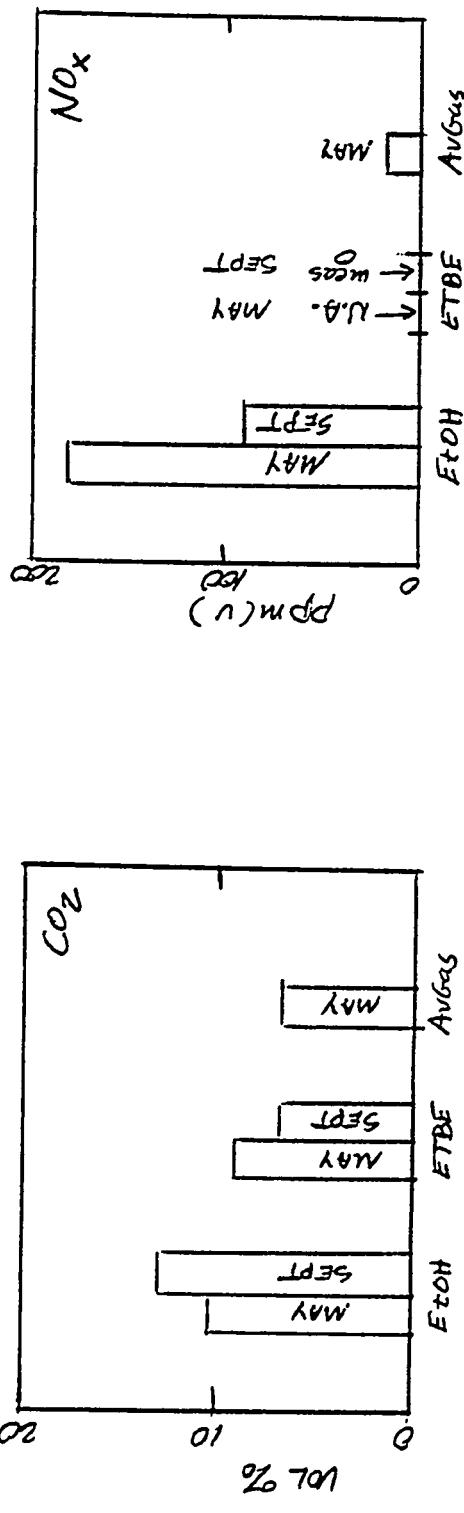
<input type="checkbox"/>	<u>lean</u>
<input type="checkbox"/>	<u>rich</u>
<input type="checkbox"/>	<u>shaded</u>

IO-360/dyno: CR 8.5:1, servo w/EtOH calibr,
 $P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.})$ *

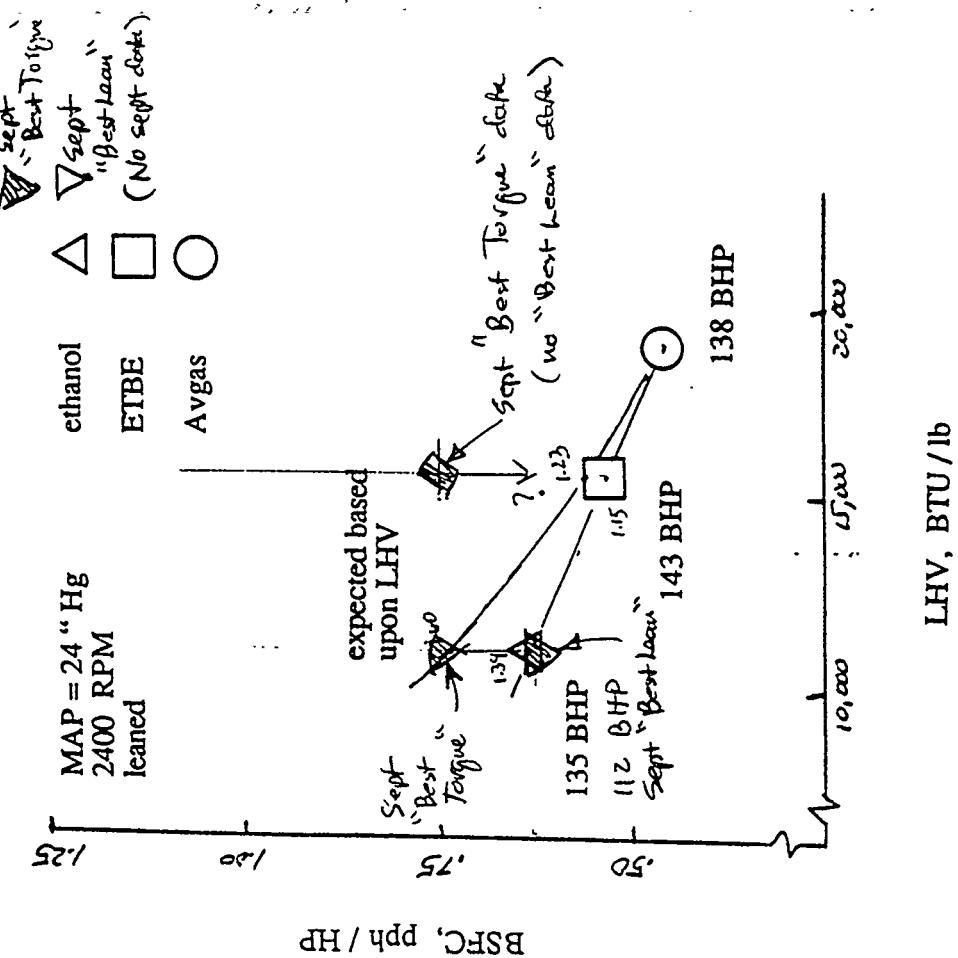
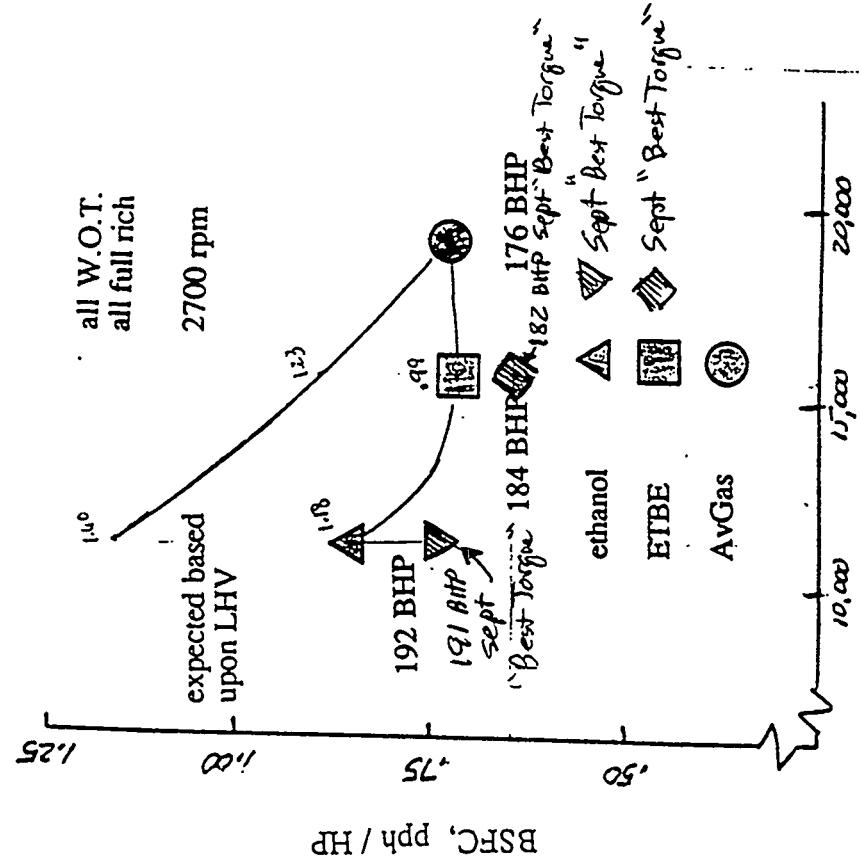
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning
 $P_{corr} = P_{raw} * (29.92 / \text{uncorr. baro.}) * (C.A.T., \deg R / 520.)$



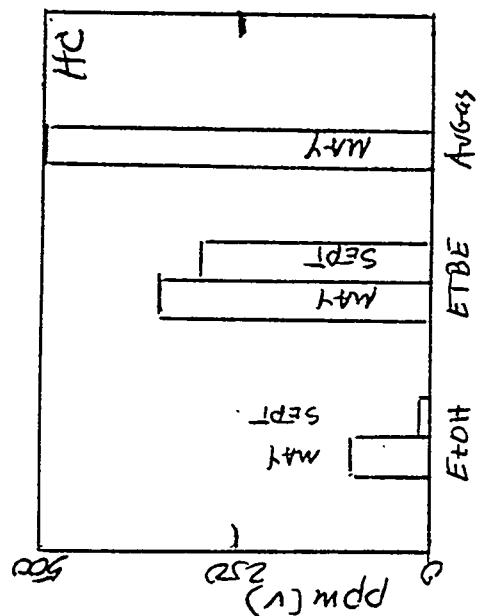
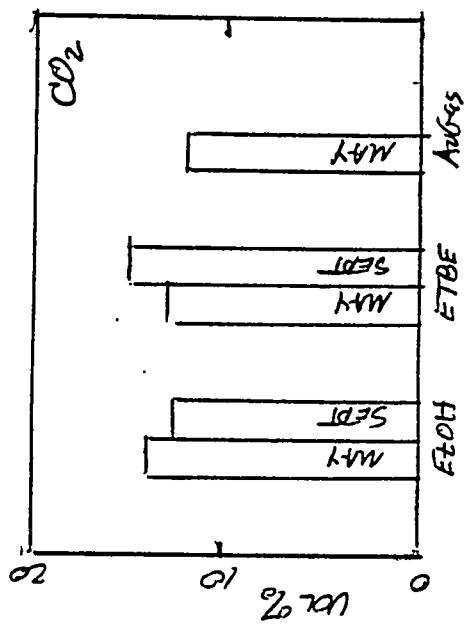
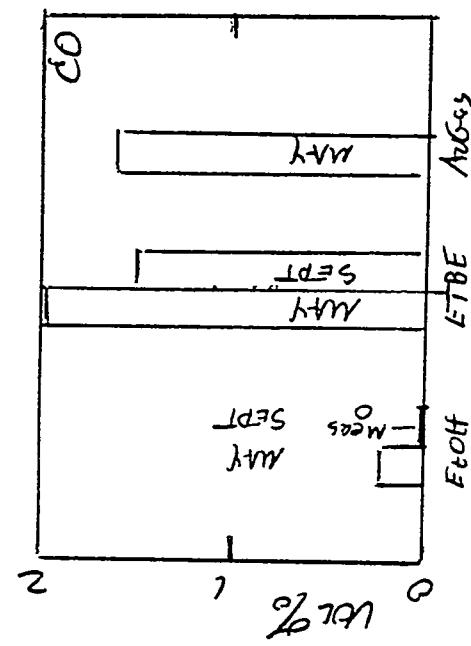
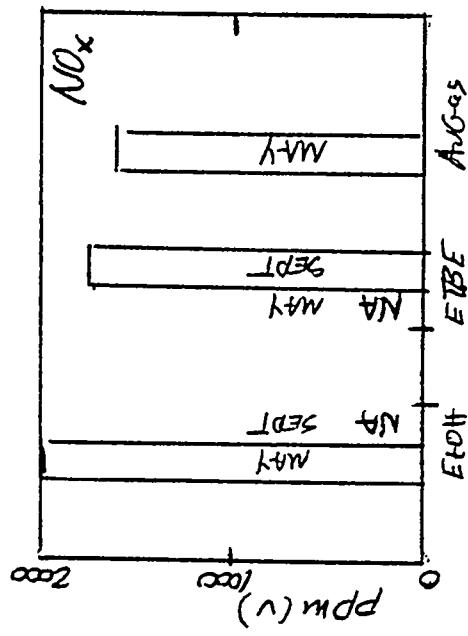
FULL POWER



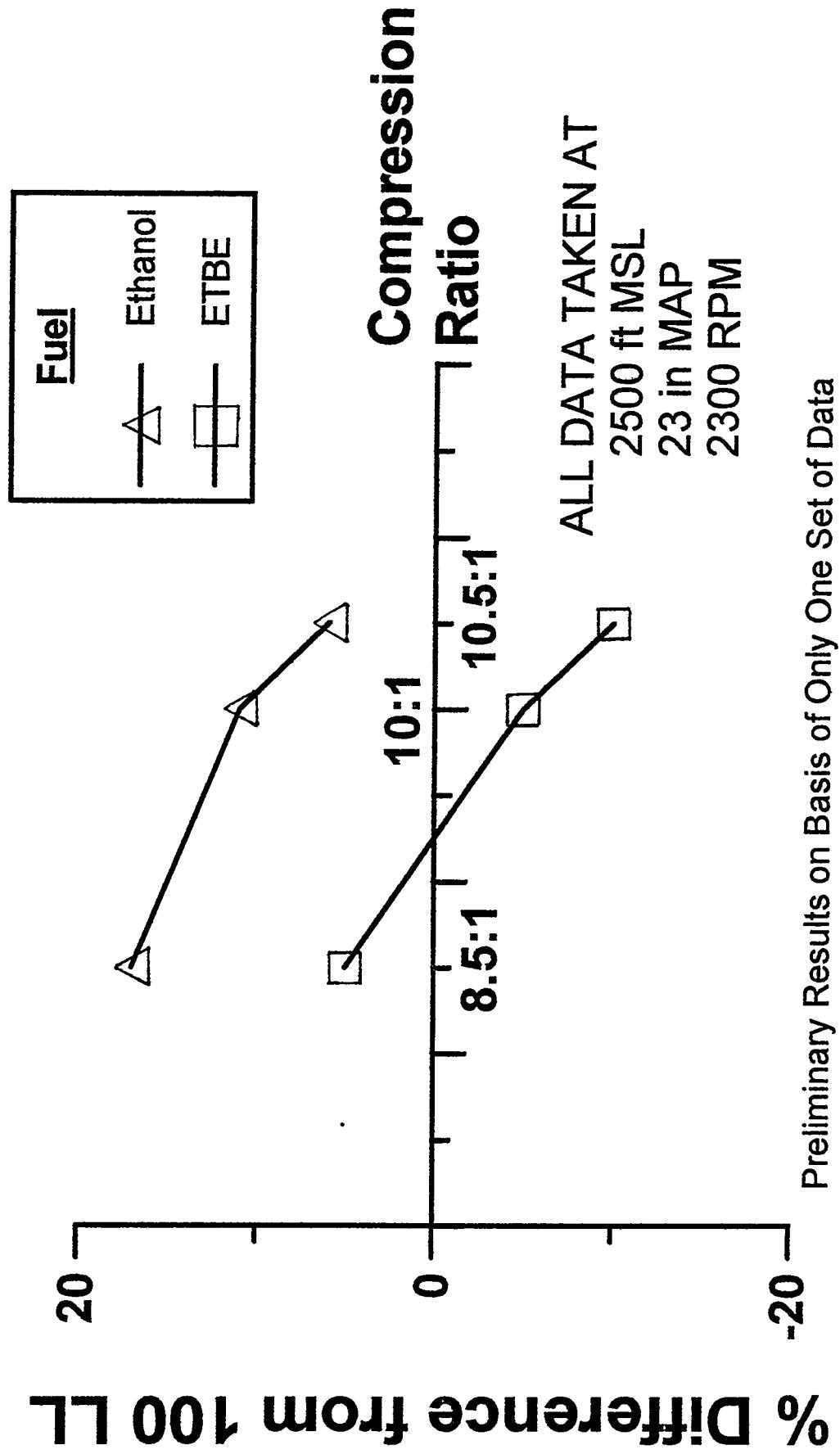
IO-360/dyno: CR 8.5:1, servo w/EtOH calibr, mags @ 25 BTDC, manual rpm leaning



CRUISE



LYCOMING AEIO - 540 D4A5



A Comparative Analysis of Ethanol Versus Gasoline as a Fuel in Production Four-Stroke Cycle Automotive Engines

Bruce Jones, Kirk Ready, Richard Bach, Dana Hansen, Eric Kaitala,
Jamie Larson, Julio Morales, and Conway Reese
Mankato State Univ.

Copyright 1995 Society of Automotive Engineers, Inc.

ENGINE RPM	GASOLINE VEHICLE POWER (corr) kW (HP)	ETHANOL VEHICLE POWER (CORR) kW (HP)	% CHANGE
2000	24.5 (18.3)	29.0 (21.6)	+18.4
2500	32.6 (24.3)	36.2 (27.0)	+11.0
3000	41.2 (30.7)	43.3 (32.3)	+5.0
3500	44.8 (33.4)	47.7 (35.6)	+6.5
4000	47.7 (35.6)	51.3 (38.3)	+7.5
4500	49.9 (37.2)	53.5 (39.9)	+7.2
5000	50.5 (37.7)	57.8 (43.1)	+14.5
5500	47.7 (35.6)	57.8 (43.1)	+21.2

Table 2. Summary of power testing results

	GASOLINE VEHICLE	ETHANOL VEHICLE
Distance Traveled	15997.8 km (9940.6 miles)	16006.1 km (9945.7 miles)
Fuel Used	799.90 l (211.39 gal)	1102.13 l (291.26 gal)
Overall Fuel Economy	20.00 km/l (47.01 MPG)	14.52 km/l (34.14 MPG)
% Change in Fuel Economy	—	27.4% Decrease
Equivalent Fuel Economy	20.00 km/IE (47.01 MPGE)	23.04 km/IE (54.18 MPGE)
% Change in Equivalent Fuel Economy	—	15.2% Increase

Table 1. Summary of fuel efficiency results from the 16,100 km test cycle

FUEL ECONOMY - Table 1 shows the results obtained during the approximately 16,100 km (10,000 mile) test cycle which consisted of 42 individual trips over the test course by both the stock gasoline vehicle and the modified ethanol vehicle. The km/IE and MPGE indicates the fuel economy base on equivalent (E) energy consumption using the energy in a liter or gallon of gasoline.

% HP	CORRECTED HORSEPOWER	AVGAS GPH	ETBE GPH	% FUEL CONSUMPTION CHANGE + = INC - = DEC	ETHANOL GPH	% FUEL CONSUMPTION CHANGE + = INC - = DEC
						CHART
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

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

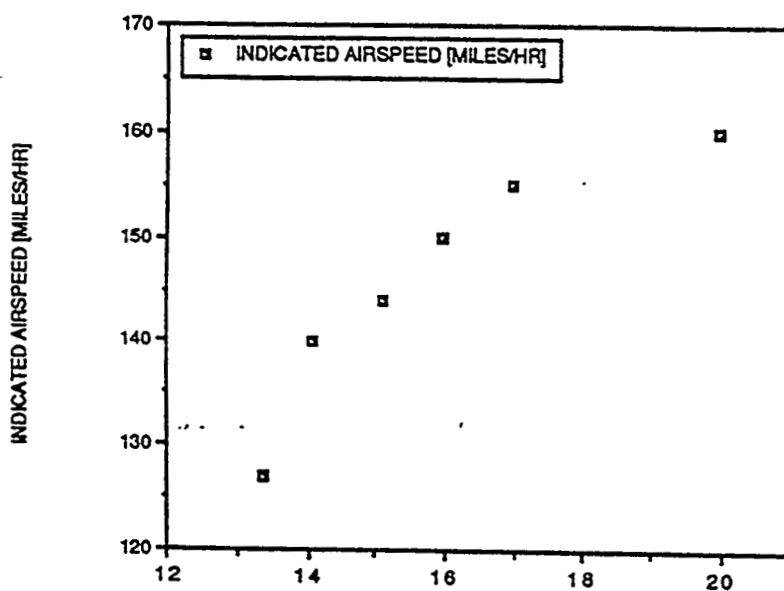
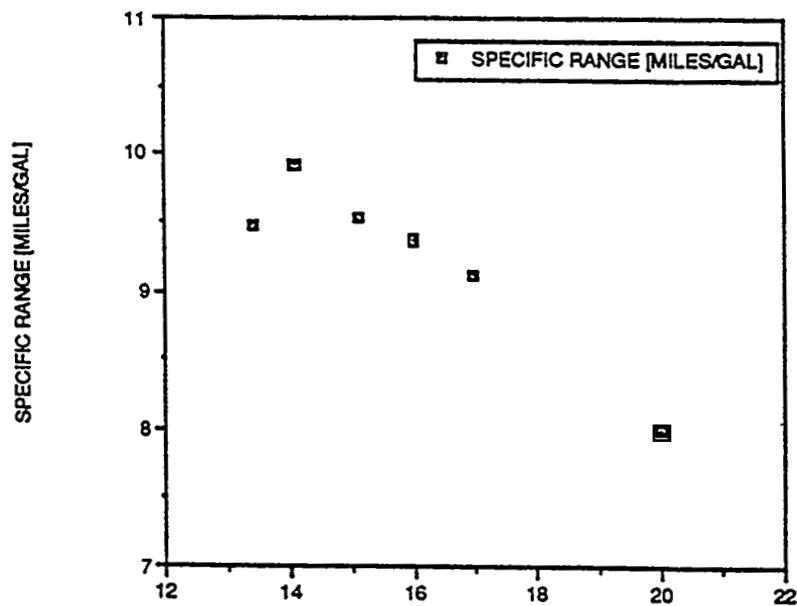


Figure 1

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

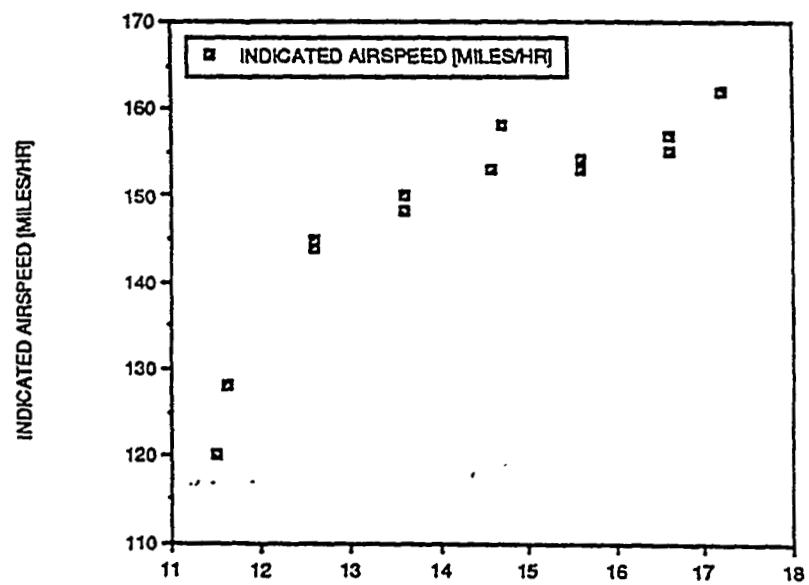
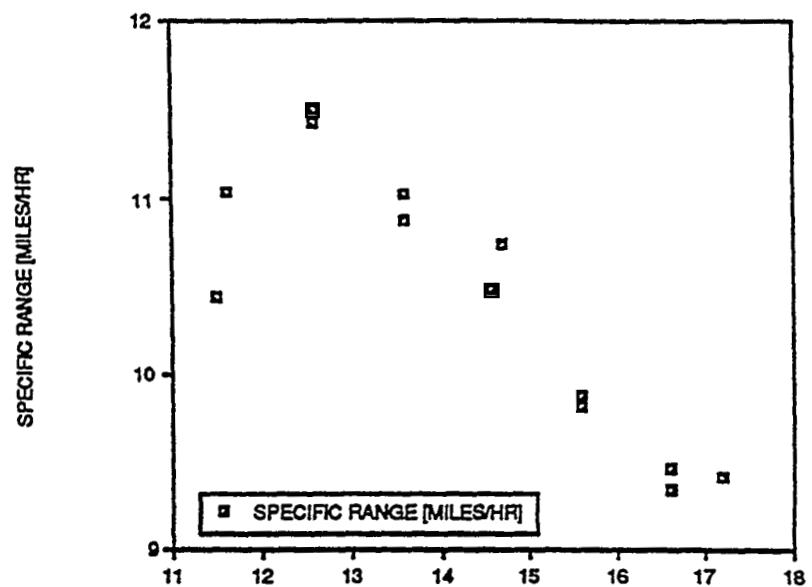
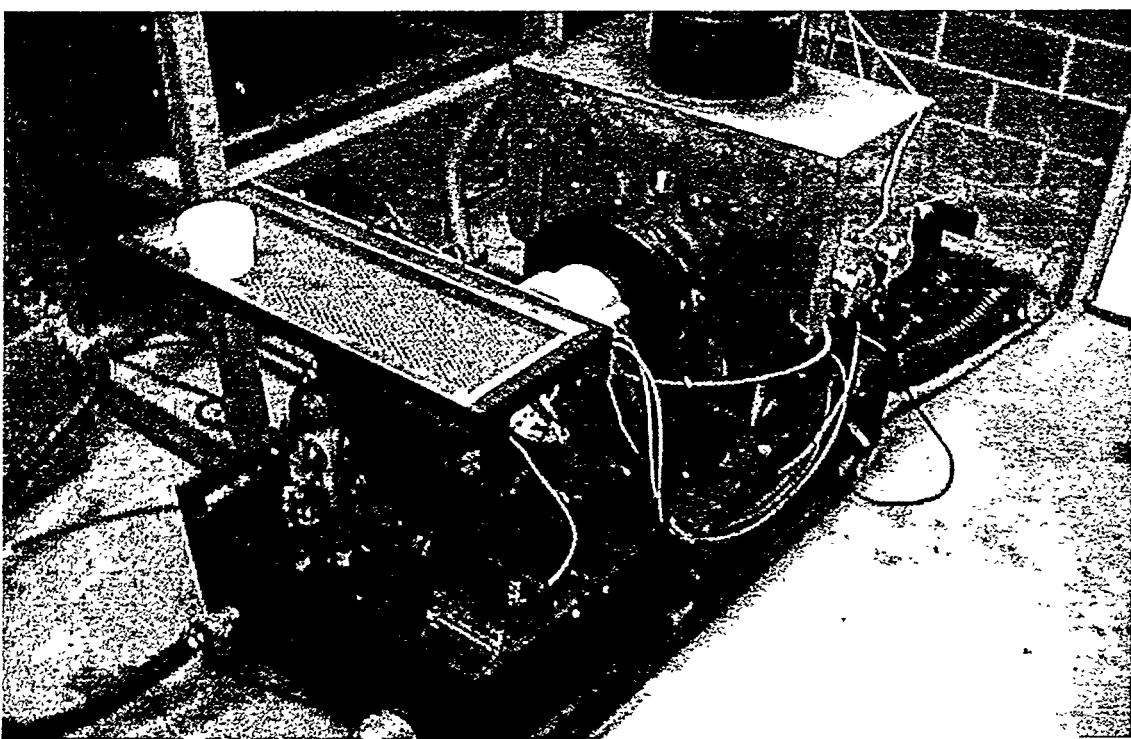
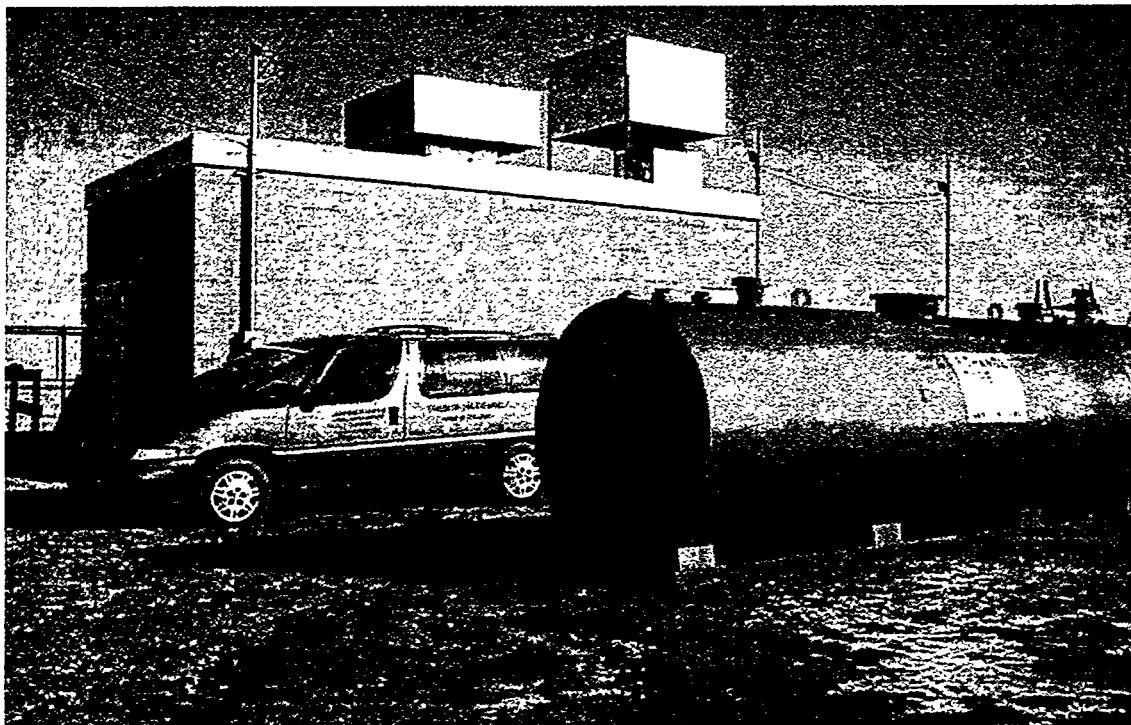
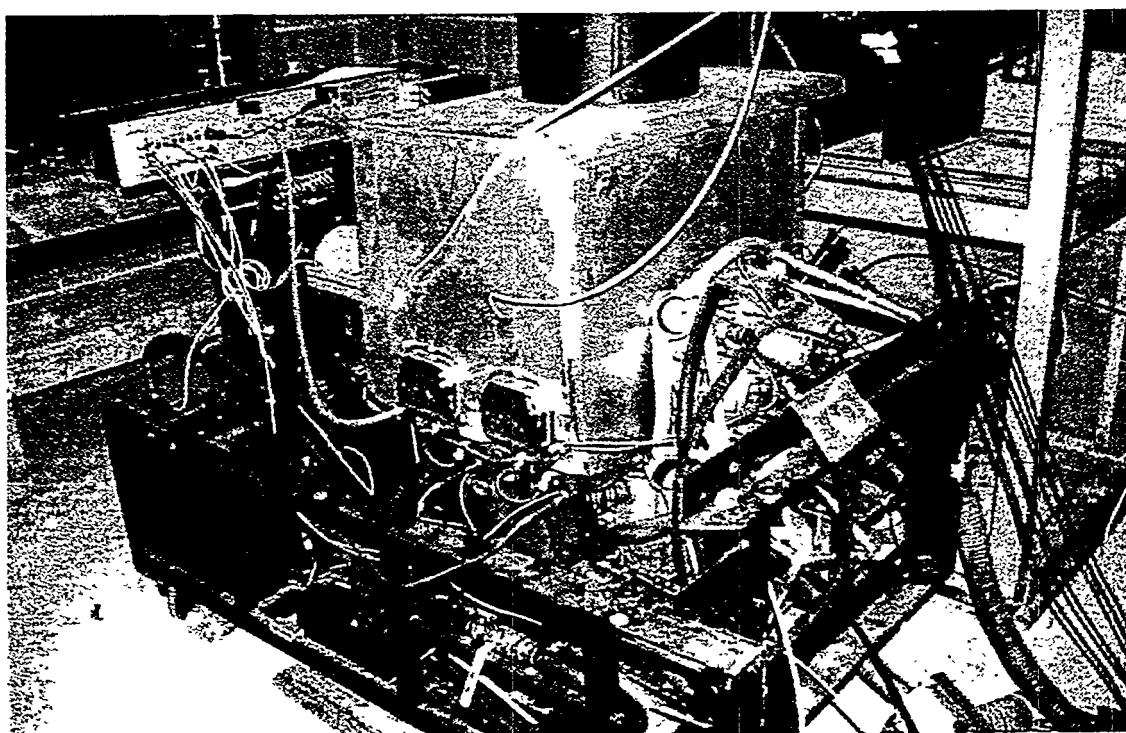
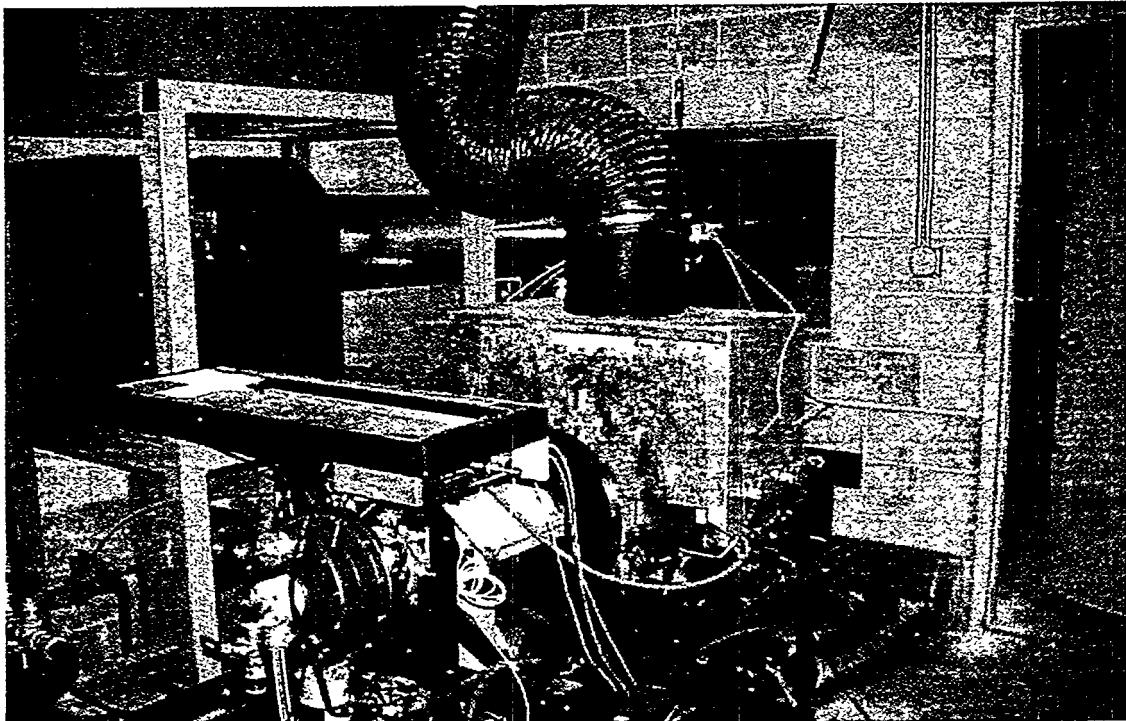


Figure 2

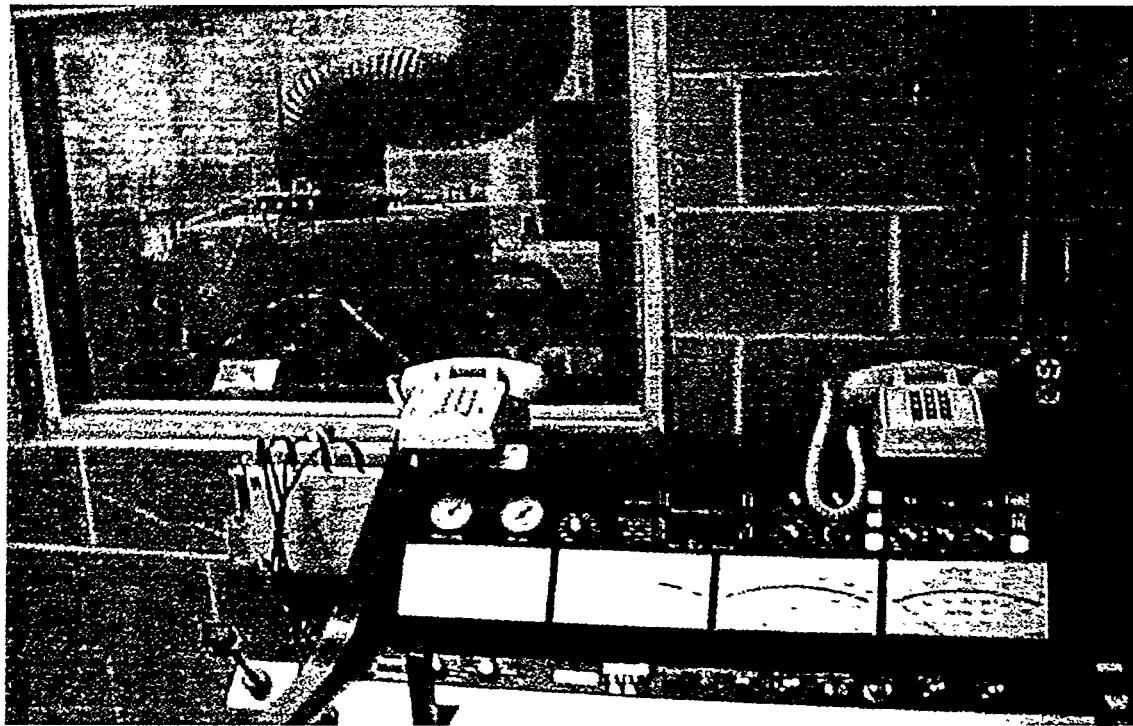
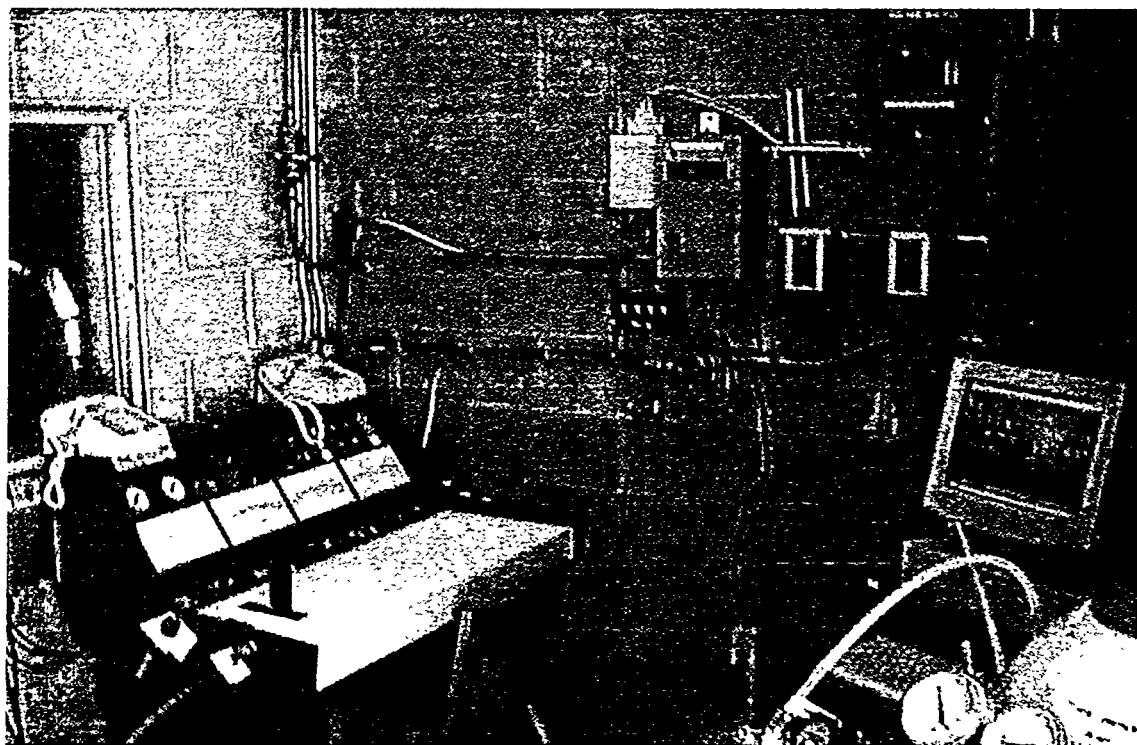
RAFDC's Piston Engine Test Stand



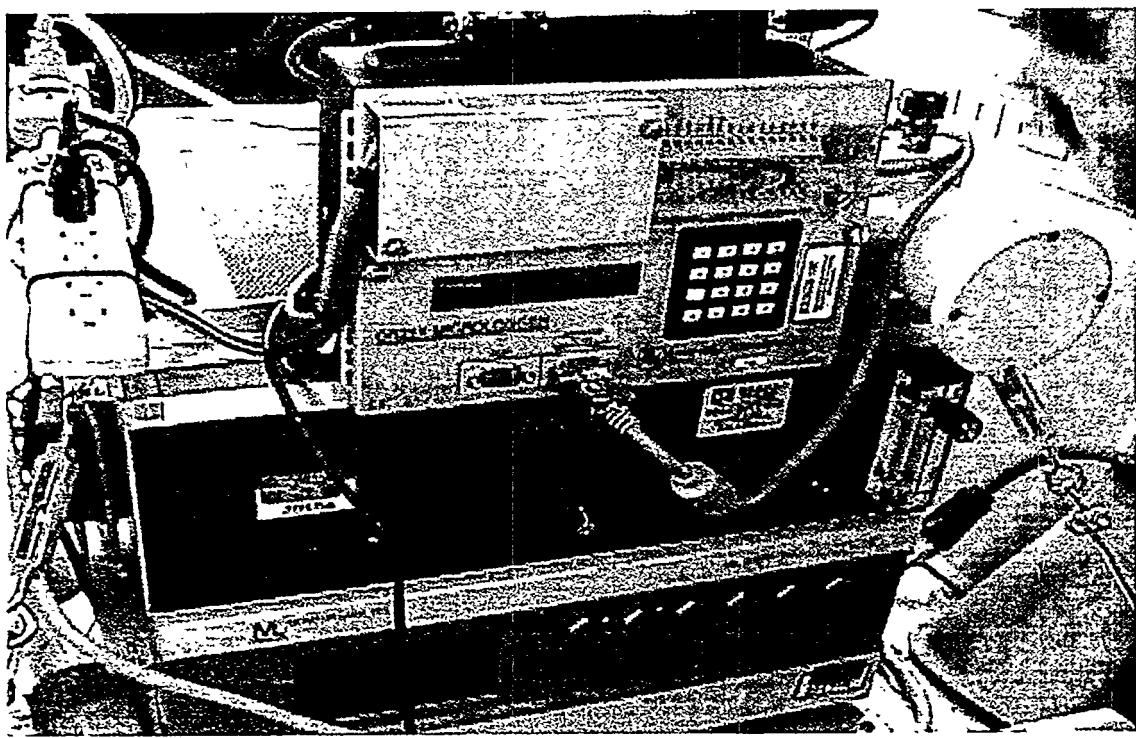
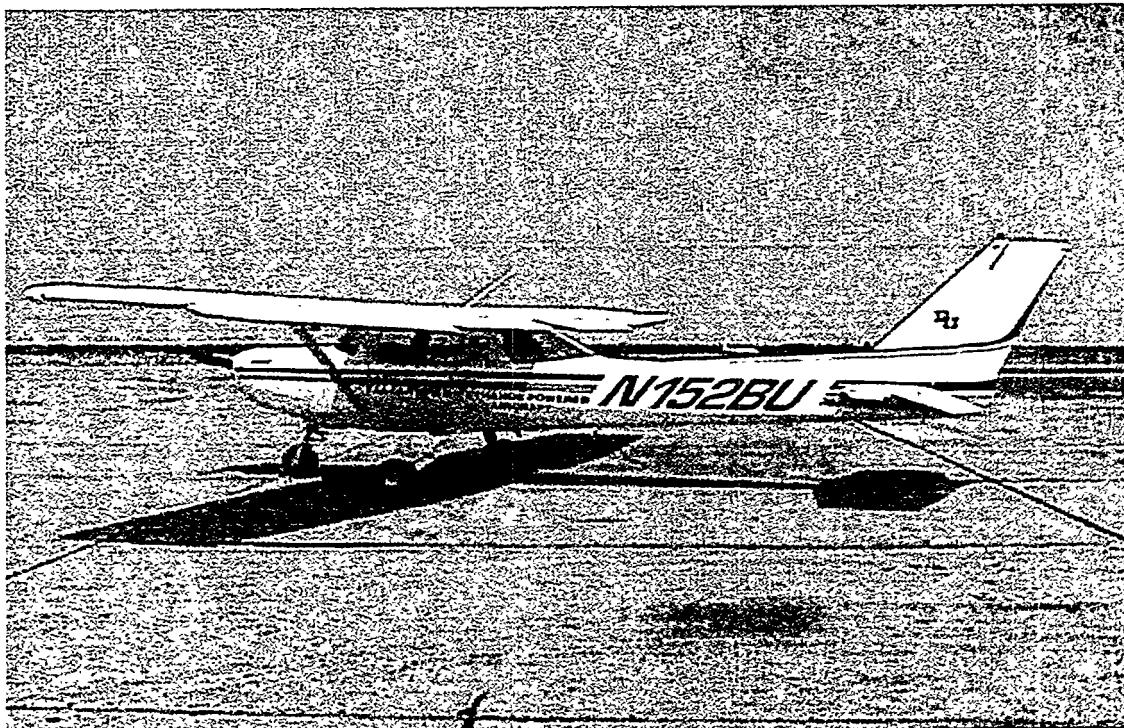
RAFDC's Piston Engine Test Stand - Engine Installation



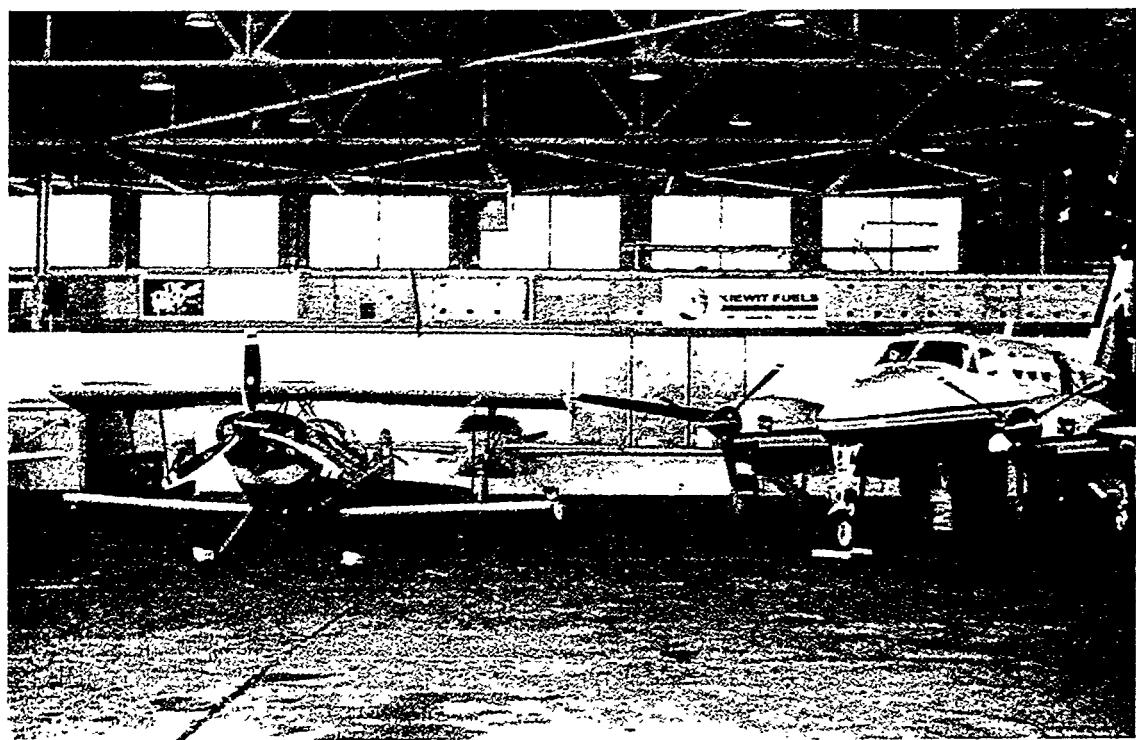
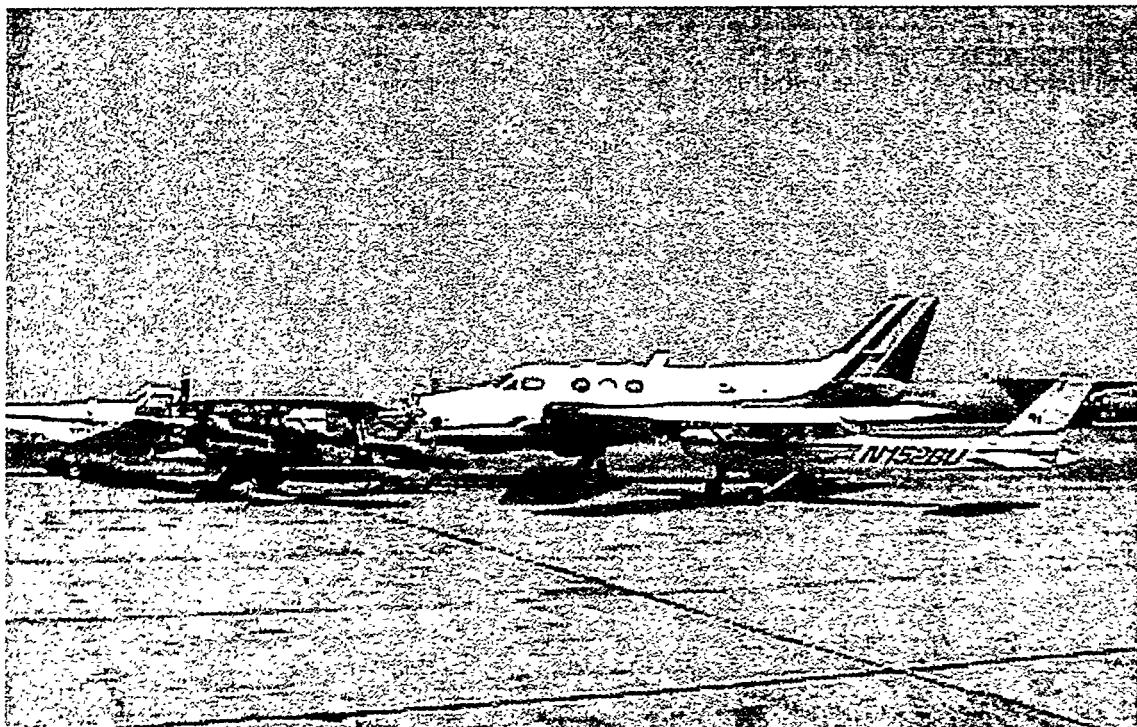
RAFDC's Piston Engine Test Stand - Control Room



RAFDC's Instrumented Cessna 152



Renewable Aviation Fuels Development Center's Fleet and Hangar



The Vanguard Squadron, Sioux Falls, SD
100% Ethanol Powered



ETHANOL

BUT WHY ???

* ENVIRONMENTAL IMPROVEMENT

- REMOVES NEED FOR LEAD
- RECYCLE CARBON DIOXIDE
- REDUCE EMISSIONS

* ENERGY SECURITY

- RENEWABLE ENERGY SOURCE

* ASSIST AGRICULTURAL COMMUNITY

- PRICE STABILIZATION

* ASSIST AVIATION COMMUNITY

- FUEL OPTIONS
- SUPPLY SECURITY

PROJECT DESCRIPTION:

After the aircraft has been test flown and the engine has completed the break-in period, the engine will undergo full emissions testing for the regulated emissions (CO, NOx and HC) plus testing of hydrocarbon types and toxic emissions. Testing will be done at different power settings, air/fuel ratios, fuel blends and spark timing.

The aircraft will then accumulate 1,000 hrs of typical operation to assess fuel consumption, startability, durability, operability and maintainability.

FOR MORE INFORMATION, PLEASE CONTACT:

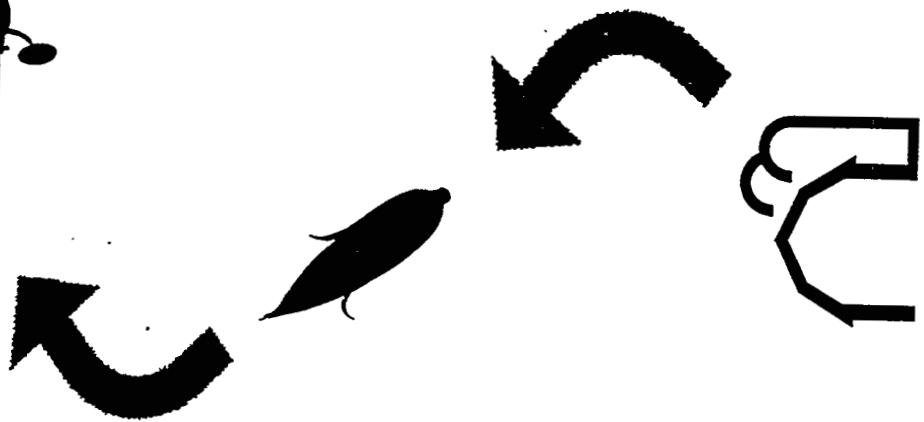
PROJECT PARTICIPANTS:

CANADIAN AERO ENGINES
(705) 326-1366 ORILLIA, ONT

SPECTRA ENVIRONMENTAL
(705) 457-3188 HALIBURTON, ONT

ENVIRONMENT CANADA
(819) 953-1601 OTTAWA, ONT

AS AN AVIATION FUEL ???



Environment
Canada



Environment
Canada

ETHANOL'S ENVIRONMENTAL BENEFITS

ETHANOL'S BENEFITS TO AVIATION

"MULTIPLE PERSONALITIES"

* ELIMINATES THE LAST SOURCE OF LEAD FROM FUELS

* BURNS CLEANER

LEANER COOLER

* BURNS CLEANER

LEANER COOLER

* 115 OCTANE

- NO PRE-IGNITION OR DETONATION

* REDUCES:

- CARBON MONOXIDE
- OXIDES OF NITROGEN
- HYDROCARBONS

* LOWER VAPOUR PRESSURE
- 2.5 VERSUS 5.5 - 6.5 FOR AVGAS

* NON-CORROSIVE TO ALUMINUM WHEN CORRECT ADDITIVES ARE USED

* RENEWABLE ENERGY SOURCE NOT RELIANT OF DIMINISHING CRUDE OIL SUPPLY

* RECYCLES CARBON

DIoxide - CO₂

(PRIMARY GREENHOUSE GAS)

- CROPS ABSORB CO₂ TO GROW
- ETHANOL IS PRODUCED FROM CROPS

- ETHANOL COMBUSTION RELEASES CO₂

* AIRCRAFT CAN STILL USE AVGAS

TEST FUEL

* 99% (200 PROOF) ETHANOL
* DENATURED WITH 1% GASOLINE
* 115 OCTANE
* LOW RVP 2.5 VS 5.5 - 6.5 FOR AVGAS

TEST AIRCRAFT



Baylor University's Aviation Sciences Department
together with the
U.S. Department of Energy,
the Federal Aviation Administration,
and Texas State Technical College
invite you to attend:

THE FIRST INTERNATIONAL CONFERENCE ON ALTERNATIVE AVIATION FUELS

International Conference on
Alternative Aviation Fuels
c/o Karin Erickson
1925 North Lynn Street
Suite 1000
Arlington, VA 22209



PLEASE CIRCULATE

(TSTC) OFFER A JOINT AVIATION SCIENCES PROGRAM.

These two institutions have joined forces to provide a four year aircraft system management degree, one of only 30 programs nationwide. Students receive an associate degree in Aircraft Pilot Training at TSTC and a bachelor of science in Aviation Sciences from Baylor.

▼ Baylor's Aviation Sciences Department has gained international recognition for its renewable aviation fuel research, with over 15 years of experience.

▼ The Renewable Aviation Fuel Development Center at Baylor has received numerous federal, state and private grants to certify aircraft on ethanol. Baylor Aviation Sciences Director Dr. Shauerk and his wife, Grazia Zanin, made the first transatlantic flight using ethanol as fuel for which he received the 1991 Harmon Trophy award.

▼ Recently, he was the first person to fly on pure ETBE (ethyl tertiary butyl ether). This June, Dr. Shauerk flew the first public demonstration on ETBE at the Paris Airshow. In addition to ethanol research, Baylor is evaluating the merits of biodiesel.

November 2-4, 1995

Baylor University
Waco, Texas
To Register, Call 800-USA-FUEL



For more information about Baylor University or TSTC's
Aviation Sciences Program, call
Patricia Pack at 817-755-3563.



Nonprofit
Organization
U. S. Postage
PAID
Permit No. 210

THE FIRST INTERNATIONAL CONFERENCE ON ALTERNATIVE AVIATION FUELS

Billings Student Center, Baylor University

THURSDAY, NOVEMBER 2, 1995

▼ 11:00 AM - 12:00 PM

REGISTRATION

Barfield Drawing Room Foyer

▼ 1:30 PM - 3:30 PM

WORKSHOP ON CERTIFICATION PROCEDURES

Barfield Drawing Room

Gus Ferrara, Private Consultant

Paul Pendleton, Federal Aviation Administration

▼ 3:30 PM - 4:00 PM

REFRESHMENT BREAK

▼ 4:00 PM - 5:00 PM

STRATEGY SESSION TO COMMERCIALIZE ALTERNATIVE FUELS IN THE AVIATION SECTOR

Barfield Drawing Room

Facilitator: Bill Holmberg, American Biofuels Association

Gus Ferrara, Independent Aviation Consultant

John Russell, U.S. Department of Energy

Russell Smith, Texas Renewable Energy Industry Association

Clay Wilkins, Texas State Technical College

All conferees are welcome to participate in this session and share their views.

▼ 6:00 PM - 8:00 PM

OPENING RECEPTION AND ADDRESS

Dr. Pepper Museum

Keynote Speaker: TBA

Guest Speaker: Linda Dascle

Federal Aviation Administration (invited)

FRIDAY, NOVEMBER 3, 1995

▼ 7:00 AM - 2:00 PM

REGISTRATION

Barfield Drawing Room Foyer

▼ 7:00 AM - 8:00 AM

CONTINENTAL BREAKFAST

Barfield Drawing Room Foyer

▼ 8:00 AM - 8:10 AM

OPENING REMARKS

John Russell, U.S. Department of Energy

▼ 8:10 AM - 8:40 AM

KEYNOTE AND GENERAL OVERVIEW

Paul MacCready, AeroVironment

▼ 8:40 AM - 9:00 AM

FUEL DATA PRESENTATION

Brent Bailey, National Renewable Energy Laboratory

▼ 9:00 AM - 9:30 AM

AVIATION GASOLINE SITUATION: CURRENT SEARCH FOR PETROLEUM ALTERNATIVES TO AV-GAS

Doug MacNair, Aircraft Owners & Pilots Association

▼ 9:30 AM - 10:00 AM

POSTER SESSION AND REFRESHMENT BREAK

▼ 10:00 AM - 11:00 AM

FUEL SUPPLIERS' RESPONSE TO ALTERNATIVE FUELS - PANEL DISCUSSION

Facilitator: Todd Sneller, Nebraska Gasohol Commission

Allen Breit, Phillips Petroleum Company

Dave Hallberg, Kiewit Fuels, Inc.

Chuck Minard, Conoco, Inc.

Richard Riley, Phillips Petroleum Company

▼ 11:00 AM - 11:50 AM

MANUFACTURERS' RESPONSE TO ALTERNATIVE FUELS - PANEL DISCUSSION

William Brugden, Teledyne/Continental Motors (invited)

Cesar Gonzalez, Cessna Aircraft Company

Rick Moffit, Textron Lycoming

Dean Vogel, Cirrus Design

▼ NOON - 1:30 PM

LUNCHEON AT CASHION BUILDING, 5TH FLOOR

Garry Mauro, Commissioner, Texas General Land Office

▼ 2:00 PM - 2:30 PM

THE RENEWABLE AVIATION FUEL DEVELOPMENT CENTER

Max Shauck, Aviation Sciences Department,
Baylor University

▼ 2:30 PM - 4:30 PM

WORLDWIDE ALTERNATIVE FUEL EXPERIENCES

Jacques Callies, Aviation Pilots Magazine, France

Mats Ekelund, Crossroads Consulting, Sweden

Mauro Furlan, Italy

Earl Lawrence, Experimental Aircraft Association, USA
Plinio Nastari, DataGro, Ltd., Brazil

▼ NOON - 1:30 PM

REFRESHMENT BREAK

▼ 4:30 PM - 5:00 PM

CONFERENCE SUMMARY

Robert Harris, Nebraska State Energy Office



TRADE SHOW

CONFERENCE REGISTRATION

- ▼ Advance Registrations are now being taken for the First International Conference on Alternative Aviation Fuels, November 2-4, 1995 at Baylor University in Waco, Texas.

Your Registration Includes:

- ▼ Admittance to all conference sessions
- ▼ One Conference Proceedings Notebook
- ▼ Opening Reception November 2
- ▼ Continental Breakfast November 3
- ▼ Luncheon November 3
- ▼ Evening Reception November 3
- ▼ Conference Exhibition
- ▼ Air Show November 4

Exhibit booths will be available for your company to showcase its products and technology during the First International Conference on Alternative Aviation Fuels.

Show Dates and Time:

1:00 pm - 5:00 pm Thursday, November 2
7:30 am - 6:00 pm Friday, November 3

Booth Rates:

8'x10' Booth Space \$300/booth

For questions about exhibiting, contact Karin Erickson at 703-528-2500.

RECEPTIONS

DR. PEPPER MUSEUM

THURSDAY, NOVEMBER 2 — 6:00 PM - 8:00 PM

Enjoy hors d'oeuvres and refreshments while strolling through the 1906 "Home of Dr. Pepper." Indulge yourself at the turn-of-the-century soda fountain featuring floats and shakes! Dress is casual.

BUZZARD BILLY'S

FRIDAY, NOVEMBER 3 — 6:30 PM - 8:30 PM

Come see what all the talk is about! Join conference attendees at Waco's most popular night spot featuring Cajun cooking, Dress scasas,

Planes will be flying through smoke that'll be pouring from the grill as local Texans serve up their traditional Texas-style barbecue. Complimentary beverages will be provided by Coca-Cola Waco!

LUNCH

- ▼ Waco tour information will be available upon registration.
- ▼ Please remit registration forms to:
Karin Erickson
Registration Manager
Conference on Alternative Aviation Fuels
Information Resources, Inc.
1925 North Lynn Street
Suite 1000
Arlington, VA 22209
703-528-2500 or 800-USA-FUEL

THE FIRST INTERNATIONAL CONFERENCE ON ALTERNATIVE AVIATION FUELS

Texas State Technical College

SATURDAY, NOVEMBER 4, 1995

▼ 9:00 AM - 10:00 AM

WORKSHOP ON ENGINE MODIFICATIONS FOR ETHANOL (OR ETBE) POWERED AIRCRAFT

Glenn Maben, Aviation Sciences Department,
Baylor University
Max Shauk, Aviation Sciences Department,
Baylor University

Dean Vogel, Cirrus Design
Gayle Wills, Vanguard Aircraft Builders

▼ 10:30 AM - 10:30 AM

ENGINE TEST FLIGHT

Glenn Maben, Aviation Sciences Department,
Baylor University

▼ 10:30 AM - CLOSE

AIR SHOW DEMONSTRATIONS

Enjoy a fun filled day of Air Show demonstrations on a variety of alternative fuel aircraft! *Come ride in propane hot air balloons* compliments of Harring Gas Company in conjunction with Squibb Taylor, Inc.

CONFERENCE REGISTRATION

- ▼ Advance Registrations are now being taken for the First International Conference on Alternative Aviation Fuels, November 2-4, 1995 at Baylor University in Waco, Texas.
- ▼ Your Registration Includes:
- ▼ Admittance to all conference sessions
- ▼ One Conference Proceedings Notebook
- ▼ Opening Reception November 2
- ▼ Continental Breakfast November 3
- ▼ Luncheon November 3
- ▼ Evening Reception November 3
- ▼ Conference Exhibition
- ▼ Air Show November 4

CANCELLATION POLICY

- ▼ All cancellations MUST be received in writing. Those postmarked after October 20, 1995 will be subject to a \$75 cancellation fee for administrative expenses. Substitutions are welcome.

- ▼ Please make checks payable to:

Baylor University, Aviation Conference

- ▼ Please remit registration forms to:

Karin Erickson

Registration Manager

Conference on Alternative Aviation Fuels
Information Resources, Inc.
1925 North Lynn Street
Suite 1000
Arlington, VA 22209
703-528-2500 or 800-USA-FUEL

HOTEL INFORMATION

- ▼ A block of rooms has been reserved at the Waco Hilton Inn. Special low room rates are available now!

Single/Double - \$669

- ▼ Please make your hotel arrangements at the Waco Hilton Inn as soon as possible, while our special reserved rooms are available. In order to receive discounted rates, please inform the reservations agent that you are attending the **First International Conference on Alternative Aviation Fuels** hosted by Baylor University. This block will be available November 1-4.
- ▼ For reservations, simply call the hotel directly at 817-754-8484 or Hilton's central reservations office at 800-445-8667. The hotel fax number is 817-752-2214.

TRANSPORTATION

- ▼ Waco is served by the Waco Regional Airport. It services Delta and American Eagle shuttle connections out of Dallas and a Continental connection out of Houston.
- ▼ Shuttlebus transportation to the Hilton is available from the Waco Airport. Simply call the hotel upon arrival. A shuttle van is also available directly from the Dallas/Ft. Worth Airport (75 min.). Waco is located 90 minutes north of Austin. Contact your local travel agent for additional information.
- ▼ A shuttle will be available on-site between the Hilton and Baylor University.



Gold SPONSORS

- ▼ Baylor University
- ▼ Federal Aviation Administration
- ▼ Texas State Technical College
- ▼ U.S. Department of Energy

BRONZE SPONSORS

- ▼ American Corn Growers Association
- ▼ Clean Fuels Development Coalition
- ▼ Coca-Cola Waco
- ▼ Information Resources, Inc.
- ▼ Texas Corn Producers Board

ASSOCIATE SPONSORS

- ▼ Air Transport Association
- ▼ Airports Council International
- ▼ American Helicopter Society
- ▼ Civil Aviation Medical Association
- ▼ Experimental Aviation Association
- ▼ Flight Safety Foundation, Inc.
- ▼ General Aviation Manufacturers Association
- ▼ Hart Publications, Inc.
- ▼ Helicopter Association International
- ▼ International Flying Farmers Association
- ▼ National Aeronautical Association, Inc.
- ▼ National Agricultural Aviation Association
- ▼ National Air Carrier Association, Inc.
- ▼ National Air Transportation Association
- ▼ National Association of State Aviation Officials
- ▼ National Biodiesel Board
- ▼ National Business Aircraft Association Inc.
- ▼ National Ethanol Vehicle Coalition
- ▼ National Renewable Energy Laboratory
- ▼ Professional Airways Systems Specialist
- ▼ Professional Aviation Maintenance Association
- ▼ Professional Women Controllers
- ▼ Regional Airline Association
- ▼ Squibb Taylor, Inc.
- ▼ University Aviation Association

(As of August 30, 1995)

CONFERENCE REGISTRATION FORM

To avoid on-site registration lines: Please print or type on form, fill in completely, and forward your payment in advance.

Name _____
Title _____
Company _____
Address _____
City _____
State _____ Zip _____
Country _____
Telephone _____
Fax # _____

Make checks payable to:
Baylor University, Aviation Conference

\$300 Full Registration Payment
\$225 Government/University Rate

Check Enclosed
 Please charge my Visa/Mastercard
Card # _____
Expiration Date _____
Cardholder's Name _____
 Please Invoice Me

On-site translators available upon request
Language needed _____ (Certain restrictions apply)

For registration questions, call Karin Erickson directly at 703-528-2560 or 800-USA-FUEL.
For expedited service, simply fax this form to 703-525-0187.

The Alternative to
Aviation Gasoline

ETHANOL

- Cost competitive
- Made in the USA
- Good for the environment
- Superior performance
- A proven aviation fuel

This Pitts Special was flown on ethanol fuel in the 1993 Paris Airshow.

Ethanol—The Alternative to Aviation Gasoline

The Future Of Aviation Fuel

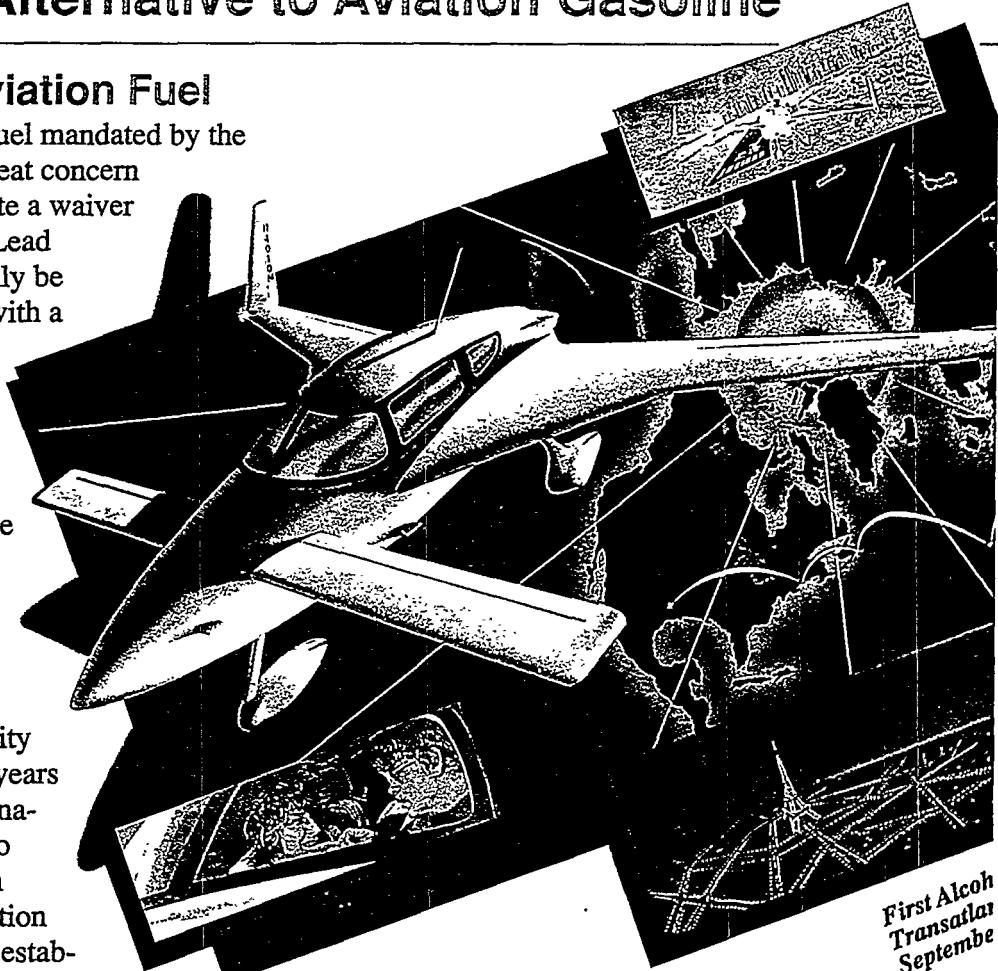
The removal of lead from fuel mandated by the *Clean Air Act* is a cause for great concern in the aviation industry. Despite a waiver granted to aviation, 100 Low Lead aviation gasoline will eventually be replaced by an unleaded fuel with a minimum motor octane of 98 as recommended by the General Aviation Manufacturers Association. Different approaches have been taken in an attempt to develop a suitable fuel. As of today, none of the proposed solutions are acceptable, either because of inadequate octane, excessive emissions, or high cost.

A project at Baylor University has proven, during the last 13 years of activity, that 100 percent denatured ethanol is the ideal fuel to replace 100 Low Lead aviation gasoline. The Renewable Aviation Fuel Development Center was established at Baylor University in 1991 to administer a multi-faceted program directed at furthering the use of ethanol as an aviation fuel.

Why Ethanol?

Ethanol has been around for some time. It was used as a fuel to power some of the first automobiles in this country, then by the Germans and the Japanese as an aviation fuel during World War II.

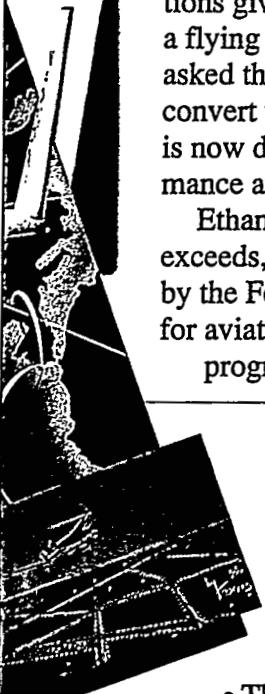
Ethanol is a simple compound that can be produced from anything containing starch or sugar. Agricultural products and the waste streams from some industries are currently used as feedstocks. An emerging, promising technology that allows the transformation of biomass, including municipi-



pal solid waste, into ethanol, considerably expands the variety of potential feedstocks making the production of ethanol even more attractive and cheaper.

Ethanol in Aviation

The Center at Baylor University has modified and flown nine aircraft on ethanol, accumulating over 1,800 hours of flying time. To demonstrate the reliability of the fuel, record flights have been undertaken. The most notable was the first Atlantic crossing flown in an aircraft powered by ethanol. Airshows on ethanol have been performed in the United States, Brazil, France, and Italy.



As a result of airshows and presentations given in South Dakota, the pilots of a flying team called the "Vanguards" asked the Baylor team for guidance to convert their aircraft to ethanol. The team is now demonstrating ethanol performance at airshows around the country.

Ethanol meets, and in some aspects exceeds, all the requirements established by the Federal Aviation Administration for aviation fuels. After severe test programs, two entire series of

Technical Characteristics

- Ethanol produces more power and burns cleaner and cooler in the engine.
- The higher octane of ethanol versus the octane of aviation gasoline allows the use of increased engine compression ratios for improved combustion efficiency.
- In an ethanol powered engine detonation is greatly reduced, resulting in less engine vibration and longer engine life.
- The lower BTU content of ethanol versus aviation gasoline is responsible for a 10 to 20 percent reduction in range depending on the compression ratio of the engine and the extent of the modifications.
- The Reid Vapor Pressure of ethanol is 2.7 while the Reid Vapor Pressure of aviation gasoline ranges from 5.5 to 7.5. The low vapor pressure of ethanol considerably reduces the likelihood of vapor lock, a major threat in aviation.

Lycoming engines have been certified by the Federal Aviation Administration to operate on ethanol.

Renewable Aviation Fuel Development Center

Renewable Aviation Fuel Development Center activities are proceeding in three main directions: research and development, certification of engines and airframes, and public education on ethanol as an aviation fuel.

Research

From previous experiences it is evident that the efficiency of gasoline engines modified to run on ethanol can be considerably improved by additional modifications such as an increase in the compression ratio or a change in ignition timing. Research to implement these changes or manufacture a new engine ideal to run on ethanol is under way.

Certification

In order to establish ethanol as a fuel, aircraft powered by ethanol must be proven in the market place and certification is a requisite for an aircraft to engage in commercial operations. The Center at Baylor is currently certifying three aircraft types on ethanol. Evidence from previous certification tests shows that the reduction in detonation in ethanol powered engines will permit a considerable extension of the time between overhauls. Certification tests will be designed to prove this conjecture. An extension of time between overhauls would result in considerable savings in operational expenses.

Education

In order to gain acceptance of the new fuel, educational programs and demonstrations of the reliability of ethanol as an aviation fuel are conducted. As part of this program assistance is given to pilots interested in the conversion of their airplane to ethanol fuel.

Ethanol

The Choice for Energy Independence, Economic Strength, and Clean Air

Photo by Laurent Simon

The United States imports approximately 50% of its petroleum impairing its economic strength and threatening its national security.

The use of petroleum as a fuel has also caused serious air pollution problems.

Additionally, as the world's finite reserves of oil are depleted the price of gasoline will increase exponentially.

The aviation gasoline situation poses a serious threat in general aviation in the United States.

Despite the waiver granted for the removal of lead, the production of aviation gasoline will probably be discontinued by the oil companies due to economic factors. Even if an adequate petroleum alternative is produced, the price will be high and will only increase in the future.

Renewable energy sources can reduce national vulnerability while assuring fuel supplies and price stability.

In aviation the alternative is already within our reach, a reality — economically and technically feasible.

Ethanol has more than adequate octane, is clean burning, is less expensive than existing aviation gasoline, and its price will decrease with improvement of production technologies and expansion of potential feedstocks.

Ethanol as an aviation fuel can assure the future of general aviation while reducing our dependence on foreign oil and benefiting our domestic economy.

To receive further information on ethanol as an aviation fuel, or to request a demonstration, airshow and/or presentation please complete the following.

Information

Demonstration

Airshow

Presentation

Name _____

Organization Name _____

Mailing Address _____

City _____ *State* _____ *Zip* _____

Area Code _____ *Phone Number(s)* _____ *Fax Number* _____

*Clip and mail to: Renewable Aviation Fuel Development Center, Department of
Aviation Sciences, Baylor University, Box 97440, Waco, TX 76798*

This material was prepared with the support of funds received from the U.S. Department of Energy (DOE) Grant No. #DE-FG47-92R701307-A001. Any opinions, findings, conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the U.S. Department of Energy, the Governors' Ethanol Coalition, or the Nebraska Energy Office.



Ethanol as an Aviation Fuel

Summary

Aviation gasoline (avgas), the only leaded fuel remaining in the United States' transportation fuel market, is to be phased out by mandate of the 1990 Clean Air Act Amendments (CAAA). Baylor University in Waco, Texas has set out to

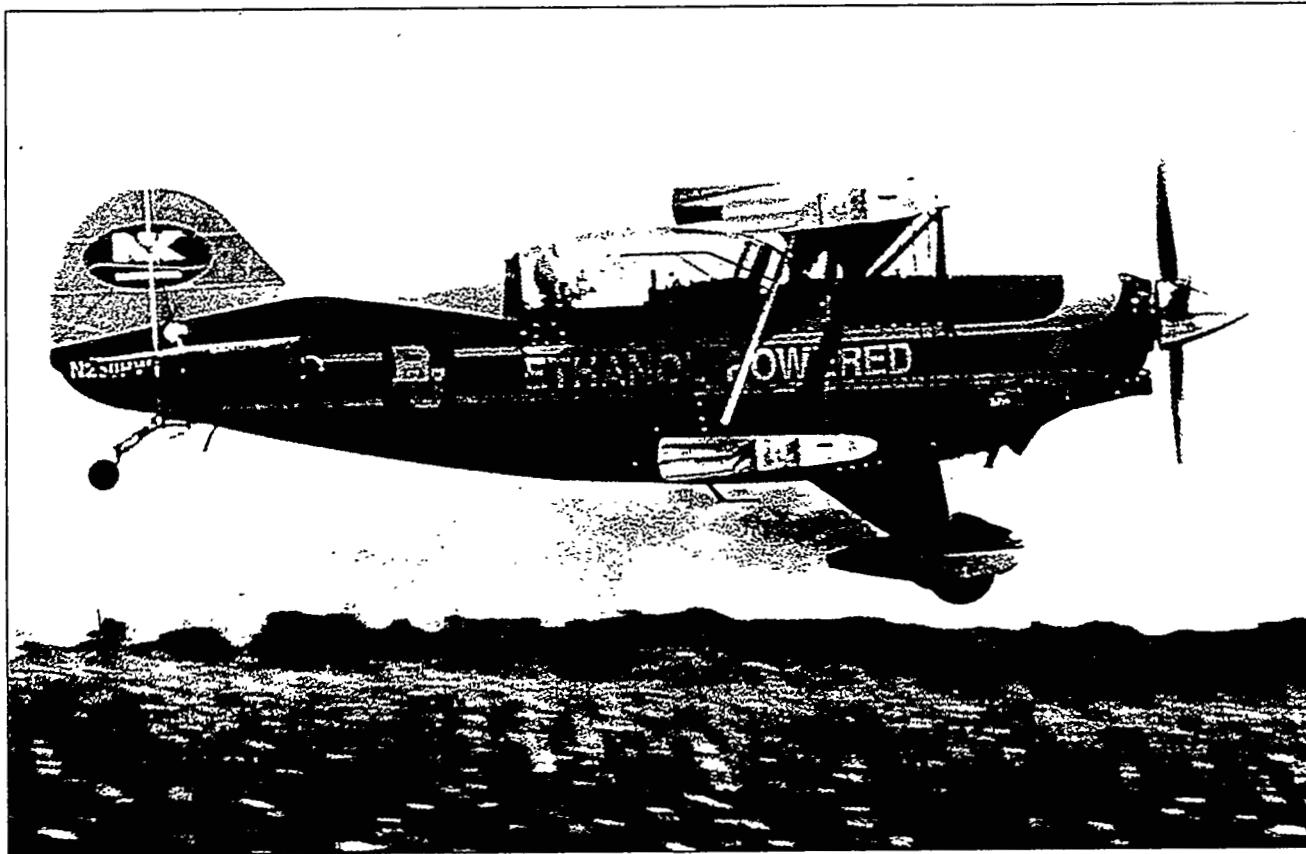
demonstrate that pure denatured ethanol represents a viable, high-octane alternative fuel in the field of aviation.

Baylor's Renewable Aviation Fuels Development Center (RAFDC) participates in airshows in the United States and abroad to

Benefits of ethanol

- ▼ Ethanol from biomass
- ▼ High octane replacement for avgas
- ▼ Cooler, cleaner-burning fuel
- ▼ Less engine wear

Modified Pitts S2B flying over corn at an airshow.



promote the fuel's superior power delivery, clean burning properties, octane levels, costs and reliability. Ethanol is usually produced from corn; however, at some of the air shows, ethanol has been sourced from manufacturers who produce it from other renewable biomass resources such as orange waste or sugar beets (see Table 1).

Project Background

The United States currently consumes over 1,000 million litres of avgas each year. Now that lead has been phased out of other transportation fuels, avgas has become the country's single biggest contributor of lead to the atmosphere. Although avgas has been temporarily excused from CAAA regulations, it is understood throughout the US aviation industry that the use of avgas in its current form will soon be discontinued.

Oxygenated alcohol fuels such as ethanol meet the emission reduction standards set by the CAAA. Ethanol is cleaner and cooler in use than avgas, prolongs engine life, delivers

more power, and is likely to present a much cheaper option as supplies become more readily available. Ethanol has an oxidising effect on aluminium, so corrosion inhibitors are added to the fuel.

Ethanol supporters still must answer those who make issue of the lower energy content of the fuel and the fact that engines must be modified in order to use ethanol. Even so, ethanol is poised to make a significant impact in fleet transport, especially in view of the CAAA requirements that apply to vehicle fleet operations in 22 "non-attainment" cities.

Work at the RAFDC involves certification of engines and airframes for ethanol use. To date, the Center has certified two series of Lycoming engines (one fuel injected and one carburetted) and both the engine and airframe of a Cessna 152 – the world's most commonly used trainer. The Center has logged more than 4,000 flight hours in nine ethanol-powered aircraft.

The RAFDC is also evaluating ethyl-tertiary-butyl-ether (ETBE) as

an aviation fuel. Preliminary dynamometer tests are very promising. An aircraft using ETBE has performed at the world's largest airshow in Paris.

The Project

The RAFDC's ethanol-powered aeroplanes were featured in 15 demonstrations during 1996. During these events, information was distributed and assistance was given to pilots seeking more information about converting their aircraft to ethanol.

Up to \$3,000 may have to be spent to modify a Cessna 152 to be able to use ethanol (where \$ is the US dollar). The Cessna was fitted with a bigger carburettor jet, a fuel pump, a fuel-flow meter and a totaliser. A small avgas tank was added to enable the engine to be primed in temperatures below 21°C. However, not all engines are expected to need this level of modification.

The RAFDC is also certifying agricultural aircraft, such as the Piper Pawnee. The Center's concentration on fleet aircraft avoids initial fuel distribution problems, since these planes are commonly refuelled at fleet sites where the correct refuelling can be guaranteed. An ethanol distribution system is presently being implemented through the US Department of Energy's Clean Airport Program.

Performance

A minor drawback of the use of ethanol fuel is the slightly reduced

Table 1: Variety of biomass sources used at different demonstration locations

Demonstration Location	Biomass Source
Idaho, USA	Potato waste
California, USA	Waste oranges
Wisconsin, USA	Waste cheese whey
Brazil	Sugar-cane
France	Sugar-beet
Italy	Sugar-beet

range. A litre of ethanol produces about two-thirds the heat of a litre of avgas. However, the effect of range loss is reduced by the higher thermodynamic efficiency of ethanol. A Cessna 152 fitted with a Lycoming 235N2C engine uses about 13.8 litres/100 km on avgas and 15.7 litres/100 km on ethanol.

The high octane level of ethanol allows the use of higher compression ratio engines that deliver more power for the same throttle setting. The lower Reid vapour pressure of ethanol helps to prevent vapour locking. Ethanol is cooler and cleaner in use than avgas and is more resistant to detonation, resulting in fewer vibrations and longer engine life.

Economics

America's farmers currently produce 20 million m³ of corn per



Farm show at Redwood Falls, Minnesota.

year, about 6% of the total crop, for use in ethanol production. Increased use of ethanol in aviation will also help to expand markets for agricultural producers who cultivate cellulosic energy crops, an alternative category of biomass

from which the fuel can also be made.

Ethanol has a tax advantage. Avgas is taxed at \$0.048/litre whilst ethanol receives a tax advantage of \$0.14/litre. Avgas costs \$0.53/litre on average whilst ethanol costs \$0.34 to 0.37/litre. The US ethanol industry provides 55,000 jobs and \$15.6 billion/year in net farm income.

Table 2: Fuel consumption at various horsepower reference points for a Lycoming IO-540 D4A5 engine with a 10:1 compression ratio

Horserpower	Avgas (l/hr)	Ethanol (l/hr)	% Increase in Fuel Consumption
180	77.2	85.2	10
210	73.1	95.4	18
225	78.0	89.3	15
238	82.5	91.6	11
270	102.2	119.2	17
300	107.9	128.7	19

Note: Avgas delivered a maximum 300 hp with this engine, while ethanol delivered a maximum 316 hp. In a Lycoming 0-235 engine running on ethanol, the RAFDC has noted a horsepower increase of as much as 20% over avgas. When using ethanol-based ETBE as an alternative fuel, fuel consumption is 5% lower than avgas at 225 hp, the most common power setting for cross-country flight.

Avgas is slightly cheaper on a per-kilometre basis than ethanol, but the lower maintenance costs associated with the use of ethanol ultimately make it a cheaper fuel option for pilots. Supporters of ethanol point to the prospects of increased avgas costs due to the need for an additive that provides an adequate octane level. They predict that ethanol production costs will drop as the base of sustainable biomass feedstocks is expanded and researchers discover new ways to optimise its production.



Project Organisation

Baylor University
Department of Aviation Sciences
Renewable Aviation Fuels
Development Center
700 S. University Parks Dr, Ste. 240
Waco, Texas 76706, USA
Contact: Grazia Zanin/Max Shauck
Tel: +1 817 755 3563
Fax: +1 817 755 3560
E-mail: maxwell_shauck@baylor.edu
grazia_zanin@baylor.edu

Information Organisation

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393, USA
Contact: David Warner
Tel: +1 303 275 4373
Fax: +1 303 275 3619
E-mail: david_warner@nrel.gov

Please write to the address below if you require more information.



CADDET Centre for Renewable Energy
ETSU, Harwell
Oxfordshire OX11 0RA
United Kingdom
Tel: +44 1235 432719
Fax: +44 1235 433595
E-mail: caddet.renew@aeat.co.uk

International Energy Agency

The International Energy Agency (IEA) is an autonomous body which was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme.

Printed on environmentally friendly paper.

CADDET

CADDET was set up in 1988 as an IEA Centre for the Analysis and Dissemination of Demonstrated Energy Technologies. Today, there are two CADDET operations: one is for energy-efficient technologies and the other for renewable energy technologies. The Centres co-operate with member countries in the exchange of high quality information on energy technologies.

Disclaimer

Neither CADDET, nor any person acting on their behalf:

- makes any warranty or representation, expressed or implied, with respect to the information contained in this brochure; or
- assumes any liabilities with respect to the use of this information.

Lone Star Flight Museum

The workshop will be held in the "briefing room" at the Lone Star Flight Museum, 2002 Terminal Drive. Your registration fee includes lunch and admission to tour the Museum following the workshop. The Museum houses one of the finest collections of restored aircraft in the nation. More than 40 aircraft are on display, most of which are completely restored and in flying condition. It includes WWII Fighters, Bombers, Liaison Trainers and Executive Planes, as well as displays of historic photographs, engines, documents and wall mounted text portraying historic world events. And the facility is the future home of the "Texas Aviation Hall of Fame."

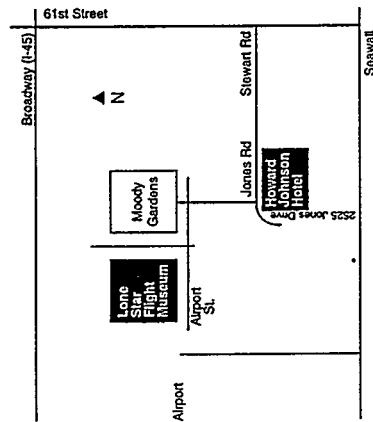
Who Should Attend

This workshop will be of interest to pilots, owners and managers of agricultural aviation operations, civil aircraft fleet operators, airport owners and operators, aircraft fuel distributors, aviation agencies, environmental agencies and organizations, the farming community, financiers, researchers, technology suppliers, policy makers, and anyone curious about progress in this field.

Texas Agricultural Aviation Association Annual Conference

This workshop is being held in coordination with the Texas Agricultural Aviation Association Annual Conference and Exhibition. Registrants are invited to stay in Galveston through Saturday to attend this workshop. Admission to the Museum is included so after the workshop you can continue to explore exhibits you may have missed during your Friday night event. If you are registering for this workshop only, we invite you to make a great weekend of it. Galveston has lots of interesting sites and outstanding restaurants.

Lodging/Workshop Location



Howard Johnson Hotel
2525 Jones Drive, Galveston

A special rate has been negotiated at the Howard Johnson Hotel for workshop attendees of \$49/night, single or double. The hotel is conveniently located within sight of the Lone Star Flight Museum. Reservation are welcome by direct phone calls to the Howard Johnson reservations office at (409) 740-1155. Please mention that you are with the Renewables Workshop to receive this rate.

Texas Renewable Energy Industries Association

Sponsored by the U.S. Department of Energy Western Regional Biomass Energy Program under contract with the Electric Power Research Institute

Presents

Introducing Renewable Aviation Fuels: Workshop & Demonstration

Part of the Texas Biomass Energy Opportunities Workshop Series

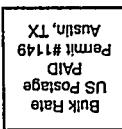


January 17, 1998
9:00 AM – 3:00 PM

Lone Star Flight Museum
Galveston, Texas

Co-organized by:
Renewable Aviation Fuels
Development Center – Baylor University

Co-sponsored by:
Texas Agricultural Aviation Association
Novartis Seeds



Texas Renewable Energy Industries Association
P.O. Box 16469
Austin, Texas 78761-6469

Surprise! Alcohol & Flying Do Mix

Farm-Grown Fuel For Aircraft: A Powerful Idea Within Our Grasp

Some may have dismissed the ethanol option after the end of the Gulf War and the decline of fossil fuel prices, but since that time, there have been exciting advances in ethanol production technology, ever-strengthening environmental regulation and concern about pollution from the public, and the end of avgas as an available fuel looms. The positive impacts of increasing use of ethanol and ETBE by aerial applicators and by the civil aviation community are considerable. Find out why ethanol is the answer to the phase-out of lead in avgas. Is it really possible to fly safely on ethanol fuels? What about performance and efficiency? Are the costs for conversion and operation of aircraft engines prohibitive? How complicated are the conversions? Can the problem of a lack of alcohol-based fuel distribution infrastructure be overcome? What's it for the Texas farming community? Can we establish a pilot project in Texas that will spark an industry? These and many other questions will be discussed in the course of this workshop.

AGENDA

REGISTRATION INFORMATION

9:00 ETHANOL AS AN Renewable Fuel and The Future of Aviation

Production and Implementation of Renewable Fuels: From the Ground Up

Name _____
Organization _____
Address _____
City _____
State _____ Zip _____
Phone _____
Fax _____
E-mail _____

REGISTRATION FEES

Early registration (received by January 12)
(fee includes refreshments, lunch)

aid museum admission)
\$30

**Late registration and at the door
(Lunch not guaranteed with late registration)**

卷之三

Send this form with payment to:

SPEAKER'S

RAFDC) at Baylor University will provide flying demonstrations following the classroom portion of the workshop. Three 100% ethanol-fueled aircraft (a Cessna 152, a Piper Pawnee fitted for aerial application duty, and a Pitts Special) will be demonstrated. Internationally acclaimed aerobatic pilot and RAFDC director, Dr. Max Shauck, will fly a show in the Pitts Special, "The Green Bearon." Dr. Shauck and his wife Grazia Zanini, made the first transatlantic flight using ethanol as fuel for which he received the 1991 Harmon Trophy award. He was the first person to fly on 100% ETHE at the 1995 Paris Airshow. The Lone Star Flight Museum sits on the edge of the flight-line at the Galveston Municipal Airport so we can just step outside to watch.

Seeing Is Believing

Center (RAFDC) at Baylor University will provide fueling demonstrations following the classroom portion of the workshop. Three 100% ethanol-fueled aircraft (a Cessna 152 a Piper Pawnee fitted for aerial application duty, and a Pitts Special) will be demonstrated. Internationally acclaimed aerobatic pilot and RAFDC director, Dr. Max Shauck, will fly a show in the Pitts Special, "The Green Bearcat". Dr. Shauck and his wife Grazia Zanini, made the first transatlantic flight using ethanol as fuel for which he received the 1991 Harmon Trophy award. He was the first person to fly on 100% ETHE at the 1995 Paris Airshow. The Lone Star Flight Museum sits on the edge of the flight-line at the Galveston Municipal Airport so we can just step outside to watch.

GARY JOHNSTON: lecturer/Researcher, Aviation Sciences Department/Renewable Aviation Fuels Development Center, Baylor University – Ethanol Certification project engineer
JOHN SARTOR: Researcher, Renewable Aviation Fuels Development Center
MAX SHAUER: Chairman, Department of Aviation Sciences, Baylor University – Director of Renewable Fuels for Aviation Projects
BILL WELLS: Vice President, Delta-T Corporation (ethanol production plants), Expert in managing, producing and marketing ethanol plants

Government agencies may mail or fax form with voucher or purchase order.



Under the Auspices of

**Baylor University
Department of Aviation Sciences
Affiliate, FAA Center of Excellence**

&

**International Centre for
Aviation and the
Environment (ICAE)**

A GUIDE TO ESTABLISHING A CLEAN AIRPORT PROGRAM IN YOUR COMMUNITY

As the world prepares for the next century, airports and aviation in general should serve as a showcase of advanced technology and operations. Voluntary initiatives should be used to meet environmental imperatives by actively reducing the global energy security burden, improving the environment, and providing new economic opportunities.

THE ICAP MISSION

“To enhance the economic, environmental and natural resource sustainability along with the image of the aviation industry in the full scope of its operations”

PROGRAM HISTORY

With the initial support of the Department of Energy, Baylor University, in Waco, Texas, launched the U.S. Clean Airports Program in mid-1996. Five communities now have Clean Airports as a result of that program:

- ★ Waco-TSTC Airport, Waco TX
- ★ Morgantown Municipal Airport, Morgantown, WV
- ★ McGregor Municipal Airport, McGregor, TX
- ★ Oklahoma City-Will Rogers International Airport, Oklahoma City, OK
- ★ Great Planes Airport, Sioux Falls, SD

The Clean Airports Program established local partnerships between stakeholders, including fixed based operators, university aviation associations, flying clubs and ground support fleet operators. There must be a commitment to solve local transportation and air quality problems by promoting the use of alternative fuels in ground equipment, ground vehicles and in general aviation aircraft when possible. Clean Airports partners work directly with local businesses and governments to guide them through the goal setting, coalition building, and commitments process necessary to establish the foundations for an airport with a focus on alternative fuels.

Since its inception, the U.S. Clean Airports Program has evolved into the International Clean Airports Program. The international dimension expands the program beyond alternative fuels to include energy efficiency, all renewable and alternative forms of energy, and broad-based environmental programs including noise, water, land use, waste minimization and recovery, air pollution and stabilization of greenhouse gases.

This expanded approach correctly positions the original focus on alternative aircraft fuels in the broader perspective of meeting the needs of a rapidly expanding aviation industry. This is occurring in a world demanding greater environmental responsibility and a need to reduce the use of fossil fuels.

The Palm Springs Airport in California is the first airport to join the program under the ICAP. Other airports and organizations have expressed interest in this important environmental initiative.



THE INTERNATIONAL CLEAN AIRPORTS PROGRAM

The impetus for establishing the International Clean Airports Program was provided by the Clean Airports Summit in Denver, Colorado (October 17-19, 1997) and the Second International Conference on Alternative Aviation Fuels at Baylor University (November 6-8, 1997).

In Denver, the focus was primarily limited to the use of alternative fuels in ground support vehicles, an expression of environmental concerns, and discussions on aircraft operations limiting fuel consumption. Alternative aviation fuels and broad-based environmental concerns were not primary agenda items.

The Waco Conference addressed a broader range of issues including discussions and demonstrations of new flight concepts; solar, LNG, ethanol, ETBE and BioDiesel powered aircraft; piston and turbine fuels provided by new refinery processes using coal, natural gas, and biomass; a full range of creative concepts to advance and improve aviation and airport operations; and broad-ranging environmental concerns including greenhouse gas emissions and aircraft emissions as the major source of air pollution at airports.

As a result of these two conferences, it became clear that there was a need in aviation for an effective and cooperative merger of corporate and government interests in safety, cost-effectiveness, speed of travel, convenience and international acceptability. With this merger, the ICAP can investigate new concepts that may be ahead of their time in the industry/government interface. There is the hope that historic conflicts between advancement and intrusion can be tempered with advanced aviation, engine, fuel, environment and communications technologies and perhaps most of all — good will.

It was felt that the International Clean Airports Program (ICAP) could bridge these oft-times supportive and sometimes disparate interests. ICAP supports the concept of cooperative and voluntary action.



*The Palm Springs
Airport in California
is the first airport
under the ICAP.*

OPERATING CONCEPTS

ICAP is an open organization in its formative stages encompassing expertise from various international groups, including those focusing on improving the aviation environment performance.

ICAP'S PRIORITY TASKS INCLUDE:

- Work with involved industries and organizations to develop concepts and plans designed to effectively mitigate the environmental impact of airport and aircraft operations. In doing so, ICAP hopes to preclude the need for more restrictive environmental legislation;
- Advocate broad-spectrum environmental, energy efficiency and renewable energy programs to include alternative ground transportation and aviation fuels, as well as the environmentally efficient use of fossil fuels;
- Promote the public perception that aviation is now, and will be more so in the future, the high-tech industry that ensures safe, rapid, cost effective and environmentally sound travel;
- Promote the aviation industry as a high-tech window to a future where human needs and true sustainability are in harmony;
- Support existing environmental programs of international and domestic aviation industries, their associations and supporting agencies;
- Work together with the aviation industry, airport administrations and environmental and public interest groups showing interest in airport and airline operations. ICAP will strive to convey concerns to the aviation industry in a cooperative manner while researching and suggesting solutions to major public environmental concerns;
- Publish periodical information, in both electronic and hard copy format on program developments and associated issues.

The effectiveness of ICAP organizational structure is greatly enhanced by advanced communication technology and its focus on cooperation, voluntary action, education and technology transfer.



PROGRAM IMPLEMENTATION

The program implementation will:

- Create a situation wherein voluntary actions preclude restrictive regulations.
- Operate a highly flexible organizational structure encouraging creativity.

ICAP's strategy consists of a multi-step implementation program. Each phase is determined by the airport's current circumstances, ongoing programs and future development plans.

Airports wanting to enter the program would:

(1) Establish a stakeholders group

Stakeholders must have an interest in the local energy and transportation sectors. Stakeholders may be fuel suppliers, airline representatives, airport authorities, fixed base operators, university aviation associations, flying clubs, fleet managers, utilities companies, and existing groups involved in environmental issues such as Clean Cities stakeholders.

(2) Appoint a Clean Airports Coordinator

The coordinator will be a responsible local airport representative with ready access to key decision-makers. He serves as leader-coordinator for the stakeholder coalition. He should seek training for stakeholders in the specific environmental and energy programs planned for the airport.

(3) Develop a program plan

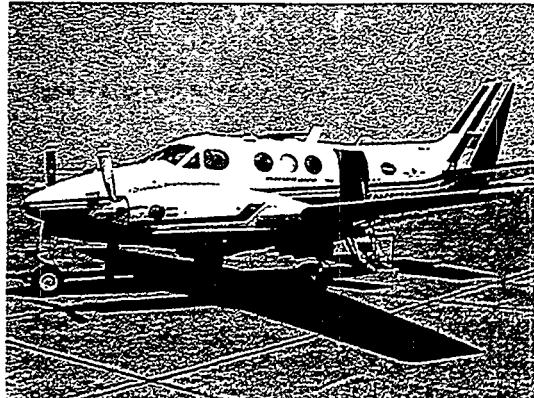
The plan outlines the goals and organizational structure, and sets forth objectives to be achieved by the Clean Airports Program. Implementation and timing of each phase is determined by participating stakeholders designated to produce a Memorandum Of Understanding (MOU) outlining the goals of the program, the means to achieve these goals and the schedule for achievement, inclusive of periodic evaluations. The MOU also specifies tasks that will improve the overall airport environment, raise public awareness of energy efficiency, alternative fuels and renewable energy technologies, and highlight environmental programs. It will benefit the airport and its public image. The plan implementation must function within the parameters of safety, cost-effectiveness and non-interference with efficient operations.

The program embraces the following aviation environmental challenges which will be organized into various implementation phases according to current airport development plans.

- Air Quality - External and Internal

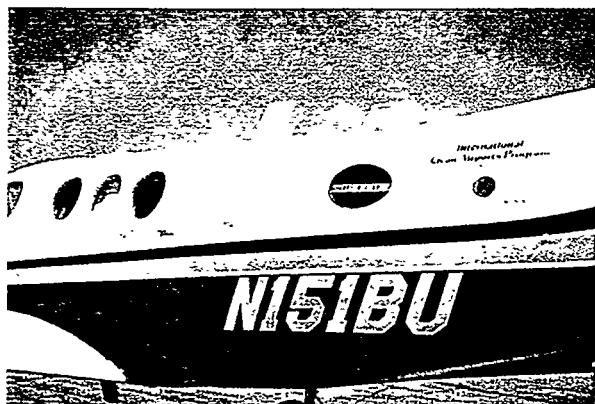
- Noise in and around airports

- Waste management



- Energy conservation, alternative fuels and renewable energy technologies

- Water quality



- Landscape and nature conservation

- Aesthetics and heritage

- Community relations

Courses in environmental management systems will be provided for the Clean Airports coordinators and other interested parties. These courses are being developed by Baylor University and the International Centre for Aviation and the Environment in coordination with other universities and organizations. A distance learning system at Baylor University will be used for the ICAP training component.

Program progress information reporting and dissemination, an important aspect of the program, will also be coordinated between ICAP and the airports involved.

ICAP FOUNDING ORGANIZATIONS

The ICAP is being jointly developed by a cooperative effort between Baylor University's Department of Aviation Sciences and Renewable Aviation Fuels Development Center (RAFDC), Waco, Texas, and the International Centre for Aviation and the Environment (ICAE), Montreal, Canada.



U.S. Clean Airport Program, is also developing a supportive education program in cooperation with other interested partners, specifically aimed at the ICAP implementation.

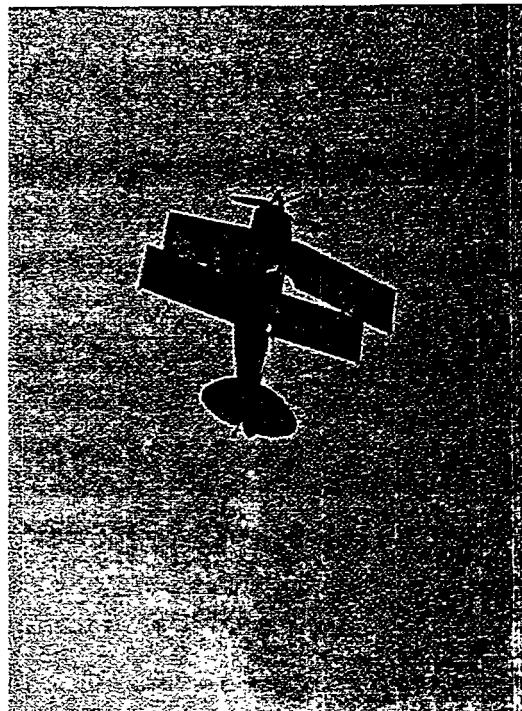
The International Centre for Aviation and the Environment (ICAE) was founded as a non-profit corporation under the Canada Federal Corporations Act, following completion of a detailed research study sponsored by the Transportation Development Centre (TDC) of Transport Canada. ICAE identifies and assess environmental problems associated with

world aviation activities and services and propose an effective strategy for their solution. ICAE is an independent and neutral institution that coordinates and promotes research and development on global environmental issues and problems. It also acts as a clearinghouse for the exchange of information between interested parties at national and international levels. As such, its main purpose is to create a synergetic relationship between government, airports, airlines, providers of aviation products and services, as well as academia, on all matters pertaining to civil aviation and the environment.

ICAE has organized and maintains a comprehensive information monitoring, storing and exchange system on the environmental impact of airports. Its scope is to foster cooperation for the enhancement and use of cost-effective standards and practices in the entire spectrum of aviation environmental sustainability.

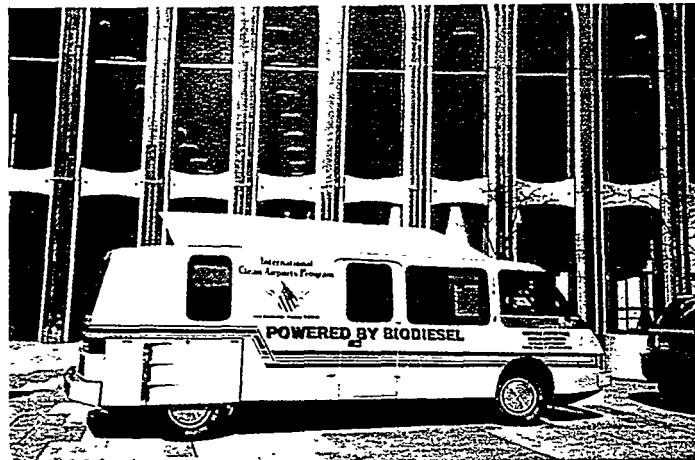


CESSNA 152: *The first aircraft series to be certified on a non-petroleum fuel.*



BAYLOR UNIVERSITY'S GREEN BEARON

This highly modified Pitts S-2B has traveled the world demonstrating the capabilities of alternative fuels such as Ethanol and Ethyl Tertiary Butyl Ether (ETBE).



THE ICAP OPERATIONS VEHICLE ON DISPLAY AT THE WORLD TRADE CENTER
This vehicle is powered by BioDiesel.

FOR MORE INFORMATION ON ICAP PLEASE CONTACT:

MAX SHAUCK OR GRAZIA ZANIN
Baylor University - Renewable
Aviation Fuels Development Center
PO Box 97413
Waco, TX 76798-7413
Phone: 254-710-3563
FAX: 254-710-3560
E-mail: AVS_Office@Baylor.edu

www.baylor.edu/~Aviation_Sciences/
-or- www.baylor.edu/~rafdc/

JEREMY L. CORNISH
International Centre for Aviation and the
Environment
380 St. Antoine St. West
Suite 3200
Montreal, Quebec
Canada H2Y 3X7
Phone: 514-283-0064
FAX: 514-283-7158
E-mail: cornisj@tc.gc.ca
www.creative.ca (temporary web location)

NEWS RELEASE

CITY OF PALM SPRINGS

DEPARTMENT OF TRANSPORTATION

3400 East Tahquitz Canyon Way, Palm Springs, CA 92262
Voice (760) 323-8179 — Facsimile (760) 322-4308

CONTACT:

Bryant L. Francis
Palm Springs Regional Airport
(760) 323-8161

FOR IMMEDIATE RELEASE:
Friday, April 24, 1998

PALM SPRINGS REGIONAL AIRPORT TO RECEIVE INTERNATIONAL CLEAN AIRPORT DESIGNATION

(PALM SPRINGS, CA) - Join the Palm Springs Regional Airport in celebration of being the world's first airport to receive the International Clean Airport Designation. The presentation will be made today at the Clean Cities Earth Day 1998 Celebration. In early 1997, Tracy Daly, Clean Cities Coachella Valley Region Coordinator, informed Allen Smoot, Director, Department of Transportation, of the newly organized Clean Airport Program, and suggested that the airport apply for designation. It has been just over one year since the Palm Springs Regional Airport began the application process.

Under the auspices of Baylor University's Renewable Aviation Fuels Development Center (RAFDC), the International Center for Aviation and the Environment (ICAE), and Airports Council International - North America (ACI-NA), the program has evolved into the International Clean Airport Program, and will seek participants in the United States, Canada, Europe, and elsewhere. The goals of the program are to enable alternative fueled aircraft to operate from each designated airport, meaning that each airport will ultimately have refueling infrastructure in place for at least one type of alternative aircraft fuel. The use of alternative fuels, such as CNG, in ground transportation and service vehicles is also encouraged (i.e. shuttles, taxis, baggage tugs, maintenance vehicles, etc.). Finally, a public awareness campaign will be established to address the issue of alternative fuels and the specific Program Plan in place at each designated airport.

-more-

Palm Springs Regional Airport, as the first designated International Clean Airport, will initiate its Program Plan this summer. The plan has several phases addressing the goals stated previously, and it is designed to accommodate additional phases in the future. The airport plans to work closely with all forms of local media as well as the public to spread the word about the program as it begins to take shape. To find out more, you are invited to attend the Clean Cities Earth Day Awards Presentation from approximately 12:30 pm to 1:30 pm. The event is being held at the new Big League Dreams Sports Park, located at 33-700 Date Palm Drive in Cathedral City, CA. See you there!

#

BAYLOR



Researching Alternative Aviation Fuel

Baylor

JANUARY 1996



Dr. Max Shauck, professor and chair of aviation sciences at Baylor University, prepares for an air demonstration in his Pitts Special S-2B biplane.

Flying High on Invention

How does one Baylor professor change aviation and attract world-wide attention to the first international conference on alternative aviation fuels at Baylor University? Just ask Dr. Max Shauck, and he will show you how it is done.

Shauck, professor and chair of aviation sciences, has made a career out of innovation in the industry. In 1980, with support from Baylor Trustee C. Gus Glasscock Jr., he developed aircraft engine modifications to use pure ethanol as fuel. In 1989, Shauck made the first transatlantic flight in an alcohol-powered aircraft. By proving ethanol was a better fuel for aviation and making it a timely demonstration, the world turned its attention to the subject with a widening interest.

That interest is also what brought leaders of the field to the Baylor conference, including: Gordon Cooper, former Mercury astronaut; Paul McCready, president of AeroVironment; and representatives from the U.S. Department of Energy, France, Sweden and Brazil.

What makes ethanol so important? The renewable, clean burning, oxygenated fuel, ethyl tertiary butyl ether (ETBE) has many advantages.

"You can always make ethanol," Shauck told the

Waco Tribune-Herald. "You can't always buy (oil) from the Arabs." Additionally, tougher environmental regulations could raise restrictions on conventional aviation gasoline which contains lead, a substance already banned from automotive gasoline.

Ethanol is made mainly from corn in the U.S., but it can be made from any material containing starch or sugar. New processes soon will allow the use of cellulose as a feedstock for ethanol. This means an expansion in feedstock, including industrial wastes and about 60 percent of landfill materials, substantially decreasing the cost of ethanol. Therefore, its availability makes it a hot topic for the future of aviation, and the Baylor conference was the first such event to capitalize on the subject.

Baylor was the perfect location for the conference since it was home to Shauck and his research. The Renewable Aviation Fuel Development Center was established at Baylor University in 1991 to study ethanol further. Today, with accumulated hours of flying time on multiple aircrafts, the reliability of ethanol has become a foundation for others to learn about.

(continues on page 2)

"You can always make ethanol. You can't always buy (oil) from the Arabs."

*Dr. Max Shauck,
Professor and Chair of
Aviation Sciences*

*On the Cover: Planes powered by ethanol fuel fly over the Baylor campus.
Photo by Dan Isminger reprinted courtesy of French magazine Aviation & Pilote.*

INSIDE THIS ISSUE

2

President Sloan speaks to BGCT messengers in San Antonio

Baylor discusses concept of ministerial renewal

3

Chancellor Reynolds to chair study on Texas' court system

School of Education Highlights

4

Colin Powell to speak at Baylor

Around the Campus

6

Baylor dedicates Clifton Robinson Tower

Alumni Association unveils new Baylor ring

Planning Council to formulate strategy and mission for future

Celebrating its "proud heritage" and proclaiming its commitment to a "bold vision," Baylor has formed the University Planning Council (UPC) in hopes of developing a common vision through which Baylor can fulfill its mission.

President Robert B. Sloan Jr. created the UPC as a standing committee, made up of representatives from every segment of the university, to provide a basis for coordinated long-range and operational planning throughout the university.

The UPC will be operated under the auspices of Dr. Cliff Williams, vice president for human resources and planning. By definition, strategic planning involves the belief that aspects of the future can be influenced and changed by what we do now.

The UPC will build on the work of the Sesquicentennial Council of 150 and the 1994-1996 University Self-Study.

"The UPC will take all these recommendations and play them out against the stakeholders' needs and the priorities set by the UPC," said Ms. Brenda Morris, assistant vice president for organizational development, who will be facilitating the UPC. Another facilitator will be Mr. Michael R. Moore, who for the past two years has worked with the Ernst & Young Foundation to facilitate a strategic management process for nine schools of business throughout the United States, including Baylor's Hankamer School of Business.

During the first meeting of the UPC Sloan outlined his core convictions for Baylor. These include:

- Remain a Christian and Baptist institution; first and foremost a Christian institution.
- Continue to gain ground on nationally recognized standards of recognition and to help shape the criteria for what greatness is.
- Improve student admission standards but hold graduation rates high.

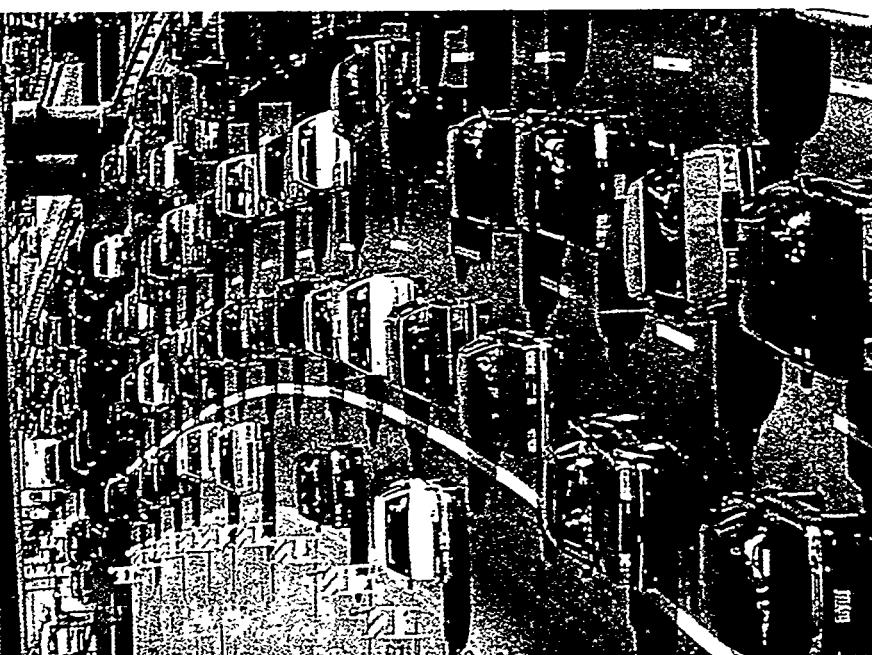
• Clarify Baylor's position with reference to the "Exploring Three Visions for Baylor" document prepared by the Self Study Committee. Our position will not include the proposed tuition increases this vision suggests.

• Meet Baylor's financial needs through increases in endowment and other sources of revenue rather than through larger increases in tuition.

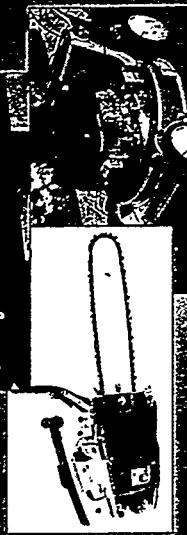
Information about the UPC is available on Baylor's Home Page on the Internet (located at <http://www.baylor.edu>). Select Administrative Departments followed by University Planning Council. A comment form is included, and feedback is greatly appreciated. ■



Ethanol power overcomes oil dependency



Unleaded
With 10% Ethanol
\$



Ethanol for aircraft too!

The Renewable Aviation Fuels Development Center (RAFDC) at Baylor University, Waco, TX, under the direction of Dr. Max Shauck, engages in research to bring the alternative fuel power of ethanol to aircraft.

Currently 300 million gallons of aviation fuel are used by piston engine aircraft—the largest single source of lead in the atmosphere today.

Research efforts at RAFDC have proven ethanol is a high octane alternative fuel ideal for such aircraft. All the benefits of ethanol can be extended to aircraft, as well as other forms of transportation.

RAFDC recently obtained full Federal Aviation Administration certification for the Cessna 152 training aircraft to operate on ethanol commercial operations. The Department of Energy has designated RAFDC as the lead organization for a program which will commission an airport to provide fueling infrastructure for aircraft burning alternative fuel, and to be a base of at least one aircraft using that fuel. In addition, Shauck carries the ethanol message to worldwide audiences through aerobatic demonstrations and public appearances.

Northrup King Co., a major agriculture service company, has signed a number of Shadwick's contracts to demonstrate the use of the American corn farmer's product in aircraft fuel.

Northrup King Co. **Renewable Aviation Fuels Development Center**
7500 Olson Memorial Hwy. PO Box 97413
Golden Valley, MN 55427 Waco, TX 76789-7413
800-652-7333 8-77553563

Ethanol Better for the environment.



Americans Prefer **Ethanol:**

It makes our country less dependent on foreign oil; presently our country imports over 50% of our fuel.

Reduces our nation's trade deficit by more than \$6 billion annually. If all fuel were 10% blends it would cut petroleum imports by 750,000 barrels a day.

Provides a market for over 600 million bushels of corn.

Supports our economy with new non-farm jobs.

Ethanol:

**Clean burning,
comes locally
produced, high
performance**

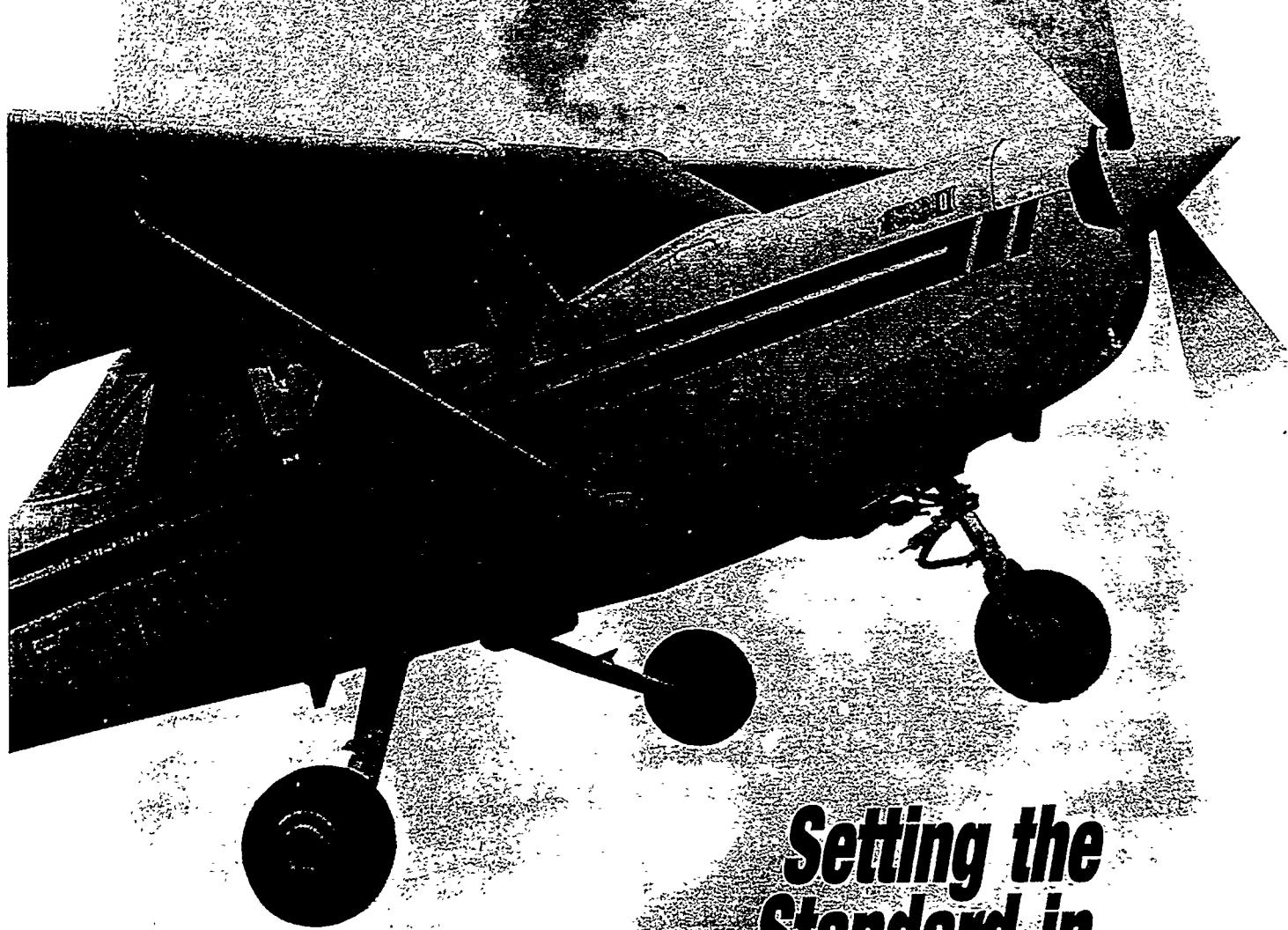
**fuel that powers
our lives and
the American
economy.**

Ethanol:

- Improves the environment by reducing the ozone forming potential of emissions.
- Eliminates the need to use gasoline antifreeze products in winter.
- Combats global warming without contributing to "Greenhouse Effect".
- Increases octane! Provides better engine performance and is warranted by all major auto manufacturers.
- Recommended by small engine manufacturers.

BAYLOR UNIVERSITY & TEXAS STATE TECHNICAL COLLEGE at Waco

Aviation Programs



*Setting the
Standard in
Aviation
Education*



***Our goal is to
enable our
graduates to
grow into
leaders in
aviation.***

The aerospace industry is a demanding field which experiences technological changes that will continue to accelerate in the next decade. With the rapid growth and advancement in technology, new opportunities in the airborne delivery of people, cargo and services have developed, increasing the demand for highly educated and trained personnel in many different areas of aviation.

Scheduled and non-scheduled airlines, charter and corporate flight operators, and small business firms seek well-educated, professionally trained individuals who can pilot an aircraft efficiently and safely through all phases and conditions of flight.

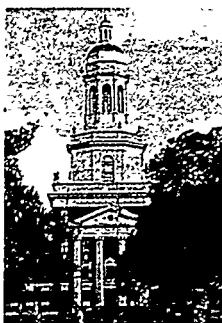
However, our goal in the Aviation Sciences Program at Baylor University and Texas State Technical College (TSTC) at Waco is not just to train skilled pilots, but to provide an education that will enable our graduates to grow into leaders in aviation and related areas.

A Unique Partnership

Baylor and Texas State Technical College at Waco offer a joint aviation sciences program. Students will earn a Bachelor of Science degree in Aviation Sciences from Baylor and an Associate of Applied Science degree in Aircraft Pilot Training (APT) Technology from TSTC.

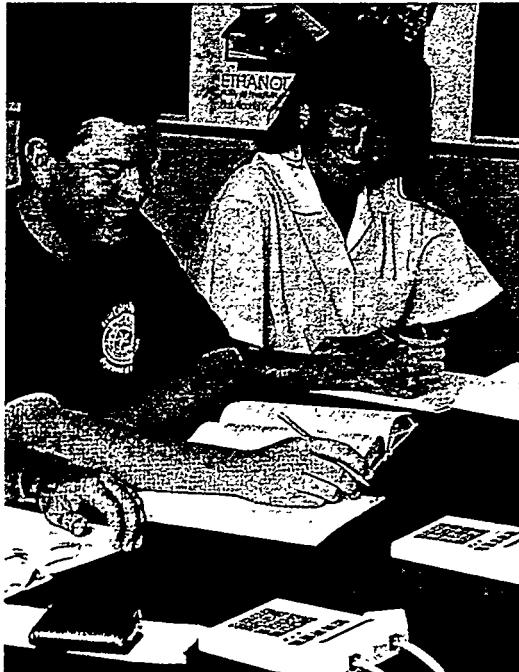
Only 31 schools in the United States offer a four-year program in aviation sciences. Baylor and TSTC have teamed up to offer the only such program designed to train professional pilots which is certified as an Airway Science Program by the Federal Aviation Administration (FAA) and the University Aviation Association (UAA). Both institutions are accredited by the Southern Association of Colleges and Schools (SACS).





An important feature of the program is the careful integration of courses offered at the two schools. The curriculum is designed and conducted so that students take their required and elective courses in an orderly sequence to ensure the best learning experience. Students attend academic classes and flight training classes simultaneously throughout the course of the program.

The academic portion of the Aviation Sciences Program takes place on Baylor's 524-acre campus, located just 10 minutes from TSTC. Highly acclaimed math and science departments provide the foundation for Baylor's program.



The flight training is held at TSTC, which offers its own airport, excellent instructors and well-maintained equipment. Each day students are immersed in flight activities, whether it be in the classroom, in the Frasca 242 twin-engine simulator, or in one of the 13 Cessna 152 training aircraft.

Leadership

The Baylor program leader is Dr. Max Shauck, professor and chair of the Department of Aviation Sciences at Baylor. Shauck began teaching math at Baylor in 1975 and has more than 40 years of experience as a pilot in all phases of aviation. In 1989, the Vice President of the United States presented Shauck the Harmon Trophy, our nation's highest award in civil aviation.

The flight and ground instructors at TSTC bring more than 75 years of aviation experience to the Aircraft Pilot Training program, providing extensive knowledge and expert training to students.



An important feature of the program is integration of the courses offered at two schools.



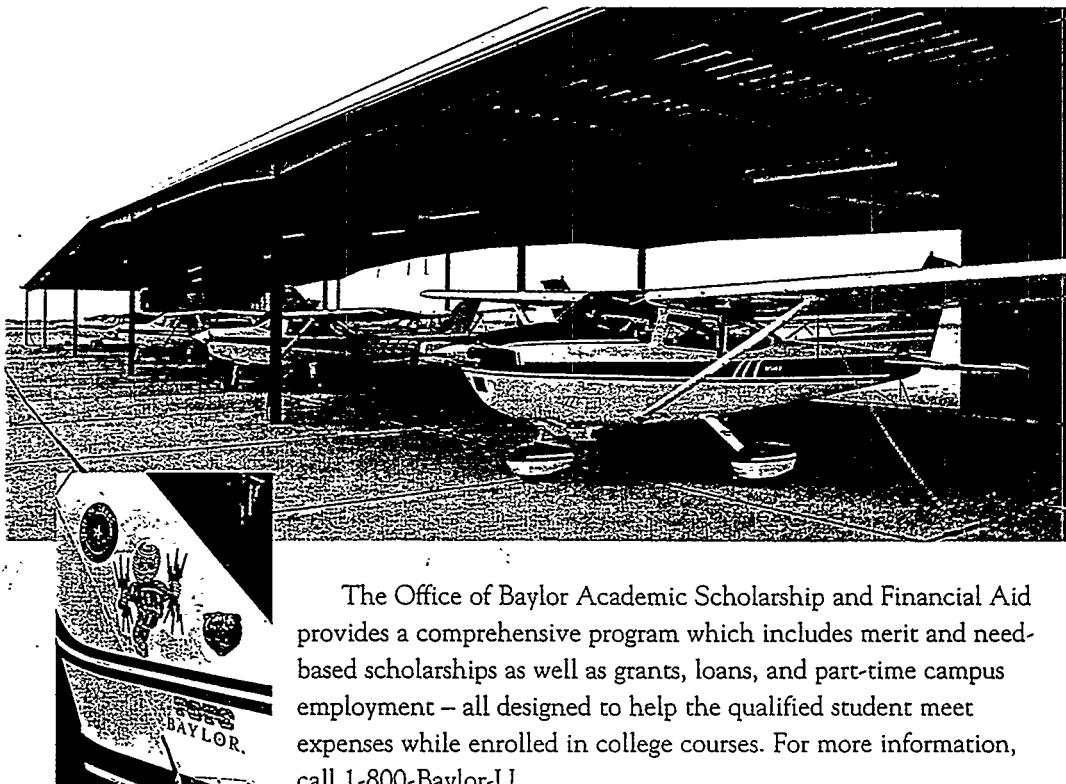
***You will be
equipped to
meet the
demands and
reap the
rewards of
the most
exciting
professions.***

If you accept this challenge, you will be equipped to meet the demands and reap the rewards of one of the most exciting professions. Graduates of the program have a variety of career choices in addition to the pilot profession.

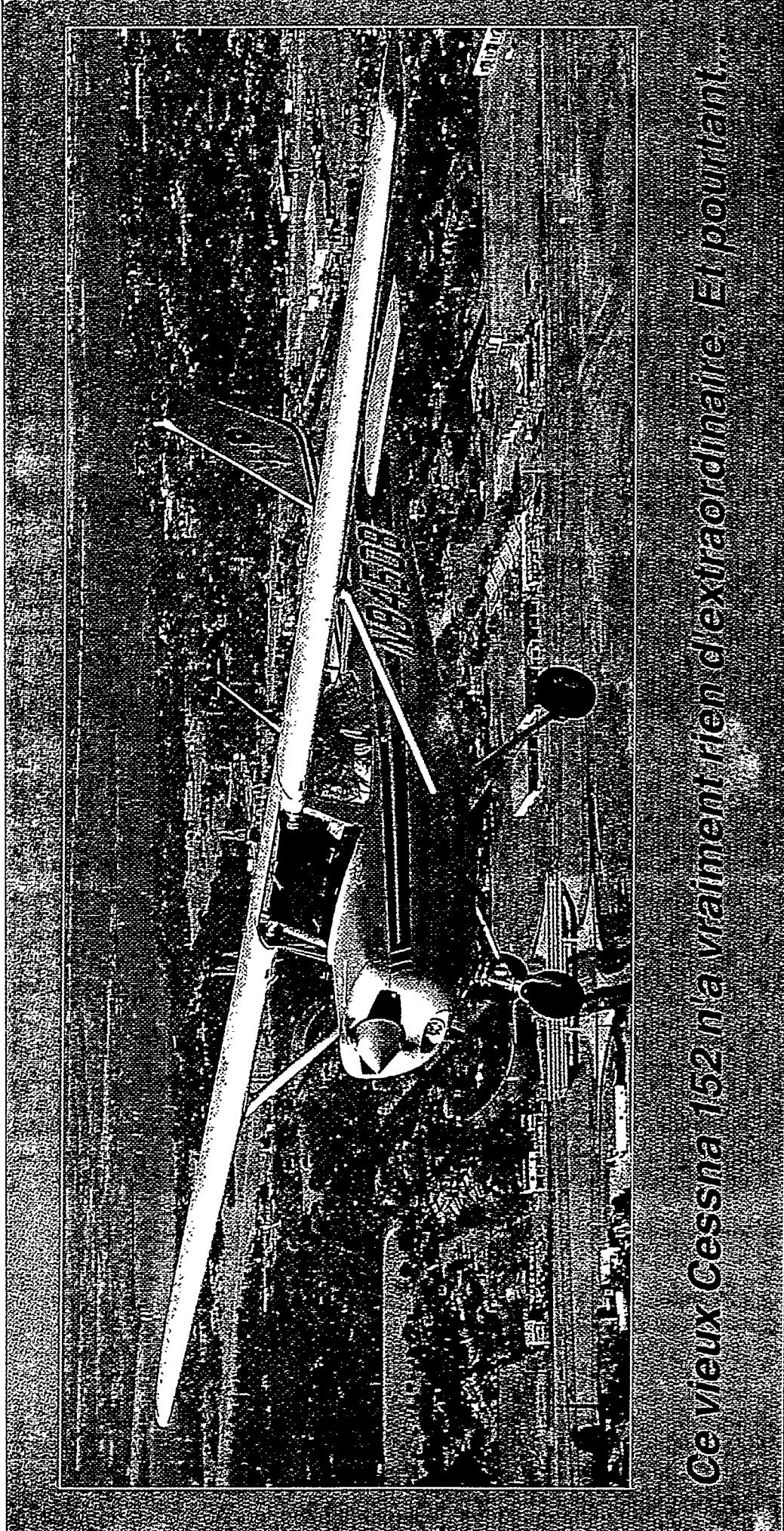
Students will have the opportunity for direct contact with a pioneering research effort in the field of alternative fuels for aviation being conducted by Baylor's nationally recognized Renewable Aviation Fuels Development Center.

Flight operations are conducted at TSTC Airport, the first airport in the nation designated as a "Clean Airport" by the U.S. Department of Energy.

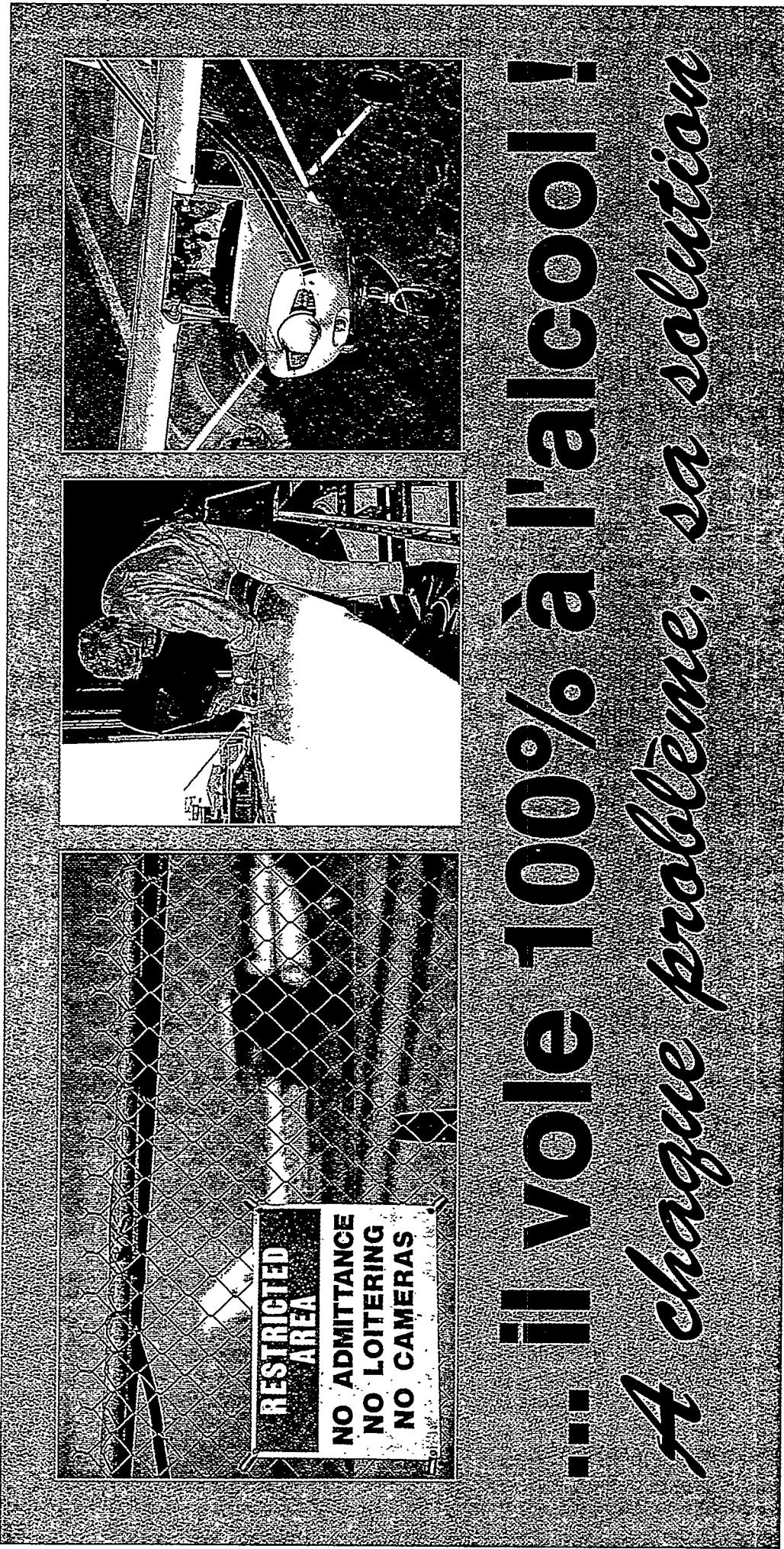
For more information about the Aviation Sciences Program, call (817) 755-3563, write to P.O. Box 97413, Waco, TX 76798-7413, or visit the Department of Aviation Sciences web site at: www.baylor.edu/departments/Aviation_Sciences/WWW/



The Office of Baylor Academic Scholarship and Financial Aid provides a comprehensive program which includes merit and need-based scholarships as well as grants, loans, and part-time campus employment – all designed to help the qualified student meet expenses while enrolled in college courses. For more information, call 1-800-Baylor-U.



Ce vieux Cessna 152 n'a vraiment rien d'extraordinaire. En revanche



**Pour 1996,
nous vous souhaitons
la réalisation de vos projets.**

*L'équipe
d'Aviation
& Pilote*

*Remerciements : Baylor University, Texas State Technical College, Dr Max Shauck, Glenn Maben, Michel Barry,
le photographe Atelier d'Affortville, l'imprimeur Maulde et Renou,
Copyright SEES. Photographies Jacques Callies.*

BAYLOR UNIVERSITY
AVIATION SCIENCES DEPARTMENT
RENEWABLE AVIATION FUELS DEVELOPMENT CENTER
(RAFDC)

BIOFUEL BLENDS TESTING IN A TURBOPROP ENGINE

SUBMITTED TO
THE FEDERAL AVIATION ADMINISTRATION (FAA)
OCTOBER 1998

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
PROGRAM OVERVIEW	3
Test Stand Construction:	3
Flat Bed Truck	3
Engine Mount	4
Engine / Propeller	5
Test Cabin, Controls and Instrumentation	6
Basic Engine Hookups	6
Emissions Bench	7
INITIAL TESTING	8
Biodiesel Blending Results	8
Emission Testing Runs	8
BINARY BLEND TESTING	11
PREPARATION FOR TRINARY BLENDS AND FLIGHT TESTS	12
FUEL SAMPLE ESTIMATED VISCOSITY TABLE	15

APPENDIX A 1: EMISSION TESTING GRAPHS

EXECUTIVE SUMMARY

Baylor University's Renewable Aviation Fuels Development Center (RAFDC) has received on loan from the Federal Aviation Administration, a PT6 turbine engine to be used in the newly constructed RAFDC mobile turbine engine test stand.

The turbine engine program objective is to test renewable fuel blends of Biodiesel, ETBE, or ethanol (in small percentages) and Jet A fuel. The purpose of this research is to attempt to reduce the emissions of the current widely used Jet A fuel. These blends are to be tested on a ground test stand first. Once this phase has been completed and the optimum fuel blend identified, it will be flight tested.

The test stand was built by RAFDC personnel to internally-generated specifications. It is a mobile test stand with the capability of being transported to different sites, thus also enabling emission tests to be made directly from an aircraft's exhaust stacks. A flat bed truck was purchased as the platform. The forward portion of the flat bed houses an enclosed engine control console and the emission sampling instrumentation. The rear of the truck bed houses the engine and its mount.

A mobile fuel tank was procured. Mixing tanks were also purchased, cleaned, inspected and installed. An IBM compatible PC with data acquisition, logging and analyzing capabilities to work with the emission testing equipment, was purchased, installed, and thoroughly tested. This installation includes all wiring and associated equipment. Labview data acquisition software was purchased and familiarization with it begun.

A turbine engine was requested and obtained from the FAA. This was done in order to save funds and assemble the stand within an allocated budget. After negotiations with the FAA Technical Center in New Jersey, the engine, a Pratt and Whitney PT6A-6, was

removed from an aircraft and shipped to Baylor. It required an overhaul before installation on the test stand.

Suppliers were located who agreed to donate the biodiesel and the ETBE necessary for the project. Ethanol was already available on site.

The driving force of the project is the awareness of the growing threat of local and global pollution caused by commercial air traffic. RAFDC's dual research in air pollution investigations using instrumented aircraft and the development of clean burning renewable aviation fuels represents a unique capability and opportunity not only to measure air pollution, but also to reduce it developing cleaner burning fuels.

Baylor is very appreciative for the opportunity to be involved in a project which has enormous potential to benefit society.

PROGRAM OVERVIEW

Test stand construction

Flat Bed Truck

A flat bed truck was purchased as the base platform for the mobile test stand. The truck under-deck structure has been modified slightly to accommodate the installation of two self-contained generators. One generator is assigned to lights, air-conditioning, and power for incidental items. The other is dedicated to the emissions monitoring equipment. The engine / propeller is self-contained and needs no power from the truck-mounted generators.

The truck aft bumper structure was also strengthened to accommodate large steel jacks. These may be bolted in place and extended for test, then retracted and removed for travel. Smaller jacks have been procured for the front of the truck. Shakedown testing runs clearly revealed the need for rigid supports.

The truck test bed seemingly includes the vehicle, the two generators comprising the electrical power supply, the engine mounting, the test cabin, the test fuel supply, and associated auxiliary equipment. All of these systems are now operating, and have received substantial engineering shakedown. Remaining minor deficiencies are being addressed, but are not deemed critical. The vehicle stabilizing jacks work very well. Some minor test deck motions can be felt if insufficient weight is transferred off the tires onto the jacks. This is easy to correct by increasing jack loads.

Generator cooling has been markedly improved by the addition of a positive ventilation fan to each generator. This eliminated unplanned shutdowns due to overheat. Further

cooling improvements are not critical until hot weather returns. This may comprise opening exhaust ports in the steel panel behind the generators, thus allowing straight-through cooling flow underneath the truck chassis.

The air compressor for the emission bench air supply is an overload for the available generator capacity. It can be accommodated in cooler weather by not using the test cabin air-conditioning. In the longer term, a self-powered air compressor is needed.

Engine Mount

Of the choices available, a simple hardmount approach was selected. This design required direct mounting of the turbine engine and aircraft-type steel tube truss engine mount directly to the steel hardmount. The design was such that a separable workstand / cart arrangement could be implemented with the existing hardmount as a future upgrade.

The hardmount was designed and constructed to withstand push or pull loads in the thrust axis direction of up to 20,000 lb. The weak points are the engine mount truss and the bolts holding the hardmount to the truck deck (for controlled breakaway). The thrust diagonals and the tie-down bolts both fail at the 20,000 lb. load (or higher) in the reverse-thrust direction. The thrust axis is arranged at 45 degrees to the truck centerline. In the event of a propeller failure or an uncontained turbine failure, the debris will miss the unarmored test cabin. In the event of a severe fuel leak and fire, the burning fuel plume in the propeller slipstream will also miss the test cabin.

The engine oil cooler and drip line catch tanks are mounted directly to the hardmount steelwork. Oil cooling is by direct cooler immersion in the propeller slipstream blast. Propeller clearance exceeds 13 inches to the deck.

The deck on the truck is a unitized steel structure secured to the frame of the vehicle. It comprises large longitudinal steel channel frames that rest directly on the vehicle frame, with lateral floor joists of 4-inch channel, and a 1/8 plate deck. The main thrust hardmount bolts tie through directly to the joist channels, bypassing the weaker plate deck. Auxiliary tie-down bolts were installed to the deckplate, with a load spreading channel on the underside to prevent accidental damage. Initial assembly and test results indicated the need for a load spreader under two of the four mounting bolts that hold the engine truss to the hardmount. This modification was made.

Engine/Propeller

The engine, a PT6A-6, has been repaired and inspected. It was reworked to an early PT6A-20 configuration by changing the outlet hardware, ITT ring, and turbine stator assembly. The fuel control had clean fuel in it, and checked out in startup tests as serviceable. The engine has been fitted with a standard 3-blade controllable pitch propeller for this series engine.

Engine, propeller, engine controls, and the associated instruments are fully operational, and have been checked to full power. The engine instruments include gas generator speed (N1), interstage turbine temperature (ITT), propeller torque (T), propeller speed (N2), fuel supply pressure (Pf), fuel flow rate (wf), oil pressure (Poil), and oil temperature (Toil). The mounting of the engine oil cooler in the bare-engine propeller slipstream provides adequate oil cooling.

The engine / propeller is non-reversing, with a two-lever control (there is no separate fuel condition lever). The fuel cutoff is a detent on the gas generator throttle control. A start / stop / emergency stop checklist has been devised that is tailored to this installation.

Test Cabin, Controls and Instrumentation

The test cabin structure was reworked from the existing half-transport box on the truck. One of the double doors adjacent to the hardmount was reconstructed into a fixed wall, and a double Plexiglas window was installed for observing the test engine directly. On the side opposite the test mount, an emergency exit door was installed, permitting safe evacuation in the event of an emergency. The entire cabin has been foam-insulated and paneled to provide a suitable acoustic and thermal environment for the test crew and instrumentation within. There is a floor hard-mount for the emissions-equipment rack at the forward end of the cabin, with access to both sides of the rack. There is a roof-mounted air conditioner for temperature and humidity control in the cabin.

Initial shakedown testing revealed a weakness in the Plexiglas view window installation. This was corrected by revising the frame design and installation to prevent bending under propwash airloads.

The technique for taking data from the turbine engine itself is manual reading of the aircraft instruments from the engine control station. Since the shaft speeds, fuel flow rates, torques, temperatures, and pressures of interest were already instrumented in this way, and because transient testing is beyond the response capability of the emissions equipment, there are no immediate plans to change the engine data acquisition from this manual mode.

Basic Engine Hookups

The oil breather is a flexible line leading down the hardmount to an opening in the deck. The engine driplines are made of hard tubing connected to a vented catch tank attached to the hardmount adjacent to the oil cooler. Oil lines to and from the cooler are of standard

aircraft hardware, and attached to the hardmount. Fuel lines are standard aircraft flexible hose, and lead to a deck-mounted fuel tank just below the test observation window. The fuel plumbing features an electric lift pump plus the standard gascolator, fuel flow transducer, and fuel pressure transducer that an aircraft installation would feature.

The engine wiring utilizes an aircraft nacelle harness and cannon plugs, and connects to standard aircraft instruments in the test cabin. These are located on a instrument panel just below the observation window. Inside the panel are the inverter and associated components. Starting batteries are fixed to the deck adjacent to the test hardmount. Provision has been made for connecting to a standard 28-volt external power cart.

Emissions Bench

The Rosemount emissions bench has all six channels installed and operational: CO₂, CO, O₂, HC, NO_x, and SO₂. Data readout was initially manual from the front panel gages. Digital data logging capability has been installed. The new 100-ft heated sample line has been successfully exercised. The design and positioning of the sample probe itself (within the engine exhaust pipe) has been finalized, tested, and verified. Sample line temperatures have been verified as between 300 and 400 F at the connection to the heated sample hose, over the full range of test conditions. The effects of exact probe positioning have been investigated and found to be relatively small. The probe position has been standardized, and is verified in each test setup. (A formal test setup checklist is being developed.)

INITIAL TESTING

Biodiesel Blending Results

The biodiesel blendstock used in this testing is derived from waste cooking oils by NOPEC in Lakeland, Florida. It was determined from small bench samples that this material will splash blend with Jet A fuel, whether as biodiesel-into-jet or jet-into-biodiesel. The observed rate of mixing is a little slower than with splash blending of alcohols into gasolines, so it is routine to stir the tank after blending. None of the bench samples has ever indicated a tendency to separate.

It has been determined that rather precise control of blend composition is easily obtained by a dipstick measurement technique. Before and after each run (or blend session), fuel depth is gaged with a dipstick and measuring tape (using a sample size of 3 identical readings, or more). Prior composition information can be used to decompose the depth into partial depths of jet and biodiesel (or other additives), analogous to the partial pressure representation of gas mixtures. To this, one component or the other can be added, and the depth change attributable to it directly measured, so that there is always a correspondence between composition and partial depths. This technique has the advantages that (1) an absolutely-level test bed is not required if before-and-after depths are taken for each and every operation on a given setup, and (2) a calibrated quantity indicator is not required. This is a very simple procedure, easy to use in the field.

Emission Testing Runs

Fuel testing in the PT-6 began with a simple exhaust sampling probe design located very near the propeller turbine outlet, far up the exhaust passage. A tubing extension was

installed to preclude the possibility of thermally damaging the expensive heated sampling line to the emissions instrument bench.

The tests included a Jet A baseline, nominal 5%, 10%, and 15% biodiesel binary blends (by volume). They served to identify the proper data presentation format, and the repeat-run requirements. They also served to raise and answer questions about the suitability of the mechanical details of the sampling probe design.

As finally defined, the data presentation required that emissions be plotted vs a suitable engine performance variable, since the emissions depended at least as strongly on these variables as on the blend percentages, and usually far more so. As finally defined, repeatability requirements demanded at least two runs conducted on at least two different times-of-day, and preferably two different days. In this way, effects of ambient conditions could be identified and shown as natural scatter. On any given test, the data trajectory could (and did) bias toward one or the other side of the scatter band. None of these restrictions were known at the outset.

The engine variable selected for (unburned) exhaust hydrocarbons was specific fuel consumption, which is directly related to the cycle thermal and combustion efficiencies. The value used was computed as fuel flow divided by the propeller shaft horsepower. The idle settings feature high fuel consumptions, while the flying power settings tend to cluster at low values. Repeat runs were not conducted in the initial stages, so these early trends can be potentially misleading. Only later did the true size of the natural scatter behavior become apparent.

In Appendix A1, fig. 1, 2, 3, and 4 show hydrocarbons for nominal 5, 10, and 15% blends. These are plotted directly upon the straight Jet A baseline data, so that any trends with blend will be visually apparent relative to the natural scatter. The second

10% blend plot (fig. 3) shows the effects of relocating the probe to the exhaust flange plane. The 15% blend plots (fig. 4) also show the effects of removing the extension to produce a measured sample line inlet temperature of between 300 and 380 F. The blends did not seem to affect the hydrocarbons significantly. The probe changes seemed to increase idle hydrocarbons by an amount comparable to the natural scatter. (This result required a new baseline and repeat blend testing.)

Fig. 5-8 in Appendix A1 show analogous data for NOx emissions. These were correlated to interstage turbine temperature (ITT) as a surrogate for the combustor temperature distribution which would actually tend to govern NOx formation. Any changes that there might be in the NOx trends due to blends or probe design are apparently smaller than the natural data scatter in this series.

Fig. 9-12 in Appendix A1 show analogous data for SO₂ emissions. These were correlated as exhaust SO₂ levels minus the measured ambient levels, and plotted vs fuel flow rate, since the fuel is the source of any sulfur atoms in the process. The use of SO₂-above-ambient compensates for instrument drift, which proved to be substantial, and for instrument scale resolution, which was low. The drift is inherent in the design of the instrument. The scale resolution choice was forced by the available span gas concentration (which was subsequently revised for better resolution). The resulting natural scatter is considerable. However, none of the blends or probe designs seemed to affect the SO₂ measurements in this series.

The effects of the changes in probe design are most clearly represented in fig. 13-18 of Appendix A1, which contain correlated emissions for the straight Jet A baselines, comparing the initial and final probe designs. Fig. 13 and 14 compare the probe effects on hydrocarbons: there seems to be a slight increase at low and high idle conditions, of about the same size as the natural scatter. Fig. 15 and 16 show that the NOx seems

unaffected by the probe changes. Similarly, fig. 17 and 18 show no discernible effects on SO₂ results.

BINARY BLEND TESTING

With the probe design fixed, attention could be focused upon exploring the range of binary blends for effects upon emissions. Fig. 19-23 in Appendix A1 show the hydrocarbon curves (all final probe data) for blends from 5% to 25% biodiesel in 5% increments. Each is plotted directly upon the Jet A baseline for direct comparison and natural scatter assessment. Across this range of binary blends, there seems to be no effect upon idle hydrocarbon emissions. (Hydrocarbon emissions in flight power settings do not appear to be a problem.)

Fig. 24-28 in Appendix A1 present the NOx results for the same blends tested. In these plots, idle settings produce the colder ITT's, and flight power settings produce the warmer ones. Up through 15% blend strengths, there were no discernible blend effects upon NOx emissions. However, at 20% (fig. 27), at least the flight power settings show NOx reductions larger than the natural scatter. At 25% (fig. 28), even the idle NOx emissions are quite substantially reduced, perhaps by a factor of 1.5 to 2.

Fig. 29-33 in Appendix A1 show the SO₂ results for the same blends. There seemed to be no effects of blend on this emission distinguishable from the natural scatter. It should be noted that the sampling system and SO₂ instrument would quite clearly show the effects of diesel power carts, generators, and air compressors, starting and stopping in the vicinity of the test setup, as a 10 to 20 ppm jump in background readings. This provides some confidence that the instrument really could have distinguished fuel blend effects,

had there been any. (At much richer blends, reductions could be expected to become apparent, as most of the sulfur-bearing kerosene would be replaced.)

PREPARATIONS FOR TRINARY BLENDS AND FLIGHT TESTS

Prudence would indicate that blends of 30 and perhaps 35% should be investigated to confirm the trend of these results. After that, it is probably more important to investigate trinary blends to see whether idle hydrocarbons can be reduced without affecting the NOx adversely.

The PT-6 testing of binary jet fuel-biodiesel blends produced different emissions trends from those obtained by other investigators working with diesel engines. In particular, diesel idle hydrocarbons seem to be reduced by blending with biodiesel, while the turbine hydrocarbons seem unaffected. At richer blends, turbine NOx emissions apparently decrease, in contrast to the diesel engine results. The turbine NOx reductions are a favorable result, especially since they can apparently be achieved at idle, with positive implications for reducing ozone in the vicinity of airports.

The biodiesel used in the tests subjectively seemed to be more viscous than the jet fuel during fuel blending operations. No gross changes were evident to the test crew in the operation or performance of the engine, however. It is possible that a higher viscosity also implies a higher surface tension for biodiesel. This might interfere with atomization, vaporization, and completeness of burning. If true, this might both explain the unaffected idle hydrocarbon emissions, and offer a way to modify them, by thinning the biodiesel with an appropriate tertiary additive. The initial plan included investigation of both ethanol and ETBE as tertiary additives.

Accordingly, some representative mixes of biodiesel with ETBE and ethanol were made and tested for viscosity. Viscosities were measured for the neat materials (including the base Jet A fuel), and for 50-50 mixes of biodiesel with the two solvents. Viscosities for a typical binary blend (75-25 jet-biodiesel), and for two extreme trinary blends (50-25-25 jet-biodiesel-solvent) were also obtained. The results are given in the table below.

The viscosity test was based upon the principle of the Saybolt viscosimeter, but used a simple field test tool normally used in spray paint work. With it, relative pour times were determined, and normalized to the pour time of straight Jet A. Ten pour times of each material were obtained, averaged, and checked for sample standard error. As shown in the table, a data point was not accepted if the standard was too large (arbitrarily set as over 0.2 seconds out of 6 seconds typical average). These pour time data are proportional to the pour times that would have been measured with a standard Saybolt viscosimeter, in turn related to the true kinematic viscosity by a well-known correlation equation.

Typical kinematic viscosity data for Jet A are available in CRC report 530 "Handbook of Aviation Fuel Properties", available from SAE Press. The kinematic viscosity of Jet A was determined from this report at the sample testing temperature of 18 C. This was converted to Saybolt seconds (the standard Saybolt pour time) with the correlation equation. The relative times from the sample tests were then converted to estimated Saybolt seconds using the Jet A result to calibrate them. In turn, these were converted to kinematic viscosities with the correlation equation.

The resulting neat biodiesel viscosity estimate is somewhat higher than JP-10 missile fuel, and so over twice as viscous as Jet A. JP-10 also has a surface tension considerably higher than Jet A, so one might reasonably suspect that biodiesel may also have a high surface tension. JP-10 is not a fuel that the PT-6 is rated to use. The 50-50 biodiesel-

solvent mixes, the 75-25 jet-biodiesel, and the 50-25-25 trinary blends all tended to exhibit viscosities the 2.1 - 2.5 Centistoke range, which is less than half again the viscosity of straight Jet A. ETBE has a lower estimated viscosity than ethanol, so those blends uniformly tend to the lower side of the range of viscosities estimated. Viscosities in this range are only a little higher than that of JP-7.

It seems reasonable to use 50-50 mixes of biodiesel with ethanol and with ETBE to displace Jet A in increments of 10 and 20% for the initial trinary blend work. The binary blend results indicate significant jet fuel displacement is required. A blend showing promise would then be a good starting point for a more carefully designed experiment. This in turn provides the basis for selecting a flight test blend.

FUEL SAMPLE ESTIMATED VISCOSITY TABLE

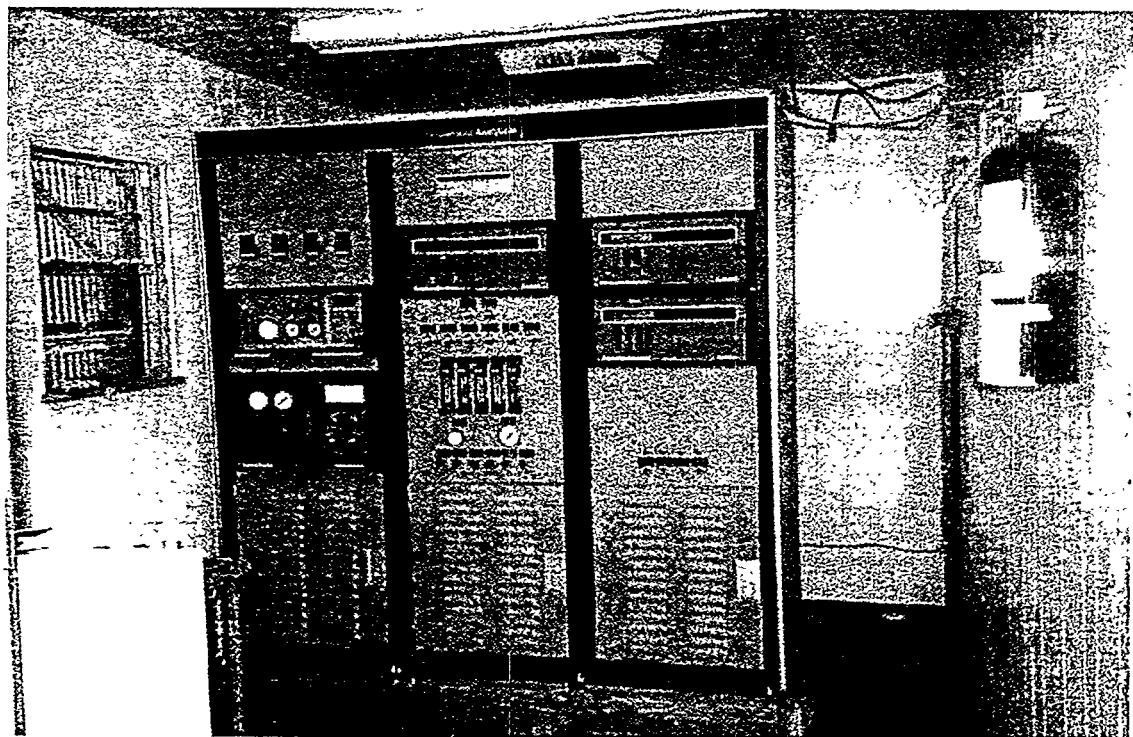
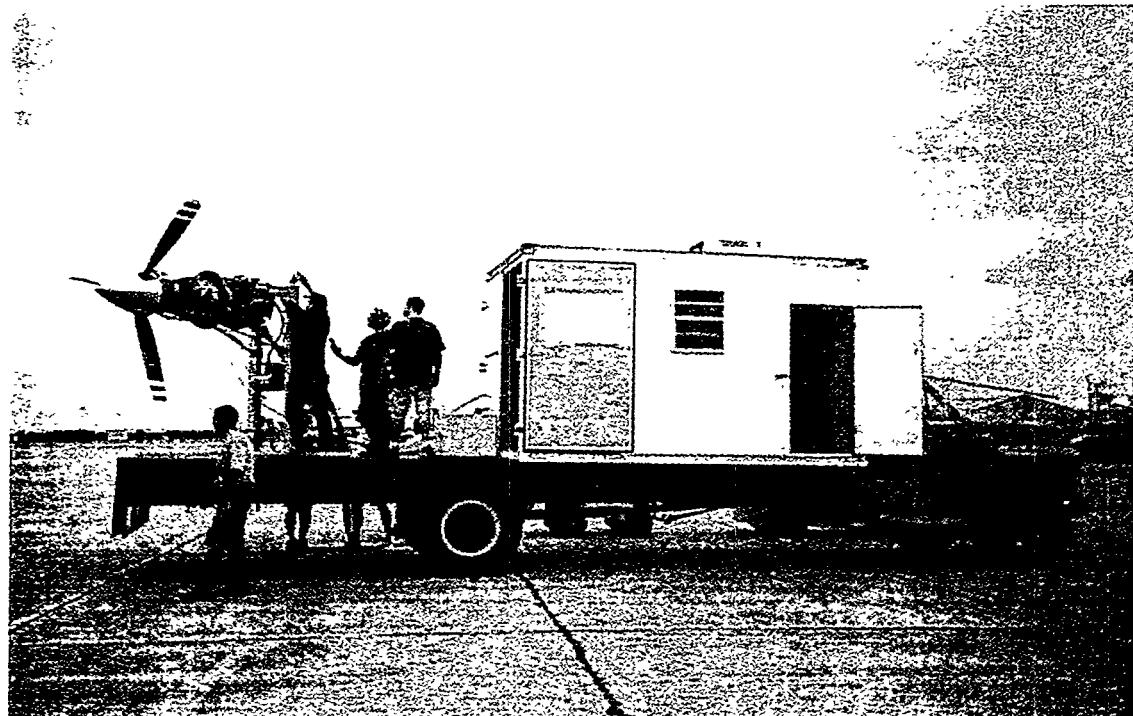
fuel description	avg	sample	avg/JetA	SUS	CS
	time	std err			
	sec	sec			
-----	-----	-----	-----	-----	-----
Jet A repeat	5.951	.145	1.00	33.3375	1.70
Biodiesel	6.940	.135	1.166	38.92	3.79
Ethanol (denat.)	6.053	.167	1.017	33.94	1.93
ETBE	5.702	.196	0.958	31.97	1.13
50 biod.-50 ETBE	6.114	.193	1.027	34.28	2.06
50 biod.-50 ethanol	6.325	.111	1.063	35.48	2.52
75 jet - 25 biod.	6.252	.161	1.051	35.08	2.37
50 j 25 b 25 ETBE	6.130	.121	1.030	34.38	2.10
50 j 25 b 25 ethanol	6.275	.110	1.054	35.18	2.41

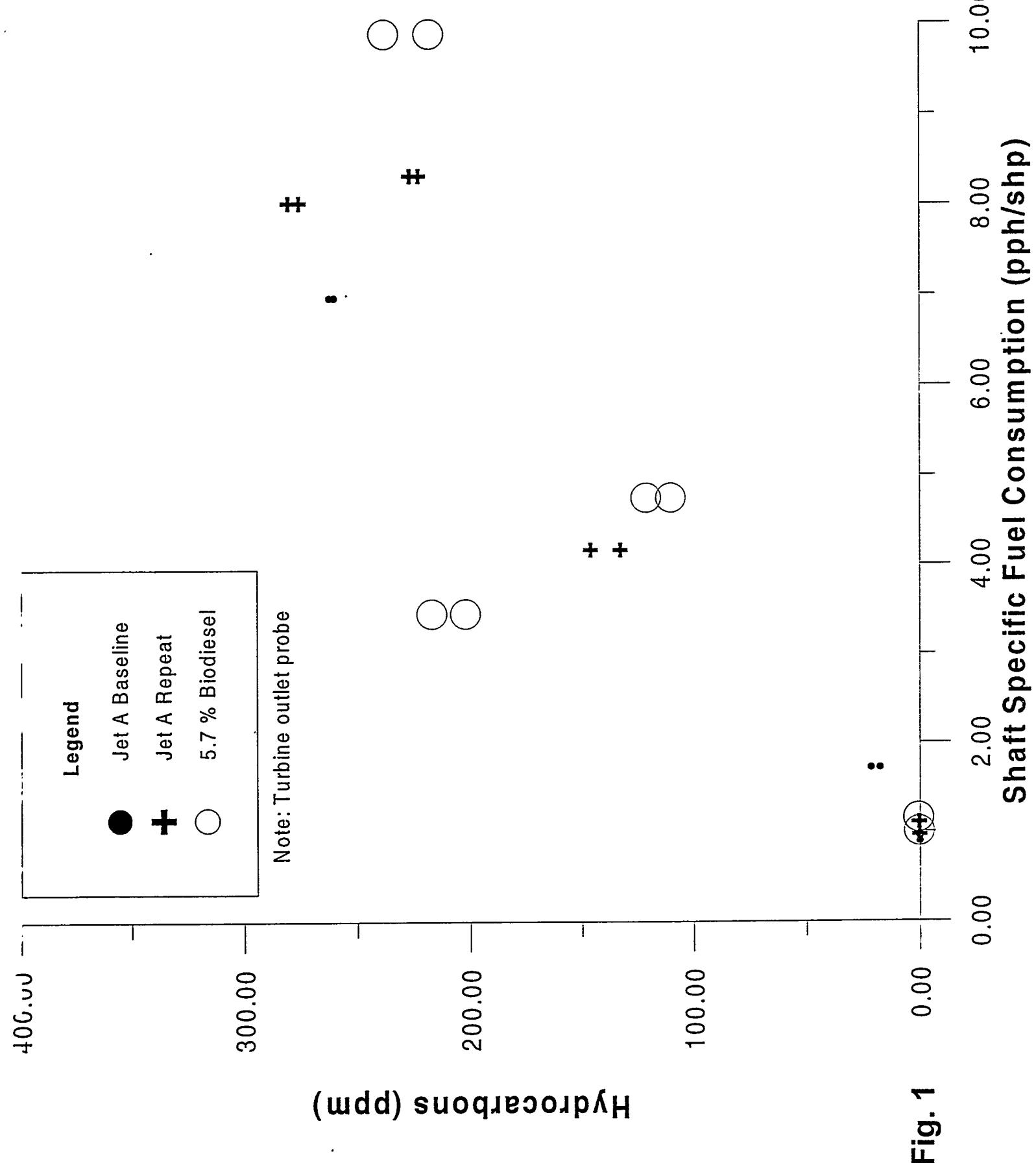
* neat Biodiesel is over twice as viscous as neat Jet A (factor 2.22)

* none of the proposed blends or additives is more than 48% more viscous than Jet A

* JP-10 is 103% more viscous than Jet A (factor 2.03)

Baylor University's Turbine Engine Test Stand and Emissions Testing Equipment





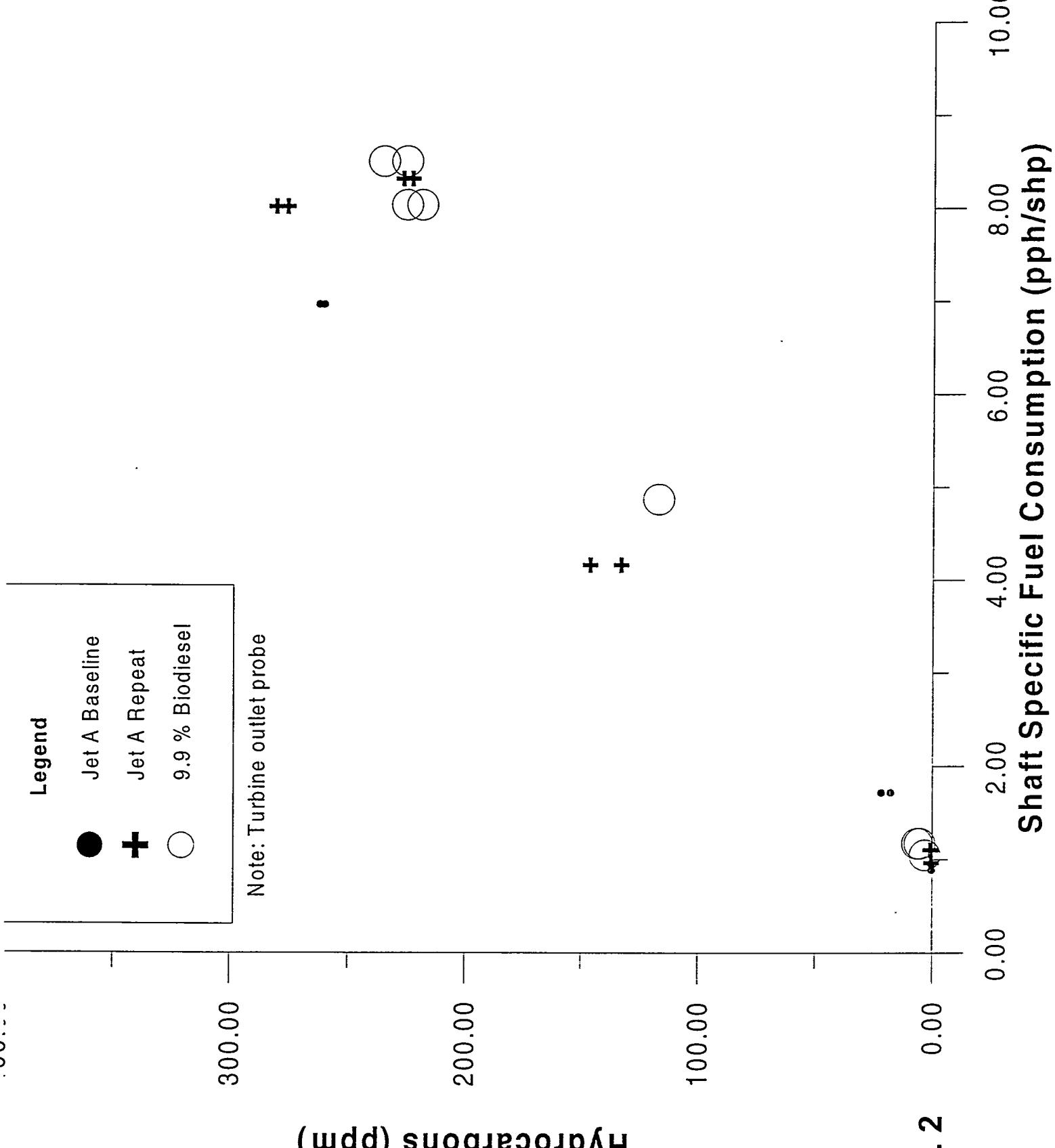
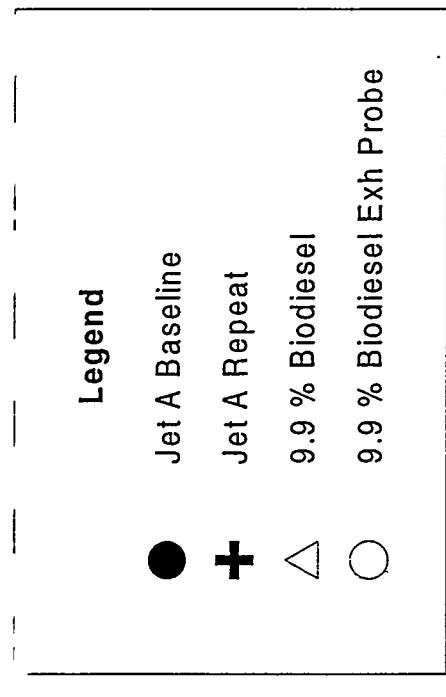


Fig. 2



Note: Turbine outlet probe except as marked

Hydrocarbons (ppm)

300.00

200.00

100.00

0.00

✚

△#△

○○

✚

△○

●

Fig. 3

Shaft Specific Fuel Consumption (pph/shp)

10.00
8.00
6.00
4.00
2.00
0.00

10.00

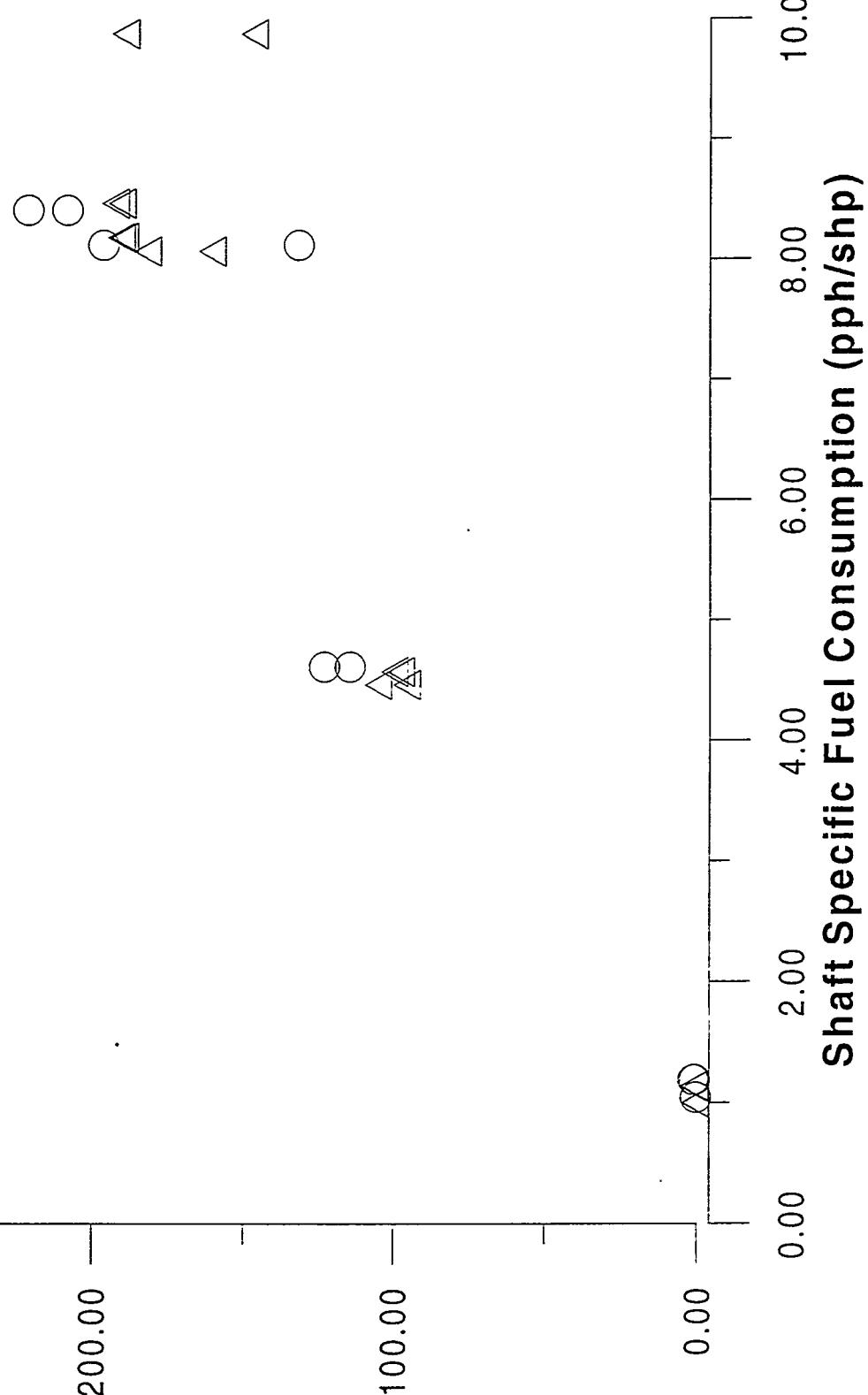
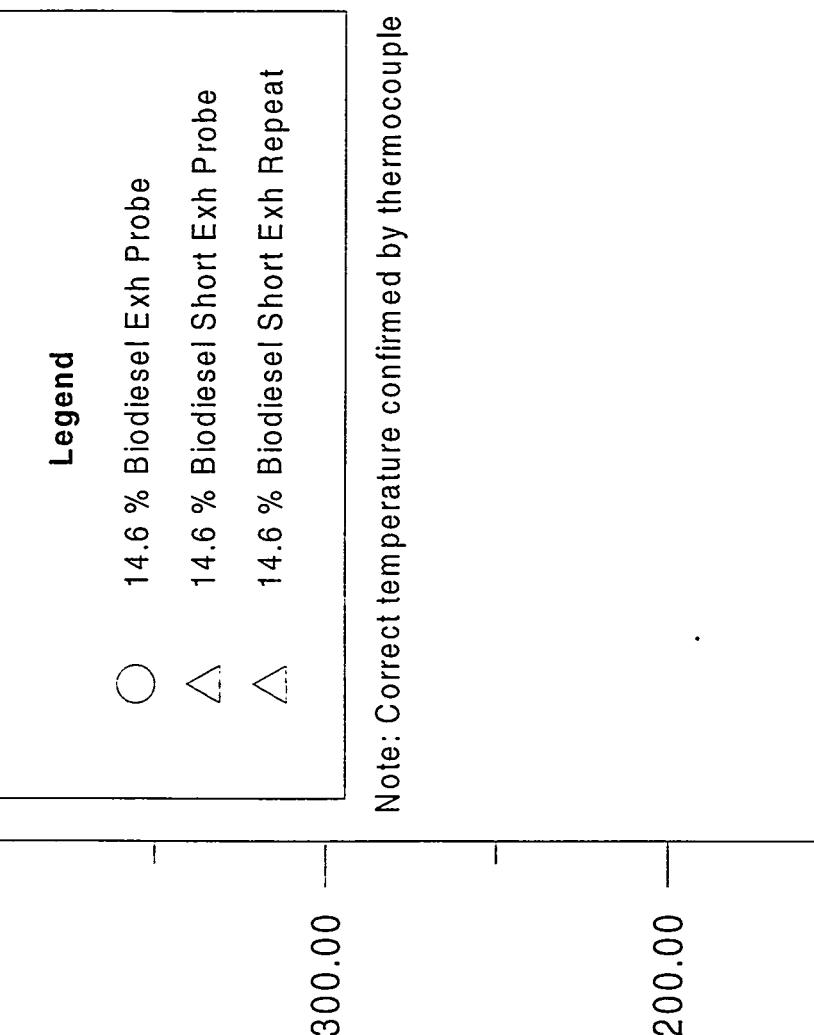
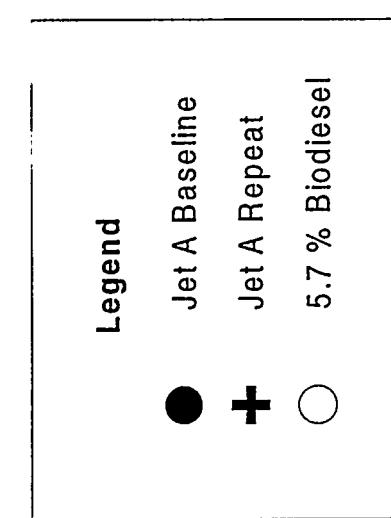


Fig. 4



Note: Turbine outlet probe

80.00

(mdd) xON

40.00

500.00

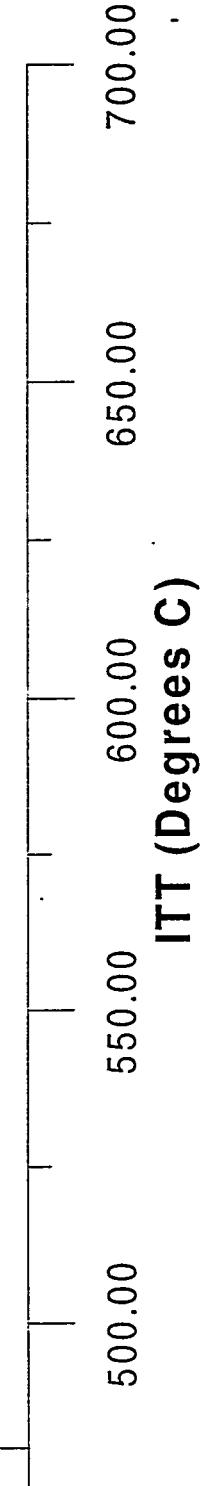
550.00

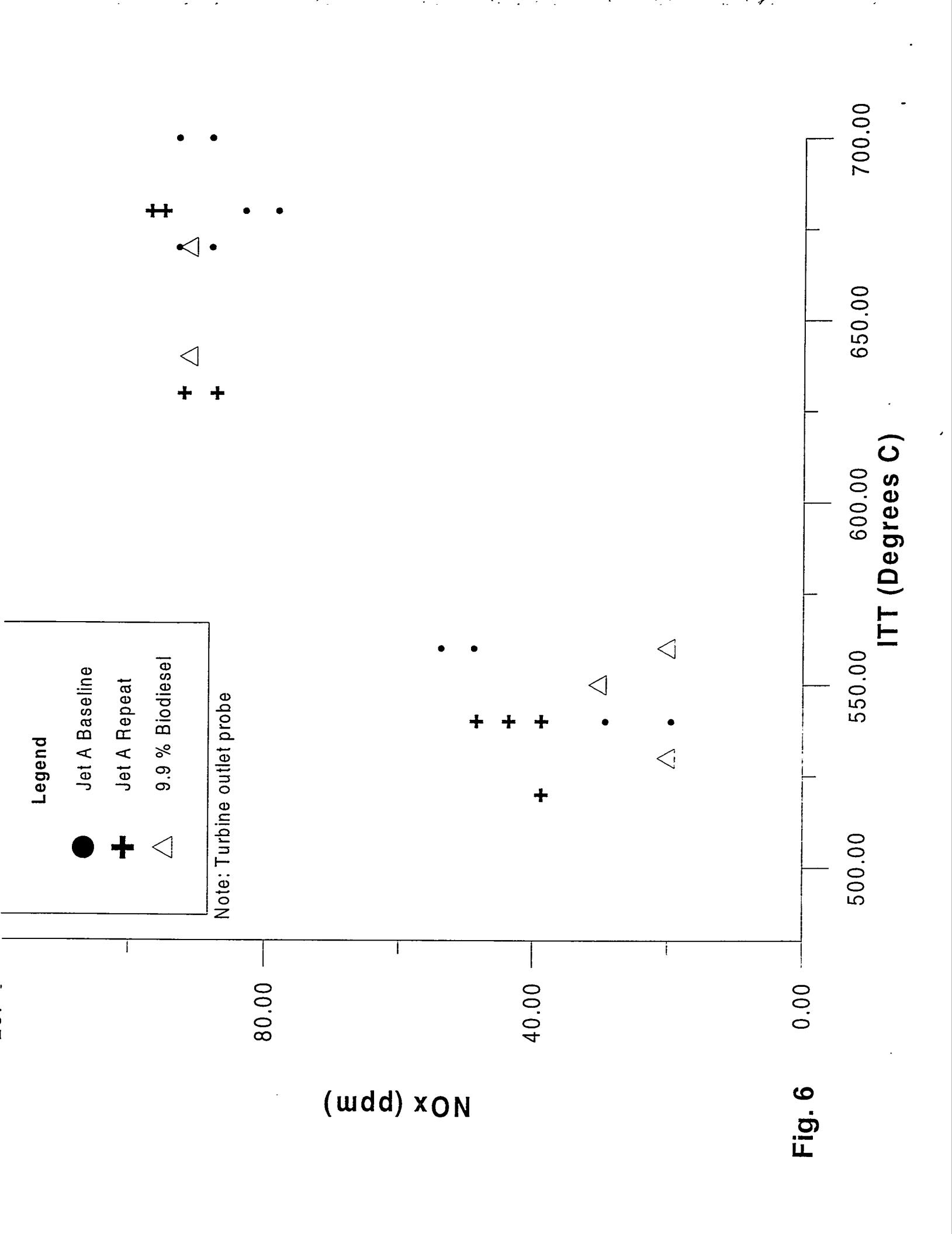
600.00
ITT (Degrees C)

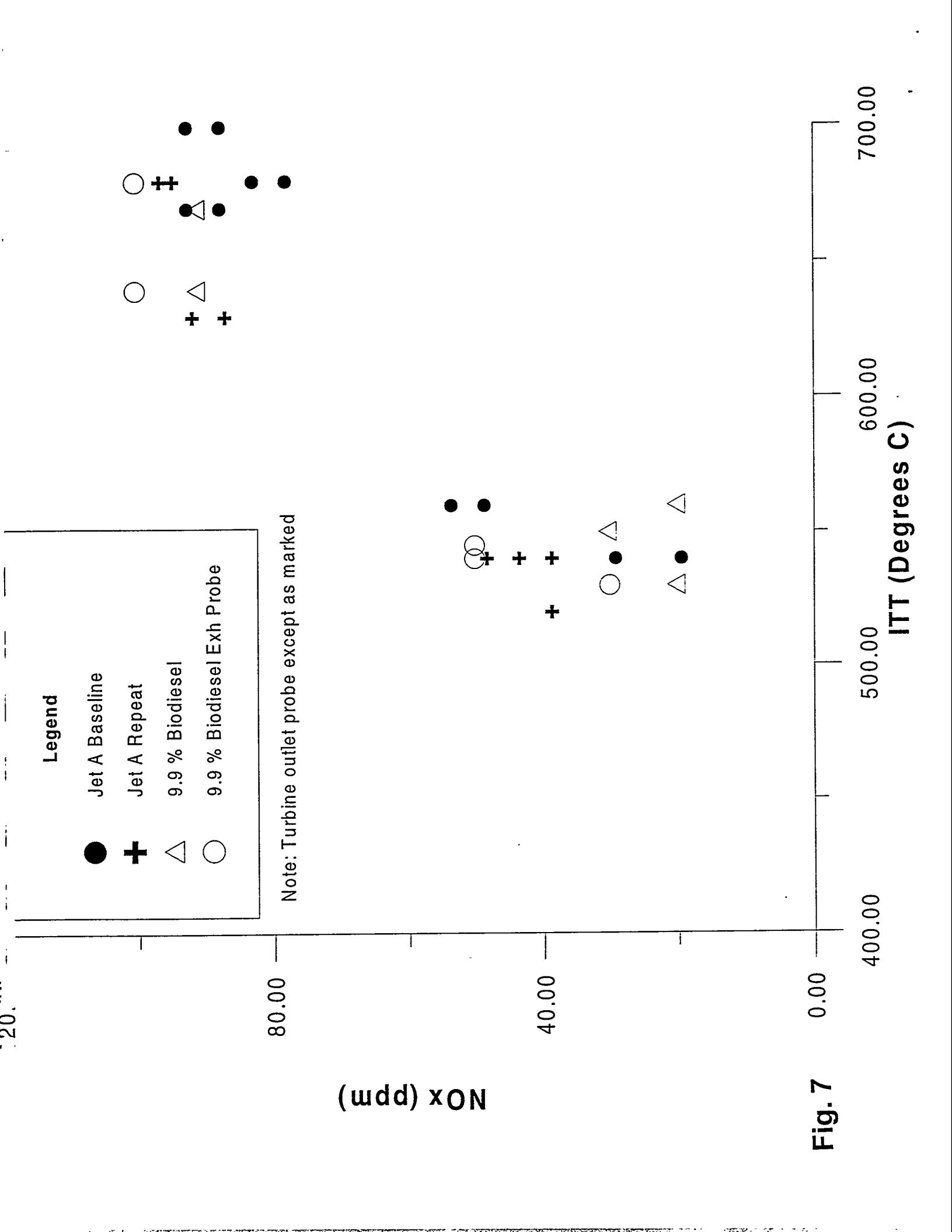
650.00

700.00

Fig. 5



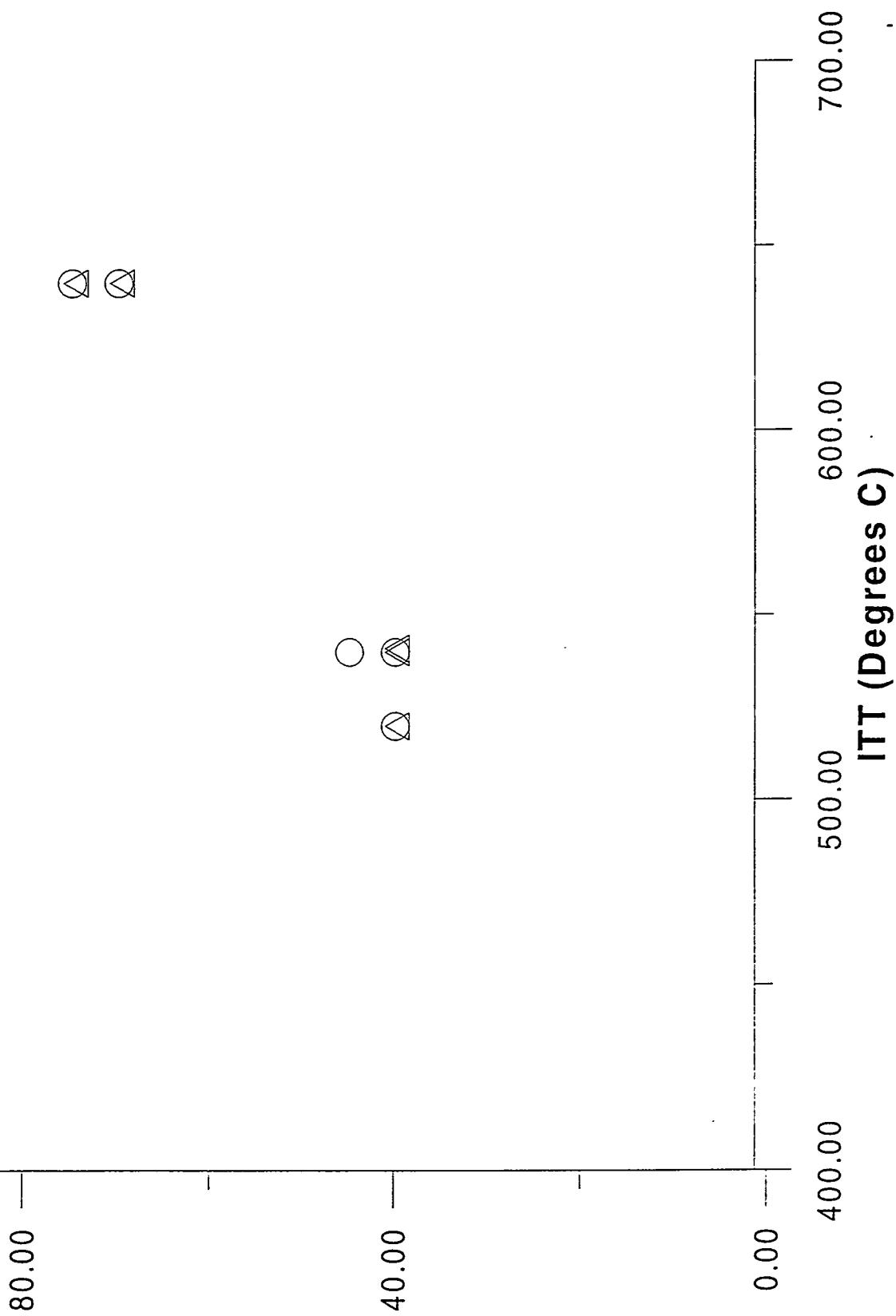




Legend

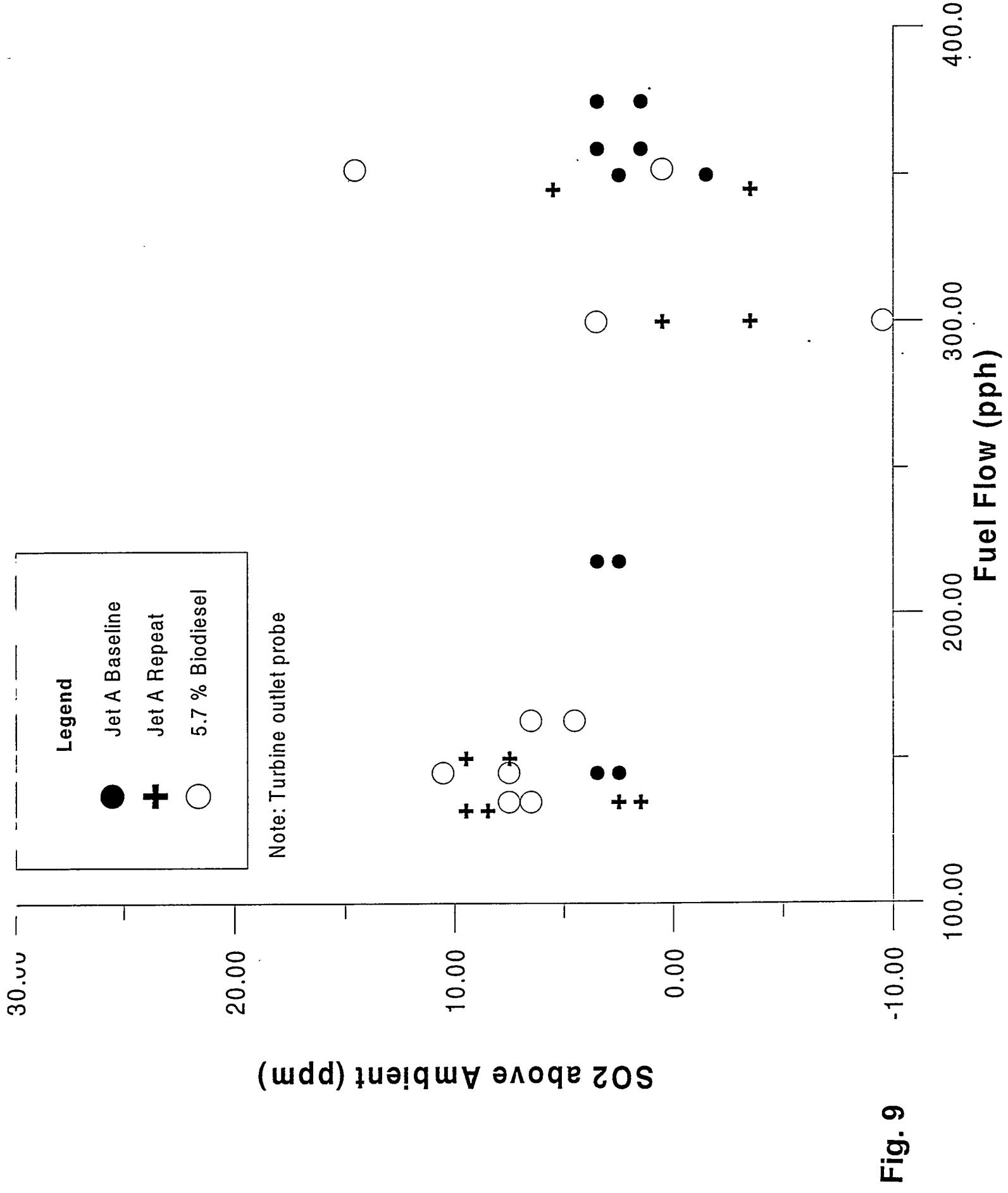
- 14.6 % Biodiesel Exh Probe
- △ 14.6 % Biodiesel Short Exh Probe
- ▽ 14.6 % Biodiesel Short Exh Repeat

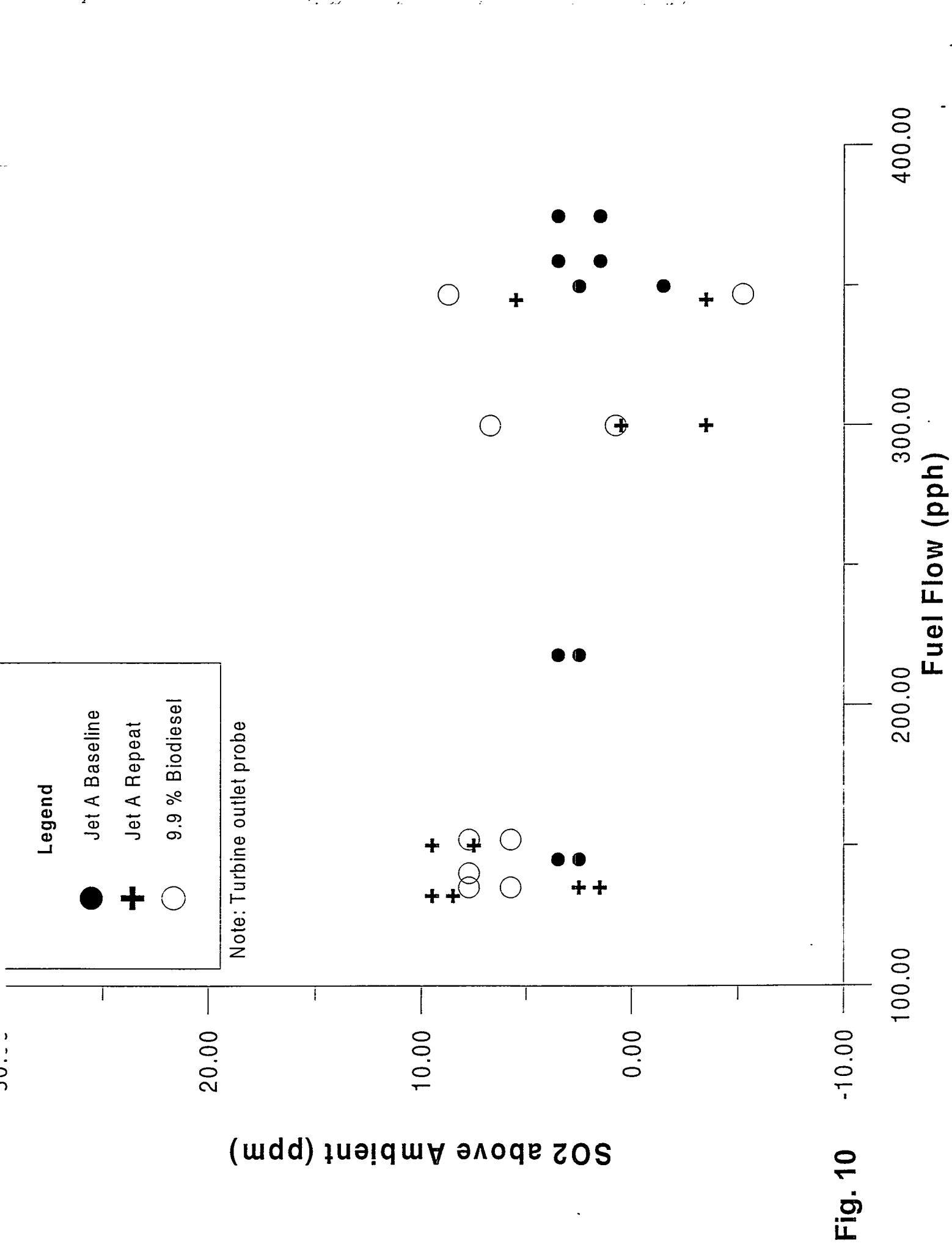
Note: Correct temperature confirmed by thermocouple

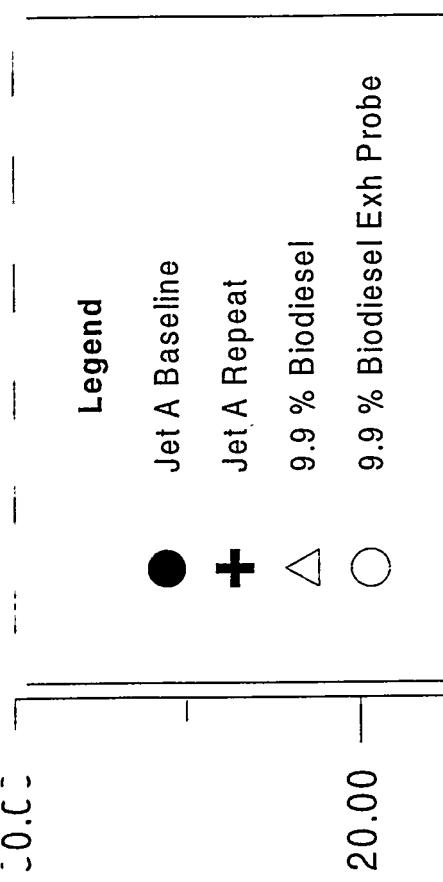


(NO_x) $\times 10^3$

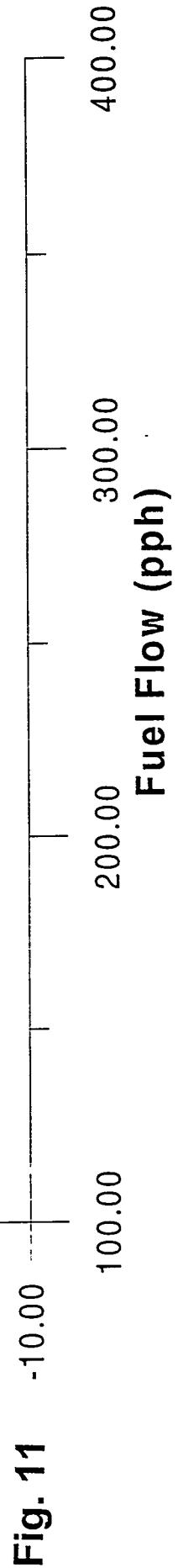
Fig. 8

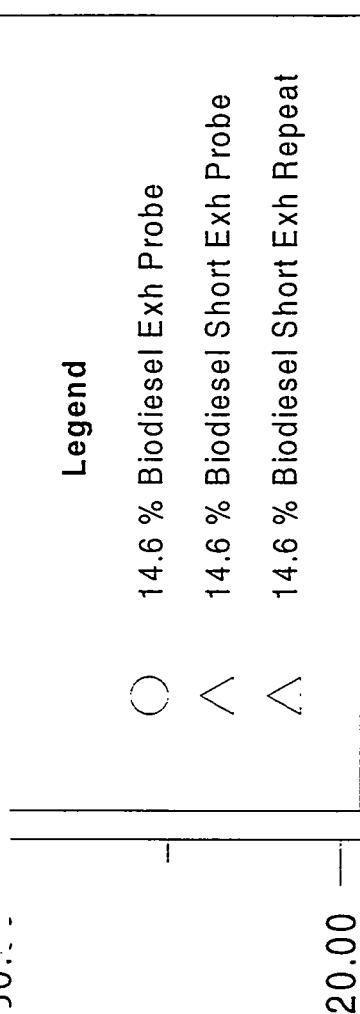






SO₂ above Ambient (ppm)





Note: Correct temperature confirmed by thermocouple

SO₂ above Ambient (ppm)

Fig. 12

400.00
300.00
200.00
100.00
-10.00

Fuel Flow (pph)

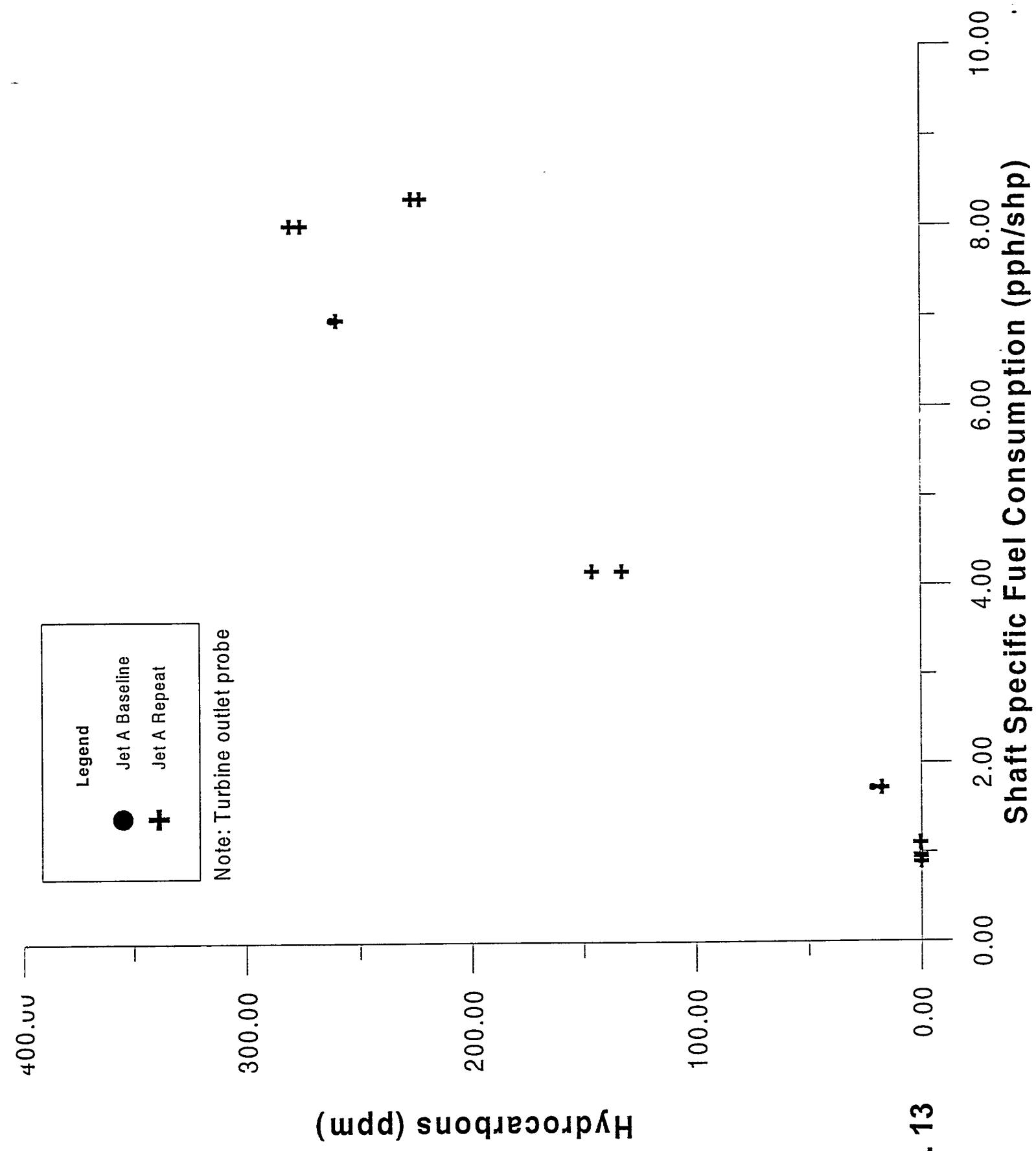


Fig. 13

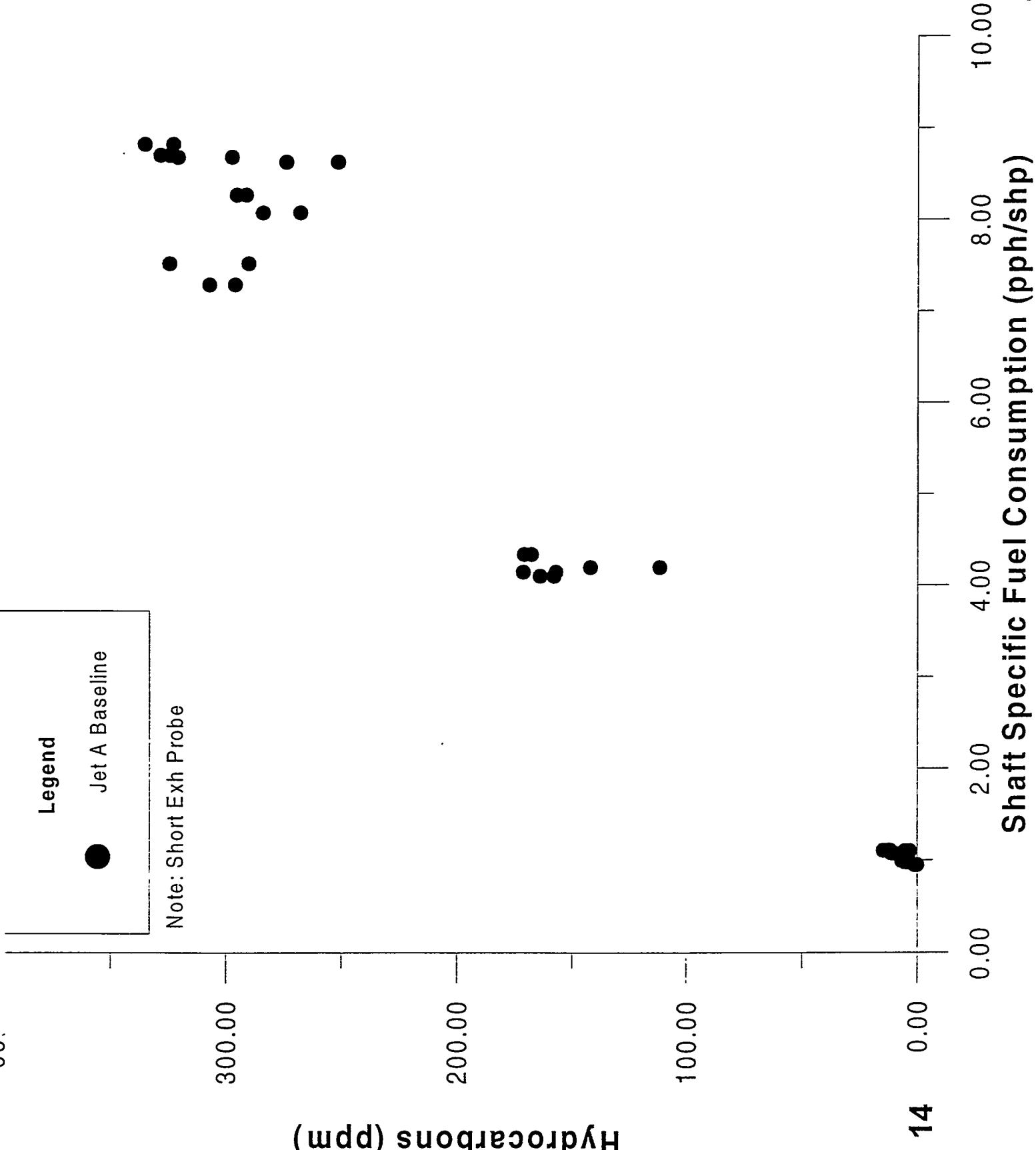


Fig. 14

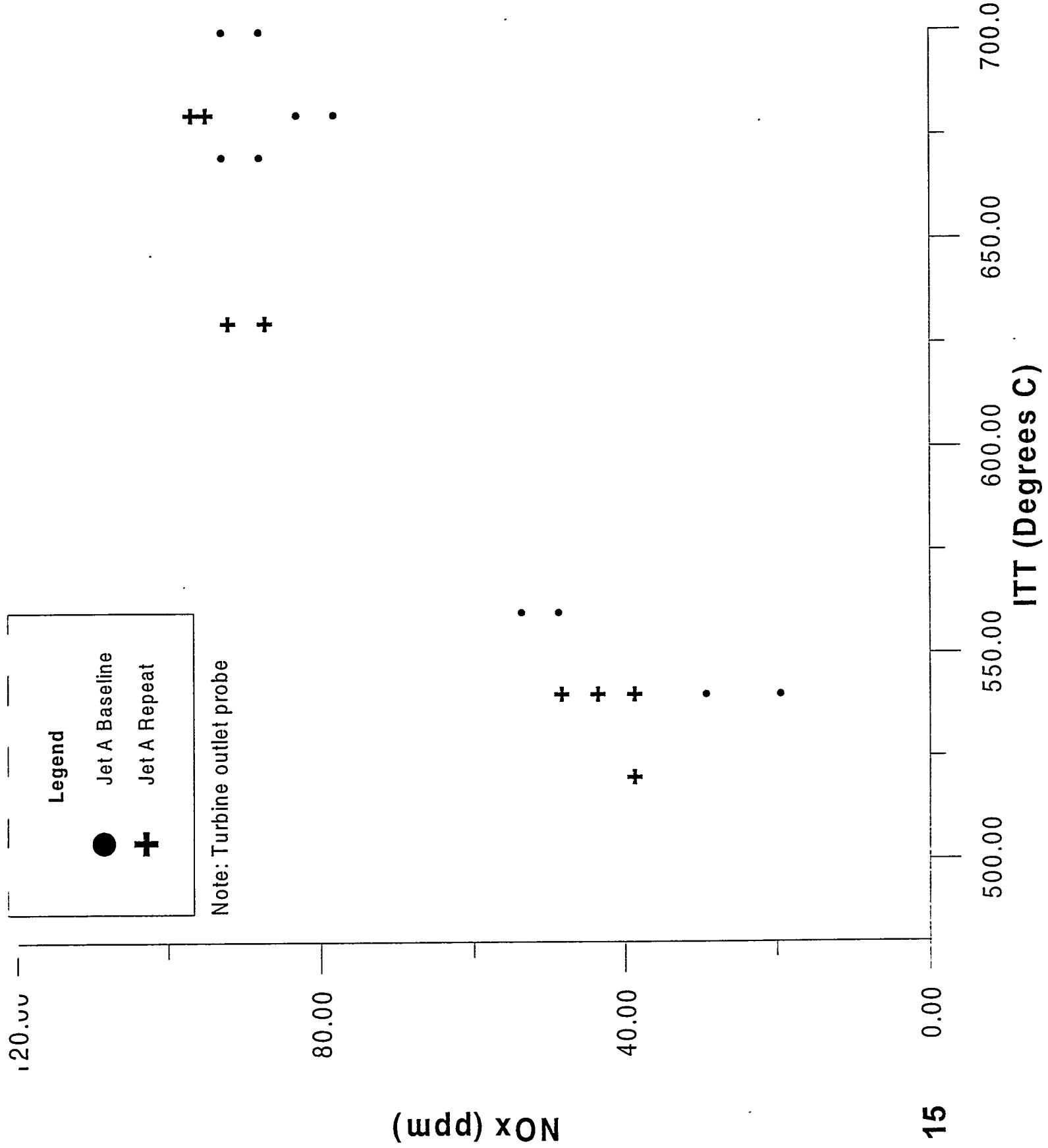
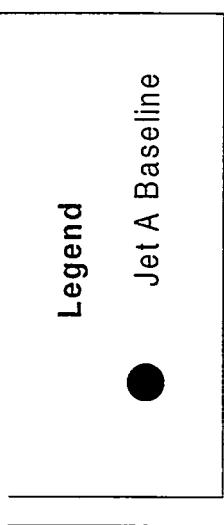
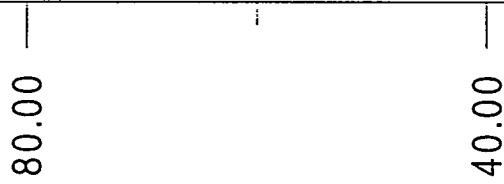


Fig. 15



Note: Short Exh Probe



(wdd) x 10⁻³

Fig. 16

700.00
600.00
500.00
400.00
0.00

ITT (Degree C)

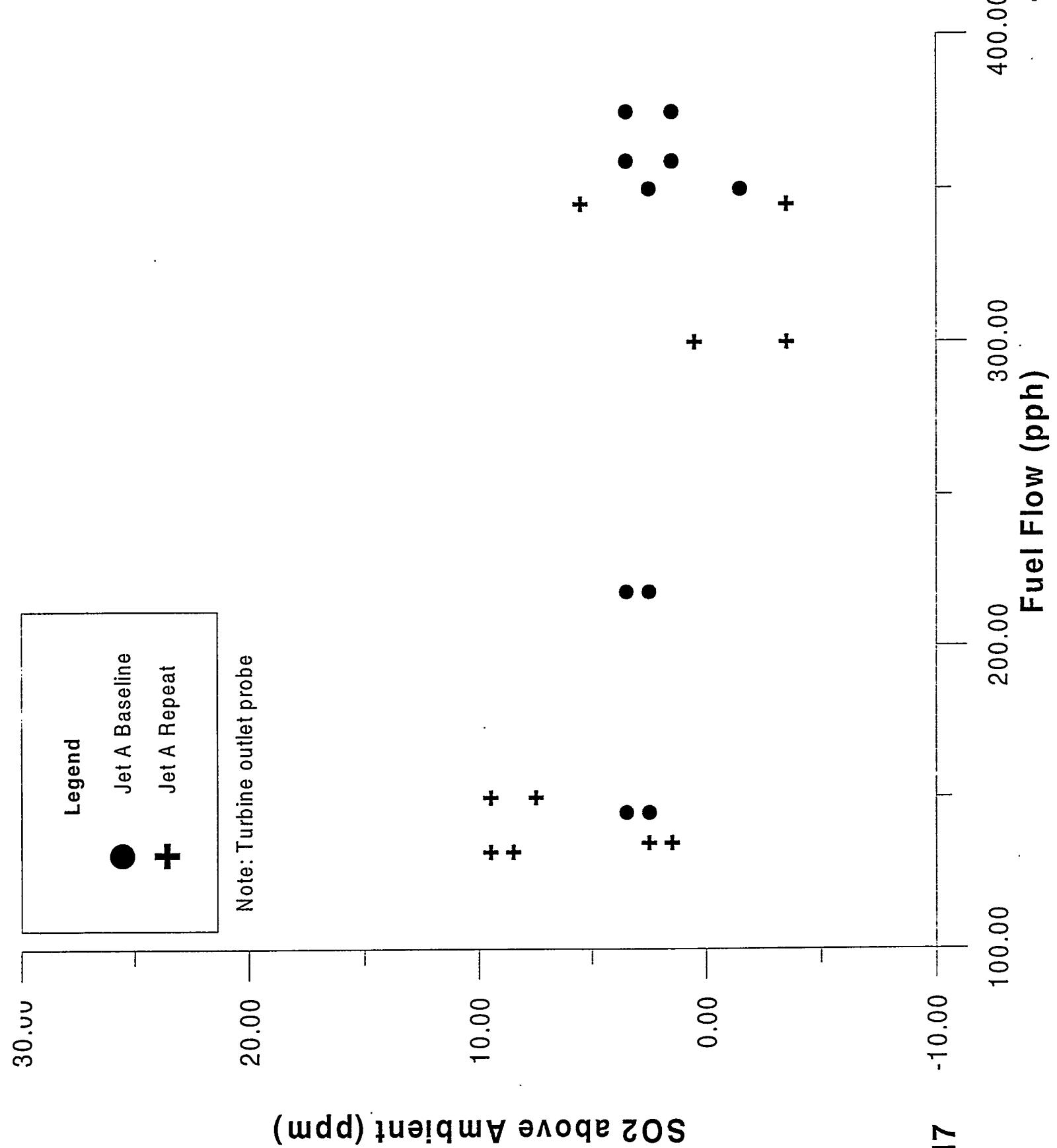
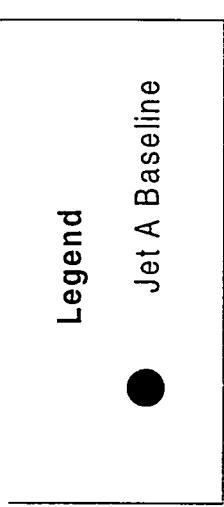


Fig. 17



Note: Short Exh Probe

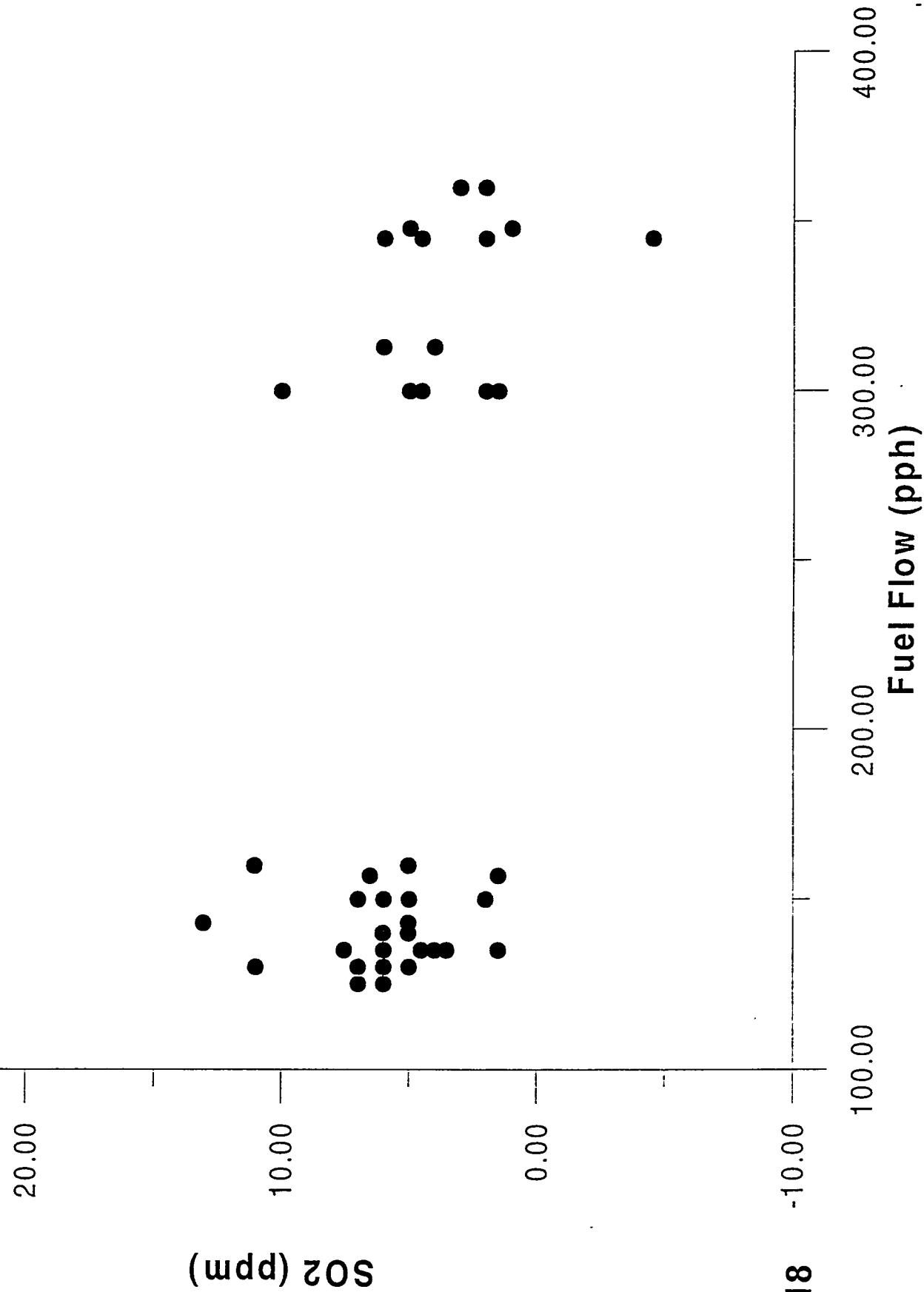


Fig. 18

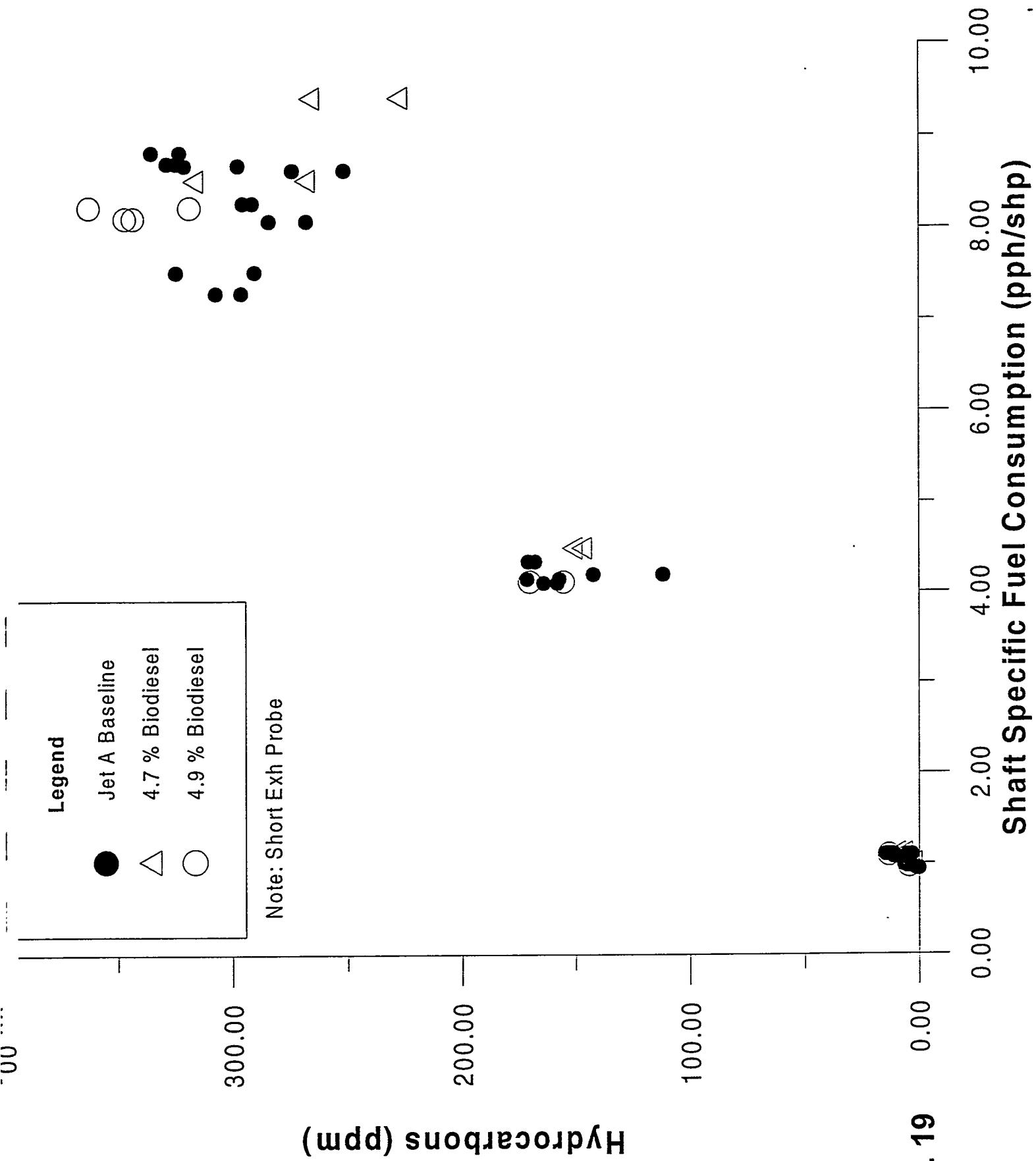


Fig. 19

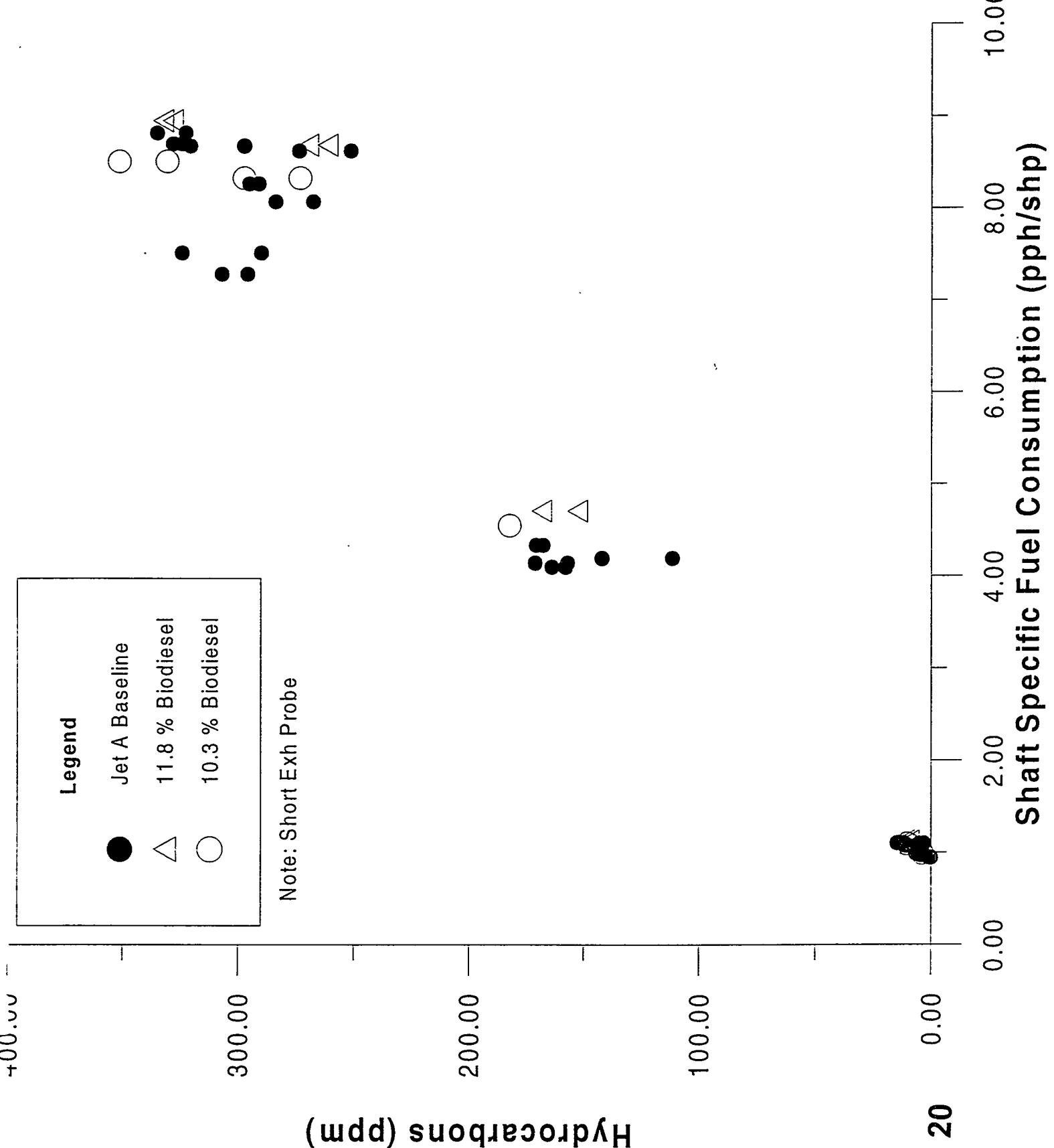


Fig. 20

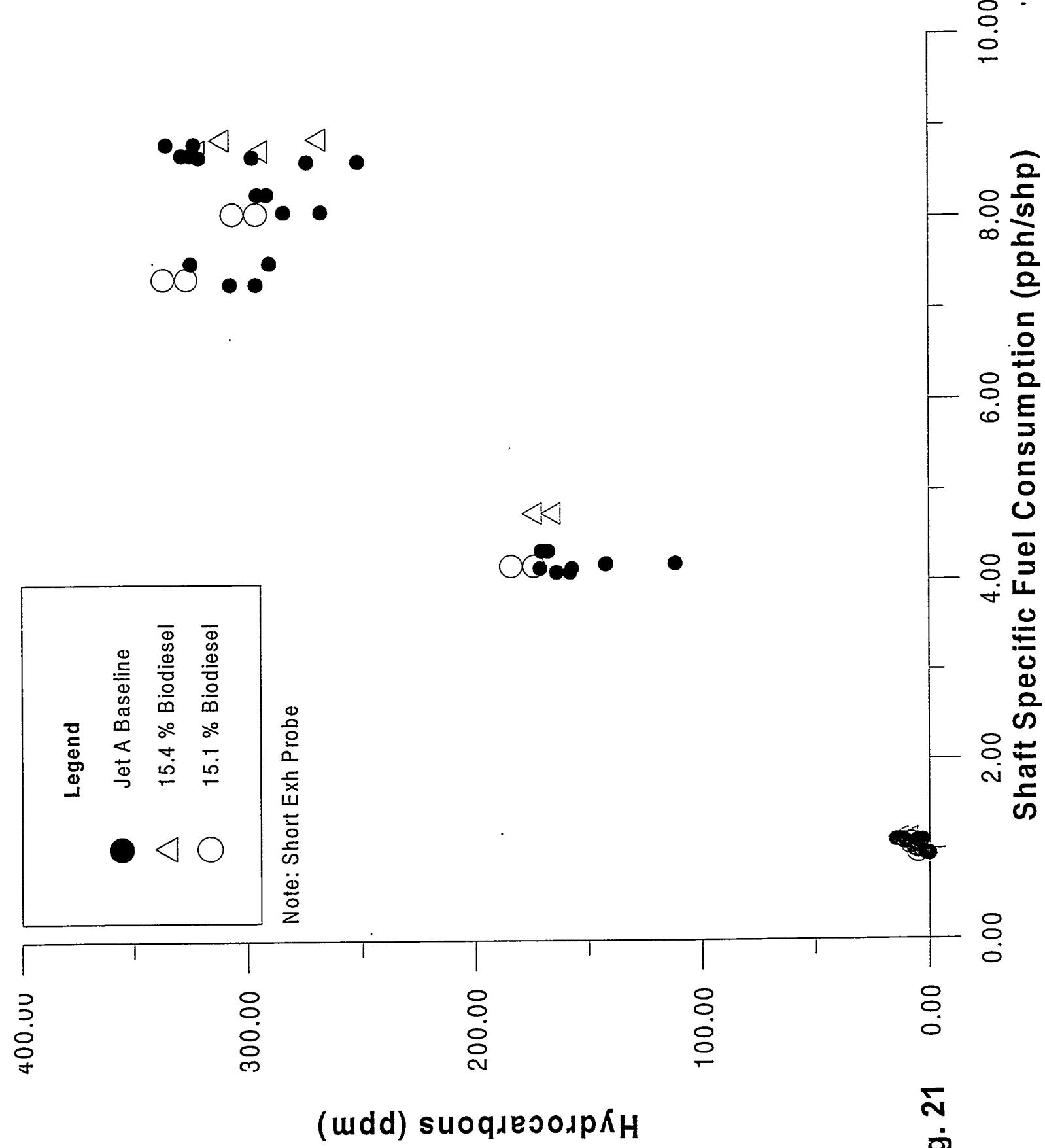


Fig. 21

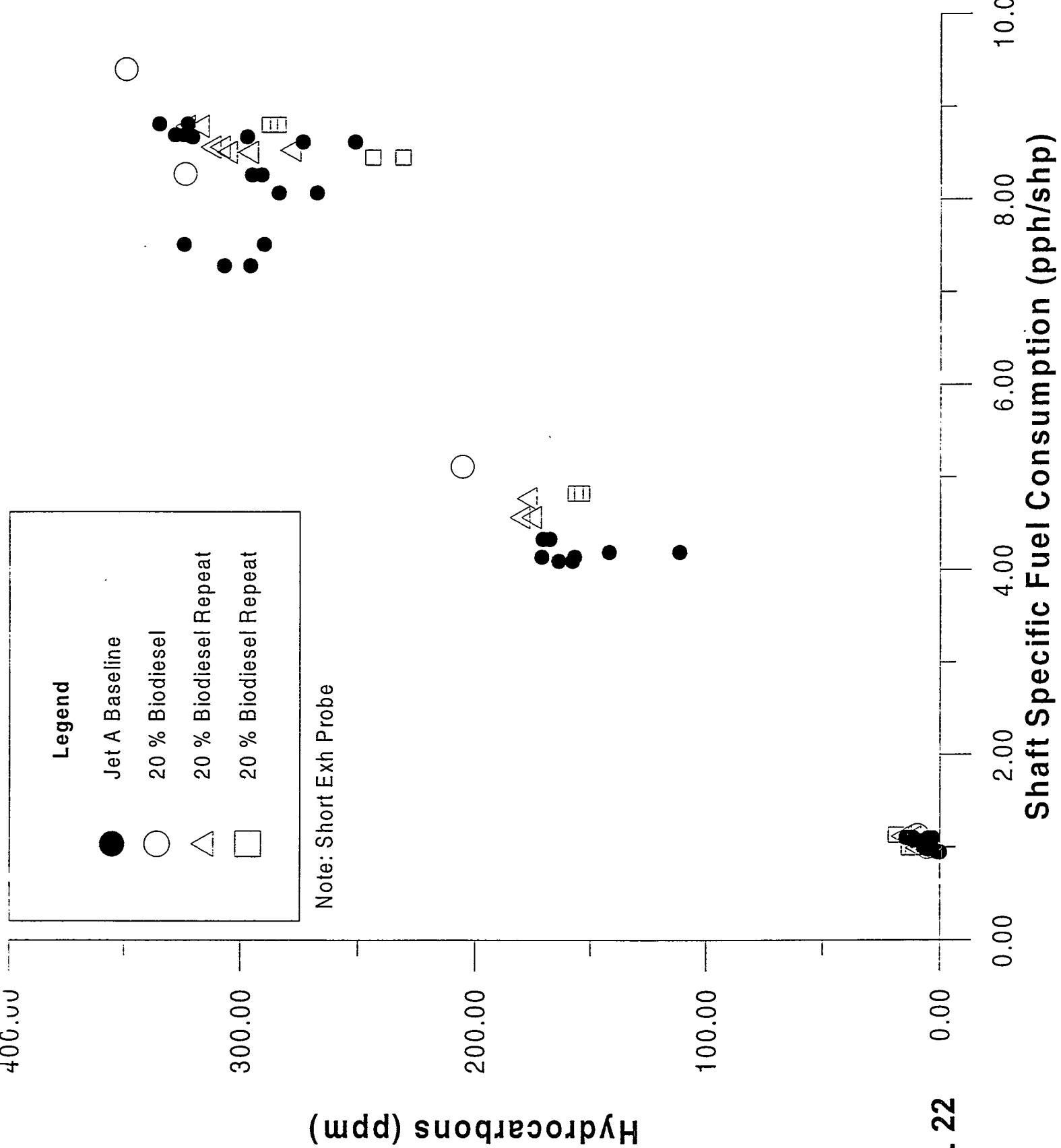


Fig. 22

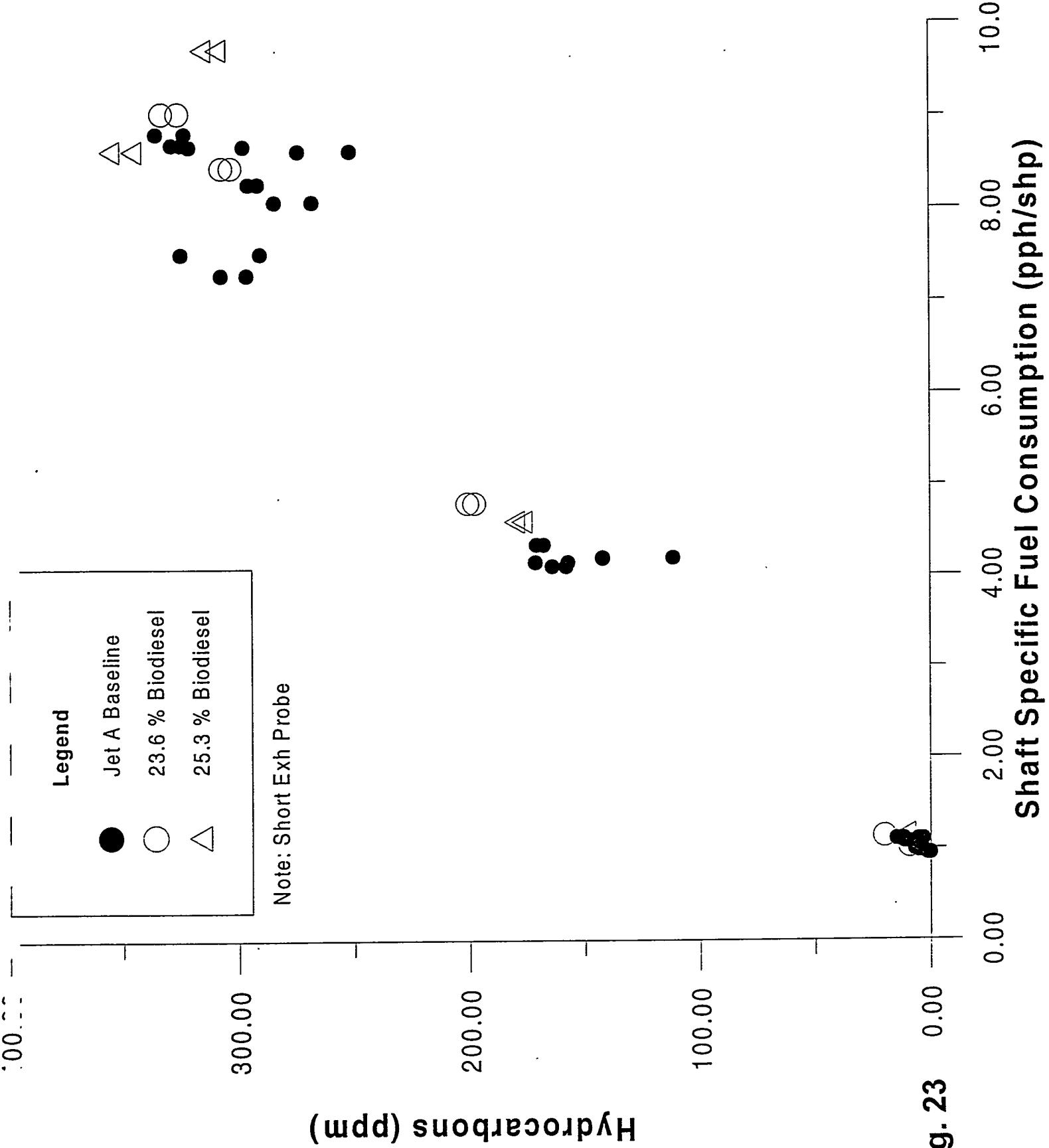
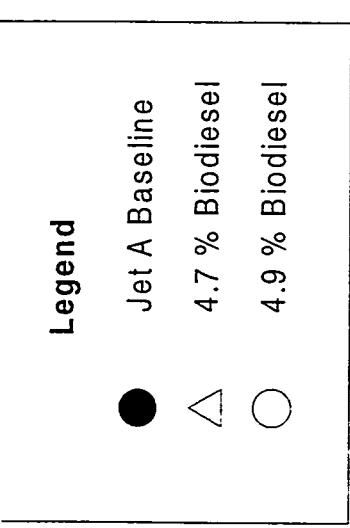


Fig. 23



Note: Short Exh Probe

80.00

(wdd) xON

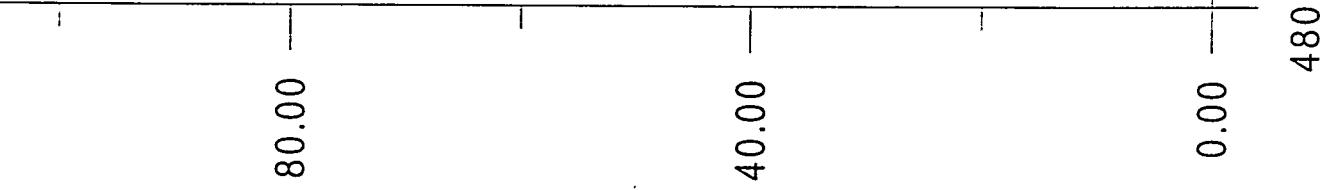
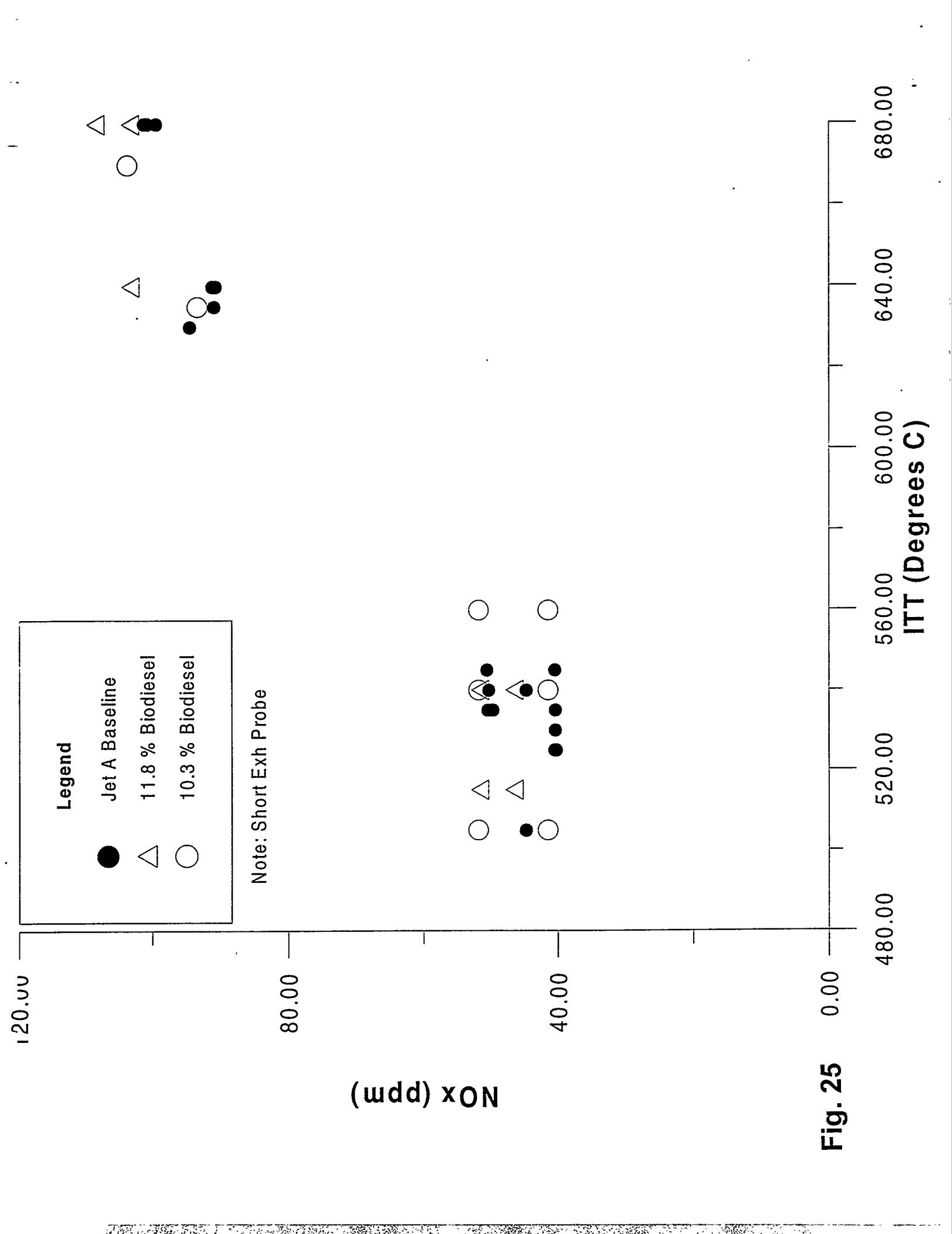
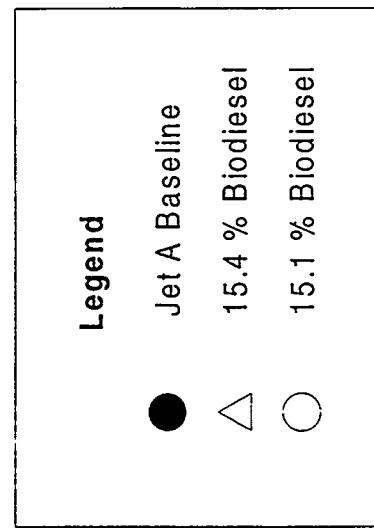


Fig. 24

680.00
640.00
600.00
560.00
520.00
480.00

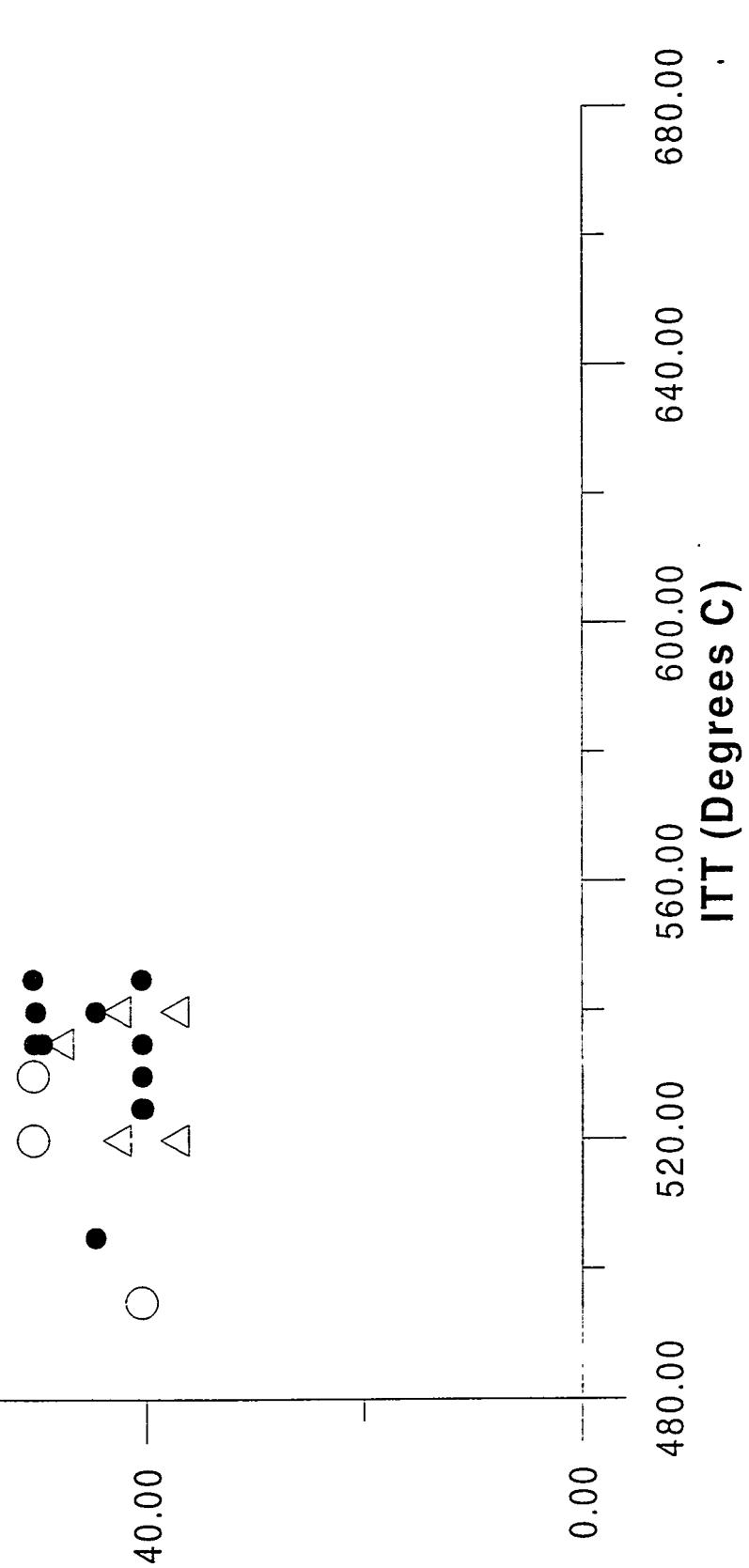
ITT (Degrees C)





(wdd) x ON

Fig. 26



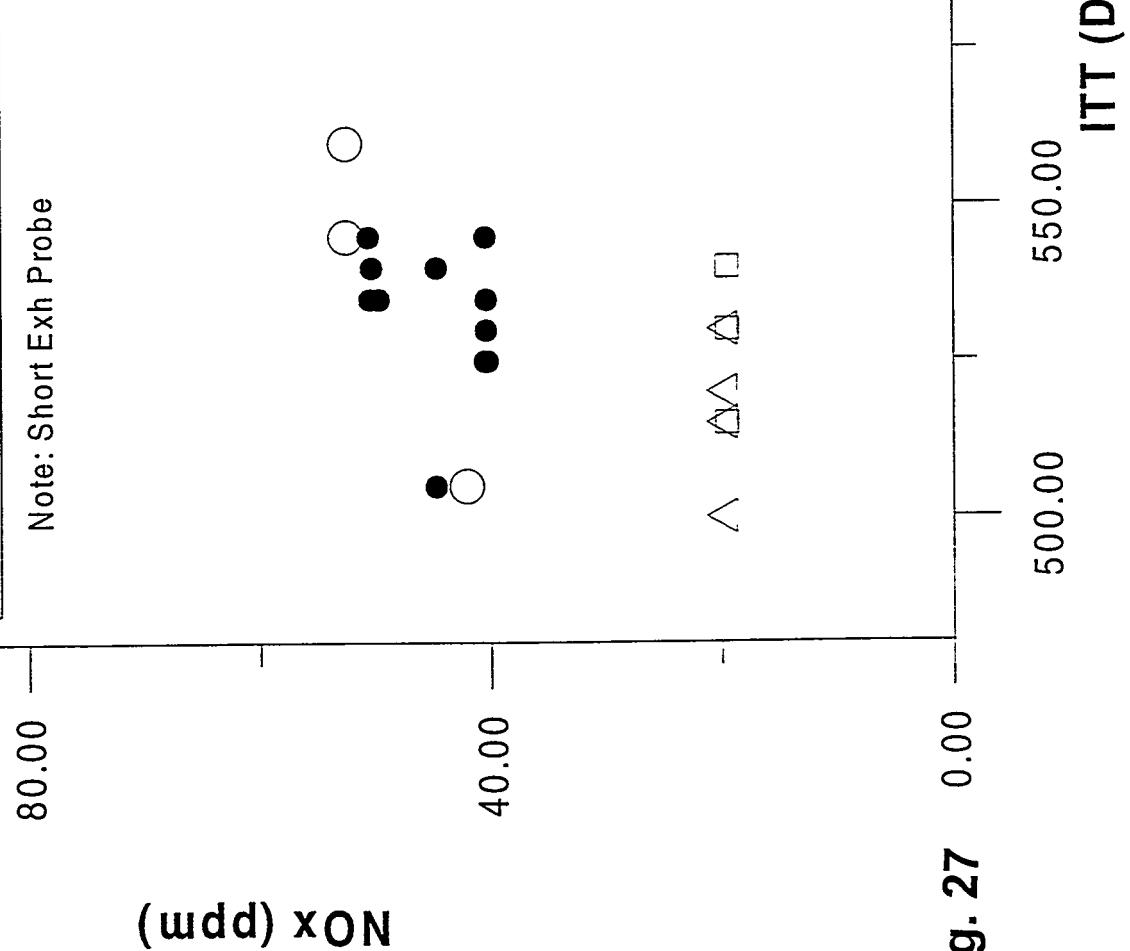
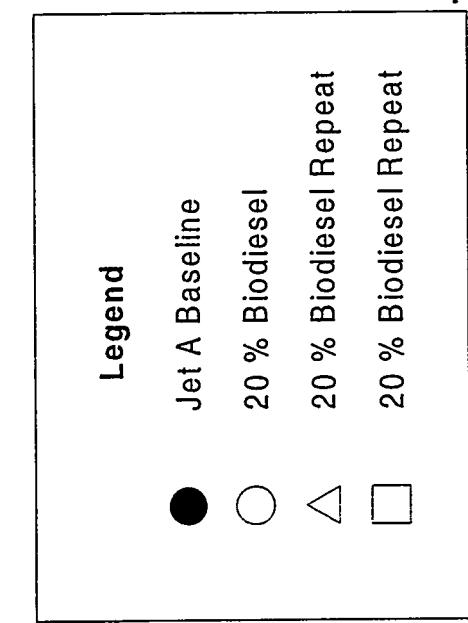
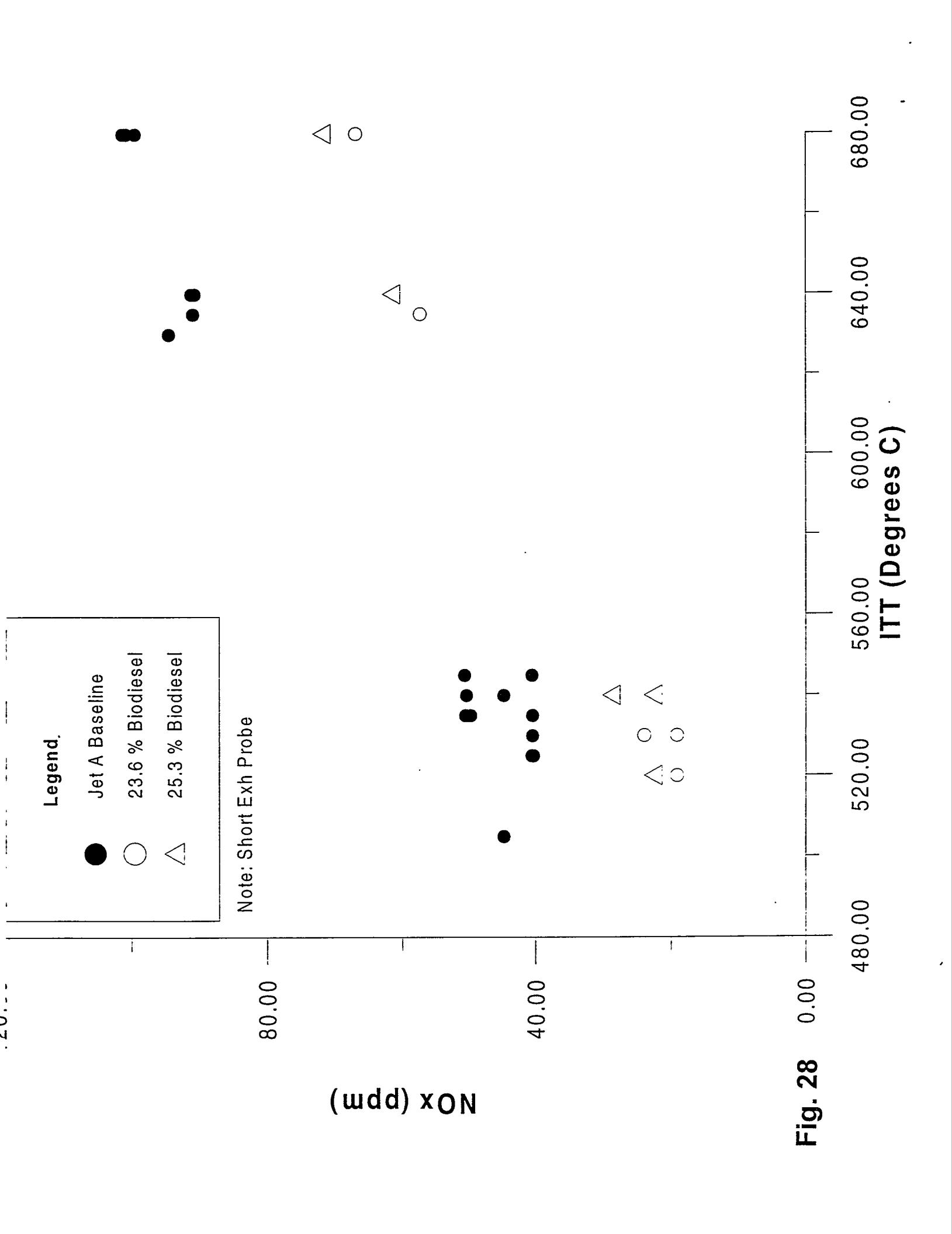


Fig. 27



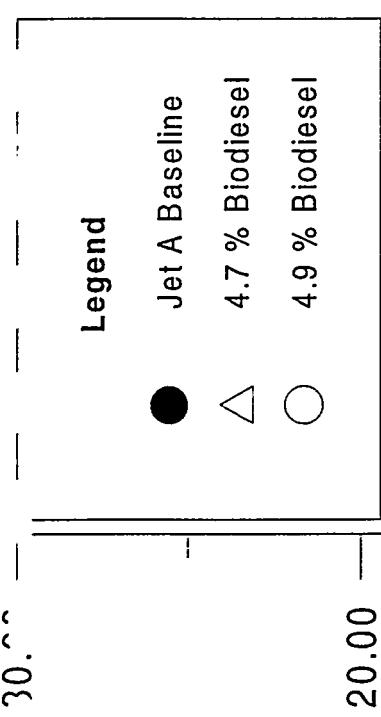


Fig. 29 SO₂ above Ambient (ppm)

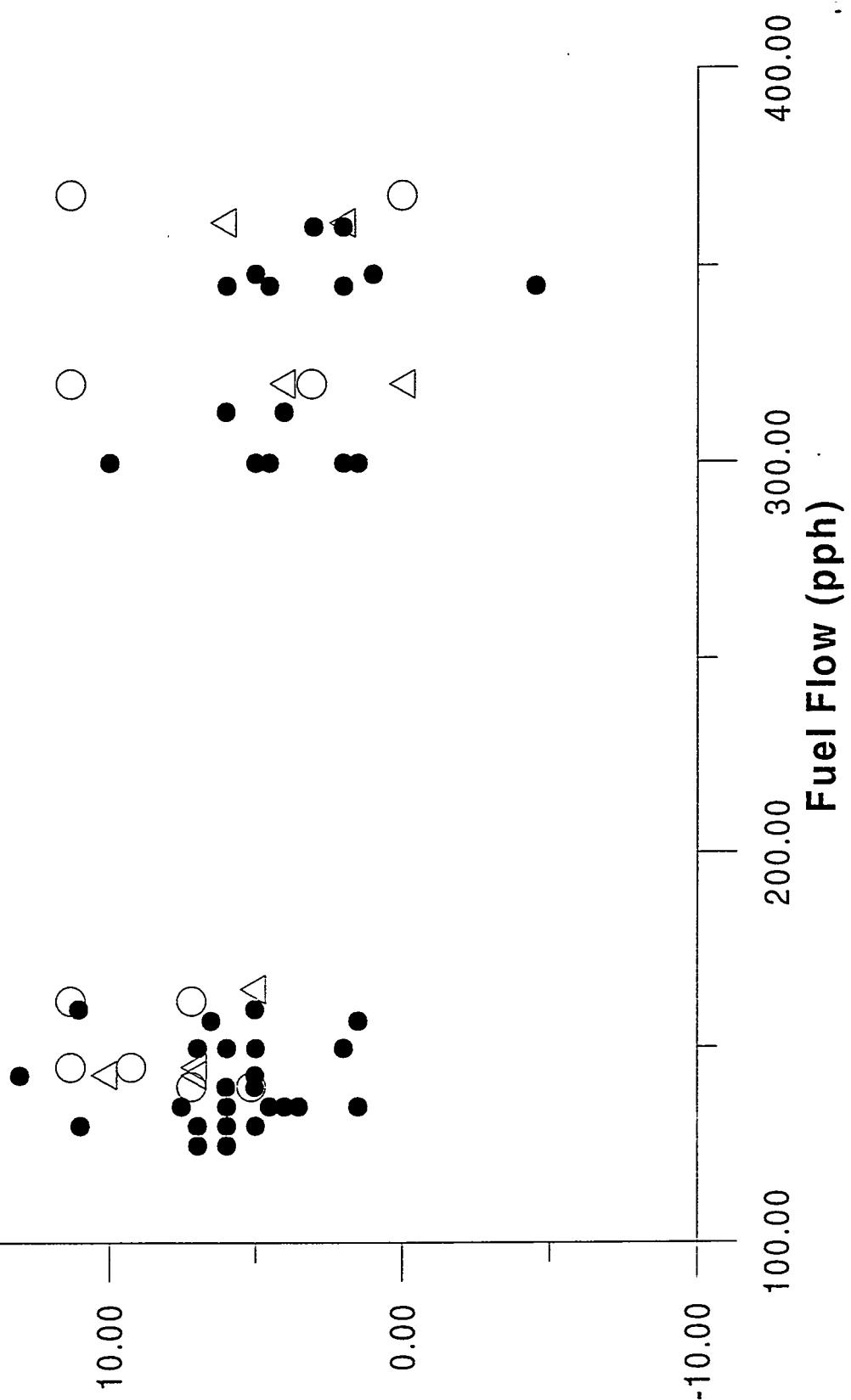


Fig. 29

Fuel Flow (pph)

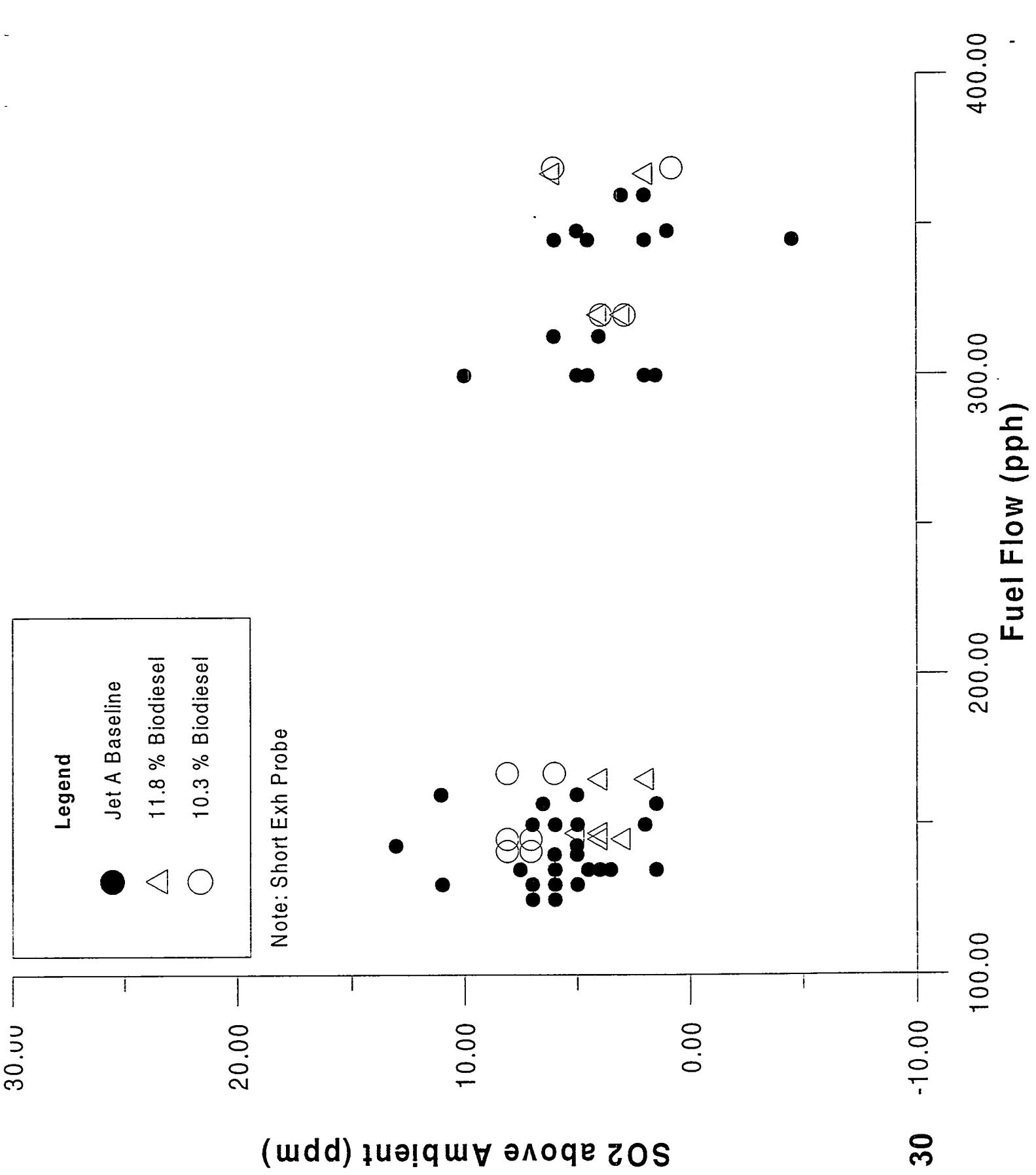
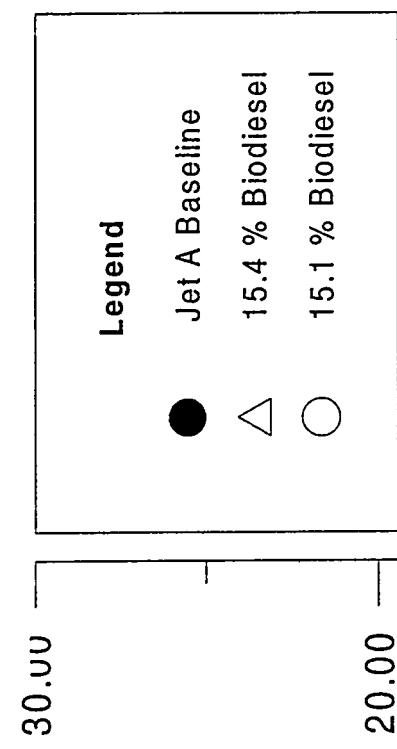


Fig. 30



SO₂ above Ambienet (ppm)

Fig. 31

Fuel Flow (pph)

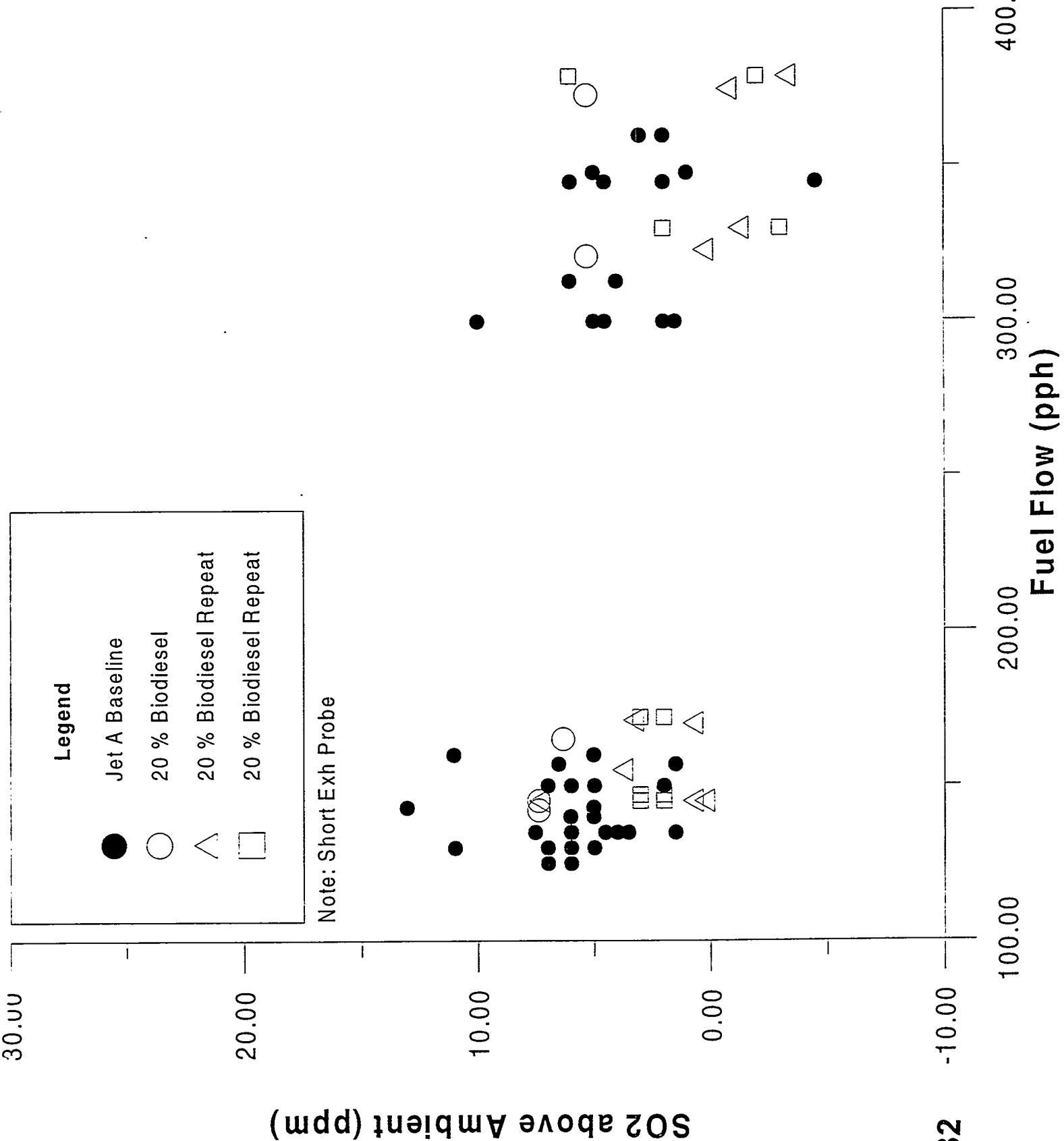


Fig. 32

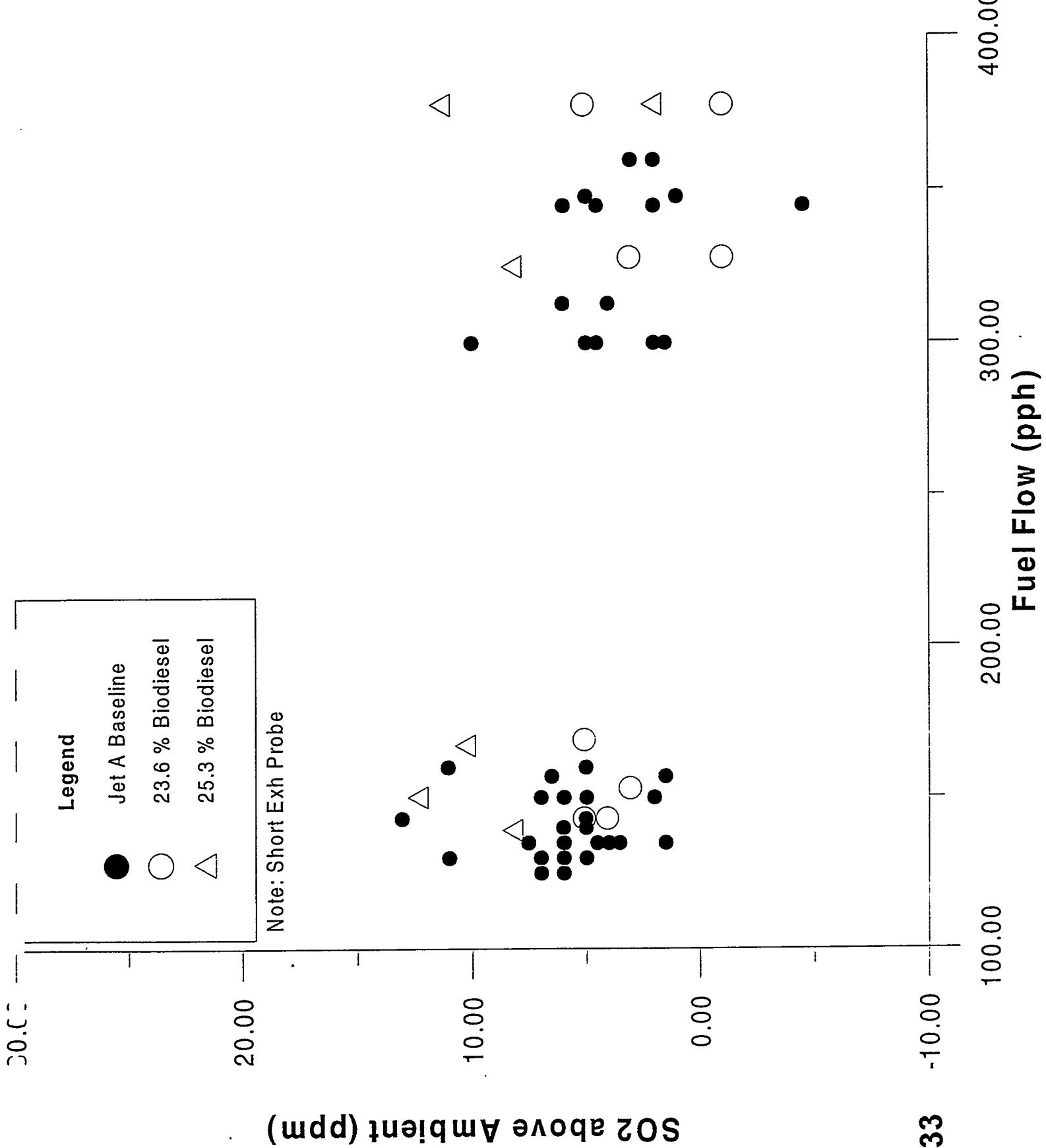


Fig. 33

BAYLOR UNIVERSITY
AVIATION SCIENCES DEPARTMENT
RENEWABLE AVIATION FUELS DEVELOPMENT CENTER
(RAFDC)

REPORT ON THE
SECOND INTERNATIONAL CONFERENCE
ON ALTERNATIVE AVIATION FUELS

SUBMITTED TO
THE FEDERAL AVIATION ADMINISTRATION (FAA)
OCTOBER 1998

TABLE OF CONTENTS

OVERVIEW	1
CONFERENCE TOPICS AND PANELS DESCRIPTION	2
DEMONSTRATION AND AIRSHOW	4
CONCLUSION	5
 —	
ADDENDUM A: AGENDA	
ADDENDUM B: ARTICLES	

Overview

The Second International Conference on Alternative Aviation Fuels was held at Baylor University in Waco, Texas, November 6-8, 1997. The Renewable Aviation Fuels Development Center (RAFDC), part of the Department of Aviation Sciences, organized the conference with major support from Environment Canada, the Federal Aviation Administration and the Department of Energy/Western Regional Biomass Program.

Baylor University and the Texas State Technical College (TSTC) provided facilities for the conference. The conference was held at the Bill Daniel Student Center, located at the heart of the Baylor campus. The student center has a central room with a 300 person capacity equipped with both sound and audio visual systems. It also has conference rooms for break-out sessions and catering and dining services available.

The Baylor University Aviation Sciences Department and RAFDC were assisted in organizing the conference by Information Resources, Inc. (IRI). IRI has an extensive background in the alternative and renewable fuels area, and has about ten years of conference management experience.

The conference's participants came from the United States and many other countries including Canada, France, Germany, Brazil, Sweden and the UK. Over 150 people attended the conference.

Conference Topics and Panels Description

Only limited comments will be made here on the results of the conference in order to allow the readers to draw their own conclusions concerning its effectiveness. A few articles are included and the conference's proceedings will be published by the Federal Aviation Administration.

Topics discussed at the conference included:

Environmental impact of aviation fuels

Aviation engines emissions

Current research on petroleum-based alternative aviation fuels and engines

Current research on non-petroleum-based alternative fuels and engines

Developments in the production and marketing of alternative fuels in North America
Future aviation fuels and engines
The Clean Airports Program
International Alternative Aviation Fuel Experiences

Environmental issues related to aviation were the topics of the first day of the conference. The panel discussions included federal and state regulating agencies and industry representatives.

An interesting demonstration of a micro-light, rubber band powered, model aircraft was performed by Dr. Paul MacCready, president of Aerovironment Inc. in the conference hall.

The opening reception took place at a private room at a local restaurant where a welcoming address was given by the mayor of Waco.

The following day the conference started with a welcoming address by the president of Baylor University.

The petroleum based alternative fuel research panel opened the activities on the second day of the conference.

The parties involved in the search for a petroleum-based alternative to Avgas presented their latest findings at the Conference. The new approach employed by the petroleum alternative proponents is a matrix of possible additives and components being analyzed in an organized fashion. This method will take at least a few more years to produce results. A petroleum-based, lead-free aviation gasoline does not seem to be a near-future alternative.

There were a large number of participants in this panel who represented a good cross-section of all of the parties involved in this research. Many comments were made during these presentations which raised questions, opposing viewpoints and further discussions. Since the audience was intensely interested and there was vigorous debate between opposing points of view, the discussions were allowed to run over the allotted time.

The second panel presented the research and development activities of the non-petroleum alternative fuel programs. Research, development, implementation of ethanol and ETBE as aviation fuels were discussed among the presenters who had extensive experiences with these

fuels. This panel also included a large number of presenters and it also inspired a lively discussion.

The next panel had to be postponed until after the luncheon.

The luncheon speaker was Mr. Bruce Fenton, representative of the Federal Aviation Administration (FAA). The subject of his speech was a description of the activities and progress in fuel research at the FAA's Technical Center in Atlantic City, New Jersey.

The first panel of the afternoon concerned production and commercialization of alternative fuels. Representatives of industry and government agencies from the United States and Canada gave an overview of the current research and development of alternative fuels in the two countries.

The next panel discussed the future of aviation, new engines, and new fuels. This session, which included a large number of panelists, was very interesting and educational for the amount and quality of new information disclosed by the presenters.

The Clean Airports Program panel followed. The Clean Airports Program, after being initiated under the aegis of the Department of Energy (US DOE) was currently undergoing reorganization. The accomplishments of the initial program were reported and the vision for the future of the program was discussed.

(As a result of the conference and the numerous discussions with speakers and attendees, the Clean Airports Program is now the "International Clean Airports Program (ICAP)" involving international organizations and agencies. The potential for this program is tremendous, due to the growing environmental concerns involving aircraft and airport pollution and the increasing environmental awareness symbolized by the Kyoto meeting and its aftermath.)

Because the discussions following some of the panels were very spirited and informative and were allowed to run over time, it was necessary to move the International panel to the reception site and stage it before the dinner. The presentations given by the International panel were extremely interesting and this panel was also allowed more time since it inspired lively discussion.

Demonstration and Airshow

The RAFDC aviation facilities (hangar, aircraft and test stands) are housed at the Texas State Technical College airport, which is located within a few miles of Baylor University. On Saturday morning, November 8, an airshow designed to demonstrate the potential of alternative fuels in both commercial and recreational aviation applications was performed. About ten ethanol powered aircraft were displayed at the airshow. Two other planes were not able to arrive on time due to bad weather.

An aerobatic airshow was flown with the Pitts S2B powered by ETBE. The Vanguard Squadron precision flying team from South Dakota performed a formation flight in their ethanol powered RV-3As. The RAFDC's King Air, an air pollution monitoring aircraft, flew some low passes in formation with the ethanol powered Cessna 152, the first aircraft to be certified on ethanol.

Tours were given of the RAFDC test stand equipped with a state of the art data collection system and emission testing equipment, and to the RAFDC's air pollution monitoring aircraft.

A commentary was presented by the Brazilian representative, Plinio Nastari, and by Bill Holmberg, president of Sustainable New Wealth Industries Inc., during the demonstrations. Two television stations recorded the flying and interviewed some of the participants. News stories about the conference were then broadcast locally and in the Dallas/Fort Worth area.

A luncheon was provided at the RAFDC's hangar. This was the concluding official function of the conference. However, many attendees and speakers opted to stay for an informal meeting at Baylor University in the afternoon and for a dinner at a local restaurant which provided an ideal setting for a very informative post-conference exchange of information.

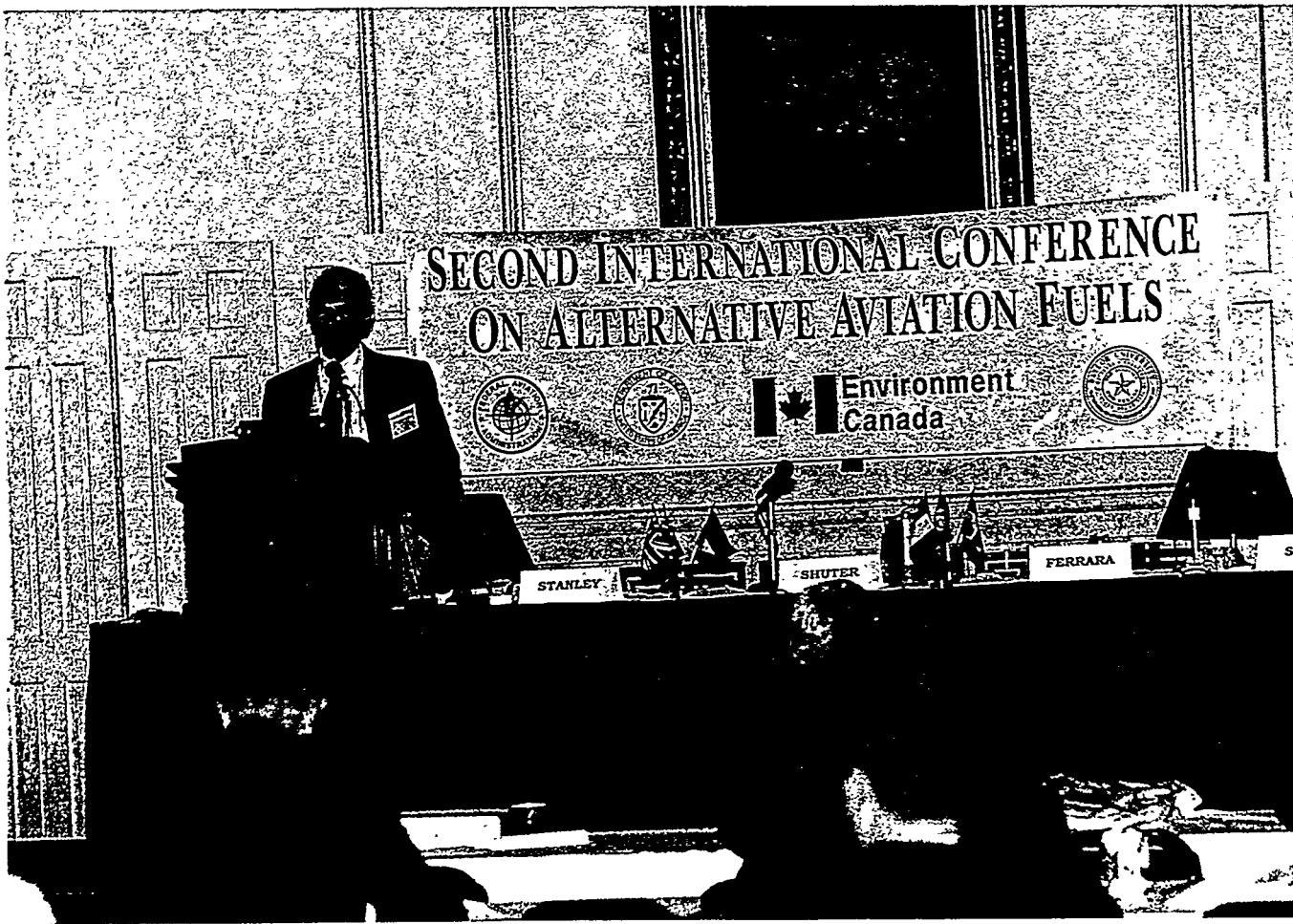
Conclusion

According to the comments received from the attendees, the conference was extremely informative and interesting. The only criticism brought up by a couple of attendees was that the discussions were allowed to exceed the allotted time. This was true, but on the other hand, other attendees commented about the value of the post-panel discussions and the excellent information and education generated.

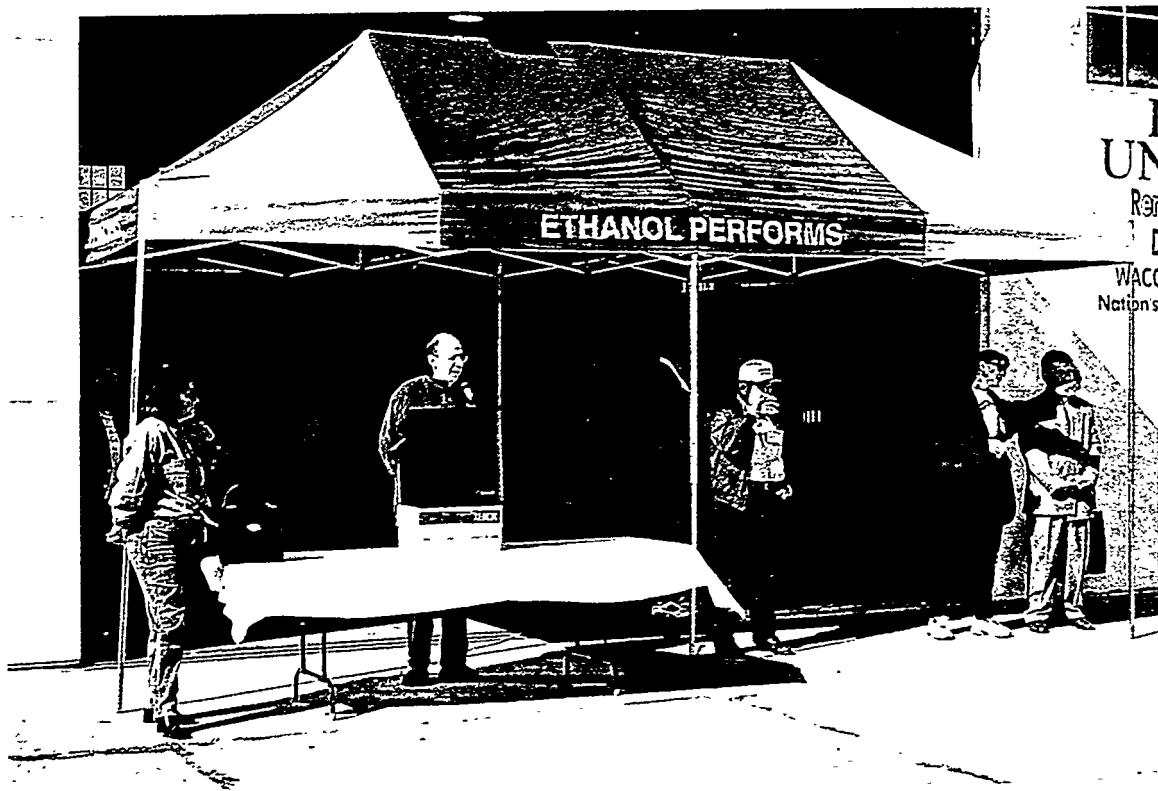
A comment frequently expressed was that there was simply too much information to be covered during the two days of the conference. This is the only conference covering the topic of alternative aviation fuels and consequently the meeting dealt with a large amount of information. In light of this experience, the organizers suggested extending the duration of the conference to two full days of sessions plus a half day of demonstrations and workshops.

Interest in this subject, alternative fuels in aviation, is on the rise. The mounting concerns related to the environmental impact of aviation coupled with the rapidly expanding aviation industry make the topic of the conference one of widespread interest.

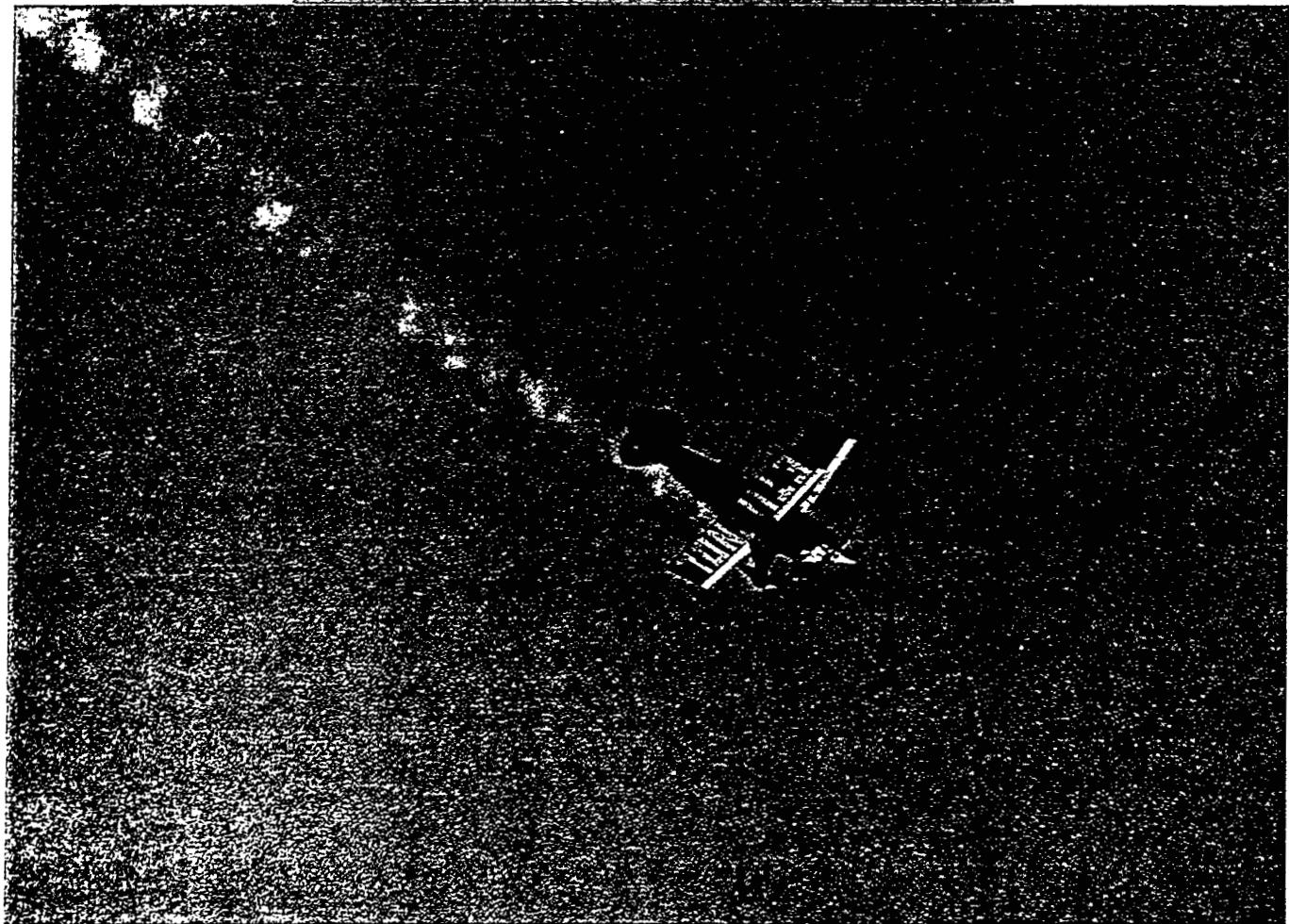
There is a growing awareness that aviation must meet its environmental responsibilities. As in the case of the automobile, clean engines technology has reach the point of diminishing returns. We have the opportunity to meet the environmental responsibilities of aviation by developing clean burning fuels for aviation which can be used in existing engines as an interim solution before the next generation of clean engine technology is developed.

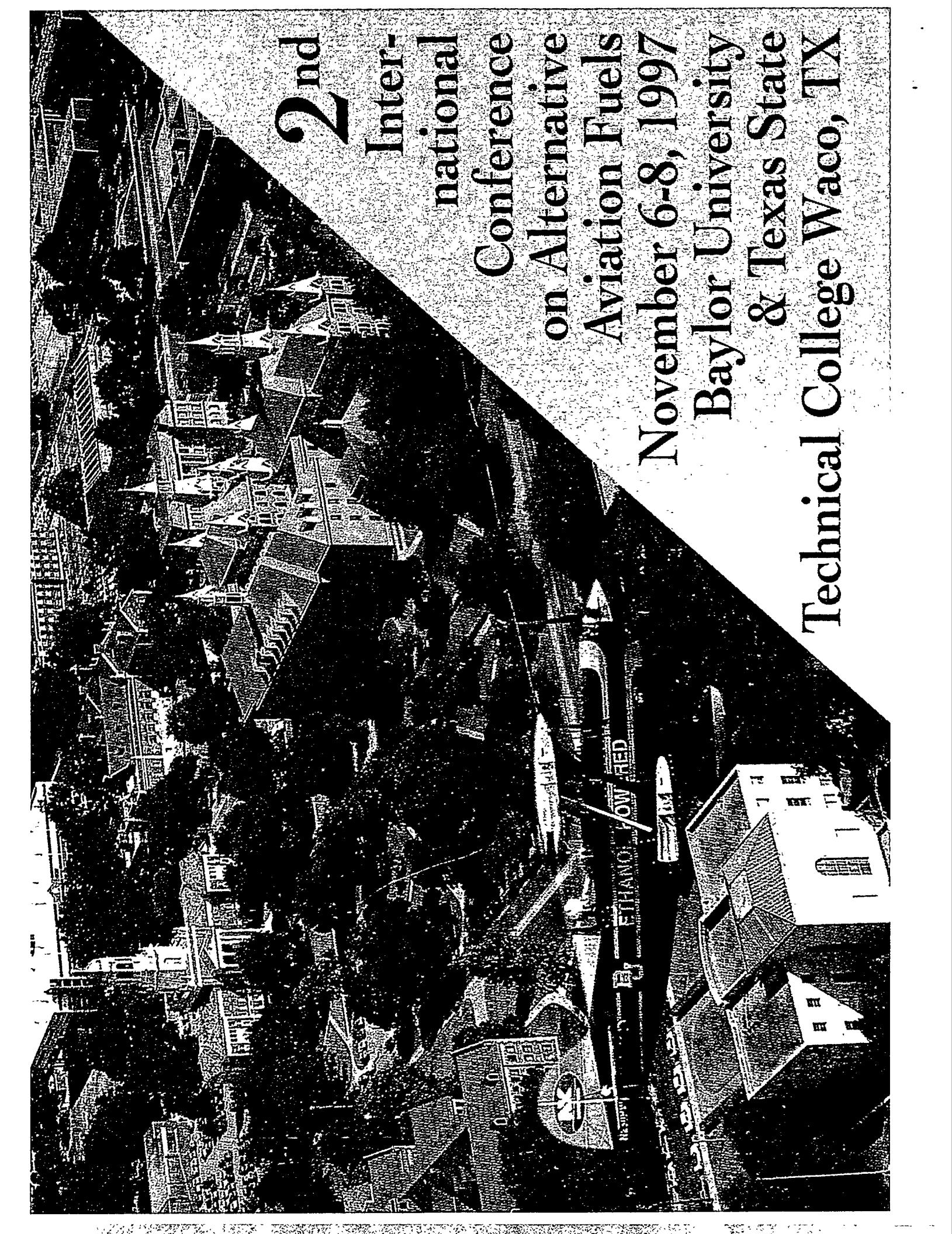


Waco, Texas: Airshow
Second International Conference on Alternative Aviation Fuels
November, 1997

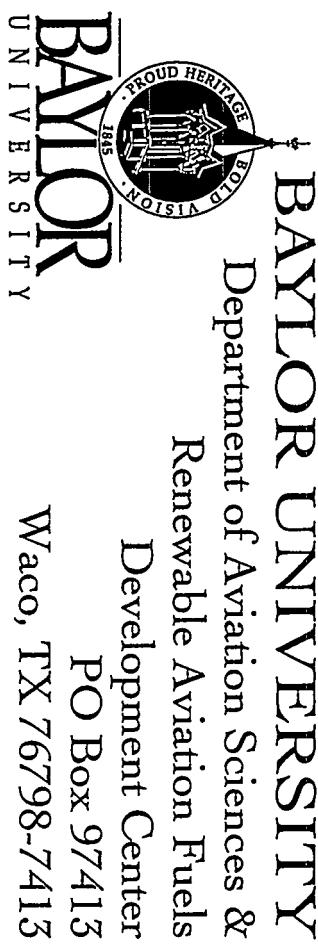


Waco, Texas: Airshow
Second International Conference on Alternative Aviation Fuels
November 1997





2nd
Inter-
national
Conference
on Alternative
Aviation Fuels
November 6-8, 1997
Baylor University
& Texas State
Technical College Waco, TX



Make your plans now to attend the
***Second International Conference
on Alternative Aviation Fuels!***

WHEN: November 6-8, 1997

WHERE: Baylor University & Texas State
Technical College, Waco, Texas

Additional conference materials will be sent to you.

*For advance information on registration, poster sessions,
paper, and exhibits, please call:
*(817) 755-3563, or fax *(817) 755-3560, or
e-mail at (AVS_Office@baylor.edu).*

**Area code will change to (254) after May.*

Baylor University's
Aviation Sciences Department
together with the
Environment Canada
Federal Aviation Administration
Natural Resources Canada
U.S. Department of Energy
Western Regional Biomass Energy Program
U.S. Environmental Protection Agency

invite you to attend

The Second International Conference on Alternative Aviation Fuels

November 6-8, 1997

Bill Daniel Student Center

Baylor University

Waco, Texas

Baylor University appreciates the support of the following organizations

- AG Environmental Products
- Air Transport Association
- American Coalition for Ethanol
- American Corn Growers Association
- BioClean Fuels Inc.
- Biomass Energy Alliance
- Chief Ethanol Fuels
- Clean Airports Program
- Clean Fuels Development Coalition
- Clean Fuels Foundation
- Environment Canada
- Federal Aviation Administration
- Hart/IRI Fuels Information Services
- Heartland Capital Corporation
- National Aeronautics & Space Administration
- National Business Aircraft Association
- Natural Resources Canada
- Nebraska Energy Office
- Nebraska Ethanol Board
- NOPEC Corporation
- Texas Corn Producers Board
- Texas State Technical College
- U.S. Department of Energy – Western Regional Biomass Energy Program
- U.S. Environmental Protection Agency
- Waco Chamber of Commerce
- Waco Transit System
- West Virginia University

Baylor University and the Texas State Technical College

These two Texas institutions of higher education offer a combined four year professional pilot education program that leads to an Associate of Applied Science degree from TSTC and a Bachelor of Science in Aviation Sciences from Baylor. The program prepares its graduates to be top performers in a sophisticated, advanced technology career.

Baylor's Department of Aviation Sciences, through its Renewable Aviation Fuels Development Center (RAFDC), has obtained the world's first governmental approval (Supplemental Type Certificate - STC) to use pure ethanol as an aircraft engine fuel in commercial operations.

RAFDC is under contract to the Texas Alternative Fuels Council to develop and test alternative, cleaner-burning fuels for turbine aircraft engines. This program is partially conducted in a RAFDC King Air while flying air quality monitoring missions for the Texas Natural Resources Conservation Commission.

Welcome to the Second International Conference on Alternative Aviation Fuels here at Baylor University.

As a result of the greater public and scientific awareness of air quality issues, airports and aircraft operations are attracting increased attention from researchers and air regulatory officials. This conference brings you the foremost authorities in aviation fuel development and implementation to share experiences and information on cleaner burning alternative fuels.

We have gathered industry, academic and government leaders from Brazil, Canada, Germany, Sweden, Italy, France, England, Australia and the United States who have extensive backgrounds in aviation. They will provide you with their perspectives on issues of concern to the aviation industry and the need and potential for alternative aviation fuels in their countries.

The Second International Conference on Alternative Aviation Fuels will explore various means to reduce the environmental impact of aviation and decrease U.S. dependence on foreign oil while imposing minimal economic disruption to current operations.

We also would like to thank all the sponsors whose contributions made this conference possible. We hope you enjoy the conference and take advantage of the numerous experts assembled for this event.

Sincerely,



Max Shauck

For more information about
Baylor University's Aviation Sciences or the RAFDC,
call Patricia Pack at (254) 710-3563.

A G E N D A

The Second International Conference on Alternative Aviation Fuels

Barfield Drawing Room • Bill Daniel Student Center • Baylor University

Thursday, November 6

11:00 am - 6:00 pm	Registration
1:00 pm - 1:10 pm	Barfield Drawing Room Foyer Opening Remarks • Dr. Max Shauck, Renewable Aviation Fuels Development Center, Baylor University
1:10 pm - 2:40 pm	New Air Quality Standards and Global and Local Environmental Impacts of Aviation Fuels Facilitator: Plinio Nastari, World Energy Council, Brazil • Jeremy L. Cornish, International Centre for Aviation and the Environment, Canada • Brian Foster, Texas Natural Resource Conservation Commission • Randall Friedl, Jet Propulsion Laboratory, NASA • Jim Davis, U.S EPA, Dallas
2:40 pm - 3:00 pm	Refreshment Break Sponsored by the South Dakota Corn Utilization Council
3:00 pm - 4:30 pm	Aviation Engine Emissions Facilitator: Ray Valente, Tennessee Valley Authority • Dave Stanley, Purdue University • Bob Shuter, ICAO Working Group on Aircraft Emissions • Gus Ferrara, Ferrara & Associates
4:30 pm - 5:00 pm	Paul MacCready's Demonstration of Remarkable Small Aircraft (Between 1 and 50 ounces) • Paul MacCready, AeroVironment
6:30 pm - 8:00 pm	Opening Reception at Ninfa's Restaurant

WELCOME FROM THE MAYOR OF WACO

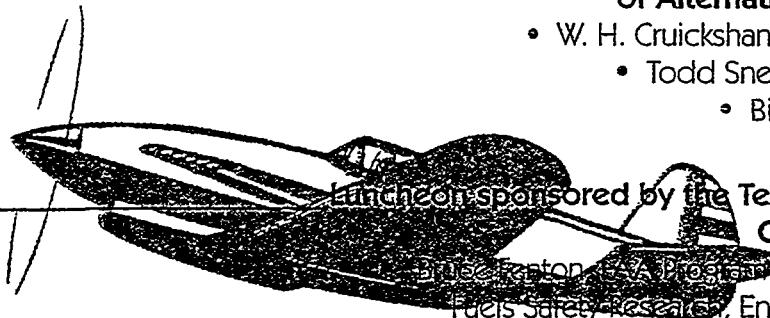
Mike Morrison

ADDRESS

Bill Wells, Delta-T Corporation

Friday, November 7

7:00 am - 3:30 pm	Registration Barfield Drawing Room Foyer
7:00 am - 8:00 am	Continental Breakfast and Exhibit Review
8:00 am - 8:10 am	Welcoming Remarks • Robert Sloan, President, Baylor University

8:10 am - 8:30 am	Video Address
8:30 am - 10:00 am	<ul style="list-style-type: none"> • Thomas A. Daschle, U.S. Senate Minority Leader <p>Current Research on Petroleum-based Alternative Aviation Fuels and Engines</p>
	<p><u>Facilitator:</u> Ron Wilkinson, Teledyne Continental Motors</p> <ul style="list-style-type: none"> • Gus Ferrara, Aircraft Owners and Pilots Association (AOPA) • Caesar Gonzalez, Cessna Aircraft Company • Ken Knopp, Federal Aviation Administration • Joe Valentine, Fuels & Lubricants Technology Department, Texaco • Lars Hjelmberg, Hjelmo Oil, Sweden
10:00 am - 10:15 am	<p>Refreshment Break and Exhibit Review</p> <p>Sponsored by the South Dakota Corn Utilization Council</p>
10:15 am - 12:00 pm	<p>Facilitator: Bill Holmberg</p> <p>Sustainable New-Wealth Industries</p>
10:15 am - 11:15 am	<p>Panel 1: Current Research on Non-Petroleum Based Alternative Aviation Fuels and Engines</p> <ul style="list-style-type: none"> • Chris Atkinson, West Virginia University • Ted Aulich, Energy & Environmental Research Center, University of North Dakota • Zoher Meratal, CDS Research, Vancouver • Ron Newberg, Canadian Aero Engines • Marv Randall, Vanguard Squadron, South Dakota • Max Shauck, Renewable Aviation Fuels Development Center
11:15 am - 12:00 pm	<p>Panel 2: Developments in the Production & Marketing of Alternative Fuels in North America</p> <ul style="list-style-type: none"> • W. H. Cruickshank, Natural Resources Canada • Todd Sneller, Nebraska Ethanol Board • Bill Wells, Delta-T Corporation • Russell Teall, NOPEC
12:15 pm - 1:30 pm	<p>Luncheon sponsored by the Texas Corn Producers Board</p> <p>Cashion Building, 5th Floor</p> <p>Brent Bailey, Program Manager for Propulsion and Fuels Safety Research, Engineering, and Development</p> 
1:30 pm - 3:00 pm	<p>Future Aviation Fuels and Engines</p> <p>Facilitator: Brent Bailey, National Renewable Energy Laboratory</p> <p>Panel I: New Engine Technology</p> <ul style="list-style-type: none"> • Chris Atkinson, West Virginia University • Leo Burkhardt, NASA GAT • Nicolas Chabbert, Socata Engines, France • Ron Wilkinson, Teledyne Continental Motors <p>Panel II: Future Fuels and Power Systems</p> <ul style="list-style-type: none"> • John Langford, Aurora Flight Sciences Corporation • Paul MacCready, AeroVironment • Pino Milito, Alisport - Silent & Light Aviation • Rudolf Voit-Nitschmann, Institute Fur Flugzeugbau, Universitat Stuttgart • Denver Lopp, Purdue University

3:00 pm - 3:30 pm Refreshment Break and Exhibit Review
Sponsored by the South Dakota Corn Utilization Council

3:30 pm - 4:00 pm The Clean Airports Program: Goals and Accomplishments
Facilitator: John Russell, U.S. Department of Energy (ret.)
• Gary Marchbanks, Oklahoma Gas & Electric Company
• Max Shauck, Renewable Aviation Fuels Development Center
• Jeremy L. Cornish, International Centre for Aviation and the Environment, Canada
• Airline Representative - inv.

4:00 pm - 5:15 pm International Alternative Aviation Fuel Experiences
Facilitator: Paul MacCready, AeroVironment
• Jacques Callies, Aviation & Pilot, France
• Lars Hjelmberg, Hjelmo Oil, Sweden
• Mauro Furlan, Italian Research Project on
Alternative Aviation Fuels, Italy
• Gordon Bowman Jones, Australia
• Plinio Nastari, DATAGRO, Ltd., Brazil
• Rudolf Voit-Nitschmann, Germany
• Russ Robinson, Environment Canada, Canada
• Tony Marmont, Beacon Energy, United Kingdom

5:15 pm - 5:30 pm Questions and Answers
• Max Shauck, Renewable Aviation Fuels Development Center

CLOSING REMARKS
Bob Harris, Nebraska Energy Office

6:30 pm - 8:30 pm Evening Reception and Dinner
at Buzzard Billy's

Saturday, November 8

ALTERNATIVE FUELS AVIATION AIR SHOW
Texas State Technical College

Announcer: _____ **Gordon Bowman Jones**
Internationally Acclaimed Air Show Announcer

9:30 am - 10:30 am Guided Tour of Baylor University's RAFDC Facilities,
Emission Testing Equipment, and
Air Pollution Monitoring Aircraft.

10:30 am - 12:00 pm Air Show Demonstrations

- "Silent" ETBE Powered Glider - Walter Mauri, Alisport - Silent & Light Aviation
- German Solar Powered Glider - Professor Rudolf Voit-Nitschmann
- Pitts Special, Ethanol/ETBE - Max Shauck, RAFDC
- Cessna 150 Tundra-fitted from Canada, Ethanol - Ron Newburg, Canadian Aero Engines
- Cessna 152 & Piper Pawnee - RAFDC
- Vanguard Squadron - South Dakota
- Cessna 180 on E85 - South Dakota
- Jet Truck Race, Ethanol vs. Biodiesel - inv.
- Motorized Cutaway of a P.T. 6 Turbo-prop Engine - Avotek - Virginia

12:00 pm - Close

LUNCH

LUNCHEON ADDRESS

Rogers Smith, Chief Test Pilot & Flight Crew Branch
Flight Research Center, NASA Dryden

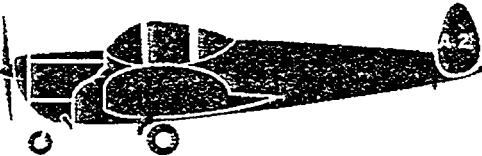
Alternative fueled planes will be flying through smoke
that will be pouring from the grill as local Texans
serve up their traditional Texas-style barbecue.

RECEPTIONS

Ninfa's Restaurant on Thursday

November 6, 1997 from 6:00 pm to 7:30 pm

*Enjoy the delights of the hottest
Tex-Mex restaurant in Waco. Dress is casual.*



Buzzard Billy's on Friday

November 7, 1997 from 6:30 pm to 8:30 pm

*Join conferees for a night of Cajun cuisine at
Buzzard Billy's newly-expanded, private dining room,
located in the heart of Waco's "night life" district.*

Dress is casual.

CONFERENCE TROLLEY SCHEDULE

For convenience of the conference attendees there
will be a trolley available for transportation from the
Hilton and the Courtyard Marriott. The trolley will be
running for the duration of the times indicated
below:

Thursday, November 6 12:00 - 6:00 pm

Shuttle pickup: Hilton & Courtyard Marriott

Shuttle drop-off: Bill Daniel Student Center

Friday, November 7 7:00 - 9:00 am

Shuttle pickup: Hilton & Courtyard Marriott

Shuttle drop-off: Bill Daniel Student Center

4:30 - 6:30 pm

Shuttle pickup: Bill Daniel Student Center

Shuttle drop-off: Hilton & Courtyard Marriott

Saturday, November 8 9:00 - 11:00 am

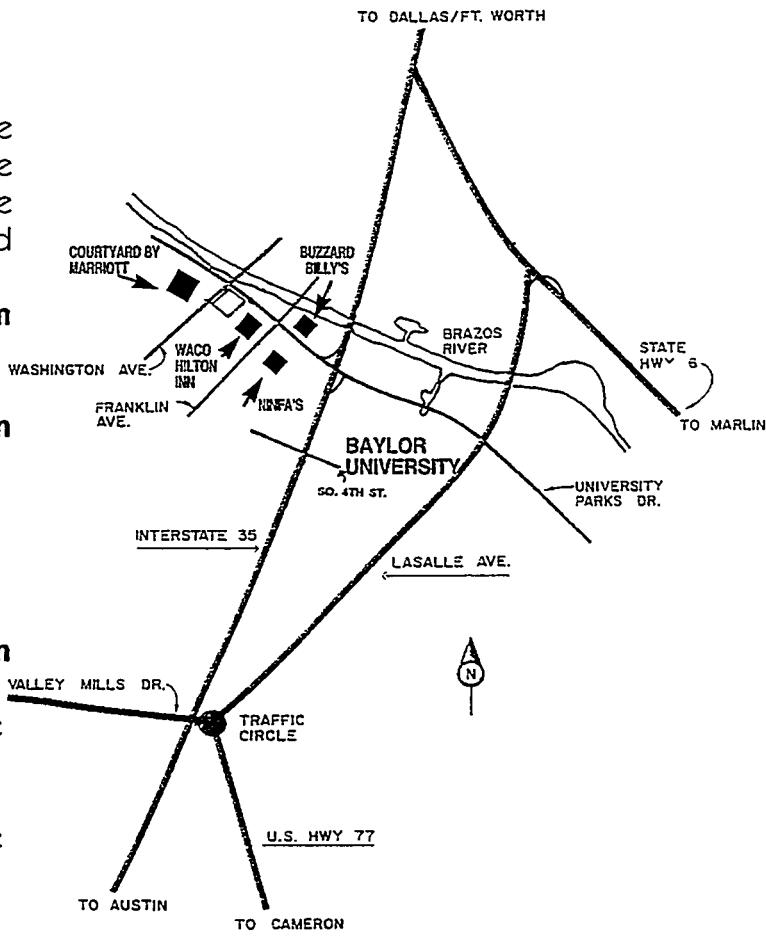
Shuttle pickup: Hilton & Courtyard Marriott

Shuttle drop-off: Texas State Technical College
Baylor Hanger

1:30 pm

Shuttle pickup: Texas State Technical College
Baylor Hanger

Shuttle drop-off: Hilton & Courtyard Marriott



Aviation & Pilote

EN VOL:
LE CYCLONE
UN CESSNA
MADE IN QUEBEC

EXCLUSIF!
FAIRINES
DÉCOLLE

DES IDÉES
POUR
NOËL

JETA-1

KEROSENE
LE CARBURANT DU FUTUR?

France : 35 FF. Belgique : 256 FB. Canada : 3,95 \$ CAN. Luxembourg : 245 FL. Suisse : 11 FS



N° 287 — DECEMBRE 1997



KEROSENE : LE FUTUR ?

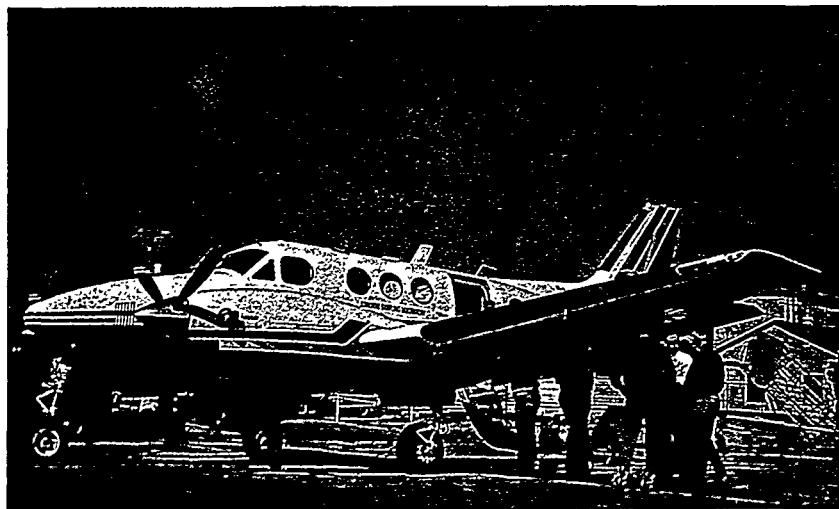
À l'invitation du Dr Max Shauck, nous venons de participer au Texas à la 2^e conférence internationale sur les carburants aéronautiques de substitution, en présentant les expériences françaises pour se passer du carburant plombé. Il semble bien qu'en France, le bio fasse un flop mais que, grâce à Renault et à la Socata, les pilotes croient de plus en plus au diesel...

CHAQUE fois que nous allons au Texas, nous rendons visite à Grazzia et Max Shauck qui travaillent à l'université de Baylor, Waco. Bien sûr, tous les deux nous parlent de biocarburants, de ce qui bouge aux États-Unis, de leurs nouveaux sponsors verts et de leurs nouveaux avions... Mais quand ils nous demandent ce qui se passe en Europe et en France en la matière, ce que nous faisons quant à nous pour sauver la planète de la pollution atmosphérique, nous sommes contraints de répondre: rien... ou presque rien. Mais j'ajouterais pour notre défense que nous avons le sentiment que le monde de l'écologie aéronautique aux USA doit énormément aux seuls Shauck.

Pourtant, durant ces dix dernières années, *Aviation & Pilote* a fait plusieurs tentatives pour intéresser les pilotes à la pollution atmosphérique et aux carburants susceptibles de remplacer l'Avgas. En



1988, nous avons été les premiers journalistes à voler sur un Cessna L19 motorisé avec un GMA 140TK, dérivé du moteur diesel J8S qui équipait à l'époque les Renault 25. Ce moteur avait été préparé pour l'aérien par un petit groupe d'ingénieurs et de techniciens de la SCOMA, un laboratoire indépendant qui travaillait en solo, sans l'assistance de la régie Renault. Ce prototype était supposé donner naissance à une gamme complète de moteurs de 150 à 700 ch, carburant au JET



A1. L'affaire a capoté pour des raisons financières et probablement techniques : nous avons entendu parler de vibrations engendrant des criques sur le bâti moteur du L19 puis, lorsque celui-ci eut été renforcé, de criques sur la cellule au niveau des attaches du bâti.

Deux Salons du Bourget sans vraiment convaincre

En 1993, nous avons cosponsorisé Max Shauck et son Pitts volant à l'éthanol pendant la durée du Salon du Bourget. Cela fut évidemment l'occasion de publier plusieurs articles sur le thème de la pollution et des biocarburants. Nous nous y sommes essayés à nouveau deux ans plus tard, en 1995, toujours avec Max Shauck mais qui volait cette fois à l'EtBE —essentiellement parce que c'est toujours un plaisir de recevoir la famille Shauck.

Mais nous doutions déjà des effets d'une telle démonstration sur le comportement des pilotes français car, pendant les deux années qui avaient séparé ces salons, personne ou presque en France n'a demandé des nouvelles de Max et de ses biocarburants.

En mars 1996, Michel Barry et moi nous sommes rendus à Waco pour essayer un Cessna 152 dont le moteur Lycoming avait été certifié pour voler à l'éthanol pur. Une aventure intéressante, positive d'après Michel Barry mais, encore une fois, personne en France n'a montré un quelconque intérêt pour cette nouveauté lorsque nous l'avons publiée. Et, cependant, le président Chirac venait d'annoncer qu'il comptait réduire les taxes sur les biocarburants comme l'éthanol pour aider le monde agricole français. Une anecdote révélatrice : après son dernier séjour parisien, Max Shauck avait abandonné derrière lui presque 1 000 litres d'EtBE. Comme il était évidemment exclu de stoc-

ker ce carburant dans nos bureaux, nous avons appelé notre ami Jacques Mangenot, un pilote dynamique et très proche de nos activités par sa charge de commandant de l'aérodrome de Meaux (Seine-et-Marne).

Jacques avait lu nos différents articles sur le sujet, il pouvait stocker légalement du carburant et surtout, il connaît nombre de pilotes et techniciens capables de mener des expériences sur la com-

bustion d'un tel carburant. Bref, devant son enthousiasme, nous lui avons offert nos fûts d'EtBE.

Je l'ai appelé avant de me rendre à Waco pour savoir où il en était de ses recherches, deux ans plus tard. Sa réponse a été la suivante : « Mais tu ne devais pas me rappeler pour me donner les coordonnées de Max Shauck ? Comment veux-tu qu'on utilise ton EtBE sans données techniques ? ».

Sans commentaire.

Mais ce manque d'intérêt est d'autant plus significatif qu'il y a dix ou quinze ans, Jacques et ses amis furent les premiers à utiliser le GPS en France et en faire la promotion.

Cette année, les Shauck nous ont demandé si l'on pouvait trouver de l'argent pour une troisième présentation à Paris. Personnellement, j'étais déjà très occupé à budgéter mon vol sur le pôle Nord et n'ai pu assister nos amis américains. Max n'est donc pas venu. Mais si, pendant tout le salon du Bourget, on nous a demandé partout des nouvelles de notre ami « Mad » Max, pilote fantastique s'il en est, personne n'en a demandé de son combat —de notre combat, devrais-je dire— pour promouvoir des carburants moins polluants.

Les ministères sont réservés

Plus d'un mois avant de m'envoler pour Waco, j'ai appelé Mme Voynet, notre nouveau ministre de l'Environnement. Les responsables de son ministère se sont montrés charmants mais il a été impossible de connaître la position officielle du Gouvernement sur les carburants alternatifs pour notre aviation. Nous avons quand même appris qu'un spécialiste reconnu attaché au ministre, M. Forrest, avait répondu par écrit à nos questions mais, indubitablement, cette réponse a dû être considérés comme trop dangereuse sur le plan politique puisque le service de presse n'a pas voulu nous la faire parvenir !

*Page de gauche :
la dizaine
d'avions
américains
volant au
biocarburant
avait été
rassemblée à
Waco pour
l'occasion*

*Dessous,
Max Shauck,
prophète
des biocarburants.*

*Ci-contre : un
King 90 qui teste
actuellement le
bio-carburant.*

Évidemment, la position de notre ministre « vert » n'est sûrement pas très confortable. On peut du moins l'imaginer. Comment la France pourrait-elle préserver son coûteux système social et répondre aux exigences économiques pour intégrer le club de l'Euro sans réduire ses dépenses ni augmenter la pression fiscale ? Serait-il réaliste d'essayer d'imposer un biocarburant qui coûterait deux fois plus qu'un carburant fossile et sans réduire de façon significative les taxes parafiscales ?

Les conducteurs de voitures et pilotes d'avions légers savent que le carburant français est le plus taxé au monde, sous toutes ses formes. Il rapporte à l'état français 140 milliards de Francs par an, soit à peu près 10 % du budget de la France. Sincèrement, je ne peux imaginer un instant notre gouvernement diminuant le montant de ses recettes pour des raisons écologiques. De plus, on peut craindre que notre ministre de l'Environnement reste longtemps prudente en matière de biocarburants, justement pour des problèmes de pollution. Mme le ministre a en effet demandé une étude approfondie sur le sujet car ses services craignent que l'accroissement de la production des carburants agricoles génère un accroissement de la pollution des nappes phréatiques du fait de l'utilisation forcenée

d'engrais pour améliorer la production !

Pour terminer notre enquête, nous avons rencontré Jean-Pierre Leroudier de l'ADECA, l'association qui prône et développe des carburants agricoles en France, en compagnie de Luc Chatin, chargé des questions sur l'EtBE chez Elf, première compagnie au monde à produire à charge constante ce type de carburant. Aucun des deux n'avait entendu parler d'aucune expérience aéronautique autre que celles de Max Shauck relatées en nos colonnes. — Une conversation très libre de plus de trois heures a été tout à fait captivante mais bien souvent *off the record*. L'opinion que nous nous sommes forgés et pouvons certainement répéter sans risquer d'être contredits est la suivante :

→ Produire de l'EtBE est plus une difficulté politique que technique. Si on le lui demande demain, Elf est capable de fournir autant d'EtBE que nécessaire pour faire voler toute la flotte française d'avions légers. Mais ceci n'arrivera jamais, à

moins qu'un décret européen impose ce coûteux carburant pour diverses raisons, notamment la nécessité de rémunérer le capital de nos agriculteurs, payer leurs heures de travail, la semence, les engrains, amortir les machines agricoles, etc.

→ Max Shauck, prophète en matière de biocarburants, ne prêche pas dans le désert car, un jour ou l'autre, sous la pression du gouvernement américain, l'usage de l'essence plombée deviendra illégitime en Aviation générale aux États-Unis et l'Europe devra s'aligner pour des raisons pratiques.



→ Nos autorités ne doivent pas oublier qu'un carburant est utilisé pour faire fonctionner un moteur le mieux possible et le plus sûrement possible ; les exigences écologiques passent après.

→ Le carburant diesel pourrait être une solution d'avenir pour l'Aviation générale. À condition que ce ne soit pas du Jet A1 auquel on aura mélangé des additifs — comme on le fait déjà pour les forces de l'OTAN qui n'utilisent plus en campagne qu'un seul carburant pour la totalité de leurs vecteurs aériens et terrestres — car les performances des moteurs à pistons sont ainsi dégradées et leur pollution, excessive.

*Les Français
Laurent Gay
(Vice-Président
des Opérations
Techniques
de Socata
en Floride) et
Pierre Schmelzle
(chef de projet
Essais Carburants
chez Elf) n'ont
pas manqué une
seconde de la
conférence.
Au cas où...*

*Une salle de
conférence qui
n'a pas fait le
plein.*

La solution du moteur diesel

Dix années après notre première expérience de vol avec un autre carburant que l'Avgas, il semble que le diesel soit devenu le carburant à la mode en France. Le moteur diesel Renault-Socata pourrait être — lorsqu'il volera — le meilleur compromis entre les exigences de notre économie et celles de l'environnement européen.

Notre ministre de l'Environnement n'a-t-elle pas essayé récemment de taxer en vain le diesel utilisé par les voitures, initiative qui justifie la forte pollution de ce carburant?

Mais l'industrie du diesel automobile peut espérer continuer de prospérer en paix: elle représente déjà 50% des ventes actuelles en

logique que le gouvernement français soutienne le développement et l'usage d'un moteur diesel aéronautique. Mme Voynet ne pouvait que tomber d'accord avec notre ministre de l'Industrie et elle a même été photographiée devant le nouveau moteur Renault-Socata.

Reste un point à vérifier, la position fiscale française en matière aéronautique, qui semble aujourd'hui décalée. Il semblerait que l'usage du Jet A1 soit, dans les textes, interdit pour faire marcher des moteurs à pistons. Or n'est-ce pas l'usage de ce carburant fortement défiscalisé ou de tout autre carburant similaire qui rend ce nouveau moteur si populaire et non l'absence de plomb? La réduction fiscale accordée aux usagers du kérósène a représenté 10 milliards de Francs en 1996. On peut se demander si le même avantage sera accordé aux usagers de l'Aviation générale utilisant pour leurs loisirs du jet ou tout autre carburant pour des moteurs à pistons? C'est acquis pour l'instant au niveau français, mais qu'en sera-t-il au niveau européen.

Concluons en tant que pilotes et propriétaires d'avions à moteurs à pistons, position inconfortable lorsque l'on traite de pollution. Pour tra-

ver à travers la France et l'Europe, nous brûlons tous les ans des milliers de litres d'Avgas.

Cela ne nous tracasse pas trop car cette fâcheuse pollution générale malgré tout du travail non seulement pour notre équipe mais aussi pour les salariés des constructeurs, motoristes, équipementiers, ateliers d'entretien, ou aéroports...

Si l'on nous demande si nous sommes des parti-

sans sincères de l'écologie, notre réponse est oui. Personne n'en doutera. Nous l'avons prouvé. Mais si l'on nous demande si nous sommes prêts à payer le prix fort en utilisant un biocarburant à 9 ou 10 FF le litre, nous sommes au regret de répondre, bien évidemment, non — comme le ferait sans doute la grande majorité de nos lecteurs. ■



*La jolie
Grazia Shauck,
cheville ouvrière
de cette deuxième
conférence verte.*

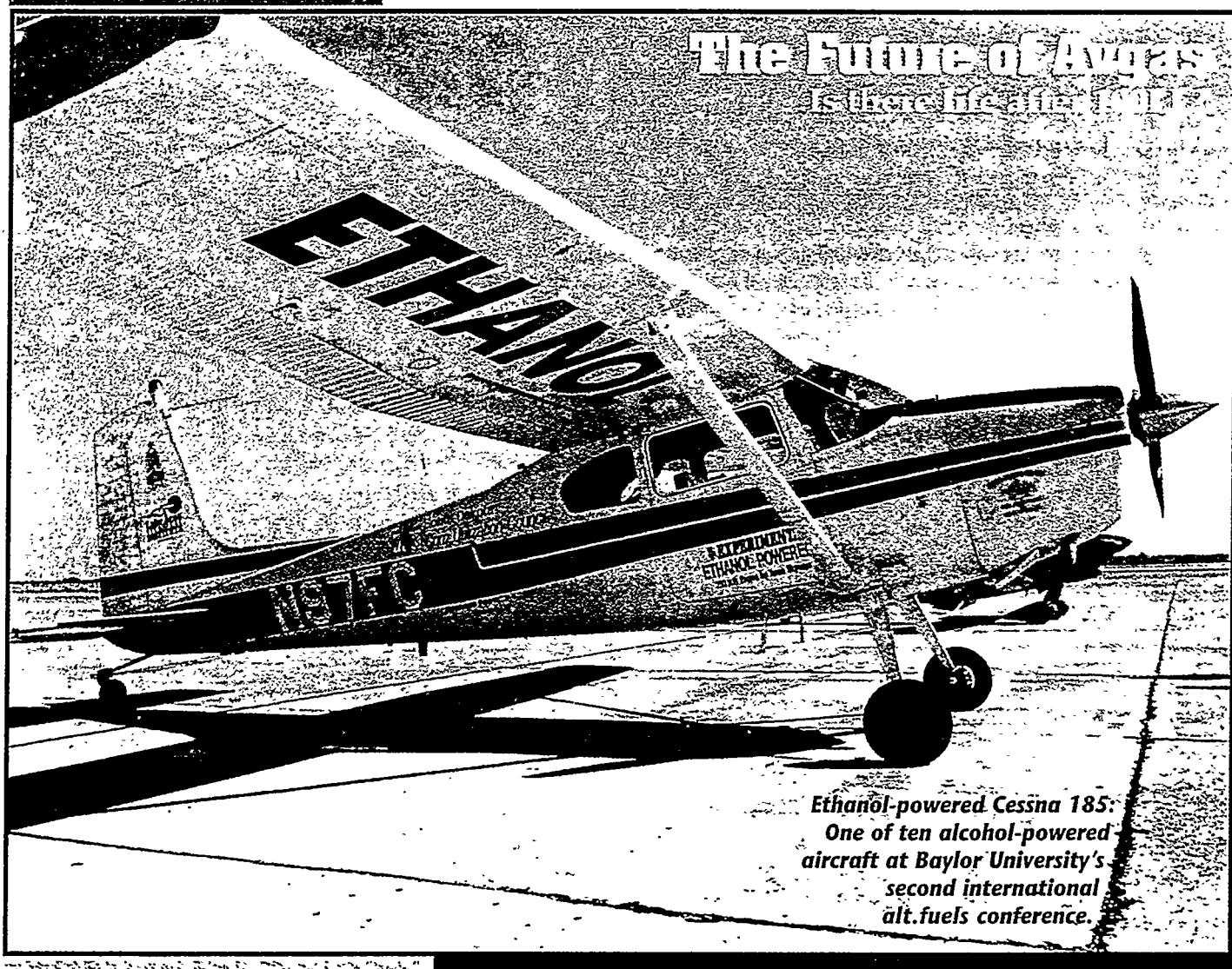


*Le leader de la
patrouille
Vanguard,
Thomas Schnaadt,
passionne la TV
local avec ses
expériences de vol
à l'éthanol.*

matière de véhicules routiers. Les moteurs diesels français ont progressé dans le bon sens de façon spectaculaire: ils sont beaucoup moins bruyants, plus efficaces et diablement moins polluants. Grâce à cela, Peugeot par exemple, exporte aujourd'hui la moitié de sa production de moteurs diesels. Du fait de ce contexte économique, il semble

TBO Advisor™

The Future of Avgas
is Ethanol



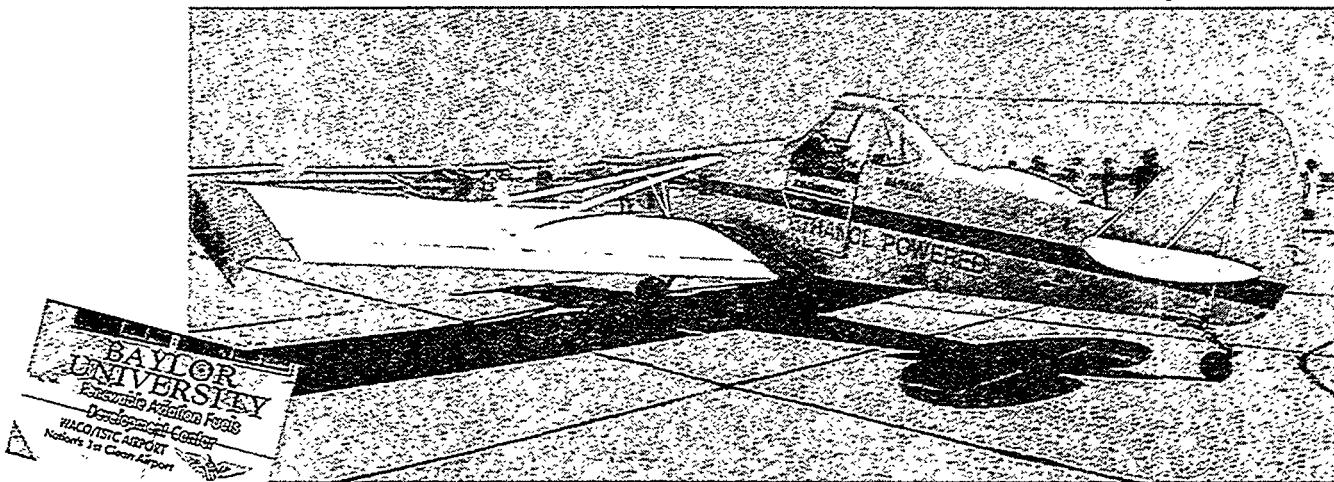
Ethanol-powered Cessna 185.
One of ten alcohol-powered
aircraft at Baylor University's
second international
alt.fuels conference.

Superior Emerges
from Chapter 11
—page 25

- The Future of Avgas page 7
- Interview: Dr. Max Shauck page 15
- A Case for Biofuels in Aviation page 20
- How Lean Is Too Lean? page 22
- News & Gossip page 3
- Mailbag page 4
- Questions and Answers page 27
- The Other Pilot page 31

The Future of Avgas

News from the 2nd International Conference on Alternative Aviation Fuels in Waco, Texas



While the fossil-fuel forces grapple with the problem of how to remove lead from 100LL, biofuel proponents point to alternatives that are cheap, non-polluting, renewable, commercially available, and in some cases already FAA-approved. But is aviation ready for cleaner, cheaper fuels?

TEXT AND PHOTOS
BY KAS THOMAS

Ask any pilot what the most serious issue facing piston aviation is, and odds are good (nearly 100%, in fact) you'll hear the word "fuels" come up. The impending demise of 100LL is among the most feverishly awaited (and debated) developments of late-twentieth-century aviation. Everyone in aviation, it seems, is waiting to see when 100LL will smack the proverbial tarmac—and what, if anything, will replace it.

Every other year, industry experts meet to discuss the fuel issue—and assess progress in the development of unleaded alternatives to 100LL—at Baylor University in Waco, Texas. The biennial International Conference on Alternative Aviation Fuels (hosted by Baylor's Aviation Sciences Department) draws together industry, academic, and governmental leaders from around the world. This year's conference, held in November, attracted top experts from Brazil, Sweden, Germany, France, and England (not to mention Canada and the U.S.), to discuss future fuels in the broadest

possible interdisciplinary context. Energy policy experts met with process chemists and petroleum engineers; GAMA representatives rubbed shoulders with university researchers; FAA reps swapped ideas with EPA and state energy commission officials. And the majority of attendees, this year, were active pilots.

As at the landmark 1995 meeting (see *TBO Advisor*, January–February 1996), this year's Waco conference emphasized a tripartite foundation for future-fuels acceptance, based on [1] economic feasibility, [2] environmental friendliness, and [3] safety. Aircraft operators are increasingly sensitive to all three factors. This year's alt.fuels conference left no doubt of that.

And the news this year—as in 1995—was not all bad, by any means. Significant progress is being made toward an unleaded future. The head of the CRC (Co-ordinating Research Council) av-fuels development group gave an encouraging account of recent progress toward unleaded avgas

(Continued on next page)

(Continued from previous page)

standards, as did a Texaco researcher (see further discussion, below). FAA has also taken an active role in spearheading fuels research at its William J. Hughes Technical Center. Much work remains to be done, but at least there are personnel and facilities—and money—being devoted to the problem.

The "problem," of course, is that avgas still contains lead. In fact, light aircraft using 100LL are now the largest single source of airborne lead pollution in North America, throwing several hundred tons of lead into the air every year. Because of its lead content, 100LL avgas is no longer shipped long distances via pipeline; instead, it is shipped in small lots, usually via truck. (Even fuel-grade ethanol—which is shipped in multi-railcar lots—makes 100LL look like a boutique fuel: In an average year, the U.S. ethanol industry produces over *five times* more fuel-grade alcohol than the entire GA fleet burns in 100LL.) The special handling precautions that must be taken with 100LL, combined with its low volume of production, make for a fuel with (as Pogo might say) a promising future behind it. It's only a matter of time before the oil companies stop making leaded avgas—with or without pressure from EPA.

Making 100LL is, after all, hardly worth the effort, if you're a multibillion-dollar, multinational oil company. The U.S. piston-powered civil aircraft fleet, for example, burns only around 305 million gallons of gasoline per year, of which roughly 90% is 100LL, the remainder being divided about equally between Grade 80 avgas (which is now essentially unleaded) and automotive gasoline. To put things in perspective, passenger cars in the U.S. burn more gasoline in a typical *day* than the combined U.S. and Canadian GA fleets burn in a full *year*. From a volume standpoint, avgas is hardly more than a drop in the bucket for a company like Shell or Exxon. And unless GA flight hours (which have been trending downward the last several years) start going back up, that drop is bound to become even smaller. At some point, the biggest companies are bound to ask whether it's worth continuing to make avgas, especially when high-quality alkylates are such attractive blending stocks for reformulated gasolines (RFGs).



The panel on "Current Research on Petroleum-Based Alternative Aviation Fuels" was headed by TCM's Ron Wilkinson (standing, left) and included—from left to right—Augusto Ferrara, Cesar Gonzalez, Ken Knopp, Joe Valentine, Lars Hjelmborg, and Paul Pendleton.

(Note: The 1990 Clean Air Act amendments imposed a reformulated gasoline requirement on fuels sold in the poorest-air-quality parts of the U.S. The RFG specs put stringent limits on aromatics and olefins, while also requiring the use of oxygenates. Alkylation units of the type used in avgas manufacture create inherently high octane blending stocks that are attractive for RFG production.)

Why not just take the lead out of 100LL? After all, a sizable portion of the GA fleet (well over half of all active fixed-wing aircraft, according to some estimates) was either certified originally to use 80/87 avgas, or is certified, now, to use automotive gasoline. One can imagine a scenario in which these planes all switch over, *en masse*, to a low-vapor-pressure "aero" version of high-test automotive unleaded. That's essentially the logic behind 82UL, the new unleaded avgas spec being considered by ASTM (the American Society for Testing and Materials, which sets industry standards for avgas, auto gas, and lots of other products). There's only one problem. The forty percent of the fleet that was originally certified to use 100-octane avgas burns 75% of the fuel—and that forty percent *can't use* 82-octane (or even 92-octane) fuel, for reasons having to do with detonation.

Teledyne Continental Motors engineering vice president Ron Wilkinson made this point clear in a presentation outlining current obstacles and recent progress in unleaded fuels testing. One of the goals of CRC's Aviation Engine

Octane Rating Group, he said, is to "determine the octane requirements of the existing fleet"—something that has never been done before. (Under existing Part 33 rules, engines are detonation-tested to make sure combustion knock doesn't occur on 100-octane fuel. But that's not the same as determining the *minimum fuel octane* at which knock will definitely be encountered in a given type of engine.) Wilkinson pointed to recent FAA-conducted test results involving two "representative" high-output engines—a Continental IO-550, and a Lycoming TIO-540—that were run on test fuels to see exactly where detonation was encountered, and under what operating conditions. The 300-hp Continental had an effective octane requirement of 98 under wide-open-throttle (WOT) conditions. The 350-hp TIO-540, on the other hand, detonated at WOT even on 100-octane fuel, at certain mixture ratios. "What it means is, more re-

(Continued on page 10)

The South Dakota-based Vanguard Squadron has been flying airshow aerobatics on pure ethanol for over five years with no problems.



Ethanol Continues to Gain Momentum

Getting ethanol to market has been an uphill battle, but there are signs that the domestic fuel-ethanol industry—forever stuck in first gear—may soon downshift into second. The reasons are both technical and policy-related.

On the technical side, enormous improvements have been made (and continue to be made) in the basic technology of alcohol production. In a sense, this is ironic, given that fermentation of agricultural products to produce ethanol is one of mankind's oldest "industrial" processes, predating even the smelting of ore to make iron. Nevertheless, it's not an exaggeration to say that more has been learned about alcohol production in the past ten years than has been learned in the entire 10,000-year history of the technology leading up to the most recent decade.

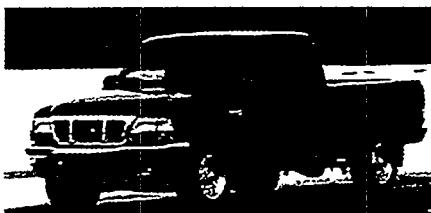
Just a few years ago, to build a 20-million-gallon-per-year ethanol plant cost about \$80 million. The typical 1985 plant was not terribly efficient with regard to energy use, threw off huge quantities of greenhouse gases, and generated tremendous amounts of waste water. Today, a 40-million-gal/yr. plant can be built for \$55 million, and the plant will be considerably better in every important way. The net electricity usage will be only one kilowatt hour per gallon of ethanol produced, and there will be no wastewater problem. (Delta-T Corporation, for example, has pioneered the use of a process that uses no steam injection.) A modern plant produces no foul odors, no EPA fines from wastewater violations, etc.—very few headaches, compared to "the old days" of just a few years ago.

Technology is also improving where feedstock utilization is concerned. Ten years ago, an ethanol plant required highly purified starches (or corn syrup) on the input side. Today, that can be augmented with grasses, municipal wastes, and other "cellulosic" sources. In the future, cellulosic materials (paper-industry waste products, for example) are expected to far outweigh food grains in importance, where ethanol production is concerned. In the past, with acid hydrolysis the only viable pretreatment method for cellulosic feedstocks, the extensive use of wood chips, grasses, waste paper, etc. on the input side wasn't feasible. Today, feedstock hydrolysis proceeds enzymatically with the aid of "engineered"

cellulases created through the magic of recombinant DNA. Soon it will be possible to use hemicellulosic feedstocks on an industrial scale—i.e., carbohydrates that, when broken down, yield monomers other than glucose. (Glucose is required for traditional yeast-based fermentations based on age-old "baker's yeast" technology.) Genetically engineered yeasts and bacteria now exist that can, for example, ferment xylose instead of glucose. This is expected to open up entirely new avenues for commercial production of alcohol.

New markets for value-added byproducts of alcohol production have also been developed in recent years. This little-publicized side of the business is critical to making large-scale ethanol production economic.

On the regulatory and energy-policy front, the big news is still the Clean Fleet requirements of EPACT (the Energy Policy Act of 1992). Under EPACT, certain fleet operators (notably government agencies) are required to phase in "clean fuel" vehicles over a statutory timetable whereby 50% of all fleets should be composed of Alternative Fuel Vehicles by 1998, and 75% by



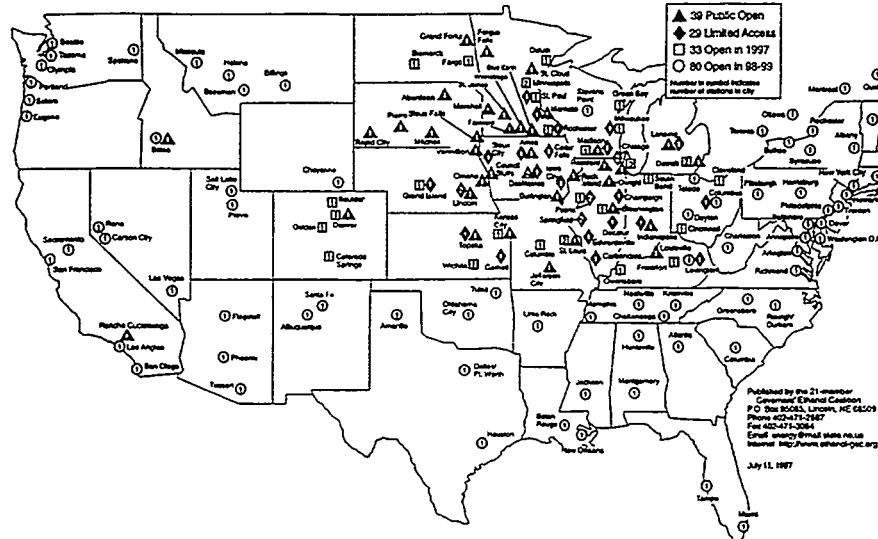
Ford will begin producing a "flexible-fuel" (E-85 ready) Ranger pickup this year. All you have to do is ask for the 3.0-liter V-6.

1999. The leading "clean fuels" here are natural gas products, and ethanol in the form of E-85, an 85:15 blend of ethanol and gasoline. At present, there are 68 E-85 fueling stations, mostly concentrated in the midwestern states; by 1999, more than 180 stations are scheduled to be online, with at least one in every state of the Union.

Another federal mandate that has had a stimulating effect on the fuel-ethanol industry is the Reformulated Gasoline (RFG) requirement of the 1990 Clean Air Act amendments. Under these amendments, the poorest air quality parts of the U.S. are required to have oxygenated gasoline. This requirement is generally met with either ethanol (blended with gasoline to give gasohol) or MTBE (methyl tert-butyl ether, a product made by condensation of methanol and isobutylene). The solution that perhaps stands to make the greatest number of people happy is to use ETBE (ethyl tert-butyl ether, made by combining ethanol and isobutylene) in place of MTBE. ARCO Chemical, among others, has been pushing ETBE as a replacement for MTBE.

The U.S. fuel-ethanol industry continues to solidify and mature. Whether ethanol can ever truly break the hammerlock that Big Oil has traditionally had on the fuels market is hard to predict. Petroleum will likely dominate the world energy economy for a long time to come. But Americans—despite importing record quantities of foreign oil—are increasingly loathe to put all their energy eggs in one basket, which means ethanol's present role as a "hedge play" in an uncertain energy market can only become stronger with time.—KT

E85 Fueling Stations



E85 Stations
Opening
Across U.S.

With the recent announcements by Ford and Chrysler to significantly increase production of E85 vehicles, the National Ethanol Vehicle Coalition announced that 181 E85 pumps will be open across the Midwest by 1999. Currently, 68 E85 stations are operating, and another 113 are planned to open between now and 1999.

Kentucky recently opened its first public E85 station in Louisville. Coal's Service Center began selling E85 on May 28. The station will be at E85 from a local producer, Parallel Products, that produces ethanol from the corn syrup of distilled soft drinks and perishable foods.

The National Ethanol Vehicle Coalition works in conjunction with the Governor's Ethanol Coalition, National Corn Growers Association, and the domestic ethanol producers to encourage and expand the availability of both E85 fuel and vehicles.

(Continued from previous page)
search is needed," Wilkinson concluded.

To this end, CRC has brought together a development group tasked with nailing down the precise octane requirements of the fleet and possible ways to meet the fleet's needs in terms of an alternative fuel formulation. The CRC group (which Wilkinson chairs) is made up of 53 experts from 30 member companies, spanning airframe, engine, and component manufacturers; oil companies; FAA; universities; and industry trade organizations (AOPA, EAA, and GAMA). Cessna, Piper, and Raytheon are represented, as are the major avgas providers, including Air BP, Chevron, Exxon, Phillips, Shell, and Texaco. Five different labs will perform duplicate tests on 27 fuel samples (and an unspecified number of engines) in order to arrive at some meaningful results vis-à-vis the performance of various engines on various fuels. The group met as recently as a month before the Waco meeting (and again in December) and should have initial test results in hand by 2Q98.

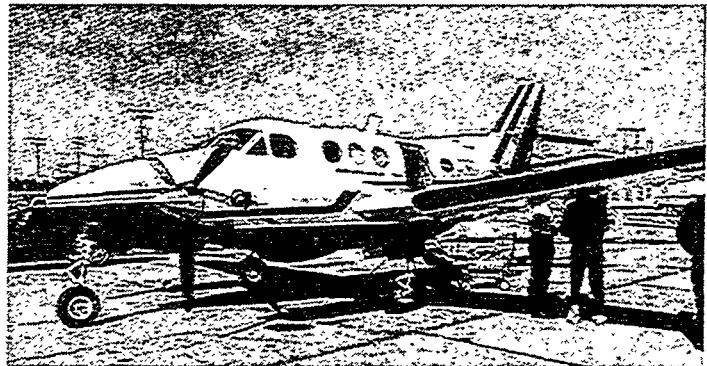
These folks mean business.

The Fuels Cube

TCM's Ron Wilkinson and Texaco's Joe Valentine (of the Fuels and Lubricants Technology Department) both talked about a sophisticated multivariate analysis technique that has been adopted by CRC's octane rating group. The problem is this: How do you test and compare the effectiveness of three separate octane-boosting additives, relative to one another, in one and the same fuel blend? Obviously, you vary the concentrations of the constituents. But how? Do you start with 1% of additives A and B, then run tests on varying concentrations of additive C between zero and 10%? Then repeat the tests holding B and C at 1% but letting A vary over a wide range? What about the situation where all three additives are present in moderate amounts (say 3%)? How can you be sure what a "moderate" amount is, when the dose-response curve changes with other additives present?

The additives in question—in case you're wondering—include MMT, MTBE, and *m*-toluidine. The first is methylcyclopentadienyl manganese tricarbonyl, an organometallic additive with good antiknock characteristics but tending to form potentially bothersome

Baylor University's Renewable Aviation Fuels Development Center (RAFDC) recently acquired this King Air, which will be used not only to measure airborne emissions in airport environments, but will serve as a testbed for biodiesel research. One engine will be run on Jet A coblended with biodiesel and/or ETBE.



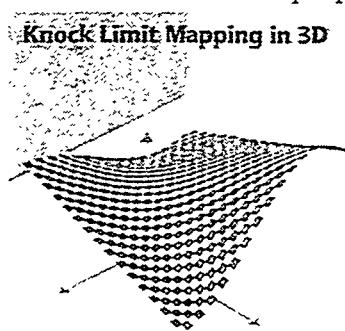
engine deposits. (It has been used in Canadian auto fuels, with mixed results.) CRC intends to include it in the test mix in concentrations from zero to 0.3 gram-equivalents of Mn per gallon of fuel. MTBE, methyl tert-butyl ether, is a widely used (in the U.S.) auto-fuel blending agent of the "oxygenate" class. It has good antiknock qualities (R+M/2 octane is about 105), tends to improve an engine's emissions, and is relatively non-toxic. CRC will test it in concentrations from zero to 30% by volume. The third additive, *m*-toluidine (or 3-amino-toluene), is an industrial chemical used in dyes and organic synthesis. Like many aromatic amines, it has octane-enhancing qualities, but nowhere near those of tetraethyl lead (TEL): in fact, *m*-toluidine is only about 2% as effective as TEL. Hence, CRC will test it in concentrations up to 10% by weight.

CRC researchers will solve the data-reduction problem roughly as follows. First, run a bunch of engine tests on a bunch of fuel samples representing different relative concentrations of the three antiknock additives. The additive concentrations will fall on equispaced

lattice points of a three-dimensional grid. The grid has MMT concentration along one axis, MTBE along another, and *m*-toluidine on a third. If you start with, say, three measurements (at three concentrations) in each axis, you have $3 \times 3 \times 3 = 27$ measurement points. Three points along any axis define a curve that can be described by a quadratic equation; hence, in 27 measurements you've got enough data so that a computer can (quadratically) interpolate points on a 3D surface representing knock-limiting performance for any given mixture of the three additives. (A cubic interpolation would require a minimum of $4 \times 4 \times 4 = 64$ data points—and would generate a considerably curvier, more interesting 3D surface graph—but the CRC group will not, initially at least, go this far.) With 27 points, the group hopes to map out the problem in sufficient detail to know where best to allocate research dollars next—an approach that seems reasonable, as far as it goes. (For details, see recently published SAE Paper No. 971496 by Texaco's Joseph Valentine.)

Texaco's Program

Texaco, it turns out, has been doing a good deal of work in this area already, as part of what Joe Valentine assured the Waco crowd is Texaco's "ongoing corporate commitment to General Aviation." (Valentine went as far as to say, at one point, that "We think we're pretty much in the lead as far as this high-octane unleaded program goes.") Texaco's research has centered on test-cell work involving a 200-hp Lycoming IO-360 engine. One of the early goals of the program was to probe the detonation limits of the IO-360 with respect to various test fuels and see if existing octane test specs (ASTM D-2700 for Motor Method octane and D-909 for Supercharge Method octane) correlate well



The CRC group will attempt to assess the relative knock performance of fuels fortified with MMT, MTBE, and *m*-toluidine by plotting points on separate axes of a 3-dimensional graph.

with observed engine behavior.

To get a good baseline for further testing, it was necessary to do some preliminary tests to see what kind of mixture strength (fuel/air ratio) would be "conservative" for detonation-testing purposes. It has long been known, after all, that the detonation performance of air-cooled engines is quite sensitive to mixture strength. (See, for example, Taylor *et al.*, NACA T.R. 699, 1940.) But what mixture strength would produce "worst case" detonation, at high power, in the IO-360? It turns out—somewhat surprisingly—that under the operating conditions used by Texaco, an equivalence ratio of 1.11 gave maximal

knock. (Equivalence ratio is just a normalized, dimensionless way of talking about fuel-air ratio, such that an E.R. of 1.0 corresponds to stoichiometry, 1.1 is 10% richer than stoichiometric, 0.9 is 10% leaner, etc.) The reason this is surprising is that most operators of Lycoming engines assume that at peak EGT (stoichiometry), they are safe from detonation. Surely, with fuel flows 10% on the rich side of peak, they are even safer. Maybe in real-world operations this could be true, but it's not what Texaco found with a ground-bound IO-360 mounted in a test cell, with marginal cooling. (Texaco's Joe Valentine admitted that on occasion the hottest cylin-

der of the test engine was, at times, 500 degrees Fahrenheit, which is quite a bit in excess of what most Mooney, Piper Arrow, and Cardinal owners ever see in flight.)

In any case, Texaco researchers decided to conduct all subsequent detonation runs at an equivalence ratio of 1.11 (fuel flow 11% richer than stoichiometry).

The next stage of testing involved running the IO-360 on test fuel blends to see if detonation was encountered. The test fuels included Texaco 100LL as a reference fuel, and some "alkylate/light naphtha/toluene" base stocks blended with varying concentrations of MTBE, toluidine, and MMT. All fuels were characterized via a battery of standard industry (ASTM) tests, including D-2700 and D-909 knock tests. (These knock tests are done in an industry-standard single-cylinder test engine that has nothing to do with aircraft engines.) This was done to verify the "official" octane ratings of the fuels. For example, the 100LL sample was found to have a D-909 (Supercharge) octane rating of 134.6, well in excess of the '130' performance number required (the '130' in 100/130).

Knock was monitored via expensive (several thousand dollars) top-of-the-line piezoelectric accelerometers custom-mounted in the cylinder head. (A fair amount of work was done just to locate the knock sensor properly. But that's another story.) Detonation was monitored both as to intensity (KI) and as to the fraction of combustion cycles (KC), a fairly common technique.

The results showed that you could get the IO-360 to knock even with unleaded fuels testing 99.6/144.8 via the Motor and Supercharge methods. For example, one test involved a fuel containing 25% MTBE, 6% amine, and .05 gram-equivalents per gallon of manganese (in a base stock corresponding to 100LL minus the lead). This was the 99.6/144.8-octane fuel. It gave a knock intensity index of 23 and a knock-cycles index of 3—basically trace detonation—under wide-open-throttle conditions.

Another fuel had 20% MTBE, 6% amine (toluidine), and zero MMT; it measured 97-octane via ASTM D-2700 and 137.6 via D-909. This fuel gave a KI reading of 36 and KC of 16 in the IO-360. Mild, but by no means negligible,

(Continued on next page)

UL Gets Cool Reception in Sweden

Of all industrialized countries, Sweden has (arguably) the toughest environmental laws. You'd think, therefore, that if any country had an answer to the "100LL problem," the Swedes would surely have one. And you'd be partly right. Hjelmco Oil, which serves the greater Baltic Sea market, has been selling unleaded avgas to the Swedish air force since 1981—six years prior to the introduction (in Sweden) of unleaded automobile gas. The same company currently offers something called 91/96UL at 55 Scandinavian airports.

If you've ever wondered what the 91/96UL fuel mentioned in Lycoming Service Instruction No. 1070L is, now you know. It's Hjelmco's unleaded avgas. And company president Lars H. Hjelmberg (who gave a presentation at the Baylor conference, and who himself flies a Piper Navajo) is happy to give anyone who'll listen the "unleaded avgas" pitch. Unfortunately, Hjelmberg's message isn't being heard by as many pilots as he'd like. Despite the fact that his fuel is specifically acknowledged in Lycoming's fuels bulletin and is the only avgas in the world that simultaneously meets the requirements of both ASTM D-910 and Swedish environmental laws, Hjelmco 91/96UL is used by only a small percentage of the approximately 70% of the Baltic fleet that could take advantage of it. Market penetration is (after six years) disappointing. Even though Sweden has a law stating that whenever there exists a product that is better than other products for the environment or for human health, the better product must be used, Hjelmco still sells less of its 91/96UL than it does of the skull-and-crossbones-labelled 100LL that it also sells. (In Sweden, any product containing more than 0.1% benzene must carry the skull-and-crossbones symbology, by law.)

The reason for 91/96UL's poor sell-

through? Consumer conservatism. "Mechanics are reluctant to tell pilots to go use a new fuel," Lars Hjelmberg points out, "and pilots themselves are very conservative as well." So despite the product's cost-competitiveness, despite the lack of cancer-causing dyes (Swedish law requires unleaded fuels to be colorless), despite the absence of ozone-harming ethylene dibromide, it's an uphill sell.

You'd think the easiest part of the selling job would be the lack of lead—no lead to foul spark plugs, form valve deposits, abrade engine parts, and coalesce as sludge. Engines can only last longer without lead. Swedish pilots apparently don't fully appreciate this. Or they may fear losing the valve seat/face lubricity that lead ostensibly provides. To counter these (and other) concerns, Hjelmco has put together a 24-page brochure outlining the benefits of 91/96UL vis-à-vis 100LL. Prominently mentioned on page 8 of the brochure is the fact that in the United States, more than 40,000 airplanes (several times the number of planes in the Baltic region served by Hjelmco) are operating on unleaded gasoline, without ill effects.

Arguably the most important selling point of 91/96UL is the fact that after six years on the market in Sweden, there have been no fuel-related problems in engines using the product. But the huge sales boost Hjelmco needs probably won't come until 100LL is actually banned. (Leaded avgas is currently produced in Sweden under a waiver.) Hjelmco is working on a true 100-octane unleaded replacement for 100LL, utilizing synthetic distillates, whose environmental qualities will be even better than those of 91/96UL. That product is still at least two years from being ready to market.

Maybe by that time, the market will be ready for the fuel.—KT

(Continued from previous page)
detonation.

Still another test blend featured 20% MTBE, zero amines, and 0.1% Mn, for an octane of 95.3/116.8. The detonation performance was unacceptable, at KI = 38 and KC = 57.

These numbers are not encouraging. If this kind of marginal detonation performance is seen with high-octane unleaded fuels in a normally aspirated Piper Arrow engine, what can we expect in a Turbo Arrow? Or a Turbo 210? Or a Duke?

The other scary dimension to this scenario involves the accepted industry tests for octane, D-2700 and D-909. If a fuel can measure 99.6 for Motor Method octane and 144.8 for Supercharge Method performance, yet detonates in a Lycoming IO-360 under worst-case conditions, how can we comfortably use such standards to rate our future fuels? As TCM's Ron Wilkinson observed: "We may very well be faced with the need for a new performance specification for aviation gasolines."

AOPA's Perspective

The Aircraft Owners and Pilots Association view was put forth in a presentation by Gus Ferrara (who attended the 1995 Baylor conference representing FAA, but who now speaks for AOPA). Ferrara underscored the points made by AOPA's Doug MacNair at the 1995 Baylor conference, namely that AOPA's chief concerns are that any replacement for 100LL be [1] safe and reliable, [2] environmentally sound, and [3] economically viable, which (in plain English) means that it should "cost no more than present fuels" and "should be usable by the entire fleet." Bottom line: AOPA is committed to a petroleum-based future, because ethanol, while *technically* viable, does not meet the distribution and ease-of-use criteria that would make it economically viable by AOPA's definition. "We are pushing for unleaded gasoline, not ethanol," Ferrara summarized.

FAA Involvement

FAA is participating in the CRC fuels consortium research effort at its Atlantic City Technical Center (now officially known as the William J. Hughes Technical Center), where significant expansion has taken place. According to FAA



"We may very well be faced with the need for a new performance specification for aviation gasolines."

—Ron Wilkinson
Teledyne Continental Motors

aerospace engineer Ken Knopp (who flew in to the conference in a Piper Arrow), FAA's test center is adding two new piston-engine test cells and a fuels laboratory building, and will play a key part in the CRC-coordinated unleaded high-octane test program. Preliminary tests have already been run on a Continental IO-550 and a Lycoming TIO-540 (see above); further testing will occur throughout 1998.

The Cessna View

Cessna's perspective on fuels was outlined eloquently by Cesar Gonzalez, Cessna senior project engineer (and a 43-year veteran of the company), who left no doubt as to the Wichita aircraft manufacturer's commitment to unleaded fuel testing. Cessna, Gonzalez pointed out, not only supports the ongoing work of the CRC consortium but continues to carry on a comprehensive in-house engineering effort aimed at meeting the fuel needs of the Cessna-built fleet (past, present, and future). For example, Cessna has designed, manufactured, and gotten FAA certification of its own simple, inflight detonation monitoring system, as well as a system for realtime blending of fuels inflight (for test purposes).

Gonzalez began his presentation by saying that "Cessna continues to follow the guidelines of the ASTM Future Fuels for General Aviation symposium of June 1998," where it was the consensus view that "the longterm survival of the [GA] fleet depends on our ability to adapt to large-pool fuels." This is code-talk for "we don't intend to support non-mainstream fuels—in particular, biofuels—to any significant degree." Gonzalez stressed the pragmatic, non-political nature of this decision. It's not that Cessna doesn't think biofuels are technically feasible; it's more that, as a practical matter, you have to make sure

your customers can use the fuels that are readily available in today's market—and that are *likely to be available* in tomorrow's market. That rules out ethanol, for most pilots, for at least the short term.

Gonzalez stressed this point, saying that "Alternative, low-volume specialty fuels"—such as methanol, ethanol, E-85, pure ETBE, and the like—"will only perpetuate the vulnerable supply situation [that GA finds itself in]." However, Gonzalez said (interestingly) that Cessna considers ETBE (from ethanol) to be an "indispensable constituent of future unleaded high-octane fuels."

By way of putting Cessna's viewpoint into perspective, Gonzalez pointed out that almost half of all piston-powered airplanes in the world are Cessna-built airplanes. Many of these airplanes are powered by low-specific-output engines that by nature are eminently qualified to use 82UL. "For low specific power applications, spark ignition engines of modest octane requirements are likely to remain the logical choice," Gonzalez said, underscoring the notion that there will probably *always* be a need for low-octane gasoline-burning engines. The proper solution for these engines is something like 82UL, which (as currently planned) will be based on large-pool motor fuel blending stocks, possibly using ETBE as a blending agent (but no alcohols), and differing from auto gas in that the (pending) ASTM spec for 82UL does not allow deposit-control additives. Once 82UL is accepted, Gonzalez noted, "we will go from eight avgas refineries in the U.S. now, to something like four hundred," as auto-fuel refineries become eligible to enter the avgas business. (Not all will actually participate, of course, but the point is clear. The avgas supply picture will only improve

(Continued on next page)

The Air Pollution Wildcard

Lower emissions have always been a selling point for biofuels, but that hasn't meant much to the aviation sector (until now) because aircraft have tended to fall through the cracks of the air-quality regulatory machine. That may be about to change.

The Clean Air Act, via something known as the National Ambient Air Quality Standards (NAAQS), sets acceptable limits for ozone, NOx, and other pollutants. Parts of the U.S. that fail to live up to NAAQS levels for, say, ozone are known as *nonattainment* areas. States with such areas are required by law to clean up their air according to statutory timetables. They do this by developing State Implementation Plans (SIPs) which target emissions sources of all kinds (power plants, dry cleaners, or whatever) and attempt to get noxious emissions down, one source at a time.

Interestingly, the top nonattainment areas in the U.S. all tend to share a common characteristic: They each have at least one (and in some cases more than one) "Top 50" airport for takeoff/landing operations. Los Angeles, for example—the country's worst ozone nonattainment area—has several ultra-high-traffic airports, as does New York City. As does Chicago. And Houston. In fact, 30 of the nation's top 50 busiest airports are located in ozone nonattainment areas.

It's not a coincidence. Major airports are bigtime polluters. Of New York City's five largest VOC (volatile organic compound) sources, two are airports. Kennedy Airport is, in fact, the No. 1 source of NOx (oxides of nitrogen) pollution in New York City, at just under 2,000 tons per year (about five tons a day). The second through fifth leading sources of NOx in New York City are (respectively) the Hudson Avenue Power Plant, the E.F. Barrett Power Plant, LaGuardia Airport, and the Hempstead incinerator. All produce over 1,400 tons of NOx per year.

Paradoxically, while major airports are bigtime emitters of VOCs and NOx, airports are *not* regulated like other polluters. States cannot include aircraft operators in their State Implementation Plans—nor can airport authorities or other arms of local government dictate aircraft operating practices—because FAA has long exercised sole jurisdiction in aviation matters. No city, state, or airport authority can (for example) require airliners to taxi on one engine, even

though this and a few other simple procedures might have an immediate salutary impact on emissions. Airports are FAA's exclusive turf.

Yet FAA promulgates no emissions regulations, except when it comes to certification of jet engines producing more than 6,000 pounds of thrust. (Such engines do have to meet emissions standards.) Ironically, the only kind of pollution control FAA routinely involves itself in is noise pollution. (When airport workers are in the hospital with terminal emphysema, they'll at least have 20:20 hearing.)

From time to time, efforts have been made to regulate airport emissions, but the result is usually bitter stalemate. The most recent attempt came in 1994, when the EPA released its Federal Implementation Plan for California's dirtiest nonattainment areas. (The proposed State Implementation Plans had been knocked down by the courts.) The government FIP called for setting declining emissions targets for airlines operating in California (consistent with similar caps set for factories and power plants), to begin in 2001. The airlines would be "free to reduce their emissions using the methods that best suited their particular situations," in EPA's words. For example, airlines could simply choose to fly their newest, "cleanest" planes into California's worst nonattainment areas, leaving older-model equipment to fly other routes.

Once the issue of aircraft emissions was on the negotiating table, all holy heck broke loose. Air-travel industry officials reacted as if their virginity had been brought into question. The officials (representing the American Association of Airport Executives, the Airports Council International—North America, and the Air Transport Association) countered that airlines could meet proposed NOx caps only by reducing service. ATA warned that allowing EPA to dictate emissions reduction procedures could lead to "serious safety concerns" and "interference with a pilot's operational control." Lawyers for the groups pointed out that the Airport Noise and Capacity Act of 1990 seemed to give FAA and DOT final say over airline ground operations. In the end, EPA—citing "the complex issues involved"—limped away with its tail between its legs.

In the wake of the 1994 battle over California emissions, airline and airport industry groups *did* ultimately arrive at a com-

promise with EPA that stopped short of putting emissions limits in effect. The airlines agreed to convert ground service equipment from diesel or gasoline to electricity or clean-burning fuels (e.g., natural gas); the airports, for their part, agreed to provide parked aircraft with electricity and A/C hookups at gates, thereby allowing airplane APUs (which are notoriously smelly) to be shut down. These are positive steps, to be sure. But according to an NRDC (National Resources Defense Council) study, ground service equipment and APUs together account for only 6% as much VOCs and 10% as much ground-level NOx as that generated by taxiing and holding commercial aircraft.

Interestingly, there is one major airline that already practices emissions reduction techniques voluntarily. Since 1981, Delta has had a policy of taxiing on the fewest engines necessary, waiting until the last minute to fire up remaining engines for takeoff, and shutting unneeded engines down as soon as practicable after landing—a regimen that saves the airline millions of dollars a year in fuel (and engine reserves). NRDC recently did a study to see what the effect would be on pollution at Newark International Airport in New Jersey if *all* aircraft followed Delta's regimen. The result: VOCs would drop 37%; NOx, 35%. The savings, in terms of tons of pollutants per year, would be comparable to shutting down a midsize steel mill.

The handwriting on the wall for civil aviation (America's last smokestack industry?) should be clear. It doesn't make much sense—to anyone other than an ATA lawyer—that an industrial source releasing 50 tons/yr of VOCs may be subject to strict regulation, yet a nearby airport (such as O'Hare International) can set loose 1,400 tons of VOCs per year with total impunity. (New York's SIP targets the boiler in one of JFK's terminals because it releases 292 tons of NOx per year. Meanwhile, arriving and departing aircraft released over 1,800 tons of NOx at JFK in 1993.)

As big cities become cleaner, big-city airports are bound to be seen, increasingly, as problem areas—"brown air" zones in need of serious air-quality remediation. Which means that unless aviation cleans up its act *voluntarily* (by, for instance, switching to biofuel blends), EPA types will surely come knocking. And this time, just as surely, they'll bring bigger guns. —KT

(Continued from previous page)

if 82UL comes online.)

But 82UL will not serve the needs of all of Cessna's customers. For that reason, Gonzalez says, we need to pursue development of high-octane unleaded (petroleum-based) fuels—and we need to see new engines that can run on a variety of fuel types (so-called multifuel engines).

Multifuel Engines

Continuing on the multifuel-engine theme, Gonzalez noted that "Future multifuel piston engines must be insensitive to octane and cetane numbers," which may (and typically do) vary from supplier to supplier and season to season. Hinting at work being done by (possibly) TCM and/or Lycoming, Gonzalez further noted that "Multifuel piston engines are accessory-intensive and therefore not justifiable for low specific power applications." English translation: MF engines will likely be diesels with high-pressure fuel injection systems and electronic subsystems (e.g., FADEC-related) whose aggregate cost will make their use on a Skyhawk-class engine uneconomical.

Clearly uncomfortable with the idea of longterm dependence on a special grade of high-octane unleaded avgas, Gonzalez indicated that high-specific-power light planes should (in the future) migrate to new-technology, multifuel engines. "Development of new

Conference attendees Lars Hjelmberg (left) of Hjelmberg Oil and Professor Rudolf Voit-Nitschmann of the Institute für Flugzeugbau Universität (of Stuttgart, Germany) discuss one of the professor's favorite subjects: electric-powered motorgliders.



piston products capable of using other transportation fuels available in large pools is key to survival," Gonzalez emphasized.

Ethanol Stirs Passions

Cesar Gozalez's put-downs of ethanol did not go unnoticed by the biofuel boosters in the audience, of whom there were many (some of whom traveled long distances). During a question-and-answer session, for example, Dr. Plinio Nastari of São Paulo, Brazil gave an impassioned defense of ethanol, pointing out that some 4 million road vehicles currently use neat ethanol every day in Brazil with no ill effects. (Quite the contrary: Not only do the vehicles not show ill effects, Dr. Nastari mentioned numerous examples of ethanol-fueled cars

that had gone 150,000 miles without engine work.) Nastari challenged Gonzalez to take a message back to Wichita: "Please have Cessna become involved in testing ethanol in its aircraft."

Gonzalez dismissed Nastari's claims that ethanol could easily be used in aircraft. "I have been to your country," Gonzalez began somberly. "And I have talked to some of those who were involved in the ill-fated, never finished attempt to convert civilian aircraft to ethanol power. That attempt, as you know, ended in failure." Gonzalez pointed out ethanol's tendency to combine with airborne moisture and noted, with a more than a hint of contempt, that Cessna had gone to considerable

(Continued on page 16)

Glossary of Acronyms

82UL—82-octane unleaded avgas. Derived from automotive gasoline feedstocks.

91/96UL—An unleaded avgas made by Hjelmco Oil in Sweden, available in the Baltic region.

AFV—Alternative Fuel Vehicle.

ASTM—American Society for Testing and Materials (Philadelphia, PA). Industry standards organization.

BTU—British Thermal Unit (the amount of heat energy required to raise a pound of water one degree Fahrenheit). Approximately 252 calories or 1,055 Joules.

CNG—Compressed natural gas.

CRC—Coordinating Research Council, an SAE-sponsored, committee-driven industry group that oversees research in key areas of interest to industry.

DOE—U.S. Department of Energy.

E-85—Ethanol 85%, gasoline 15%. A qualifying "clean fuel" under EPACT. (There is also an E-95 formulation.)

EPACT—Energy Policy Act of 1992; an extension of the 1990 Clean Air Act amendments.

EPA—U.S. Environmental Protection Agency.

ETBE—Ethyl tertiary-butyl ether. A high-octane fuel blending agent made by combining ethanol with isobutylene.

FADEC—Full authority digital engine control.

FFV—Flexible-fueled vehicle. Auto-industry term for a vehicle that is configured to use more than one fuel interchangeably: e.g., the 1998 model-year Ford Ranger with 3.0-liter V-6 is an FFV.

M-85—Methanol 85%, gasoline 15%. A qualifying "clean fuel" under EPACT.

MMT—Methylcyclopentadienyl manganese tricarbonyl. A metallic antiknock additive.

MON—Motor Octane Number (as set forth in ASTM D-2700).

MTBE—Methyl tertiary-butyl ether. A high-octane fuel blending agent made by combining methanol with isobutylene.

NOx—Oxides of nitrogen: N₂O, NO₂, NO.

OAT—Outside air temperature.

PN—Performance Number, an indication of relative antiknock performance for fuels that would otherwise score over 100 on the "octane" scale.

(R+M)/2—The arithmetic average of a fuel's MON and RON.

RAFDC—Renewable Aviation Fuels Development Center (Baylor University), headed by Grazia Zanin.

RFG—Reformulated gasoline, required in the smoggiest parts of the U.S. under the 1990 Clean Air Act amendments. Must contain oxygenates (e.g., MTBE) and be low in sulfur, aromatics, and olefins.

RON—Research Octane Number (per ASTM D-2699).

RTV—Room-temperature-vulcanizing synthetic rubber.

RVP—Reid vapor pressure.

SAE—The Society of Automotive Engineers, an important technical and standards organization for the U.S. transportation industry.

STC—Supplemental Type Certificate. A type of approval granted by FAA for modifications to an aircraft or engine's "type design."

TEL—Tetraethyl lead, the principle antiknock additive in 100LL.

VOC—Volatile organic compounds (the cause of evaporative emissions), an important precursor of smog.

WOT—Wide Open Throttle.

A Conversation with Dr. Max Shauck

Few individuals have made a greater contribution to the advancement of biofuels in aviation than Dr. Max Shauck, head of Baylor University's Aviation Sciences Department. A former Navy fighter pilot, Shauck holds a Ph.D. in mathematics from Tulane University and together with his wife, Grazia Zanin, oversees the pioneering work of the Renewable Aviation Fuels Development Center at Baylor University. The husband/wife team's 1989 trans-Atlantic flight in an ethanol-powered Velocity brought them the coveted Harmon Trophy, civil aviation's highest honor. Since then, Shauck and Zanin have been instrumental in obtaining the first FAA approval for operation of a Type Certificated aircraft on pure ethanol (the Cessna 152) and have pursued diverse research interests involving ethanol, ETBE, and biodiesel fuels. We caught up with Professor Shauck at the conclusion of the 1997 International Conference on Alternative Aviation Fuels in Waco, Texas, where we taped this interview.

TBO: During one of your talks yesterday, I couldn't help but notice that you referred to the 1973 oil embargo as "the first Arab oil embargo," which to me implies a *second* embargo. How concerned are you that we may face another oil embargo or shortage of some kind?

Shauck: I don't think it's a question of *if*—it's a question of *when*. In 1973, we [the United States] imported 37% of our oil. We import something like 53% today. We're more vulnerable to short-term supply problems now than ever. And it's costing us a bundle. If you consider how much money we spend to maintain a military presence in oil-exporting parts of the world, it's quite amazing. Scary, in fact.

TBO: Even without a fuel crisis, I take it you think we should be working hard toward a non-petroleum-based energy future based on ethanol?

Shauck: For our own energy independence, yes. I don't think it makes good sense to put all your eggs in one basket. Critics say it's not economically feasible. But that overlooks one thing. When you can use a feedstock they pay you to take, rather than corn, it changes the economics. One of our speakers yesterday [representing the Iowa corn producers] said corn is not going to be the final answer. I don't know how many people caught the full implications of that statement. Ethanol is \$1.20 per gallon in bulk, right now. But that price keeps going down every year. DOE projections are that longterm, it will cost 60 cents per gallon when [ethanol] is made from cellulose—agricultural waste, indus-

trial and municipal waste, energy crops.

TBO: What do you mean by "energy crops"?

Shauck: Switch grass, fast-growing trees, sweet sorghum, casaba, hemp. High-cellulose crops that can be grown efficiently in marginal areas. As opposed to food crops like corn or beets.

TBO: What's driving the move to ethanol, in aviation, today?

Shauck: The meat of this thing is the lead. I got started using biofuels before the lead issue became paramount. But that's what the driving concern is today. And what I see is that the price of avgas, at least if you're going to maintain the octane level, is going to go sky-high. Or else, you're going to have to do something they haven't done yet, as far as high-octane unleaded is concerned.

TBO: Critics say it's just not practical for real-world airplanes to convert to ethanol . . . that the fuel-system mods aren't practical, and the range issue is not addressed properly.

Shauck: I'm an airshow pilot. I live in the real world. I mean, when I'm flying inverted close to the ground, I care about whether the fuel works, you know? I'm very sensitive to the criticism that is often levelled at "environmentalists," that we don't have our feet on the ground, that we're a little bit fuzzy when it comes to producing hard data. That's why we've gone to great pains to back up all of our claims with actual data. We've documented everything. You don't get an STC to burn ethanol without doing your homework. I can tell you, our figures are *conservative* on the range issue. I'll be the first to admit that ethanol will never give the range numbers that avgas gives you, but as I've said before, the range shortfall with ethanol just is not that great. I think when the choice comes down to flying on ethanol, or not flying at all, the inconveniences of ethanol are going to seem very minor to most pilots.

TBO: What about ETBE? You seem to be a big proponent of that fuel. What's so good about it? Is it cheap?

Shauck: I'm not sure what ours costs. ARCO Chemical supplies ours for us. I know it can be made for 60 to 70 cents per gallon. It's cheaper than ethanol. ETBE is made from ethanol and natural gas products. It's 43% ethanol by mass, I think. It's an interesting fuel because it has a high heat of combustion. We saw a 5% increase in range at 70% power, on Monty's [Monty Barrett of Tulsa, OK] test stand. Also, I feel it gives a somewhat better throttle response than ethanol, although that's admittedly subjective.

TBO: How do you answer critics who say that going to ethanol or ETBE only pushes General Aviation into another highly vulnerable niche-fuel market?

Shauck: I believe ethanol is here for the long run. Fossil fuels are not. And avgas is very clearly not here for the long run. We are certainly being opposed from a lot of different directions. AOPA is one. EAA has not actively opposed us but has not rushed to embrace us with open arms. I believe that ethanol will have its ups and downs, but in some sense it's a self-fulfilling prophecy to say that ethanol is a *niche market* fuel. As long as we don't control the fuel industry, we're going to be labelled a niche product and everything petroleum-based is going to be mainstream, by definition. Do you see what I mean?

TBO: What's holding ethanol back? I mean, from a technical standpoint you've certainly proven its worthiness as a replacement for 100LL. Why isn't aviation moving in that direction?

Shauck: Good God, the *politics!* The massive resistance . . . You know what really bothers me? I can understand the oil industry not supporting what we're doing. That's to be expected. What bothers me are the people whose livelihood does not depend on the sale of oil, who oppose us. When Doug MacNair of AOPA was talking to EPA about why lead shouldn't be removed from avgas, he said it was because "we do not have an alternative." He actually said that!

There are a million ways to stop someone who wants to do something new. The best is just to ignore him. That's what's happening to us.

TBO: You've countered that in the past by doing transoceanic flights, setting world records.

Shauck: That certainly worked in Europe. Every magazine and newspaper in Italy covered us when we made the trans-Atlantic flight. We were on TV shows, radio shows—the media met us wherever we went. At home, I think we got one story in *USA Today*.

I'm not going to do any more record flights. That's beating a dead horse. We're beyond that stage now. It's time to move on to the next stage.

TBO: What can the average plane owner do to support biofuels?

Shauck: Go to bat for us with the big aviation organizations. Write letters to EAA. Tell chapter presidents that you want to see information on how to fly with ethanol. If a person really loves flying, he should support ethanol. When a person waits around for the government to solve problems, nothing happens. I'm a bit disappointed in General Aviation, because I thought there would be a group of self-reliant people who would not *want* government to solve their problems for them. Instead, I've come to find that pilots are apathetic. I wish I didn't have to say it, but the FAA people we deal with are the most receptive people in the industry.

(Continued from previous page)

lengths to get away from alcohol-based anti-icing systems. "It has taken us fifteen years to get alcohol tanks off all our airplanes," he said. "These systems were a constant source of problems, due to poor stability [of the alcohol]. We had many problems with water, and corrosion."

"You must bear in mind, we have seen airplanes standing still for two years, *then flown*," Gonzalez intoned. "Inactive, for two years! These planes flew, with the same two-year-old fuel in the tanks, and because that fuel was avgas, they got away with it. It worked. No one was hurt. I can tell you, this sort of thing would be absolutely unthinkable with ethanol. You would not dare to get in a plane that had sat that length of time with ethanol in the tanks."

A discussion ensued about the water-separation characteristics of pure alcohol versus gasoline-alcohol blends. (Pure, or neat, ethanol keeps water in solution, whereas gasohol blends tend to form azeotropes, which can cause power interruption.)

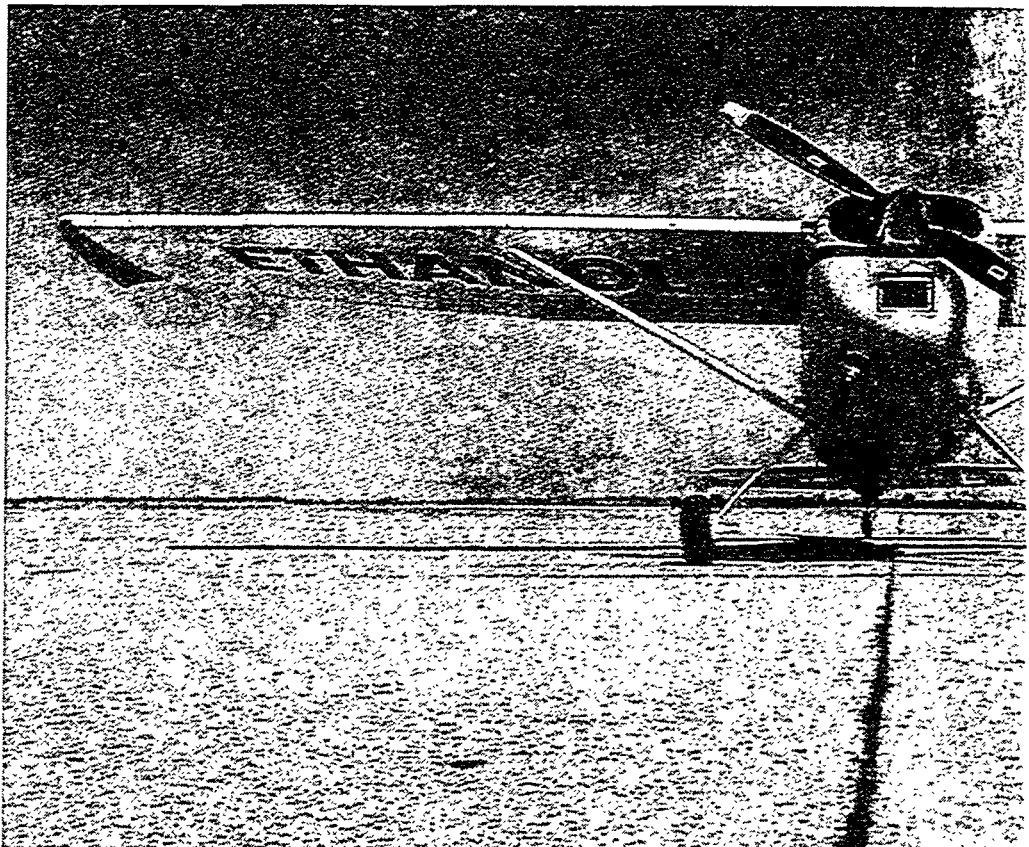
Emotions nearly boiled over at one point when Gonzalez alluded, rather boldly, to ethanol's poor cold-weather starting characteristics. "I was in São Paulo during a cold snap," he said, adding rather caustically: "I believe it was fifty degrees outside. And I remember seeing the taxi cab drivers, early in the morning, passing a gas can from one to the other, trying to get their engines started."

Dr. Nastari shook his head and fumbled for a microphone. "That's not true," he said. "I have *never* seen that."

Gonzalez remained firm. With grave seriousness in his voice, he noted: "Brazil is a warm country. In your country, ethanol may be a viable option. But we have airplanes *all over the world*, not just in your country. Cessna builds airplanes that operate from the North Pole to the furthest deserts. Any future fuel for these airplanes must work for operators in *all parts of the world*, not just in one country."

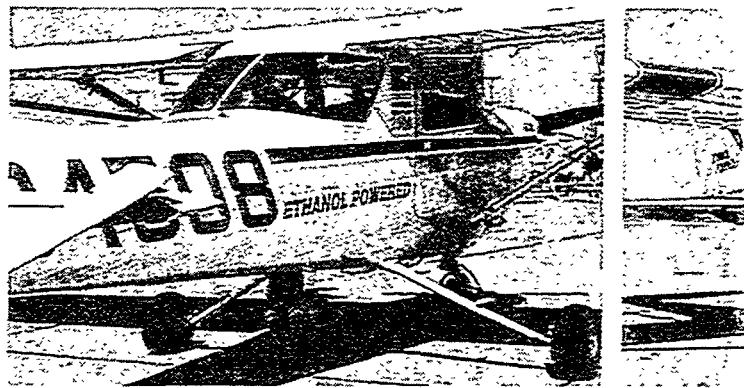
The Pro-Ethanol View

Ethanol's critics—a group that includes not only Cessna's Cesar Gonzalez but AOPA and oil-company reps—got set straight on a number of key points as the pro-biofuel camp present-



ed expert after expert who testified to alcohol's flyability. For example, Marv Randall of the Vanguard Squadron (a South Dakota-based formation-aerobatics act that performs in alcohol-powered RV-3 airplanes) recounted that group's experience using pure (neat) ethanol in Lycoming IO-320 engines. In five years of operation on pure ethanol, at OATs down to minus-35°F, Randall said "there have been no fuel-related engine problems at all." According to Randall, converting an IO-320 to use ethanol does require a few modifications—but they are by no means major. "We had to Alodine our aluminum fuel tanks," Randall explained, "and we replaced aluminum fuel lines with Teflon flex lines. About the only required change that we didn't do ourselves was to get alcohol-tolerant fuel diaphragms put in our Bendix RSA fuel servos, which we had to work with the manufacturer on. We also had to have our injector nozzles bored out about 10% to allow for a richer fuel flow."

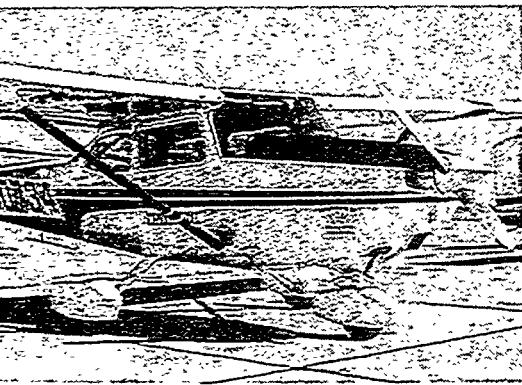
As with most ethanol-powered airplanes, the Vanguard Squadron's RV-



Top: Ethanol-powered Cessna 185 (owned by South Dakota State University). Above: Baylor's ethanol-powered 152 is now STC-approved: 'Experimental' doesn't appear on the door any more. Above right: Another ethanol plane—an O-320-E2D Skyhawk.

3s use a small auxiliary fuel tank (a Weed-Eater gas tank) filled with gasoline for priming in cold weather. It gets filled once or twice a season.

Randall was one of half a dozen pilots who flew in to the conference in an ethanol-powered airplane. Not surprisingly, ethanol wasn't available at every stop along the way. Two fuel stops were required on the trek from Sioux Falls to Waco, and at both, avgas was taken on. There were no operational problems. "At our first stop, I guess we ended up with about



a fifty-fifty mix of ethanol and 100LL in the tanks," Randall noted. "And at our second stop, that became more like an 80:20 mix. It didn't matter. The engine behaved normally. You just get a little better range on the avgas, that's about all you notice."

But even the range deficit on ethanol (often cited by ethanol's critics as a major downside to the fuel) is an overblown issue, according to Randall. "Most of us [in the Squadron] have put ten-to-one pistons in our engines," he said, "and with the high-compression pistons we see only about a seven percent range difference on ethanol versus 100LL."

This sentiment was echoed by University of North Dakota chemist Ted Aulich, who gave a talk centering on

UND's recent testing of E-85 in three modified Cessna singles. (E-85 is an 85:15 blend of ethanol and gasoline, currently available at 68 pumps around the U.S.) The UND airplanes—which flew in to the conference and were on the static-in-spection line—include a Cessna 180, a 182, and a 172, all with special Texas Skyways-modified engines. According to Ted Aulich, the range loss experienced by these test aircraft with 85% ethanol is only 10% (compared to avgas) despite a 30% lower caloric content of the fuel. The reason for the difference is that ethanol cools much more than gasoline as it evaporates, causing intake air to be cooler and denser—in effect, giving "free" supercharging.

The Canadian Experience

Canadian Ron Newberg (of Orillia, Ontario) gave a presentation describing his work getting the first Canadian approval for an ethanol-powered airplane—a Cessna 150 "bush plane" which has been flown as a tundra-tire taildragger, a ski plane, and (soon) a floatplane. The aircraft is powered by a Continental O-200-A with Slick LASAR ignition (providing spark advance up to 37°). The aircraft flew to Oshkosh last summer and, as of the Waco show, had accumulated 130 troublefree hours of ethanol operation in 18 months.

Newberg demolished the myth that ethanol-powered vehicles can't operate in cold weather. He described in detail (with words and pictures) operating the ski-equipped 150 at minus-20°C. Starting the engine at that temperature does require gasoline; to that end, the plane is fitted with a three-liter header tank (out of a Cessna 185) mounted on the firewall and plumbed into the priming system. "We fill it once every eight months or so," Newberg said.

Newberg's presentation—preceded, as it was, by talks by ethanol operators from the Dakotas—left no doubt that ethanol (which freezes at minus-114°C)

is a good cold-weather fuel.

Ethanol Availability

Availability is, of course, still somewhat of a problem with ethanol. Todd Sneller, administrator of the Nebraska Ethanol Board and chairman of the Clean Fuels Development Coalition, gave a terse, no-nonsense assessment of progress in this area during an afternoon panel on production and marketing of alternative fuels, and the news was not all rosy. Sneller started by pointing out that today, alternative fuels (ethanol, liquefied natural gas, etc.) account for only about 3% of fuel sold in the U.S. Gallon-wise, that's a not insignificant number: in 1995, for example, just over a billion gallons of ethanol were produced for fuels use. But there's a great deal of year-over-year fluctuation in the numbers, due to the way fuel taxes and energy policy are micromanaged from one election year to the next. In 1996, only 700 million gallons of ethanol were produced. For 1997, that number is expected to top out at 1.59 billion gallons. Fluctuations like these, ironically, are often pointed to by politicians as a reason why alternative fuels are "unreliable" for policy planning purposes. To fix this will require that the ethanol production industry matures to a point where political dithering with tax breaks, etc. doesn't wag the dog quite so much. We're almost at that point now, according to Sneller, but we still face some formidable obstacles getting ethanol accepted as a mainstream fuel.

The alternative-fuels production and delivery infrastructure, Sneller pointed out, are at a huge disadvantage relative to petroleum. Ethanol is transported exclusively by truck and train, in small lots. (No pipeline operator wants neat ethanol flowing through the lines.) It's difficult—or at least costly—to get bulk ethanol delivered from Nebraska, say, to Oregon. As a result, the cost-per-gallon to transport ethanol is relatively high. And it means ethanol is extremely vulnerable to rail problems. Even when railroads are operating at peak efficiency, small-lot shipments tend to get re-aggregated at depots in ways that can slow overall delivery unpredictably. Boxcars get shuttled, waylaid, and rerouted like packets over a data network; you never can be sure, ahead of time, exactly what route a shipment will take.

(Continued on next page)

(Continued from previous page)

or when it will arrive. This plays havoc with customer expectations. In the fuels industry (as in most industries these days), just-in-time delivery is demanded by customers. No one wants to tie up capital in inventory any longer than necessary.

Petroleum products have the advantage of being able to travel over the ultimate just-in-time delivery system: a pipeline. This option isn't open to ethanol, at least for now.

Pump availability is also a bit of a problem. To put it bluntly, most gas stations do not have any means of accommodating an extra underground storage tank and a "fourth pump" to dispense alternative fuels. One may question the need for three grades of automotive gasoline (87, 89, and 92-octane), but the fact remains, the major petro-monopolies own the pumps. Getting "shelf space" in this market won't be easy.

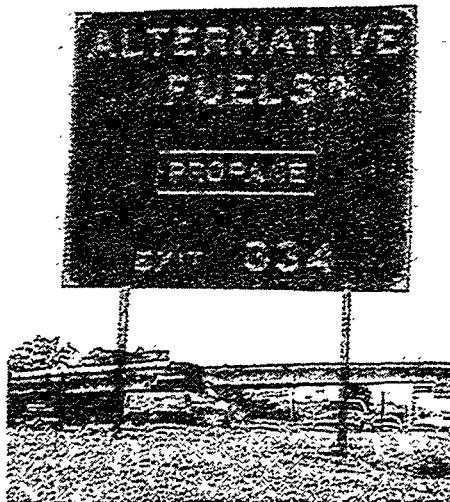
Even if shelf space were available, there are hardware compatibility issues. Specific types of hoses and filters are required for E-85, for instance.

In terms of competing with *avgas*, ethanol may find itself on a more level playing field. *Avgas*, after all, is already a fully segregated, non-pipeline, non-mainstream specialty product, delivered in small lots, just like ethanol. But there is still the problem of limited "shelf space." Few FBOs are able to devote an entire underground (or above-ground) tank to ethanol.

Shauck Talk

Baylor University's professor Max Shauck—who (with wife Grazia Zanin) heads up Baylor's alternative fuels program—gave a brief overview of the history of alternative fuels research at the university and technical problems (real or imagined) that have been overcome along the way. Although much of Professor Shauck's current work involves ETBE (and biodiesel blends, soon to be flight-tested in a school King Air), he is still very much a believer in ethanol as a proven alternative to 100LL.

Shauck pointed out how, in the early days (which is to say, the early 1980s), he had a lot of concerns—as anybody would—over ethanol's fuel properties. "We were very concerned about lubricity, at first," Shauck explained, alluding to the well-known difficulties experienced by users of *methanol*. "I used a



Road sign on I-35 in Waco, TX.

top lube [additive] for a long time, because I couldn't afford to buy a new engine if I had a problem." It later became evident that ethanol was not only not having any detrimental effect on lubrication, it was actually (if anything) promoting better wear characteristics—perhaps by keeping parts cooler. (One of the first effects you notice when running pure ethanol is that CHTs run about 50° cooler.)

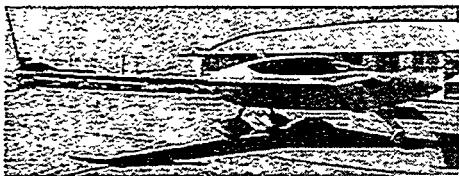
"We had a chance, finally, to document this effect"—of low wear—"during our AEIO-540 certification. As you know, to get an STC approval requires that you tear an engine down, measure all the parts that are subject to wear, then reassemble the engine, run it for 150 hours, and tear it back down again to measure the parts. We noticed that not only were the parts exceptionally clean, but the wear was extremely low. In fact, the DER"—FAA Designated Engineering Representative—"who looked at the parts said that the engine's TBO when operating on ethanol could probably be extended by a hundred percent."

Materials compatibility issues were addressed head-on: An independent third party—the prestigious Southwest Research Institute of San Antonio, TX—was asked to perform rigorous compatibility testing of any and all manner of gaskets, elastomers, and small parts used in aircraft engines, fuel systems, and FWF accessories. "SRI found there were no problems with any of our elastomers," Shauck

notes. "The only problem was with aluminum, which forms an oxide when exposed to ethanol. We were able to get around this by Alodining every aluminum part that came in contact with fuel, but lately what we've found is that the ethanol industry has started to put antioxidants in [the ethanol] at the point of manufacture, because they've had some of the same problems with their own aluminum tank plugs becoming oxidized."

In terms of potential performance problems with ethanol, Shauck admitted that the most serious one involves latent heat content: ethanol, gallon for gallon, contains only about two-thirds the BTUs of avgas. Many ethanol critics make the mistake of assuming that this means that pilots using ethanol as fuel can expect a 33% shortfall in range and/or endurance. Not so, says Professor Shauck. Ethanol's heat of vaporization is nearly triple that of gasoline. (If you pour a few drops of ethanol in your left hand and a few drops of avgas in your right hand, your left hand will feel much colder.) The cooling that happens in the engine intake system when ethanol evaporates gives a kind of refrigerant supercharging: the charge density is greater, equivalent to a sudden density-altitude drop of, say, 5,000 feet. Shauck is quick to point out that the power increase (from charge refrigeration) does not totally offset the BTU deficit of the fuel—you still have a net range reduction of perhaps 10% to deal with. (The exact amount depends on many factors, including the compression ratio of the engine—which can be raised, to good advantage, when operating on ethanol.) "I don't think we'll ever achieve one hundred percent of the range you'll get on avgas," Shauck says of ethanol. "But I think we can live with the kind of range we're now getting."

With pure ethanol as the fuel, most engines can go to a much higher compression ratio (i.e., a taller piston) with no adverse effects. This has been shown over and over again, Shauck said, perhaps most recently in the certification of the O-235 to use ethanol. The school's O-235 dyno tests used an engine with 9.7:1 pistons (P/N LW-18725). Ordinarily, O-235 models using this piston (such as the O-235-



The Shaucks flew this Velocity across the Atlantic on ethanol in 1989—a feat that brought them the Harmon Trophy.

F2A) are rated at 125 horsepower; the standard "Cessna 152" engine has 8.5:1 pistons. Dyno tests on the ethanol engine showed that the engine peaked at 150 horsepower. (Shauck's group succeeded in getting STC approval for the use of pure ethanol in the Cessna 152 in May 1996.)

Interestingly, detonation has never been a problem in any of the engine tests. Shauck said that even when mixtures were leaned at wide-open throttle, ethanol refused to detonate, even in the highest-compression engines. This is evidently partly because of ethanol's inherently high octane rating, and in part due to the enormous cooling effect ethanol has on an engine. But it also has to do with the fact that ethanol is *monomeric*: It is a homogeneous, single-molecular-structure fuel—unlike gasoline, which is a heterogeneous zoo of straight-chain, branched-chain, and cyclic hydrocarbons, all with different tendencies toward thermal cracking.

Recently, Shauck has begun to turn his attention to ETBE (ethyl tertiary-butyl ether), which is made from ethanol and natural gas products. Two and a half years of testing (mostly in Shauck's Pitts) have proven ETBE to be a reliable, versatile, high-octane replacement for 100LL, with "somewhat better throttle response" than ethanol and a higher caloric content, to boot. (ETBE has about 85% of the latent heat content of gasoline, versus ethanol's 66%.) What's more, ETBE—Shauck has found—can be used in an aircraft engine with none of the hardware modifications required for use of pure ethanol.

Shauck said that in the coming year he will not only be continuing his work with ethanol and ETBE in piston engines but will (for the first time) run a turbine engine—a PT6A in one engine of a King Air recently acquired by Baylor's Renewable Avi-

ation Fuels Development Center—on blends of Jet A, biodiesel (diesel fuel made, in part, from vegetable oil), and ETBE.

Summary

This year, as in 1995, attendees of the Baylor alt.fuels conference (who spanned a wide range of backgrounds) were more or less evenly divided among those seeking a petroleum-based solution to the 100LL-replacement problem, on the one hand, and (on the other) those pushing for a "biofuels" future. Despite a lack of consensus on which way aviation could (or should) go, the mood was convivial and cooperative. Many constructive ideas were generated. Attendees got candid assessments of progress (or lack of same) in key areas involving unleaded avgas and biofuels, not only in the U.S. but around the world.

Arguably the best news to come out of the conference was that a broad-based "ecumenical council" representing all of the major players in U.S. General Aviation has finally come together to study the "unleaded avgas" problem in earnest, with preliminary results promised for spring of 1998. What it really means is that by this time next year, we should know whether an economical, petroleum-based, unleaded alternative to 100LL (i.e., a fuel that can truly meet the needs of the turbocharged and high-compression engines certified on 100-octane) is forthcoming, and if so, what its basic recipe will be. At the present time, it appears that the recipe is bound to include traditional aviation alkylate, light naphtha, toluene, and an ether (MTBE or ETBE). It will almost certainly also contain either MMT (the manganese additive) or *m*-toluidine (an aromatic amine), or both.

Ethanol continues to face an uphill struggle. The primary barriers to entry are not price-based (ethanol is already cost-competitive with avgas, and will doubtless become even more so) but infrastructural: The fossil-fuel giants own the means of distribution. There are thousands of FBOs dispensing avgas, but essentially none selling fuel-grade ethanol. As a start toward breaking this deadlock, Baylor University and the U.S. Department of Energy have instituted a Clean Airports Program (in parallel with the

Clean Cities Program). To qualify under this program, an airport must have at least one alternative-fuel aircraft based there and a refueling facility that handles an alternative fuel (such as ethanol). Since its inception in March 1996, the Clean Airports Program has seen airports in Texas, Oklahoma, West Virginia, and South Dakota sign on. (For information on how to get your airport involved in this program, contact RAFDC at the address shown below.)

Ethanol's ace-in-the-hole continues to be emissions. Without the RFG and clean-fleet provisions of the 1990 Clean Air Act amendments (and EPACT), it's doubtful that ethanol would be a billion-gallon-per-year player in the U.S. liquid fuels industry today; and even more doubtful that it would play any future role in aviation.

Exactly where avgas is headed isn't clear, except that everyone agrees on one thing: It's time, at last, for aviation to divorce itself from "ethyl" (tetraethyl lead)—the fuel additive pilots can't live with, and can't live without.

For Further Information

The World Wide Web is a good place to start if you need information on alternative fuels. The links are too numerous to list here. To get started, browse to <http://www.altavista-digital.com> and do a search on the keywords that most interest you. Pages with extensive cross-listings include those of the U.S. Dept. of Energy (www.doe.gov), the National Renewable Energy Laboratory (www.nrel.gov), and the Renewable Aviation Fuels Development Center (www.baylor.edu/~rafdc). The Vanguard Squadron, last time we checked, had a very good web site at <http://www.dakota.net/~schnaidt/avlinks.html>. If your main interest is ethanol, be sure to visit <http://www.ethanol.org> (the American Coalition for Ethanol). For a comprehensive discussion of the Brazilian experience, we recommend the study at <http://www.mct.gov.br/GABIN/CPMG/CLIMATE/PROGRAMA/ing1/alcohol.htm>.

For information on the Baylor fuels program, ethanol STCs, etc., write the Renewable Aviation Fuels Development Center, Baylor University Aviation Sciences Dept., P.O. Box 97413, Waco, TX 76798. Phone: (254) 710-3563.

A Case for Biofuels in Aviation

by M.E. Shauck and M.G. Zanin
Renewable Aviation Fuels Development Center
Baylor University, Waco, TX 76798-7413

In the last 15 years, the technical and the economic feasibility of biomass based fuels for general aviation piston engines has been proven. Exhaustive ground and flight tests performed at the Renewable Aviation Fuels Development Center (RAFDC) using ethanol, ethanol/methanol blends, and ETBE have proven these fuels to be superior to aviation gasoline (avgas) in all aspects of performance except range. Two series of Lycoming engines have been certified. Record flights, including a transatlantic flight on pure ethanol, were made to demonstrate the reliability of the fuel. Aerobatic demonstrations with aircraft powered by ethanol, ethanol/methanol, and ETBE were flown at major airshows around the world.

The use of bio-based fuels for aviation will benefit energy security and improve the balance of trade, domestic economy, and environmental quality. The United States has the resources to supply the aviation community's needs with a domestically produced fuel using currently available technology. The adoption of a renewable fuel in place of conventional petroleum-based fuels for aviation piston and turbine engines is long overdue.

Introduction

Mandates of the Clean Air Act Amendments of 1990 banning lead from all motor fuels have prompted an effort to find an unleaded alternative to the existing aviation fuel. Avgas is today the single largest contributor of lead in the atmosphere in the U.S. Environmental regulations have forced oil companies to use dedicated systems for the production and distribution of avgas. As a result of its special handling requirements and low sales volume, it is predicted that the oil companies will eventually quit avgas production. For this reason, pilot organizations, the Federal Aviation Administration (FAA), engine manufacturers, and some of the producing companies, are all searching for a replacement aviation fuel.

The main difficulty in manufacturing an unleaded gasoline for aviation is the high octane needed by many aircraft engines. The American Society for Testing Materials (ASTM) has formed committees to direct the search for an unleaded fuel suitable for aviation. Guidelines on the specifications of the fuel were suggested by the General Aviation Manufacturers Association (GAMA), but progress has been slow. Results obtained from testing various blends of fuels have been presented to the ASTM committee, but none of them, as of today, completely satisfies the requirements set for the new fuel.

Because of these difficulties, the current consensus among the organizations involved in the research is to settle for a fuel of between 96 to 98 octane. Accordingly, the FAA Technical Center is testing various fuels in various engines, trying to determine a minimum octane rating which will meet the needs of the general aviation fleet. The development of a fuel with a lower than 100 octane rating could satisfy the requirements of about 70% of the general aviation aircraft in the U.S. fleet. However, the remaining 30% of the fleet requires 100 octane fuel, and it uses 80 % of the aviation fuel sold in this country.

There is also a need to find an alternative to Jet A which is used throughout the world in all turbine powered aircraft. This need is prompted by environmental concerns about particulate pollution caused by this fuel. Particularly vulnerable to this pollution is the region of the tropopause along the heavily traveled North Atlantic corridor. Pollutants in this fragile environment have a much longer residence time than at lower altitudes and consequently have a magnified impact. Studies have shown that blends of biodiesel into Jet A decrease these emissions. It is expected that ETBE will have the same effect. RAFDC is in the process of conducting both ground and flight tests to determine performance and emission levels of blends of biodiesel and ETBE in Jet A.

Technical Considerations

In November 1995, RAFDC hosted the "First International Conference on Alternative Aviation Fuels" at Baylor University in Waco, Texas. Major support for this conference was granted by the U.S. Department of Energy, the FAA, Baylor University, and Texas State Technical College. Aviation experts from Brazil, Canada, France, Greece, Italy, Sweden, and the United States gathered to discuss the future of aviation fuels. Government agencies, oil companies, academic institutions, aircraft manufacturers, state energy offices, state aviation organizations, and media were represented. Organized to reflect all viewpoints, the speakers and panelists included both supporters of unleaded petroleum based fuels and those who favored renewable biomass alternatives.

Although disagreeing on the solution, everyone agreed on the problem—the days of 100LL aviation gasoline are numbered.

At the conference, the proponents of the "petroleum solution" enumerated both real and alleged problems with biomass fuels. A "legitimate problem" is the loss in range caused by the lower energy density of biomass fuels. Petroleum fuel proponents assume that the loss of range in an aircraft powered by ethanol is directly proportional to the caloric content of ethanol when compared to gasoline's (40% less). But, extensive ground and flight tests have shown that the range loss varies from a maximum of 25% with 7:1 compression ratio engines, down to 10% range loss for engines with 10.5:1 compression ratio. Brazil's experience has shown that automobile engines using ethanol achieve optimum mileage at a compression ratio of approximately 12.2:1. RAFDC, under a contract with the FAA, will be testing aircraft engines with compression ratios as high as 13:1.

Many of the petroleum fuel proponents at the conference were not aware of the substantial increase in performance when operating on ethanol. The higher latent heat of vaporization results in an increase in volumetric efficiency which produces more power and lower operating temperatures. The wider range of flammability produces smoother combustion and decreases the likelihood of inappropriate combustion. Additionally, it causes less internal engine buildup of combustion byproducts. All of these factors combined to prompt the FAA Designated Engineering Representative (DER) who witnessed the certification of the

Lycoming IO-540 to estimate that the time between overhaul (TBO) for engines operating on pure ethanol could easily be increased by 100%.

The issue of materials compatibility was also raised during the conference. RAFDC had experienced problems caused by the interaction between ethanol and aluminum. The problem was solved by anodizing all fuel-wetted aluminum parts. However, the ethanol industry, experiencing the same problem with its storage tanks, began adding an antioxidant to the ethanol. This additive prevents the reaction between ethanol and aluminum thereby eliminating the need for additional alterations.

To ensure that there are no other materials compatibility problems, RAFDC conducted soak tests of elastomers and metallic components. In addition, RAFDC had Southwest Research Inc. (SWRI) of San Antonio conduct materials compatibility, luminosity, and lubricity tests on denatured ethanol, a 50/50 blend of ethanol and methanol, and avgas. This extensive testing showed no adverse effects on any materials (besides aluminum), acceptable luminosity characteristics, and slightly better lubricity properties than avgas (it should be pointed out that the difference between the lubricity of ethanol and avgas was so slight as to fall in the range of experimental error; consequently, we assume the lubricity of ethanol and avgas to be about the same). The lubricity test results were a surprise, as even ethanol proponents believed that it would be necessary to add a top lubricant when using ethanol as a neat fuel. The results of all these tests were corroborated during the 150 hour engine test stand certification of the IO-540. On all measured components (as part of the procedure certain components are measured before and after the test), equal or less wear was measured than is usually detected during similar tests on avgas. This was probably due to a combination of smoother operating characteristics, adequate lubricity, cooler operating temperatures and less internal combustion byproduct buildups.

RAFDC has obtained FAA certifications for two series of aircraft engines and certification of a training aircraft and an agricultural aircraft are expected to be completed shortly. One series of aircraft engines certified is fuel injected while the other is carbureted. Thus, FAA approval has been received for engines whose delivery systems cover all the range of those in use. This ex-

perience will considerably simplify and shorten the process in pursuing further engine certifications.

During the conference, most of the issues raised in opposition to biofuels by the petroleum fuel faction were refuted. A Brazilian participant related his country's experience with ethanol, pointing out that in Brazil, 4.3 million vehicles operate on neat ethanol and there are no unsolved technical problems whatsoever.

Even if there was no consensus at the conference among the attendees as to what the next fuel for General Aviation will be, at least there was dialogue. The main purpose of the conference was to exchange information, and this was accomplished. Everybody at least agreed that general aviation is facing a serious problem.

Market Potential: Reciprocating and Turbine Engines

The piston engine fleet in the United States uses approximately 305 million gallons of avgas per year. In the next few years, as stated above, due to a variety of regulatory and economic reasons, 100LL avgas will have to be replaced. Development of other unleaded petroleum alternatives is underway, but none of these, as of today, has an adequate octane rating to satisfy the needs of the 30% of aircraft that burn 80% of the avgas. The octane number of a fuel is a measurement of its resistance to detonation. Ethanol exhibited better detonation resistance than avgas during the FAA certification tests. Consequently, at the very least, ethanol should be the fuel of choice for the aircraft requiring a high octane fuel, which consists of a market of 240 million gallons per year of fuel.

The turbine fuel market in the United States consists of 16.4 billion gallons per year. RAFDC is planning to test blends of 20% biofuels in Jet A. The adoption of such a blend would result in an enormous expansion of the renewable fuels industry and a reduction of over 3 billion gallons a year of imported oil. The potential environmental benefits are a powerful impetus for the development of a biofuel blended turbine fuel.

Implementation Strategy

There are two major impediments to the

commercial success of ethanol in General Aviation. The first is not surprising. It is the opposition of the petroleum industry. The second is the lack of public education and general complacency concerning the issue of alternative fuels. Lack of knowledge among organizations and agencies also results in insufficient support for this program and consequent slow progress in implementing ethanol as an aviation fuel.

"In Brazil, 4.3 million vehicles operate on neat ethanol and there are no unsolved technical problems whatsoever."

Since distribution of ethanol for General Aviation could initially represent a problem, RAFDC intends to initially target flight schools and agricultural operations since the aircraft engaged in these activities almost always refuel at a single location.

RAFDC has conducted flight demonstrations, forums, and workshops in conjunction with aviation events for the past 15 years. With the certification of a training aircraft and an agricultural spray aircraft, RAFDC will continue to concentrate on these types of activities to encourage operators to use ethanol and help them to convert their fleets.

It is expected that the current placement of E-85 pumps around the country, as part of the National Ethanol Vehicle Program, will greatly benefit the implementation of ethanol as an aviation fuel.

Conclusion

The necessary technology to establish the adoption of a biobased fuel for piston engine aircraft is available.

This is a market for which ethanol has distinct performance advantages and is competitive at today's ethanol prices. With the demise of 100LL avgas on the horizon, and the competitive economic position of ethanol versus even the existing aviation fuel, the potential success of this program is unquestionable.

Aviation gasoline represents a potential market of 305 million gallons per year. Organizations representing the farming interest and ethanol producers should seriously consider supporting this effort. Gaining the aviation market could, in addition to providing a substantial expansion in the ethanol industry, contribute to a public acceptance of ethanol as a general transportation fuel. □

ADVANCES OF ALCOHOL FUELS IN THE WORLD

ISAF XI

Beijing, China

1998



PROCEEDINGS
OF

XII INTERNATIONAL SYMPOSIUM ON
ALCOHOL FUELS

BEIJING, CHINA

21—24 SEPTEMBER, 1998

Editors

Zhu Qiming

Pan Kuirun

Pan Wei

Huang Zhaoxiang

Huang Weiguo

Liang Yu

Tsinghua University Press

<http://www.tup.tsinghua.edu.cn>



PERFORMANCE AND EMISSIONS COMPARISON BETWEEN AVGAS, ETHANOL AND ETBE IN AN AIRCRAFT ENGINE

Johnson Gary, Shauck Maxwell, Zanin Grazia

*Renewable Aviation Fuels Development Center
Department of Aviation Sciences, Baylor University
P. O. Box 97413, Waco, Texas 76798, USA*

Abstract

Baylor University's Renewable Aviation Fuels Development Center (RAFDC) has been involved for the last 18 years in the research, development and certification of bio-based fuels as alternatives to the leaded gasoline used in general aviation's piston engine aircraft.

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 fuel which contributes lead to the atmosphere is Avgas.

The Federal Aviation Administration (FAA) is currently providing research support to RAFDC in order to improve the efficiency of aircraft engines on alternative bio-based fuels and to measure and compare their performance and emissions. Three fuels are being compared: Avgas, ethanol and Ethyl Tertiary Butyl Ether (ETBE). All of these fuels have been interchangeably used in aircraft during extensive test flights. Currently, an aircraft engine, a Lycoming IO-360, is installed in a test stand and dynamometer tests are being conducted on the three fuels. Data is being recorded, analyzed and compared on the performance and emissions of the engine.

Program Overview

The Baylor University's Renewable Aviation Fuels Development Center (RAFDC) objective is to establish renewable fuels as alternative fuels to the leaded aviation gasoline currently used by General Aviation.

The United States currently consumes over 300 million gallons of Avgas each year. While aviation fuel represents only a small fraction of the gasoline market in this country, as a result of reducing lead in other fuels, the 100LL is now the single largest contributor of lead into the atmosphere. Although Avgas has been temporarily exempted from the CAAA mandate it is understood by the U.S. aviation industry that its use must soon be discontinued in its current form.

As of today, there is no petroleum alternative that can reach the 100 octane required by the high compression aviation engines.

Oxygenated alcohol fuels such as ethanol and ETBE burn cleaner and cooler than Avgas, prolong engine life, deliver more power, and will likely present a cheaper option as fuel supplies become more readily available.

The RAFDC has been testing ethanol, methanol, various blends of the two, and

ETBE in reciprocating engines. As a result of RAFDC's work, two Supplemental Type Certificates (STC) were granted by the Federal Aviation Administration (FAA) for two series of Lycoming engines to operate on pure ethanol. These certificates represent a significant achievement since they are the first official FAA recognition of the viability of ethanol as an airworthy alternative fuel. Additionally, the most common training aircraft in the world, the Cessna 152, has received FAA certification to use 100% denatured ethanol as its fuel. The Cessna 152 used by RAFDC for certification, is currently being instrumented to be employed during the Summer of 1998 in air monitoring investigations in the state of Texas. Another aircraft type is in the process of obtaining FAA certification to use ethanol as a fuel in commercial operations.

The development of ethanol as a transportation fuel is motivated by environmental imperatives such as the need to replace lead in gasoline, to provide oxygen to lower carbon monoxide levels, to reduce carcinogenic or highly photochemically reactive aromatic hydrocarbons and to reduce the quantity of CO₂ in the atmosphere.

RAFDC has also been evaluating ethyl-tertiary-butyl-ether (ETBE) as a fuel for aviation. An aircraft using 100% ETBE has performed at the world's largest airshow in Paris, France, in 1995. This aircraft, currently employed in airshows and demonstrations, uses alternatively Avgas, ethanol or ETBE.

As part of the search for alternatives to aviation gasoline, RAFDC has received a grant from the FAA Technical Center to improve the efficiencies of ethanol powered

aircraft engines and to test other non-petroleum alternatives to aviation fuel.

A fuel injected Lycoming IO-360 is the engine being tested on a Superflow dynamometer at the RAFDC's test-stand facilities. The injection unit is a modified Bendix/Precision Automotive RSA-5 AD1, in which the passages in the mixture plate and lower idle valves are enlarged. It is coupled with a standard flow divider and larger injectors.

Fuel Characteristics

Ethanol is a high octane (111.7 motor), high oxygen content fuel that burns more completely than gasoline in the combustion chamber. With simple modification to the fuel system to allow more fuel flow, ethanol burns cooler and cleaner, it resists detonation and it produces higher thermal efficiency and power than combustion of gasoline in a conventional engine. Due to the low Reid Vapor Pressure (RVP), an ethanol powered aircraft will have less tendency to vapor lock than a gasoline powered aircraft.

The only drawback associated with the use of ethanol is a slight reduction in range (20 to 10 percent depending on engine compression ratio) due to its lower caloric content. (See the characteristics comparison in table 1 --"EtOH" refers to ethanol.)

ETBE is another oxygenated fuel. It is used as an octane enhancer in motor gasoline and has numerous technical characteristics that make it a valuable blendstock for reformulated gasoline. ETBE is produced from ethanol and isobutylene, produced from domestic natural gas liquids or obtained as a co-product in domestic oil refining and petrochemical production. ETBE is composed of 43% by volume of ethanol.

Neat ETBE has a Reid Vapor Pressure of 27.5 KPa and a desirable low blending RVP of 31.0 KPa (for concentrations giving 2.7% oxygen) that is not affected by the RVP of the basic gasoline.

ETBE's high motor octane number (98 to 104) allows a higher compression ratio in the engine which improves fuel efficiency.

Table 1 - Fuel Characteristics

item	avgas ¹	EtOH ²	ETBE ³
mass % oxygen	0.0	34.7	15.7
motor octane	100	112	98-104
caloric value*, MJ/kg	44.2	27.2	36.0
stoich. A/F	14.7	9.0	12.2
specific gravity	.69-.79	.789	.746
RVP, K Pa	38-48	16	30
latent heat, MJ/kg	.34-.35	.92	.31
normal BP, C	66	78	73
solvent type	nonp.	polar	nonp.

* lower caloric value shown, with water uncondensed, for all three fuels

Engine Tests

Performance and emission data were only obtained after the engine was warmed up, as evidenced by cylinder head temperatures exceeding 93 C and oil inlet temperatures exceeding 32 C. The engine was mapped over a wider range of throttle and rpm settings than can be obtained with a fixed-pitch propeller. From that larger set of data, the full power and maximum cruise data were abstracted for reporting herein.

The procedure used to set mixture was the source of most of the variability in the fuel consumption and emissions data. Power performance was relatively unaffected by this variable. Since the dynamometer

testing was done in fully manual mode, without dyno servo control of speed, it was possible to "peak" the rpm with mixture as a measure of "power" or "rich" mixture. "Lean" mixture was defined by leaning until the engine began to stumble, and then enriching slightly to smooth out the operation.

Full Power Performance

The full throttle power curves for all three fuels are shown in figure 1. These data have been corrected to sea level standard conditions by the ratio of atmospheric pressures and by the square root of the ratio of air inlet temperatures. Both alternative fuels produce more power in this engine than avgas, at the same conditions. The power increases obtained do, in fact, rank in order of increasing oxygen content, with ethanol the highest.

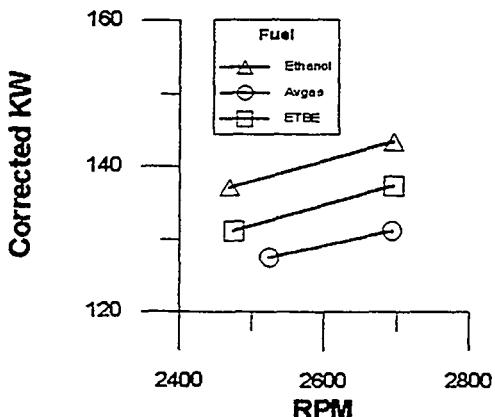


Figure 1 - Full Power Comparisons

The power obtained on avgas in these tests is slightly below the nominal rating for this engine (134 KW), as measured at 2700 rpm. The difference may be attributed to the air resistance of the air flowmeter and the long air inlet flex hose necessary in the test configuration. This avgas curve should be the basis from which any fuel power comparisons are made, not the nominal rating.

Figure 2 is a plot of air consumption vs thermal efficiency for the three fuels in this engine. Thermal efficiency was calculated directly from power, fuel flow measurements, and each fuel's lower caloric (or lower heating) value. Air consumption reflects volumetric efficiency. Ethanol and ETBE both show significantly higher power and efficiency, but only ethanol shows increased air consumption.

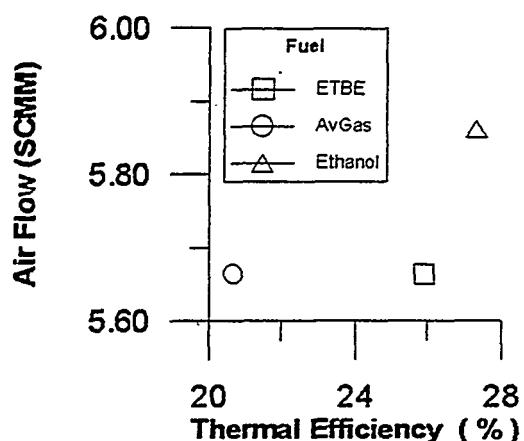


Figure 2 - Full Power Thermal Efficiency

The increase in efficiency with these alternative fuels is due in part to the higher charge density brought about cooling from fuel evaporation. Ethanol's latent heat is substantially higher than avgas, so this effect is considerable. However, ETBE has a slightly lower latent heat than avgas, so incoming charge cooling plays little or no role in that case, yet it is also more efficient.

Therefore, physical-chemical effects must play a strong role. ETBE (and ethanol) contain no multiply-bonded carbon chains or ring compounds, items long known as hard to combust efficiently at very short time scales. By testing these three particular fuels to eliminate latent heat as a variable, RAFDC was able to positively identify this physical-chemical effect in actual test data.

Cruise Fuel Consumption

Brake specific fuel consumption data at cruise conditions vs lower heating value are shown in figure 7. The normal assumption made in estimating consumption for alternate fuels is the simple heating value ratio. The data clearly shows that these fuels exhibit higher thermal efficiency since consumption of ethanol and ETBE is not linearly related to the heating value ratio.

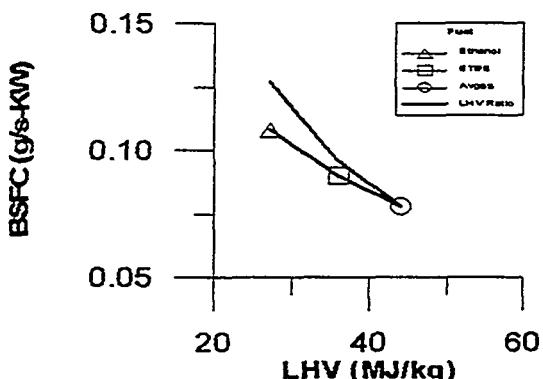


Figure 7 - Cruise Fuel Consumption

The difference is large enough to be evident in spite of the qualitative procedures used to establish mixture settings in these tests. In fact, fuel consumption trends at full power are even more favorable to the alternate fuels.

Full Power Emissions

Full power emissions (figs 3, 4, 5, and 6) reflect increased efficiency with the alternative fuels. The formation of NOx compounds and the complete combustion of carbon to the dioxide form are associated with hotter flames and more efficient combustion. Likewise, exhaust hydrocarbons (unburned fuel) and incompletely oxidized carbon (monoxide) are associated with lower efficiency and cooler flames. The full-power emissions rank in the same order as the corresponding

thermal efficiencies, with enough contrast from max to min values to overcome the natural variability in such measurements. Emission levels are consistent with the full rich mixture setting used at full power.

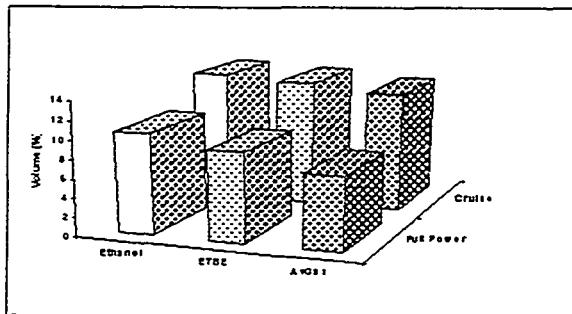


Figure 3 - CO₂ Emissions

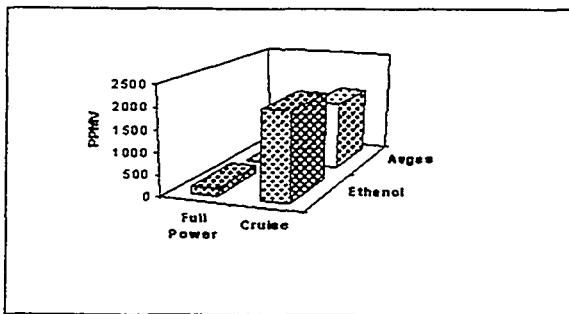


Figure 4 - NOx Emissions

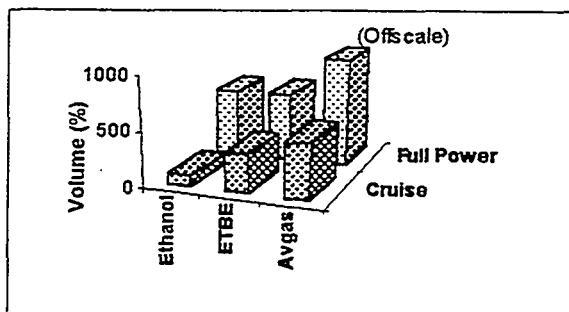


Figure 5 - Unburned Hydrocarbons

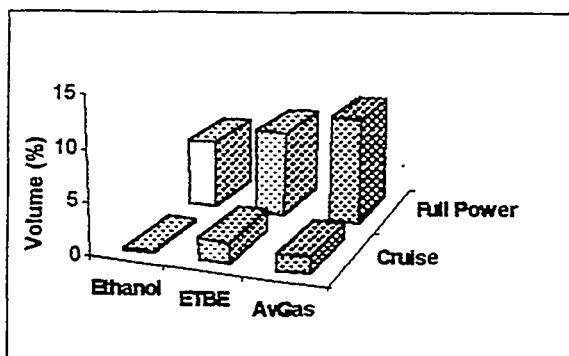


Figure 6 - CO Emissions

Cruise Emissions

The corresponding emissions data for max cruise are also shown in figs 3, 4, 5, and 6. The contrast from max to min is generally less than at full power, but the same ranking with thermal efficiency is evident. The levels are quite different from full power, consistent with the leaned cruise mixture setting.

Conclusion

The commercial viability of renewable clean burning fuels is increasing. Among the reasons: rapidly expanding global demand for transportation fuels with resulting rapid price increases are inevitable in the near future; environmental degradation associated with emissions from the use of fossil fuels is becoming a growing problem.

In this paper the emissions of ethanol and ETBE have been compared with those of aviation gasoline in a Lycoming IO-360 aircraft engine. Ethanol and ETBE emissions of hydrocarbons measured less than 50% of those on avgas. Although emissions of CO₂ for avgas, ETBE and ethanol are very close, the actual net increase when using ethanol is much less than avgas since the biomass used to produce ethanol sequesters CO₂.

Ethanol emissions of NOx showed an 18.5% increase compared to avgas.

Carbon monoxide levels in avgas emissions measured 40% greater than those of ethanol, and 20% greater than those of ETBE.

All of the above comparisons were made at full power and full rich mixture settings.

During previous certification tests of ethanol on calibrated test stands, attempts to induce detonation by standard procedures of abrupt leaning at full power with cylinder head temperatures held at red line, failed to induce it. This experience is consistent with the motor octane rating of 111.7 for ethanol compared with 99.6 for avgas. Avgas requires TEL to achieve its high octane number and is the only fuel still containing lead. Ethanol requires no additive to achieve its high octane number.

The most critical performance characteristic of an aviation fuel is the power available. At full power, ETBE developed about 5% more power than avgas, and ethanol developed about 9% more power than avgas.

Although not shown, the full-power, full-rich Brake Specific Fuel Consumption (BSFC) of ETBE and avgas was essentially identical, while that of ethanol was measured at only about 15% more. (Compare these actual data with expectations of 23 and 62% more consumption based on the heating value ratio.) This data is consistent with previous results both in flight and during tests performed on other test stands. Flight test data has shown a 10 to 15 percent reduction in range operating on neat ethanol compared with range on avgas.

These results have shown that both ETBE and ethanol are overall cleaner burning fuels than avgas and while ethanol use suffers a small range reduction, as expected, it increases power available.

Since the lead must come out of avgas, the issue of octane becomes very important, particularly for those engines which are octane critical now. These engines use a

very substantial amount of the total fuel consumed in the U.S. since they are used on the larger piston engine twin engine aircraft. These aircraft typically fly many times the hours flown on small low powered aircraft. Thus the issue is an economic one as well as environmental.

Since the quality of emissions will be a driving force in the choice of the new aviation fuel for the general aviation piston engine fleet, it is important to note that, overall, both ETBE and ethanol are cleaner fuels than avgas.

References

- (1) Coordinating Research Council, Inc, CRC Report 530 "Handbook of Aviation Fuel Properties", 3rd printing, published by Society of Automotive Engineers (SAE), Warrendale, PA, USA, May 1988.
- (2) Bailey and Russell, SAE Paper 810444 "Emergency Transportation Fuels: Properties and Performance", publ. SAE, Warrendale, PA, USA, 1981.
- (3) taken from properties supplied by the manufacturer.

Acknowledgments

This work would not have been possible without support from the U.S. Federal Aviation Administration's Technical Center, and from the U.S. Department of Energy.



**MAKING A BUSINESS
FROM
BIOMASS
IN
ENERGY, ENVIRONMENT, CHEMICALS,
FIBERS, AND MATERIALS**

**PROCEEDINGS OF THE THIRD BIOMASS
CONFERENCE OF THE AMERICAS**

Montréal, Québec, Canada August 24-29 1997

IMPLEMENTATION OF ALTERNATIVE BIO-BASED FUELS IN AVIATION: THE CLEAN AIRPORTS PROGRAM

M.E. Shauck and M.G. Zanin

**Renewable Aviation Fuels Development Center
Department of Aviation Sciences Box 97413
Baylor University, Waco, Texas 76798 USA**

ABSTRACT

The Renewable Aviation Fuels Development Center at Baylor University in Waco, Texas, was designated, in March 1996, by the US Department of Energy (US DOE) as the national coordinator of the Clean Airports Program. This program, a spin-off of the Clean Cities Program, was initiated to increase the use of alternative fuels in aviation.

There are two major fuels used in aviation today, the current piston engine aviation gasoline, and the current turbine engine fuel. The environmental impact of each of these fuels is significant. Aviation Gasoline (100LL), currently used in the General Aviation piston engine fleet, contributes 100% of the emissions containing lead in the USA today. In the case of the turbine engine fuel (Jet fuel), there are two major environmental impacts to be considered: the local, in the vicinity of the airports, and the global impact on climate change.

The Clean Airports Program was established to promote the use of clean burning fuels in order to achieve and maintain clean air at and in the vicinities of airports through the use of alternative fuel-powered air and ground transportation vehicles.

Keywords: renewable, alternative aviation fuels, clean airports, turbine, jet fuel, pollution

BACKGROUND

Local, state and national governmental entities, along with many private individuals and companies are currently engaged in the effort to improve the quality of the air while at the same time reducing the United States' dependence on imported petroleum.

Several federal, state and local laws and ordinances have been enacted to address the problem, but the use of petroleum-based fuels continues to degrade the quality of the air, representing a health hazard for the population and endangering the environment. Furthermore, we continue to import higher percentages of petroleum, therefore increasing our economic and political vulnerability by becoming more dependent for our oil supplies on politically unstable nations.

Airports are major centers of transportation and commercial activities and consequently areas of massive fuel combustion. Recognizing the fact that airports, while being essential to the economic development of a community, are also major sources of pollution, the Department of Energy's/Baylor University's Clean Airports Program is targeting airports to encourage and facilitate the conversion of aircraft, ground support vehicles, and airport's equipment to clean burning alternative fuels. This new initiative is called the Clean Airports Program. This program is based on the Department of Energy's successful Clean Cities Program.

With the knowledge and experience gained at RAFDC in developing ethanol as an aviation fuel, air as well as ground transportation vehicles are now capable of efficient, safe, clean and economical operations. The use of alternative, clean, domestically produced fuels in aviation is a significant step toward clean air and energy independence.

WHY CLEAN AIRPORTS

The aviation community is confronted today with a great challenge: working to ameliorate a major cause of environmental and health concern. Fuel combustion at airports, in their vicinities and in the higher levels of the atmosphere is increasingly becoming a threat to human health and to the environment. There are two major fuel related issues in question: pollution from jet fuel use (commercial and military aircraft), and the phase-out of leaded aviation gasoline (general aviation).

Pollution from jet fuel use

Jet fuel, used by commercial and military aviation worldwide, is a cause of concern on two different levels: local pollution at airports and in their vicinities, and global impact on climate change.

Local Pollution at Airports. Ground level ozone is formed when oxides of nitrogen (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight. Ozone is the most serious air pollution problem in the United States. Children under the age of 13, adults over 65 and people with respiratory illnesses are the most susceptible to being affected by high levels of ozone. Approximately 62 million people in these categories live in areas designated as ozone non attainment areas (American Lung Association, 1993). These are regions which violate existing federal ambient air quality standards. In addition to posing health problems, high levels of ozone cause several billions of dollars of damage annually. Ozone also causes extensive damage in the industrial sector by accelerating the aging process in various materials.

An example of the seriousness of the problem caused by aircraft emissions is the contribution of pollution from the New York City's airports. According to a study conducted in 1994, Kennedy airport was found to be the single largest contributor of NOx and the second largest contributor of VOCs. LaGuardia Airport was the fourth largest contributor of NOx and third largest contributor of VOCs (FAA, 1993). Airline passenger miles are growing twice as fast as ground vehicle miles, consequently, airlines will contribute increasingly larger percentages of pollution (Gordon, 1991).

Ozone pollution is targeted by the Clean Air Act Amendments (CAAA) of 1990 which established health based standards for NOx, VOCs, ozone and other pollutants. Areas that fail to meet these standards are required to develop State Implementation Plans (SIPs). SIPs are plans to reduce emissions within the non attainment areas to attain compliance with the regulations. Ozone SIPs attempt to reduce VOCs and NOx emissions one source at a time. As part of an ozone SIP, power plants, industries, commercial activities, and private car owners can be asked by the state to reduce emissions.

It is peculiar, therefore, that aircraft emissions at even the largest airports are not yet regulated by the SIP process. Since 30 of the busiest airports are in ozone non-attainment areas, some sort of regulatory action is bound to be enacted.

Global impact on climate change. Measurements of air quality at heights between 9 and 12 km. in the North Atlantic flying corridor, were made by the German Research Department for Air & Space Travel (DLR). NOx, Ozone, CO₂, Water Vapor, and other air traffic emission products were analyzed. The data collected proved that emissions of air traffic cause great concentrations of air pollutants in traffic corridors. The following remarks are excerpts from an article published in Germany on this study (Von Stamm, 1995).

"Jet aircraft emissions are so dangerous because they are emitted directly into the upper atmosphere. In the troposphere, where the mixing and weather phenomena take place, rain washes pollutants out in a short time (days or weeks). In the tropopause, the effects of exhaust gases increase because of lower temperatures. The stratosphere, which is above the tropopause, is even more sensitive because of the lack of vertical movement, the pollutants have more residence time and accumulate in the traffic corridors. In those corridors, 44% of the fuel is burned and 5% of NOx is emitted. At higher altitudes of the stratosphere, at lower temperatures, nitrous oxide (NO) destroys the ozone layer, which should protect life on Earth from UV-B-radiation. Furthermore, sulfur dioxide and the soot particles magnify the destructive power of the ozone-killer Chlorine, which is set free from fluoro-chloro-hydrocarbons in the stratosphere."

"The effect on the climate of an airline flight to Brazil (for a single person) is equal to 4.5 times that of a land vehicle for an entire year. A flight to Rio, for a single passenger, is therefore as harmful as 4 and a half years of driving by car, while a domestic flight equals the harmfulness of one passenger's year total traffic by car, bus and rail."

"In the next 10 years the worldwide number of airline passengers will double. Passengers flying on Pacific routes will quadruple while 15,000 more aircraft will be flying around the globe. If one takes into account the expected rate of growth in air traffic and the catastrophic effects of jet emissions in sensitive climate zones, then the air polluting potential of air traffic will rise in ten years from the supposed current 3.9% of total pollution to almost 50%."

"Despite the introduction of more modern and cleaner jet engines, the load of pollutants caused by air traffic will increase rather than decrease in the future as a result of the enormous rate of growth of the industry."

RAFDC is initiating a research program to test blends of Jet fuel with Biodiesel and ETBE. The purpose of the program is to clean up fuel's emissions. Accordingly, emission testing will be an important part of the project. The best performing blends will then be used in one of the two engines of RAFDC's King Air, an aircraft fully instrumented to perform airborne air pollution monitoring.

Phase-out of Leaded Aviation Gasoline

The phase-out of tetraethyl lead from motor fuel in the U.S., as mandated by the Clean Air Act, is a cause of great concern to the aviation industry. The industry standard is a 100 octane, leaded fuel known as 100 LL (low lead). Since the phase out of lead from the rest of the motor fuel, Avgas is the only remaining leaded fuel in the United States. Although a temporary informal waiver has been granted by the Environmental Protection Agency (EPA) to general aviation, EPA and the California Air Resources Board have considered regulating the use of this fuel in order to eliminate hazardous air pollutants.

The Federal Aviation Administration, aircraft manufacturers, engine manufacturers, professional aviation organization and the oil industry are attempting to develop an alternative to the leaded aviation gasoline (AVGAS) used in today's piston engine aircraft. Following are some of the economic and regulatory reasons, urging the development of an unleaded aviation fuel:

- To avoid lead contamination, fuel suppliers are not able to transport leaded fuels in either pipelines or tankers used to carry unleaded fuels.
- In the future, used oil from engines using leaded gas will likely be classified as toxic waste.
- The Montreal Protocol requires elimination of all use of ethyl-di-bromide by 1998. This lead scavenger is necessary in any engine using lead additives.
- According to the most current public information, existing alternate octane boosters cannot achieve the standard 100 octane. A substandard octane fuel, now under consideration, could not be used in certain aircraft engines which consume almost 1/2 of the fuel used today.
- Increased use of alkylates in the new reformulated gasolines for automobiles will cause the price to increase and could result in supply shortages for their use in Avgas production.

- Piston aviation engines emissions are not yet regulated. Volatile organic compounds and nitrogen oxides are being investigated by the EPA.

Many attempts have been made to develop an acceptable gasoline-based replacement fuel. Difficulties in producing such a fuel that satisfies both technical and economic guidelines are due to the high octane requirements, high costs of its constituents and environmental considerations.

A program at the Renewable Aviation Fuels Development Center (RAFDC) at Baylor University has proven, in the course of seventeen years of research and development, that 100% denatured ethanol has all the desired technical characteristics to replace 100 LL Avgas (Shauck and Zanin, 1992).

Ethanol is a high octane alternative fuel that can be easily adopted for use in small aircraft. Engines can be modified to use ethanol with relatively minor adjustments. Not only are there numerous performance advantages with ethanol, including smoother operation, increased power, and superior resistance to knocking, but it also enjoys a relative cost advantage compared to Avgas. In addition, since ethanol burns cleaner than petroleum-based fuels, there are also significant environmental benefits.

All of the aircraft modified to use ethanol are for all practical purposes flexible fuel aircraft, since they can burn either ethanol, ETBE, gasoline, or any mixture of these fuels.

Ethanol is currently being demonstrated on a widescale basis, and has received FAA certification for use in two series of aircraft engines and in the most popular training aircraft in the world, the Cessna 152 (Shauck and Zanin, 1997).

CLEAN AIRPORTS IMPLEMENTATION

The goal of this program is to implement the use of alternative, clean fuels at airports by providing a refueling facility for alternative fuels. To apply for designation as a clean airport, it will be necessary to enlist stakeholders to coordinate and oversee the program, to draft and sign a Memorandum of Understanding (MOU) among them, and to appoint a Clean Airport Coordinator. If the criteria are not met at the time of designation, commitments have to be made to develop a program and the facilities in a timely manner. In brief, the criteria are the following (a Clean Airports Program brochure produced by the U.S. DOE is available to the public to further clarify details):

General Aviation Airports

- Appoint a clean airport coordinator
- Form a stakeholder committee
- Develop a program plan

The program plan will include a schedule to fulfill the following goals:

- The airport will serve as home base for at least one alternatively fueled aircraft
- The airport will have refueling infrastructure for at least one type of alternative fueled aircraft
- The airport will use alternative fuels in at least some of its ground vehicles
- Establish a public awareness campaign about alternative fuels (such as a display or an education program or a demonstration program)

The Clean Airports Program establishes local partnerships among a particular group of stakeholders, including fixed base operators university aviation programs, and flying clubs, which are committed to operating aircraft on alternative fuels. Clean Airports partners work directly with local businesses and governments to shepherd them through the goal setting, coalition-building, and commitments process necessary to establish the foundations for an alternative fuels airport.

Commercial Airports

- Appoint a clean airports coordinator
- Form a stakeholder committee
- Develop a program plan

The program plan will include a schedule to fulfill the following goals:

- Develop assessment of current environmental impact of airport
- Develop a set of appropriate environmental goals and the means of realizing these goals
- Establish a public awareness program about the environmental conditions at the airport and the ongoing efforts to improve them

A prominently displayed exhibit in the main terminal of a commercial airport will fulfill this last requirement. Alternative fuel suppliers will provide information on their products and their implementation at the airport. RAFDC would provide information and exhibit material concerning the environmental impact of aircraft fuels, emissions, and possible measures to improve it. Pamphlets and a newsletter will be developed for this exhibit.

RAFDC's Suggested Future Courses of Action:

- Form alliances that include major metropolitan airports and general aviation airports where appropriate (example: Will Rogers-Wiley Post-C. E. Page, airports in the Oklahoma City area under a single airport authority)

- Develop criteria for certification of a clean airport coordinator (suggestions: short courses by distance learning offered on regular basis, periodically scheduled teleconferences to exchange and update information)
- Yearly conference (including workshops and clean airport coordinator certification—possibly, this year, held in conjunction with the 2nd International Conference on Alternative Aviation Fuels at Baylor University, November 6-8)
- Establish a nationwide Newsletter to report progress and share information
- Clean airports can become the base for an airborne air pollution monitoring operation (providing an environmental service for the whole metropolitan area while monitoring transport of air pollutants for the whole region)
- Joint recognition of the program from the FAA, EPA and DOE.

CLEAN AIRPORTS DESIGNATIONS AND FUTURE IMPLEMENTATION

Texas State Technical College (TSTC) airport in Waco, Texas, was the nation's first Clean Airport to be designated in June 1996. This is the airport housing RAFDC's facilities. There is an ethanol fueling site and four aircraft powered by ethanol at this airport. An education/demonstration program has been in place for many years.

The second airport designated in August 1996 was the Morgantown Municipal Airport in Morgantown, West Virginia. The Mechanical and Aerospace Engineering Departments at West Virginia University (WVU) have converted a Cessna 150 to use ethanol as its fuel. A refueling site and an educational exhibit on the project are in place.

In April 1997, McGregor Municipal Airport in McGregor, Texas, was the first non-controlled airport to be designated as Clean Airport. There is a 1000 gallon underground tank dedicated to ethanol. One ethanol powered Pitts Special, an acrobatic aircraft, is based at the airport as well as electrical carts and alternative fuel powered airport equipment.

Another airport, Tea airport in Sioux Falls, South Dakota, is ready to be designated. It has a refueling site in place and six aircraft converted to use ethanol. These aircraft have been involved in demonstration flights around the U.S.

The next airports to be designated, in June 1997, are Will Rogers International Airport and its two satellite airports, Wiley Post and C.E. Page, in Oklahoma City.

Many other airports around the country are interested in the designation. RAFDC is continuously receiving requests for information on the designation procedures.

The program is still new and open to suggestions. A session dedicated to the Clean Airports Program will be held at the 2nd International Conference on Alternative Aviation Fuels on November 6-8, 1997 at Baylor University in Waco, Texas.

By joining the Clean Airports Program, airports could make a significant contribution to the nation's efforts to diversify U.S. fuel consumption patterns and improve air quality by increasing the use of alternative fuels.

CONCLUSION

The United States spends more than \$50 billion each year to import oil, accounting for more than forty percent of the trade deficit. Ninety-seven percent of our total transportation energy comes from oil. Furthermore, U.S. oil consumption is growing while production levels are declining. At this time, the U.S. is over fifty percent dependent on imported oil.

Moreover, transportation use is the single largest (eighty percent) contributor to air pollution in many cities. According to the American Lung Association, approximately \$50 billion is spent each year on health care as a direct result of air pollution.

Airports are major contributors to pollution. The problem facing the aviation industry today is similar to the one the automobile industry had to face approximately 10 years ago: the engines had been cleaned up as much as possible, the only remaining method of improving emissions had to be the reformulation of the fuel.

The aviation industry must develop and implement strategies to deal with its environmental impact in its own self interest, as opposed to resisting change and dealing with drastic regulatory action.

By introducing and encouraging the use of alternative fuels in aircraft and at airports, the U.S. Department of Energy/Baylor University Clean Airports Program actively reduces the nation's energy security burden, improves the environment, and provides new economic opportunities for our country.

REFERENCES

- American Lung Association (1993). "Breath in Danger II", New York
- FAA (1993) "Airports Activity Statistics for Certified Route Carrier, 12 Months ending December 31, 1993"
- Gordon, Deborah, (1991) "Steering a New Course, Transportation, Energy, and the Environment", Union of Concerned Scientists", Pg. 23.
- Shauck, M. E., Zanin, M. G. (1992) "Ethanol in Reciprocating Aircraft Engines" Proc. 1992 AIAA/FAA Joint Symp. on G.A. Sys., Wichita, Kansas.
- Shauck, M. E., Zanin, M. G. (1997) "Certification of the Cessna 152 on 100% Ethanol," Proc. of Intl. Aerospace Congress 97, Sydney, Australia.
- Von Stamm, P., (1995) "Eine Kaseglocke aus Schadstoffen über dem Globus" (German publication received from Dr. Marco Morosini, University of Ulm, Chemistry Department, Ulm, Germany)



INTERNATIONAL AEROSPACE CONGRESS 97

CONGRESS PAPERS

VOL 2

24-27 FEBRUARY 1997
SYDNEY, AUSTRALIA

CERTIFICATION OF THE CESSNA 152 ON 100% ETHANOL

M. E. Shauck, M. G. Zanin
Renewable Aviation Fuels Development Center
Baylor University, Waco, Texas
Tel. (817) 755-3563

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 carbured, 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 $0.8 \times 1.10 = .88$ 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 $16.0 \times .90 = 14.4$ 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($108 \times 1.05 = 113$). 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.

Bibliography

1. SHAUCK, M.E., TURNER, D.W., "Ethanol as an Aviation Fuel," Proceeding of the VI International Symposium on Alcohol Fuels Technology, pp. 352-356, Ottawa, Canada, May, 1984.
2. SHAUCK, M. E., TURNER, D. W., AND RUSSELL, J. A. , "Flight Test Comparison of Avgas Versus Ethanol/Methanol Blends," Proceeding of VII International Symposium on Alcohol Fuels Technology, pp. 402-405. 1986, Paris, France, October, 1986.
3. SHAUCK, M. E., "Performance Report on an Alcohol Powered SIAI Marchetti SF-260 C Aircraft," Proceeding of the VIII International Symposium on Alcohol Fuels Technology, pp. 669-670, Tokyo, Japan, 1988.

4.SHAUCK, M. E., ZANIN, M. G., "Certification of an Aircraft Engine on Ethanol Fuel," Proceeding of the IX International Symposium on Alcohol Fuels Technology, Florence, Italy, November, 1991.

5.SHAUCK, M. E., ZANIN, M.G., "The First Transatlantic Crossing in an Aircraft Powered by Ethanol Fuel" Same as #4.

6.SHAUCK, M.E., ZANIN, M. G., "Ethanol in Reciprocating Aircraft Engines," Proceedings of the 1992 AIAA/FAA Joint Symposium on General Aviation Systems, Wichita, Kansas, March, 1992.

7.SHAUCK, M.E., ZANIN, M.G., "Ethanol as an Aviation Fuel: An Overview of the Program at Baylor University," Proceeding of the X International Symposium on Alcohol Fuels Technology, Colorado Springs, Colorado, November, 1993.

8. SHAUCK, M. E., Tubbs, J., ZANIN, M.G., "Certification of a Carbureted Aircraft Engine on Ethanol Fuel," Proceeding of the FAA Symposium on General Aviation Systems, University of Mississippi, Starkville, Mississippi, May, 1994.

9. SHAUCK, M.E., ZANIN, M.G., "Certification of an Agricultural Spray Aircraft on Ethanol Fuel," Proceedings of The Sixth National Bioenergy Conference, Reno/Sparks, Nevada, October 2-6, 1994.

10. MABEN, G.D., SHAUCK, M.E., ZANIN, M.G., "ETBE as an Aviation Fuel" Proceedings of the XI International Symposium on Alcohol Fuels

Technology (ISAF XI), Sun City, South Africa, April 14-17, 1996.

Acknowledgments

The authors wish to acknowledge the support of the following organizations: Texas Higher Education Coordinating Board (THECB), USDOE Regional Biomass Programs, American Coalition for Ethanol (ACE), and Minnesota Corn Research (MCR).



**ELEVENTH
INTERNATIONAL
SYMPOSIUM
ON
ALCOHOL FUELS**



**SUN CITY
SOUTH AFRICA
14—17 APRIL, 1996**

ETBE AS AN AVIATION FUEL

G. D. Maben, M.E. Shauck, M.G. Zanin
Department of Aviation Sciences
Baylor University
Waco, TX 76798

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. Baseline 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 manufacturers 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.

Acknowledgments

The authors would like to acknowledge the support of the following organizations:

ARCO Chemical Company
Aviation&Pilote (French Aviation Magazine)
Ecofuel S. p. A. (Italy)

Federal Aviation Administration (FAA)
Kiewit Fuels Inc.

References

Ferrara, G. 1994. "Forum on Unleaded Aviation Fuel Program." *Presentation to Experimental Aircraft Association Fly-In*. Oshkosh, WI: Federal Aviation Administration.

GAMA, 1991. *GAMA Suggested Guidelines: Unleaded High Octane Aviation Gasoline Minimum Characteristics*. Ocean City, NJ: General Aviation Manufacturers Association.

Lynd, L.R, J.H Cushman, R.J. Nichols and C.E Wyman. 1991 "Fuel Ethanol from Cellulosic Biomass" *Science*, 251:1318-1323.

MacNair, D. 1995. "Current Search for Petroleum Alternatives to Av-Gas." *Presentation to The First International Conference on Alternative Aviation Fuels*, Waco, TX: Aircraft Owners & Pilots Association.

NTIS. 1992. *Biofuels Program Plan FY 1992 - FY 1995*. Springfield, VA: U.S. National Technical Information Service.

Nussbaum, B. 1991. *Communication with Authors*. Washington, D.C.: Field Operations and Support Division, Office of Mobile Sources, U.S. Environmental Protection Agency.

U.S. Department of Energy's Alternative Fuels Hotline. 1996. *Environmental and Energy Information*. Arlington, VA: Information Resources, Inc.

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

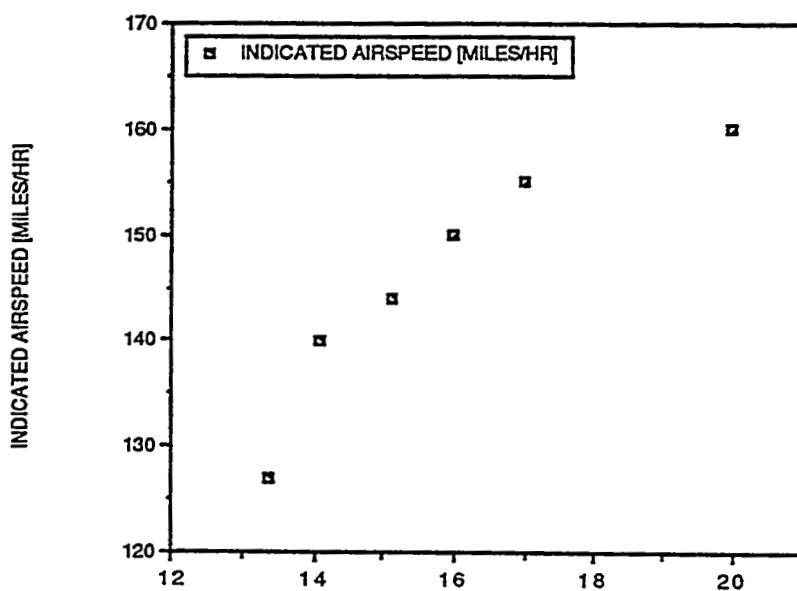
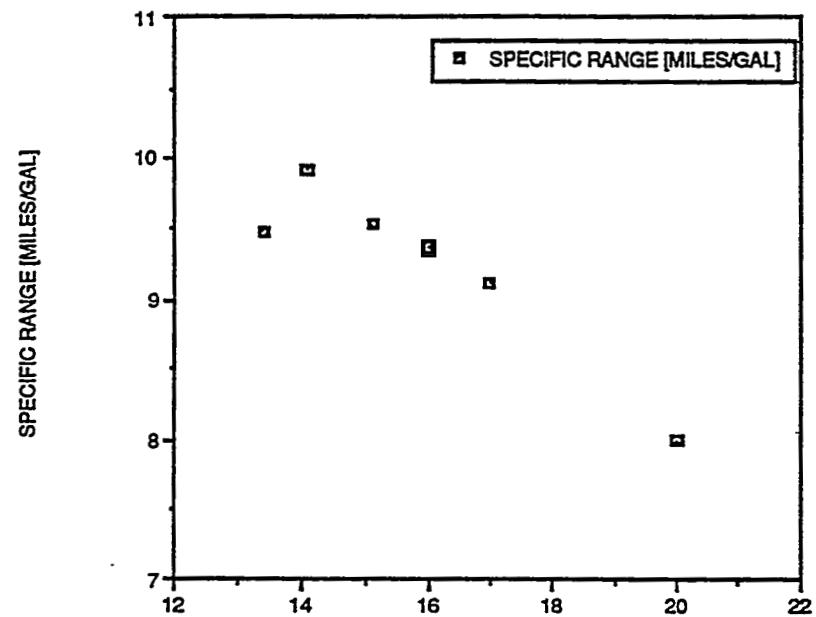


Figure 1

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

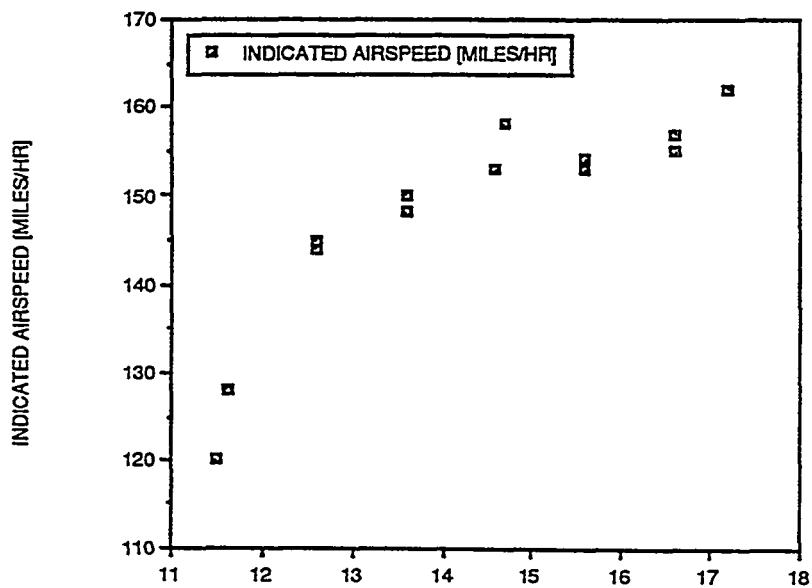
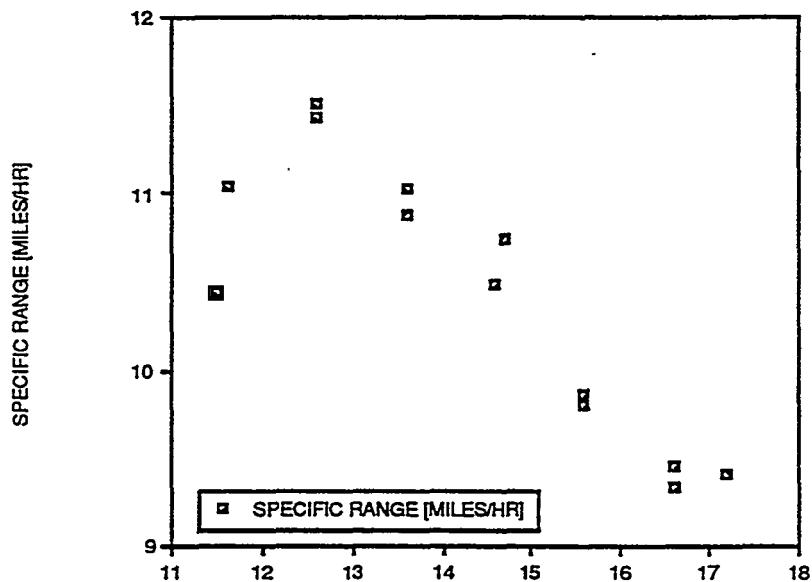


Figure 2

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

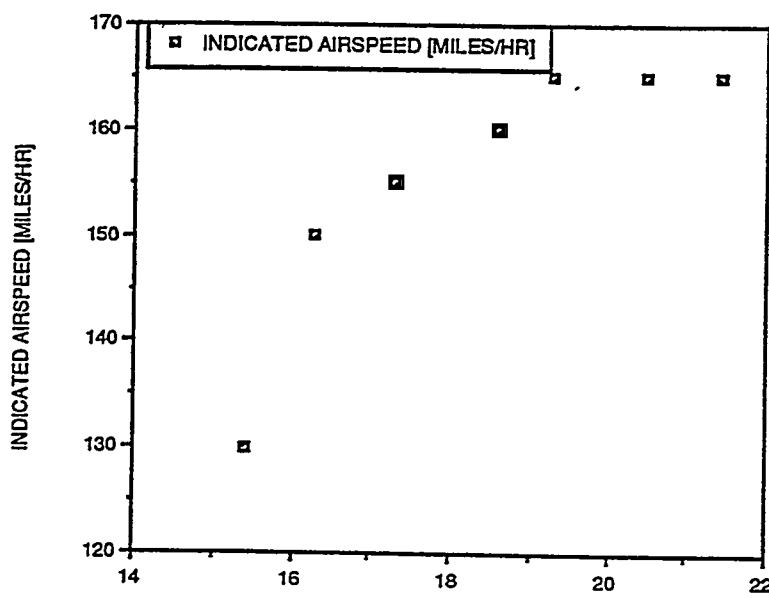
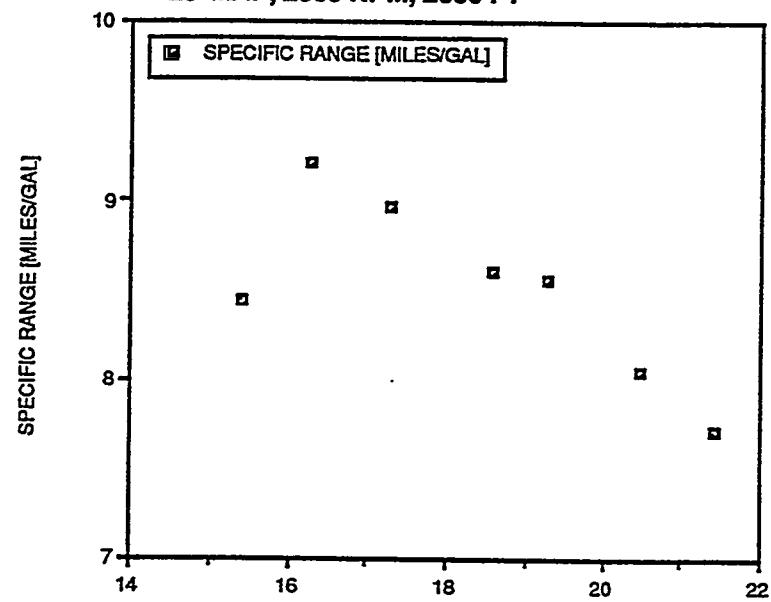


Figure 3

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

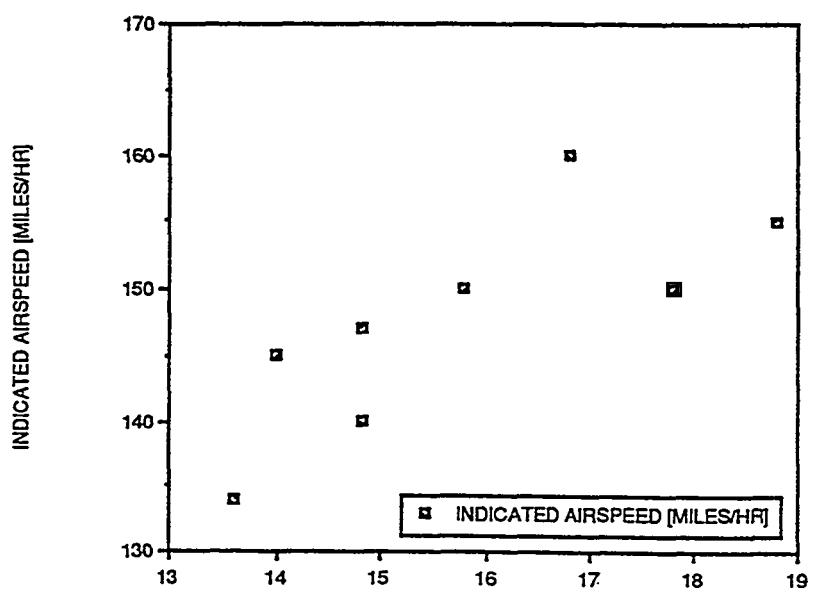
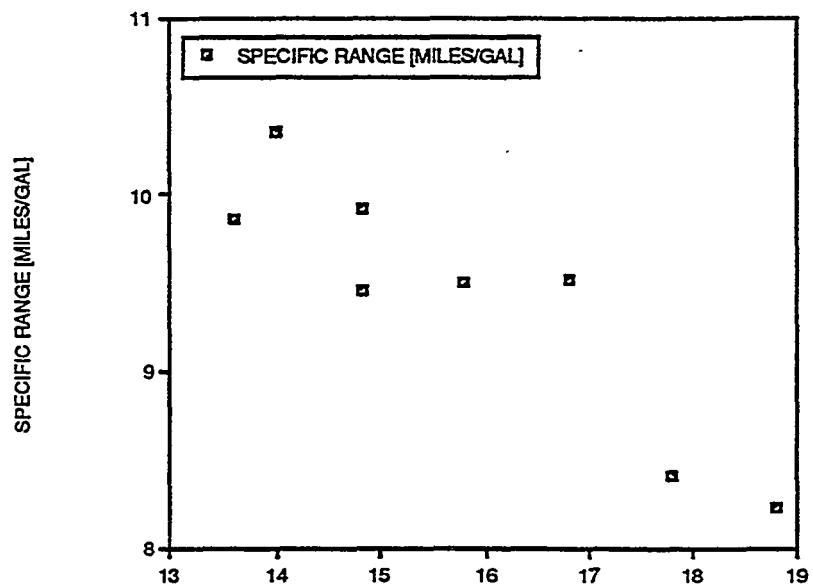


Figure 4

% HP	CORRECTED HORSEPOWER	AVGAS GPH	ETBIE 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:
4. MAX POWER AVAILABLE ON ETBIE:
5. MAX POWER AVAILABLE ON ETHANOL:

300 HP
304 HP
316 HP



June 4-6, 1996
Hyatt Regency
at Union Station
St. Louis, Missouri

Program Proceedings



Sponsored by the
National Corn Growers Association and
National Corn Development Foundation

A CASE FOR BIOFUELS IN AVIATION

M. E. Shauck *, M. G. Zanin
Renewable Aviation Fuels Development Center
Baylor University
PO Box 97413
Waco, Texas 76798-7413

Abstract

In the last 15 years, the technical and the economic feasibility of biomass based fuels for general aviation piston engines has been proven. Exhaustive ground and flight tests performed at the Renewable Aviation Fuels Development Center (RAFDC) using ethanol, ethanol/methanol blends, and ETBE have proven these fuels to be superior to aviation gasoline (avgas) in all aspects of performance except range. Two series of Lycoming engines have been certified. Record flights, including a transatlantic flight on pure ethanol, were made to demonstrate the reliability of the fuel. Aerobatic demonstrations with aircraft powered by ethanol, ethanol/methanol, and ETBE were flown at major airshows around the world.

The use of bio-based fuels for aviation will benefit energy security, improve the balance of trade, domestic economy, and environmental quality. The United States has the resources to supply the aviation community's needs with a domestically produced fuel using current available technology. The adoption of a renewable fuel in place of conventional petroleum-based fuels for aviation piston and turbine engines is long overdue.

Key Words: Ethanol, ETBE, Biodiesel, Renewable Aviation Fuels, Renewable Aviation Fuels Development Center (RAFDC).

Introduction

Mandates of the Clean Air Act Amendments of 1990 banning lead from all motor fuels have prompted an effort to find an unleaded alternative to the existing aviation fuel. Avgas is today the single largest contributor of lead in the atmosphere in the U.S. Environmental regulations have forced oil companies to use dedicated systems for the production and distribution of avgas. As a result of its special handling requirements and low sales volume, it is predicted that the oil companies will eventually quit avgas production. For this reason, pilot organizations, the Federal Aviation Administration (FAA), engine manufacturers, and some of the producing companies, are all searching for a replacement aviation fuel.

The main difficulty in manufacturing an unleaded gasoline for aviation is the high octane needed by many aircraft engines. The American Society for Testing Materials (ASTM) has formed

committees to direct the search for an unleaded fuel suitable for aviation. Guidelines on the specifications of the fuel were suggested by the General Aviation Manufacturers Association (GAMA), but progress has been slow. Results obtained from testing various blends of fuels have been presented to the ASTM committee, but none of them, as of today, completely satisfies the requirements set for the new fuel.

Because of these difficulties, the current consensus among the organizations involved in the research is to settle for a fuel of between 96 to 98 octane. Accordingly, the FAA Technical Center is testing various fuels in various engines, trying to determine a minimum octane rating which will meet the needs of the general aviation fleet. The development of a fuel with a lower than 100 octane rating could satisfy the requirements of about 70% of the general aviation aircraft in the U.S. fleet. However, the remaining 30% of the fleet requires 100 octane fuel, and it uses 80 % of the aviation fuel sold in this country.

There is also a need to find an alternative to Jet A which is used throughout the world in all turbine powered aircraft. This need is prompted by environmental concerns about particulate pollution caused by this fuel. Particularly vulnerable to this pollution is the region of the tropopause along the heavily traveled North Atlantic corridor. Pollutants in this fragile environment have a much longer residence time than at lower altitudes and consequently have a magnified impact. Studies have shown that blends of biodiesel into Jet A decreases these emissions. It is expected that ETBE will have the same effect. RAFDC is in the process of conducting both ground and flight tests to determine performance and emission levels of blends of biodiesel and ETBE in Jet A.

Technical Considerations: Outcomes of the "First International Conference on Alternative Aviation Fuels"

In November 1995, RAFDC hosted the "First International Conference on Alternative Aviation Fuels" at Baylor University in Waco, Texas. Major support for this conference was granted by the U.S. Department of Energy, the FAA, Baylor University and Texas State Technical College. Aviation experts from Brazil, Canada, France, Greece, Italy, Sweden and the United States gathered to discuss the future of aviation fuels. Government agencies, oil companies, academic institutions, aircraft manufacturers, state energy offices, state aviation organizations, and media were represented. Organized to reflect all viewpoints, the speakers and panelists included both supporters of unleaded petroleum based fuels and those who favored renewable biomass alternatives.

Although disagreeing on the solution, everyone agreed on the problem -- the days of 100 Low-Lead aviation gasoline (100LL avgas) are numbered.

At the conference, the proponents of the "petroleum solution" enumerated both real and alleged problems with biomass fuels. A "legitimate problem" is the loss in range caused by the lower energy density of biomass fuels. Petroleum fuel proponents assume that the loss in range in an aircraft powered by ethanol is directly proportional to the caloric content of ethanol when compared to gasoline's (40% less). But, extensive ground and flight tests have shown that the range loss varies from a maximum of 25% with 7:1 compression ratio engines, down to 10% range loss for engines with 10.5: 1 compression ratio. Brazil's experience has shown that automobile engines using ethanol achieve optimum mileage at a compression ratio of approximately 12.2:1. RAFDC, under a contract with the FAA, will be testing aircraft engines with compression ratios as high as 13:1.

Many of the petroleum fuel proponents at the conference were not aware of the substantial increase in performance when operating on ethanol. The higher latent heat of vaporization results in an

increase in volumetric efficiency which produces more power and lower operating temperatures. The wider range of flammability produces smoother combustion and decreases the likelihood of inappropriate combustion. Additionally, it causes less internal engine buildup of combustion byproducts. All of these factors combined to prompt the FAA Designated Engineering Representative (DER) who witnessed the certification of the Lycoming IO-540 to estimate that the time between overhaul (TBO) for engines operating on pure ethanol could easily be increased by 100%.

The issue of materials compatibility was also raised during the conference. RAFDC had experienced problems caused by the interaction between ethanol and aluminum. The problem was solved by anodizing all fuel wetted aluminum parts. However, the ethanol industry, experiencing the same problem with its storage tanks, began adding an anti-oxidant to the ethanol. This additive prevents the reaction between ethanol and aluminum thereby eliminating the need for additional alterations.

To ensure that there are no other materials compatibility problems, RAFDC conducted soak tests of elastomers and metallic components. In addition, RAFDC had Southwest Research Inc. (SWRI) of San Antonio conduct materials compatibility, luminosity and lubricity tests on denatured ethanol, a 50/50 blend of ethanol and methanol, and avgas. This extensive testing showed no adverse effects on any materials (besides aluminum), acceptable luminosity characteristics, and slightly better lubricity properties than avgas (it should be pointed out that the difference between the lubricity of ethanol and avgas was so slight as to fall in the range of experimental error, consequently, we assume the lubricity of ethanol and avgas to be about the same). The lubricity test results were a surprise, as even ethanol proponents believed that it would be necessary to add a top lubricant when using ethanol as a neat fuel. The results of all these tests were corroborated during the 150 hour engine test stand certification of the IO-540. On all measured components (as part of the procedure certain components are measured before and after the test), equal or less wear was measured than is usually detected during similar tests on avgas. This was probably due to a combination of smoother operating characteristics, adequate lubricity, cooler operating temperatures and less internal combustion byproduct buildups.

RAFDC has obtained FAA certifications for two series of aircraft engines and certification of a training aircraft and an agricultural aircraft are expected to be completed shortly. One series of aircraft engines certified is fuel injected while the other is carbureted. Thus, FAA approval has been received for engines whose delivery systems cover all the range of those in use. This experience will considerably simplify and shorten the process in pursuing further engine certifications.

During the conference, most of the issues raised in opposition to biofuels by the petroleum fuel faction were refuted. A Brazilian participant related his country's experience with ethanol, pointing out that in Brazil, 4.3 million vehicles operate on neat ethanol and there are no unsolved technical problems whatsoever.

Even if there was no consensus at the conference among the attendees as to what the next fuel for general aviation will be, at least there was dialogue. The main purpose of the conference was to exchange information, and this was accomplished. Everybody at least agreed that general aviation is facing a serious problem.

Market Potential: Reciprocating and Turbine Engines

The piston engine fleet in the United States uses approximately 305 million gallons of avgas per year. In the next few years, as stated above, due to a variety of regulatory and economic reasons,

100LL avgas will have to be replaced. Development of other unleaded petroleum alternatives is underway, but none of these, as of today, has an adequate octane rating to satisfy the needs of the 30% of aircraft that burn 80% of the avgas. The octane number of a fuel is a measurement of its resistance to detonation. Ethanol exhibited during the FAA certification tests better detonation resistance than avgas. Consequently, at the very least, ethanol should be the fuel of choice for the aircraft requiring a high octane fuel which consists of a market of 240 million gallons of fuel.

The turbine fuel market in the United states consists of 16.4 billion gallons per year. RAFDC is planning to test blends of 20% biofuels in Jet A. The adoption of such a blend would result in an enormous expansion of the renewable fuels industry and a reduction of over 3 billion gallons a year of imported oil. The potential environmental benefits are a powerful impetus for the development of a biofuel blended turbine fuel.

Implementation Strategy

There are two major impediments to the commercial success of ethanol in general aviation. The first is not surprising. It is the opposition of the petroleum industry. The second is the lack of public education and general complacency concerning the issue of alternative fuels. Lack of knowledge among organizations and agencies also results in insufficient support for this program and consequent slow progress in implementing ethanol as an aviation fuel.

Since distribution of ethanol for general aviation could initially represent a problem, RAFDC intends to initially target flight schools and agricultural operations since the aircraft engaged in these activities almost always refuel at a single location.

RAFDC has conducted flight demonstrations, forums, and workshops in conjunction with aviation events for the past 15 years. With the imminent certification of a training aircraft and an agricultural spray aircraft, RAFDC will continue to concentrate on these types of activities to encourage operators to use ethanol and help them to convert their fleets.

It is expected that the current placement of E85 pumps around the country, as part of the National Ethanol Vehicle Program, will greatly benefit the implementation of ethanol as an aviation fuel.

Conclusion

The necessary technology to establish the adoption of a biobased fuel for piston engine aircraft is available.

This is a market for which ethanol has distinct performance advantages and is competitive at today's ethanol prices. With the demise of 100LL avgas on the horizon, and the competitive economic position of ethanol versus even the existing aviation fuel, the potential success of this program is unquestionable.

Aviation gasoline represents a potential market of 305 million gallon per year. Organizations representing the farming interest and ethanol producers should seriously consider supporting this effort. Gaining the aviation market could, in addition to providing a substantial expansion in the ethanol industry, contribute to a public acceptance of ethanol as a general transportation fuel.

DOT/FAA/CT-94/63

FAA Technical Center
Atlantic City International Airport,
N.J. 08405

Proceedings of the 1994 AIAA/FAA Joint Symposium on General Aviation Systems

May 24-25, 1994
Mississippi State University
Starkville, Mississippi

September 1994

Final Report

This document is available to the public
through the National Technical Information
Service, Springfield, Virginia 22161.



U.S. Department of Transportation
Federal Aviation Administration

CERTIFICATION OF A CARBURETED AIRCRAFT ENGINE ON ETHANOL FUEL

M. E. Shauck, J. Tubbs, M. G. Zanin
Renewable Aviation Fuel Development Center
Department of Aviation Sciences
Baylor University
Waco, TX. 76798-7413

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.

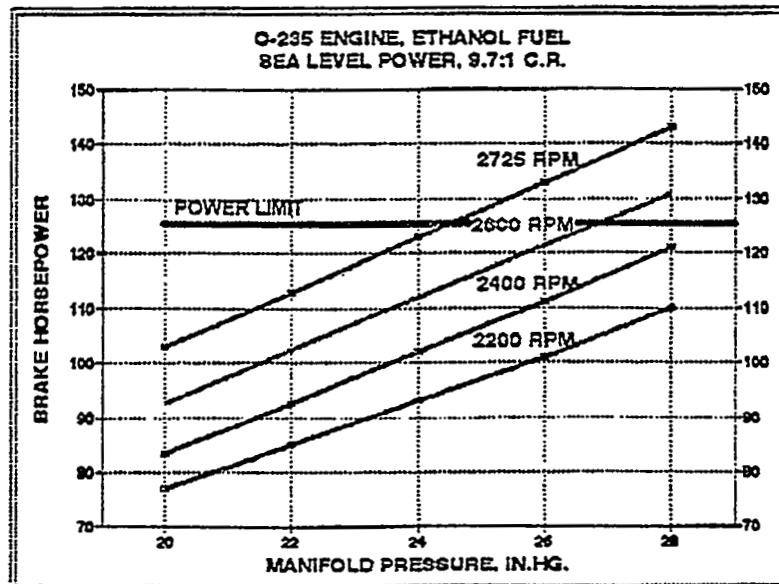
TEST DATA SUMMARY:							
BLOCK NO	1	2	3	4	5	6	7
START DATE	12/29/92	01/5/92	01/13/93	01/28/93	2/08/93	2/11/93	2/15/93
FINISH DATE	02/11/93	01/7/93	01/28/93	02/07/93	2/11/93	2/13/93	2/17/93
TOTAL HOURS							
TEST TIME	30HRS	20HRS	20HRS	20HRS	20HRS	20HRS	20HRS
HOT TIME	15HRS	15HRS	12HRS	15HRS	15HRS	0	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.

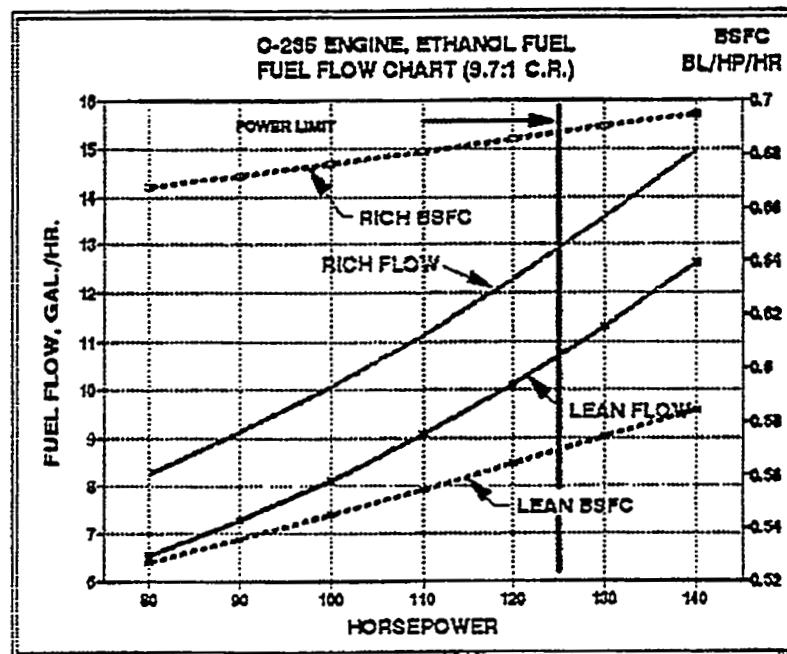
ENGINE OPERATING PARAMETERS

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 than 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.

BIBLIOGRAPHY

1. FERRARA, A. M. , WARES, R., "The Performance of Alternate Fuels in General Aviation Aircraft", Federal Aviation Administration Technical Center, Report No. DOT/FAA/CT-88/13
2. FERRARA, A.M., "Alternate Fuels for General Aviation Aircraft with Spark Ignition Engines", Federal Aviation Administration Technical Center, Report No. DOT/FAA/CT-88/5.
3. RUSSELL, J.A., "Characterizations of Certain Key Properties of Enhanced Ethanol Fuel", Southwest Research Institute Report, July 1988.
4. SHAUCK, M.E., TURNER, D.W., "Ethanol as an Aviation Fuel" Proceedings of the VI International Symposium on Alcohol Fuels Technology, pp. 352-356, Ottawa, Canada, May, 1984.
5. SHAUCK, M.E., TURNER, D.W., and RUSSELL, J.A., "Flight Test Comparisons of Avgas versus Ethanol/Methanol Blends" Proceedings of VII International Symposium on Alcohol Fuels Technology, pp. 402-405. 1986, Paris, France, October, 1986.
6. SHAUCK, M.E., "Performance Report on an Alcohol Powered SIAI Marchetti SF-260 C Aircraft", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, pp. 669-670, Tokyo, Japan, November, 1988.
7. SHAUCK, M.E., ZANIN, M.G., "The First Transatlantic Crossing in an Aircraft Powered by Ethanol Fuel", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, Florence, Italy, November, 1991.
8. SHAUCK, M.E., ZANIN, M.G., "Certification of an Aircraft Engine on Ethanol Fuel", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, Florence, Italy, November, 1991.
9. SHAUCK, M.E., ZANIN, M.G., "Ethanol in Reciprocating Aircraft Engines" Proceedings of the 1992 AIAA/FAA Joint Symposium on General Aviation Systems, Wichita, Kansas, March 1992.
10. SHAUCK, M.E., ZANIN, M.G., "Ethanol as an Aviation Fuel: An Overview of the Program at Baylor University", Proceedings of the IX International Symposium on Alcohol Fuels Technology, Colorado Springs, USA, November 1993.



BIOENERGY '94

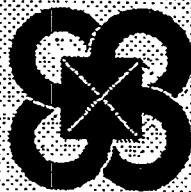
using biofuels for a better environment

*October 2 - 6, 1994
Reno/Sparks, Nevada*

TECHNICAL PAPERS

Volume 1

**PROCEEDINGS
OF THE SIXTH NATIONAL
BIOENERGY CONFERENCE**



*Hosted by
The Western Regional Biomass Energy Program*

CERTIFICATION OF AN AGRICULTURAL SPRAY AIRCRAFT ON ETHANOL FUEL

M. E. Shauck, M. G. Zanin

**Renewable Aviation Fuel Development Center
Department of Aviation Sciences
P.O. Box 97413
Baylor University, Waco, Texas 76798-7413**

ABSTRACT

A Piper Pawnee, one of the most common agricultural spray aircraft, is currently undergoing Federal Aviation Administration (FAA) certification to allow the use of denatured ethanol as its fuel. This certification is part of a broader effort to introduce ethanol as a replacement for aviation gasoline. Various reasons brought about the choice of an agricultural spray aircraft to be certified on ethanol. One is the minimization of initial fuel distribution problems. Agricultural aviation often requires only single fuel storage since most of the flying is local. Additionally, corn produced ethanol is the natural fuel of choice for farming operations. The increased power developed on ethanol compared to aviation gasoline (avgas) is very important when operating heavily loaded spray aircraft at very low altitudes.

The power-plant, a Lycoming IO-540, is already certified. The aircraft is currently flying on ethanol in order to satisfy the airframe requirements. The effort is being supported by a consortium of organizations of corn producing states. Upon completion of certification, the aircraft will be demonstrated around the mid-western states. Certification will allow the use of the aircraft in the commercial arena. Many mid-western agricultural spray operations and ag-pilots have already expressed interest in converting their aircraft to ethanol fuel.

1. INTRODUCTION

The Renewable Aviation Fuel Development Center (RAFDC) activities at Baylor University concentrate in three basic areas:

Research: To improve the efficiency of gasoline engines modified to run on ethanol additional modifications such as an increase in the compression ratio and/or a change in ignition timing are necessary. Research to implement these changes or manufacture a new engine ideal to run on ethanol is under way. This work is being conducted under a grant from the Federal Aviation Administration (FAA) technical center.

Education: Educational programs and demonstrations of the reliability of ethanol as an aviation fuel are carried out in order to gain acceptance of this fuel. Demonstrations have included aerobatic exhibitions at some of the largest air shows in the United States, Europe and South America. The current demonstrations program is supported by a grant from the U. S. Department of Energy administered by the Governor's Ethanol Coalition.

Five officially recognized records for long distance flight on ethanol have been awarded by the National Aeronautic Association. The last record set was the first transatlantic flight made on ethanol. For this flight, the program was awarded the Harmon Trophy in a ceremony at the White House.

Certification: Certification is a requisite for aircraft to engage in commercial operations. The Renewable Aviation Fuel Development Center at Baylor University is currently certifying three aircraft types: a Cessna 152, a Pitts Special, and a Piper Pawnee.

The Piper Pawnee project started as a result of the authors coming across an article in a trade journal of the Agricultural Aviation Association. The article described the concerns of the crop-dusters in South Dakota about the continuing availability of avgas for their operations. The article was sent to the executive director of the South Dakota Corn Utilization Board who was also made aware of the work being done at Baylor to develop ethanol as an aviation fuel. A proposal to certify a spray aircraft on ethanol fuel was submitted to the South Dakota Corn Utilization Board. Other agricultural organizations in North Dakota, Nebraska, and Alabama supported the proposal. A Piper Pawnee spray aircraft was purchased and the conversion and certification process for the use of ethanol as its fuel was initiated.

Since ethanol is for the most part in this country produced from corn, it is a natural choice to include agricultural aircraft in the first group of aircraft to be certified to use ethanol as a fuel. Our increased dependence on imported oil is especially dangerous in the area of agriculture. Without a reliable supply of a liquid fuel to power the farm machinery needed to produce our crops we are in a precarious situation. The use of ethanol, a domestically produced fuel, in agricultural aircraft is a start on the road to energy independence. As an aviation fuel, ethanol provides a less expensive and better performing alternative to avgas.

With the lead coming out of all gasoline, the FAA is currently testing unleaded gasoline alternatives to avgas. Lead is critical as an anti-knock additive in aviation fuel due to the high compression ratios and operating temperatures of aircraft engines. The project at Baylor University has been conducting flight and ground testing of aircraft and aircraft engines powered by ethanol, an unleaded fuel, for 14 years. Results have conclusively demonstrated that it produces more power, burns cooler and cleaner and resists detonation better than avgas.

The FAA requires that both the engine and the airframe be certified for a new fuel. This paper discusses the modifications necessary to utilize ethanol in the Piper Pawnee, summarizes the engine certification results, describes the FAA requirements for airframe certification and presents results from the flight testing.

2. MODIFICATIONS

Modifications to the Piper Pawnee involved the fuel delivery system, the fuel tank material, and the starting system.

Fuel Delivery. The only modification to the engine was made to the fuel delivery system, in this case a Bendix RSA-5AD1 fuel injection unit. This modification is necessary to permit more fuel flow to the engine to compensate for the lower heating value of ethanol (ethanol has 75,000 BTUs per gallon while avgas has 125,000 BTUs per gallon). The lower idle valves and the mixture control valves were replaced to allow the appropriate fuel/air ratio for ethanol. Injector nozzles with larger orifices were installed allowing an increase of fuel flow at the same pressure drop.

Materials Compatibility. Materials compatibility testing was carried out by the Southwest Research Institute in San Antonio, Texas. The tests demonstrated that standard elastomers in aircraft systems were compatible with ethanol. An area of concern which surfaced in the early days of the testing was the compatibility of ethanol and some of the aluminum alloys in fuel tanks. This problem was then solved by anodizing the tanks. Recently, the ethanol producers have been adding an anti-oxidant called DCI-11 because of a similar problem they had with aluminum floating caps in storage tanks. This compound has eliminated the problem with aircraft aluminum fuel tanks. One potential problem with the Piper Pawnee was the compatibility of ethanol with the fuel bladder. The manufacturer was contacted and recommended a bladder made from a different material, which was installed.

Cold Start System. The Reid Vapor Pressure (RVP) of ethanol is 2.7 while the RVP of avgas must fall in the range of 5.5 to 7.5 by American Society of Testing Materials standards. This means that ethanol resists vapor lock much better than avgas, a major safety advantage. It also, however, presents a problem when starting the aircraft at or below temperatures of 65 degrees Fahrenheit. This problem is solved very simply by the addition of a small (1 gallon or less) tank of gasoline connected to a primer system. In cold weather, with a few shots of prime, the engine starts very easily. Once started, the engine driven fuel pump delivers ethanol to the engine and the operation proceeds normally.

3. ENGINE CERTIFICATION

Since FAA certification of the Lycoming IO-540 has been discussed in an earlier paper, only a brief summary will be presented here.

The engine certification test consists of:

Engine Conformity: The FAA representative witnesses removal, inspection and measurement of cylinders, valves, pistons and rings. The measurement of the designated components before the endurance test allows quantification of the wear experienced during the test run.

Pre-endurance Power Test: Prior the endurance test, to insure that the engine develops rated power on ethanol, power output is determined using a dynamometer. The IO-540 developed well in excess of the rated 260 horsepower.

Endurance Test: The engine was run for 150 hours on the test stand according to a schedule prescribed in Federal Air Regulations (FAR) 39.49. This schedule requires that for much of the 150 hours, the engine is operated at high power settings and limiting cylinder head temperatures and oil temperatures.

Post-Endurance Performance and Detonation Test: A corrected brake horsepower of 285 horsepower was measured on the dynamometer following the endurance test. This represents approximately 10% more than the rated horsepower of the engine. The protocol required by the FAA was followed in an attempt to induce pre-ignition and/or detonation. The report of the designated engineering representative (DER) of the FAA reads as follows: "No pre-ignition or detonation could be induced for any test condition. The engine would smoothly transition and stabilize after the mixture changes were made, even to just above cut off." The DER concluded that the use of ethanol extends the limits of detonation over avgas.

Post-Endurance Test Engine Inspection: The engine was removed from the test stand and engine disassembly was conducted under FAA surveillance. The wear measured after the endurance test was much less than limits set by the FAA and less than the wear evidenced in similar tests conducted with avgas.

The engineers involved in the detonation testing and the post-endurance engine inspection estimated that the use of ethanol as a fuel would extend the engine Time Between Overhaul (TBO) by at least 50%.

4. AIRFRAME CERTIFICATION

The only changes to the aircraft are the increase in the size of the nozzles and valves in the fuel injection unit and the addition of an auxiliary starting tank. Thus, the only applicable airframe tests are the hot weather operation tests and the climb cooling tests.

Hot Weather Operation Tests : This test is performed to determine whether or not there is a potential danger of vapor lock when using the fuel under consideration. The Federal Air Regulations require that each fuel system be free of vapor lock at a temperature of 110 degrees Fahrenheit under critical operating conditions. The critical operating conditions are at maximum fuel flow and maximum angle of attack. These criteria were established primarily because of the auto gas certifications since auto gas has a variable RVP and, in general, has a higher RVP than avgas.

In the case of ethanol, it is not clear whether the test will even be required since the RVP of ethanol with 2-5% unleaded gasoline as denaturant has an RVP of 3.0. The American Society of Testing Materials (ASTM) requirements for avgas requires an RVP of 5.5-7.5. Thus ethanol exceeds the requirements for resistance to vapor lock.

Climb Cooling Tests. This test is conducted to determine that the maximum engine operating temperatures are not exceeded in the most critical operating conditions. The maximum cylinder head temperature for the engine is 475 degrees Fahrenheit and the maximum oil temperature is 245 degrees Fahrenheit.

The climb cooling test will be conducted by stabilizing the engine temperatures in flight with the engine operating at not less than 75% of the maximum continuous power rating. After the engine temperatures have stabilized, the climb will be started at the lowest practical altitude and continued for one minute with the engine operating at take-off power. At the end of one minute, the engine power will be reduced to maximum continuous power and the climb will be continued at maximum continuous power until reaching the aircraft service ceiling or until the temperatures have stabilized for at least 5 minutes after the occurrence of the highest temperature recorded.

5. FLIGHT DATA

Full Power Comparisons : All engines tested in this program have developed more power on ethanol than on avgas. The smallest increase obtained was 7% in the IO-320 with 7.0:1 compression. The greatest increase measured was 20% in the O-235 with 9.7:1 compression. In the IO-540 with 8.5:1 compression the increase in power was 10%. The engine tested in the Piper Pawnee has a 7.2:1 compression, and we would expect a power increase in the range of 8%.

The following sets of data on avgas and ethanol were taken within one hour of one another so that density altitudes were very close at the same indicated altitude. The aircraft has a fixed pitch prop which means that a power increase can be determined by

comparing RPM's (revolutions per minute) obtained in level flight at full throttle operation, however the flight test data does not give the exact amount of horsepower increase.

FULL POWER TEST

Ethanol

Altitude (in ft. above mean sea level)	Gallons per Hour	RPM
2500	35	3150
3000	32	3000
4000	28	2925

Avgas

2500	27	2900
3000	25	2875
4000	21.7	2800

Flow Rate Comparisons : As mentioned above, the other engine test with a comparable compression ration was the IO-320 with 7.0:1 compression. For that aircraft the increase in flow rate on ethanol at comparable power setting on avgas was 25%. The following data was taken at 2000 ft. above mean sea level for both ethanol and avgas. The average fuel flow increase over four different power setting was 25.6%.

RPM	Avgas GPH	Ethanol GPH	% increase
2000	9.8	14.0	23.5
2100	12.8	16.0	25.0
2200	13.8	17.2	26.4
2300	14.1	18.1	28.4

Data taken on other aircraft with higher compression ratios are as follows:

Aircraft	Compression	Fuel Flow Increase
1. Pitts Special S2B	8.5:1	15%-20%
2. SIAI-Marchetti SF260	8.5:1	15%-20%
3. Pitts Special S1S	10:1	10%-15%
4. Velocity	10.5:1	7%-10%

Clearly, it is desirable to incorporate high compression pistons in the modifications for ethanol. This is true both from an economic and a performance standpoint. Ethanol performs well up to 15:1 compression ratios. The limiting factor is not the fuel in this case, but the strength of the engine.

6. CONCLUSION

The use of ethanol as the fuel for the piston engine aircraft used in agricultural aviation has been demonstrated to be desirable from both a performance and economic standpoint. The problem of initial distribution of the fuel is almost non-existent with agricultural operators as they stage from a single airport or transport their own fuel.

The extra power available and the cooler operating temperatures are of critical importance to applications in agricultural aviation, as these aircraft typically fly with very heavy loads and operate near the upper limit of the cylinder head temperature and oil temperature of the engine.

From all the data obtained during certification tests, engine time between overhaul will be extended from 50 to 100%. This combined with a lower fuel cost, guaranteed availability and improved performance makes ethanol an extremely attractive fuel for agricultural aviation.

BIBLIOGRAPHY

1. FERRARA, A. M., WARES, R., "The Performance of Alternate Fuels in General Aviation Aircraft", Federal Aviation Administration Technical Center, Report No. DOT/FAA/CT-88/13.
2. FERRARA, A.M., "Alternate Fuels for General Aviation Aircraft with Spark Ignition Engines", Federal Aviation Administration Technical Center, Report No. DOT/FAA/CT-88/5.
3. RUSSELL, J.A., "Characterizations of Certain Key Properties of Enhanced Ethanol Fuel", Southwest Research Institute Report, July 1988.
4. SHAUCK, M.E., TURNER, D.W., "Ethanol as an Aviation Fuel", Proceedings of the VI International Symposium on Alcohol Fuels Technology, pp. 352-356, Ottawa, Canada, May, 1984.
5. SHAUCK, M.E., TURNER, D.W., and RUSSELL, J.A., "Flight Test Comparisons of Avgas versus Ethanol/Methanol Blends", Proceedings of VII International Symposium on Alcohol Fuels Technology, pp. 402-405. 1986, Paris, France, October, 1986.
6. SHAUCK, M.E., "Performance Report on an Alcohol Powered SIAI Marchetti SF-260 C Aircraft", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, pp. 669-670, Tokyo, Japan, November, 1988.
7. SHAUCK, M.E., ZANIN, M.G., "The First Transatlantic Crossing in an Aircraft Powered by Ethanol Fuel", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, Florence, Italy, November, 1991.
8. SHAUCK, M.E., ZANIN, M.G., "Certification of an Aircraft Engine on Ethanol Fuel", Proceedings of the VIII International Symposium on Alcohol Fuels Technology, Florence, Italy, November, 1991.

9. SHAUCK, M.E., ZANIN, M.G., "Ethanol in Reciprocating Aircraft Engines", Proceedings of the 1992 AIAA/FAA Joint Symposium on General Aviation Systems, Wichita, Kansas, March 1992.
10. SHAUCK, M.E., ZANIN, M.G., "Ethanol as an Aviation Fuel: An Overview of the Program at Baylor University", Proceedings of the IX International Symposium on Alcohol Fuels Technology, Colorado Springs, USA, November 1993.
11. SHAUCK, M.E., TUBBS J., ZANIN, M.G., "Certification of a Carbureted Aircraft Engine on Ethanol Fuel", Proceedings of AIAA/FAA/MSU 3rd Joint Symposium on General Aviation Systems, Starksville, Missouri, May 1994.