FINAL REPORT FORM
COVER PAGE

Principal Investigator: Thomas E. Ehresman

Title: Spark Ignition Direct Injection Fuel Nozzle

Institution of Affiliation: N/A

Address: 616 N. Colorado Ave.

Loveland, CO 80537-5352

Telephone: Office(970)669-6185 Cell (970)214-2471

Fax (970)669-1044 (employers fax)

E-mail Address: pointaero@aol.com

Web Site: Currently none

Title of Project: Spark Ignition Direct Injection Fuel Nozzle eliminating use of Leaded Fuels while enabling continued use of current high power density aircraft piston engines.

Project Dates: August 1, 2008 to May 31, 2009

Approved funding: $10,580

Monies Spent: $10,637

Monies Due the Fdtn: $0

Report Due Date: July 15, 2009

Signature of P.I.: ____

Date Submitted: July 08, 2009

SUMMARY

The Project goal- generally stated is as follows: The certain unavailability of 100LL Aviation gasoline presents numerous problems to many high power density piston aircraft engines. This Project seeks to develop a direct injection fuel system that can ignite fuel as it is injected eliminating the combustion chamber ignition limitations due to compression ratios, high charge air temperatures, pre-ignition and other factors which can cause air charge burn anomalies and possible engine damage and power loss.

Specifically, The testing and research done in this phase of the project specifically defined the configuration of the piezoelectric element and it's specific role in the arc system. It also helped define two nozzle systems for prototype testing in the next phase.

Of note is the Patent Pending status of arc configurations found in the first grant period. This is in addition to the Principals US Pat. No. 7131423. These systems will allow many different types of fuel to be used in the same engine by adjusting delivery pressure, timing and quantity to suit the type of fuel being used at the time. This will allow engines equipped with this system to truly be multi-fuel engines with no detriment to power or reliability and dependability.

DISCUSSION The following issues discussed remain unchanged from the First grant project. The fact that the project goal, total scope and project plan remain unchanged is encouraging. This indicates that the initial planning and concept is realistic and within reach. The issues and discussions are included again to provide the reader a broader understanding of the Project. Additional information is added updated due to this second round of research.

This project seeks to address the need for an engine that can operate on fuels that are not as specialized as aviation gasoline. Specifically, to allow high power piston aircraft engines to remain operational as 100LL is phased out of production.

A. **Problem**

Aviation gasoline, known as 100LL (One hundred octane Low Lead) is a highly specialized fuel because of it’s operating environment. Its specifications are different in most aspects, from automotive fuel. These differences require the refineries to separate the supplies, equipment, additives, and transportation systems from all other fuels. In fact, since the pipelines used for other gasoline products cannot be used for 100LL, the vast majority of the transport is by over the road tankers.

The major factor in this problem is the gasoline additive TEL (Tetra Ethyl Lead). In the 1970's the US Environmental Protection Agency began the process to eventually outlaw TEL because of it's toxic nature and it being a known carcinogen. The additive was outlawed and removed from all US gasoline products in approximately 1987, except aircraft piston engine gasoline. The EPA did, however require the decrease in lead which is where 100LL comes from.

The push remains to remove TEL from aviation gasoline and the third world and former European Eastern Block countries which still use it as a gasoline additive. Combine this with the fact that there is only one manufacturer of TEL left in the world, and you can see the tenuous position in which the high power aviation piston engine finds itself.

The timeline for the elimination of TEL has not been set but most industry observers agree it is short; because of market forces as much as environmental pressures. As demand for TEL drops, the price will continue to rise causing greater hardship for the users who have no viable alternative.

The FAA, EPA, and many other organizations have tried for decades now, to find a suitable replacement additive or fuel to allow continued operation of the 100,000+ aircraft engines which currently require 100LL. Methanol is too corrosive and would require additional range or payload limitations. Other additives which work well to raise octane are more dangerous than TEL. The experiments with the 92UL (unleaded) aircraft fuel show it to be inadequate for the higher power engines. A re-engine program to install newly designed engines with the required power output is, for most operators, cost prohibitive and/or a high risk investment. A new Bio-fuel is in testing but leaves the engine a single fuel rich burn engine instead of a multi-fuel lean burn type.

B. **Solution**

The technical issue at the center of this problem is: How to delay burning of the fuel to prevent detonation, an engine destroying event occurring when low octane fuels are used in engines requiring high octane fuels.

The proposed solution is to use the direct injection technology just coming into use in the off-road and automotive industry, to control the introduction of fuel into the combustion chamber when the combustion is desired, and to use a piezoelectric element for generation/triggering of the ignition spark. In this manner, until combustion is desired, there is no fuel present in the cylinder to pre-ignite or detonate, causing engine damage. The key to the successful implementation of this technology into the high power density aircraft piston engine is to provide a reliable means of ignition at the same instant the fuel is injected into the cylinder. This is the specific scope of this project.

The Lindbergh Grant enabled the completion of the projects first and second stages, the first of which was to investigate two main factors in reliable ignition of an injected spray using the internal piezoelectric element: the correct piezoelectric material to use for the element and the best electrode configuration for ignition. the second was to obtain and test up to three piezoelectric elements and determine the best type and configuration for the element.

C. **Results**

The scope of this phase of the research included the following two areas:

1. Purchasing exemplar piezoelectric elements and fabrication of the test sensor system.

2. Purchase of an operating High Pressure direct Injection System and testing of the piezoelectric elements

Testing item 1. The customized piezoelectric elements hoped for never materialized due to the following reasons. A. The Morgan Ceramics corporation, which provided very helpful information in the first grant, had key personnel leave between the first and second grant time frames. After a month an a half of trying to reestablish ties and procure some customized samples, it became apparent that the time and effort to acquire these samples was beyond the scope and time frame of this grant. Another piezoceramic company would not even answer emails or calls.

The decision was then made to purchase standard, readily available piezo-igniter capsules to use in testing. These capsules are very similar to the type needed for arc generation and provided the information required to more accurately define system configuration.

The system was fabricated and both the system pressure signature and voltage produced by the fabricated sensor (for testing item 2) were acquired and downloaded to computer for analysis.

The test results for item one showed the following:

Although the igniter capsule energy is sufficient to produce arcs of ½" or greater in length under ambient air pressures, they carry little energy. When tested under cylinder compression pressures, they would not jump more than a .020" gap: wholly inadequate for the igniter system.

Testing item 2. The pressure tests and voltage tests in operation in an actual high pressure direct injection system again pointed out the inadequacy of the standard igniter capsule to produce energy levels capable of generating a high energy arc.

In testing item 2, it was also discovered that the volume change introduced in the high pressure side of the injection system by the injector line tee and the sensors, caused undesirable changes in the injection system operation. This undesirable result means that the volume of high pressure fuel required to produce an arc from a large piezo element would either require entire injection system redesign or relegate the sensor to the trigger role. The latter was chosen.

These tests have shown that the piezo element will be a trigger for the arc generator and not the sole source of the arc.

Testing also showed the difficulty of installing a sensor inside the high pressure system of the nozzle without adversely affecting the injector system operation. External sensors are in use presently in such systems and will be adapted to the trigger task in the next phase of the project (outside the scope of this grant).

D. **Application**

So what? What does this phase of research do towards obtaining the goal of eliminating TEL (lead) from gasoline and without adversely affecting peoples job's and lives?

This phase solidified the configuration of the arc generating system. This included the generator and sensor systems needed to reliably produce an arc of sufficient energy to ignite the injected fuel stream in close proximity to the injector.

E. **Future**

The Principal will continue pursuing other grants and resource streams. Other organizations have been queried and a high initial interest was shown. The economic downturn which started in the fall of 2008 has put the interested parties in "survival" mode and talk of capital investment has all but gone. Therefore, the principal investigator will continue inquires with such organizations as the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), the US Environmental Protection Agency (EPA), the National Science Foundation (NSF), the US Department Of Transportation (DOT), and others who supply grants and resources for projects such as this.

F. **Other**

As mentioned in the previous final report, this technology holds great promise for turning piston engines into "lean-burn", multi-fuel engines with little modification of the engine itself. It can also aid in increased efficiencies and decreased emissions in the design of newer piston engines outside of aviation.

PERSONNEL

A. The Principal performed all of the research for this grant and has spent at least 185 hours directly on this phase of the project.

B. As mentioned in E above, he plans to search for other resources through grants and any other resources available, to allow continued progress on this project. He plans to remain in the Aviation Industry in R & D and Certification.

EQUIPMENT

Major equipment purchased for this phase of the project were a diesel generator set ($1180), IoTech Personal DAQ 3005 ($1004), and the high pressure transducer ($793). Additional smaller cost items are detailed in the financial report.

The equipment will come into use again in the next phase of the project and will remain with the Principal. Useful life of the major equipment, with proper maintenance, is at least 10 years.

As stated in the first phase report, the computers, 3D CAD software, oscilloscope, wave form analysis software and other instruments used are owned by the Principal and/or his company, Pointman Aeronautics, LLC.

FUNDING

At this time no additional funding has been secured. See E. FUTURE.

ACCOUNTING

A. See Financial Report Form

B. See Financial Report Form attachments

C. See Financial Report Form attachments

D. Narrative: The full Grant amount of $10,580 is figured in the report.

The Financial Report Shows the majority of the expense to be labor, as expected. Much of the equipment, materials and needed parts for fabrication of the test rig were borrowed or obtained free of charge from the Principals employer and the Principals contacts in the industry. Computer equipment, software, electrical instruments for setup, testing, and other necessary equipment were provided by the Principal. For this reason, the Financial Report only reflects actual Lindbergh Grant Foundation moneys spent and not the accumulated value of the equipment and parts necessary to complete the tests. This accumulated value would be much higher.

Labor hours were originally figured for partially replacing the Principals' hours lost from diversion of normal working hours towards this project. The labor and equipment costs were fairly close to the estimate. Again, in this phase of the project as well as the first one, the figuring is for the full amount spent on this phase of the project, not just the Lindbergh funds. This gives a realistic, rather than idealistic view of how the project finances actually turned out. However, in this second grant, the near identical totals of the estimate and actual spent make this difference minute.

Publications/Publicity/Photo's

No additional Grant announcements were accepted by publications for this second phase.

Photo 1. Modified Injector line. This modification allowed testing of a piezo electric element by direct exposure to the high pressure of an injection event. It also allowed direct measurement of the pressures in the injection event.

Photo 2. Exploded view of the piezo element test assembly. The ignition capsule is the black cylinder with the silver tip. This fit directly into the modified spark plug barrel insulator for signal measurement.

Photo 3. Piezo ignitor/plug assembly installed on the modified injector line for operational testing.

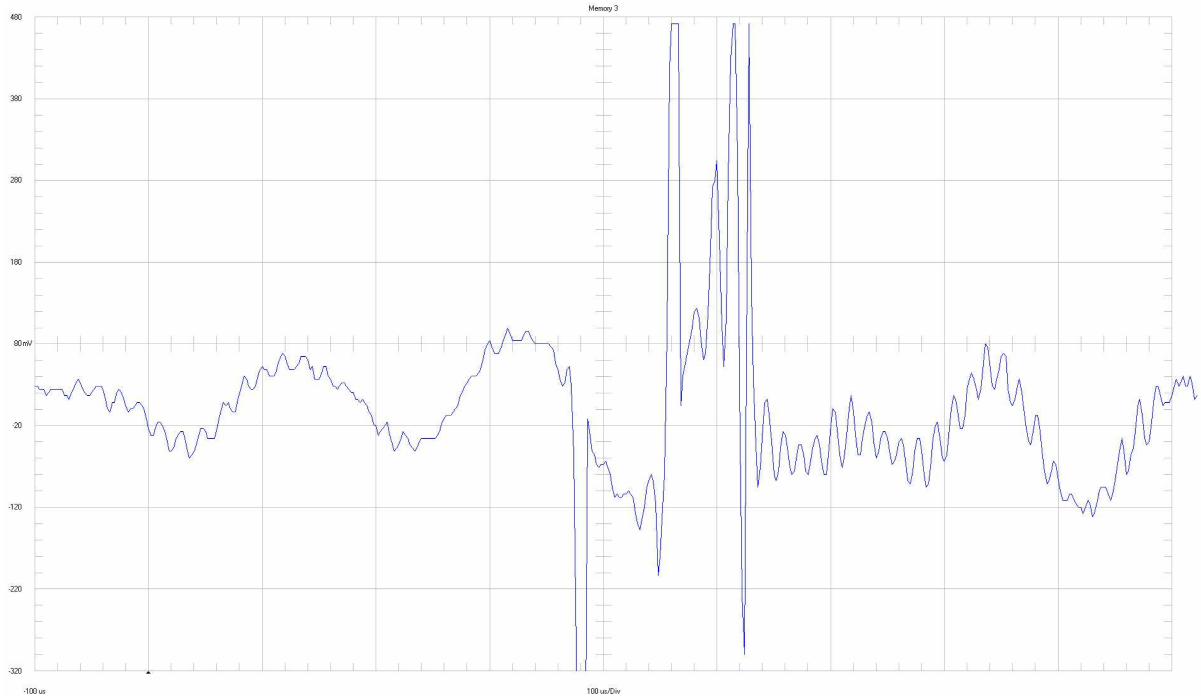

Photo 4. Wave form generated by the piezo/plug assembly. Note the low voltage generated. A maximum of approximately 1 volt was noted.

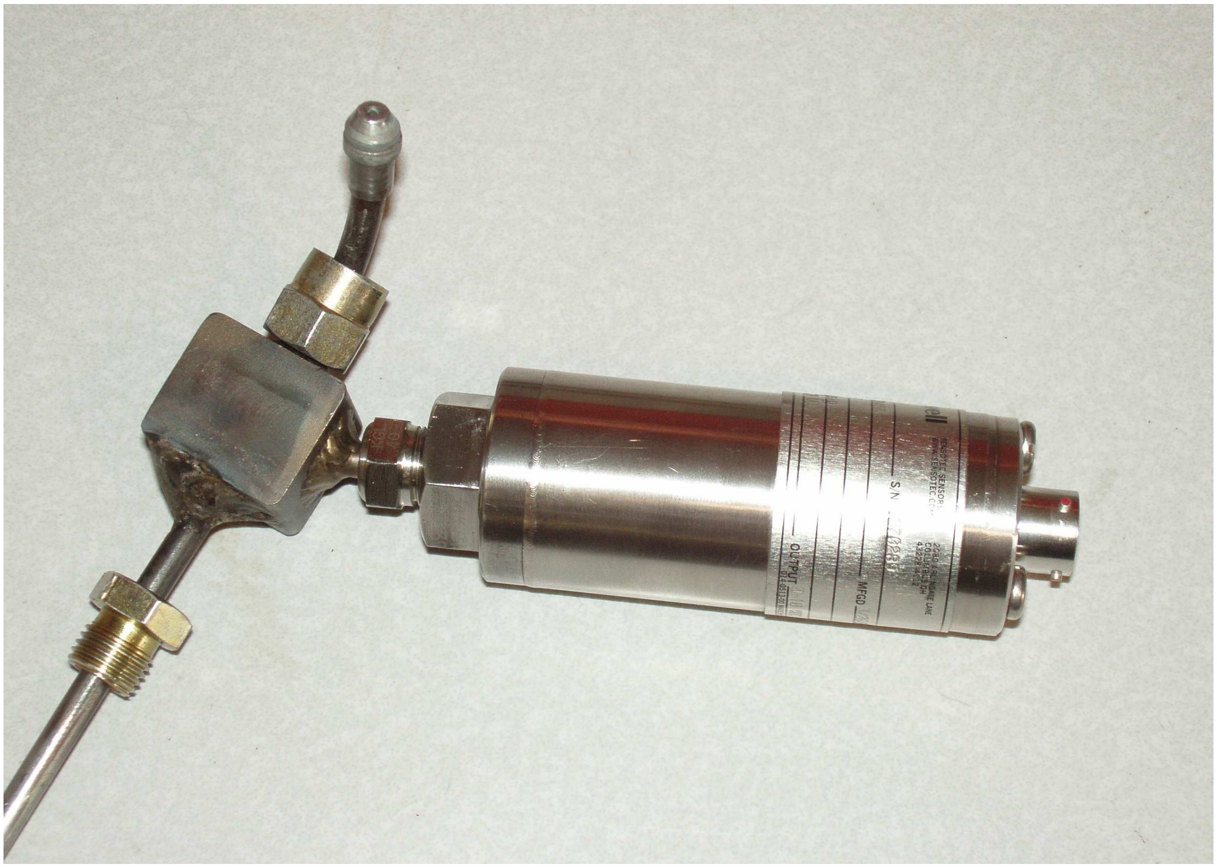

Photo 5. High Pressure Transducer installed in modified injector line. This setup allowed real-time measurement of the injection event. Transducer is a Honeywell A-5 rated to 30,000 psi.

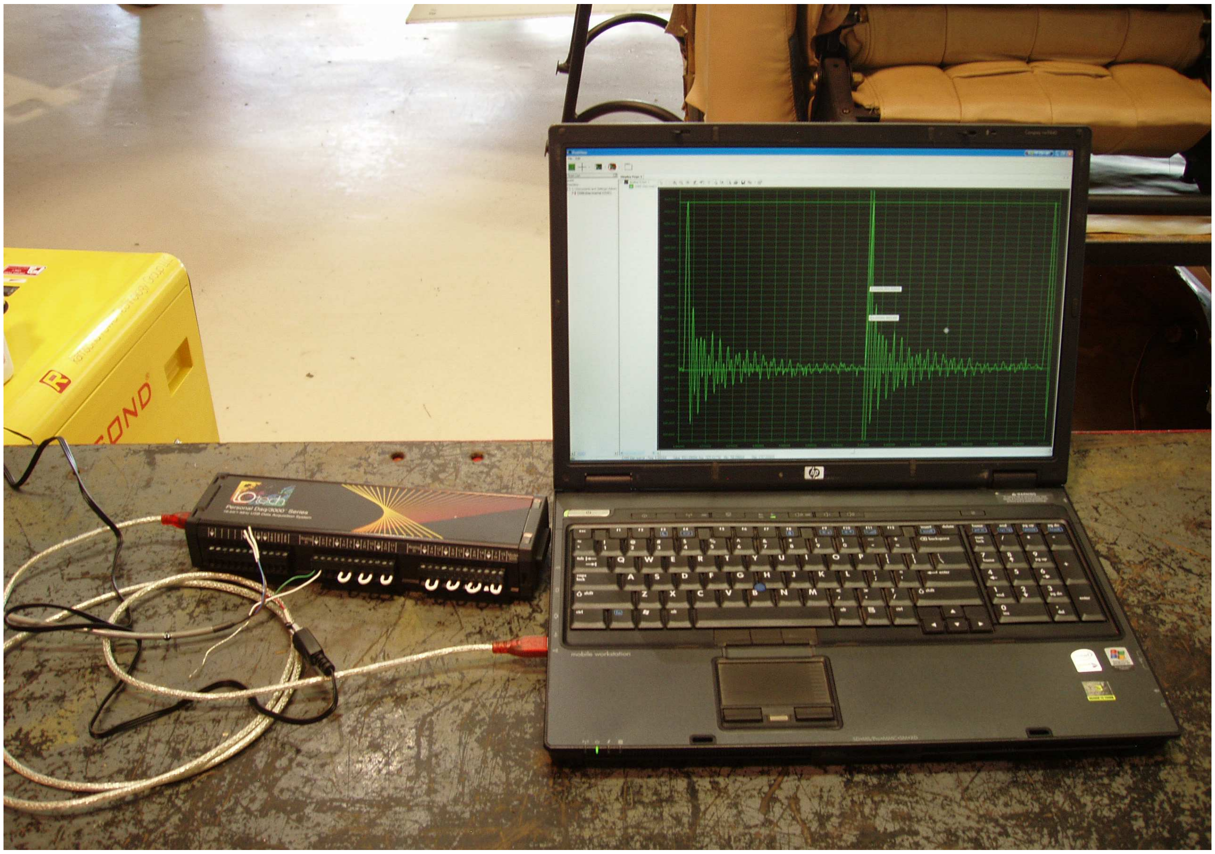

Photo 6. Acquisition of the wave form generated by the high pressure transducer in operation. The box on the left is the IoTech Personal DAQ 3005. The laptop is the Principals HP nw9440 work station.

A word from the Principal Investigator:

In conclusion, I would again like to thank the Lindbergh Foundation for having the insight and fortitude to promote the use of technology for the environments good. Very few environmental organizations realize mankind's responsibility to *actively enable* and *encourage* the earth to thrive, not just “leave it alone”. The Lindbergh Foundation does realize this and promotes it actively. I would also like to thank the Stanford Foundation for their generosity. Keep up the good work!