SAE
Wichita Section

Society of Automotive Engineers
Wichita Section
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http://wichita.sae.org/

The Prescription for the Unleaded Avgas Dilemma

Presented by

Cesar Gonzalez

Thursday, March 28, 2013

6:30 PM Dinner
7:30 PM Presentation

About the Speaker

Cesar Gonzalez has been involved in military and general aviation service, piloting, design, and research activities for 65 years, first in Argentina and then in the US. Following his retirement from Cessna in 1998, he continues as an independent consultant in the design of powerplant systems, fuels, and fuel systems for general aviation.

Dinner at Monterrey Mexican Grill

5905 W Kellogg Drive, Wichita, KS 67209
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Located on the South side of W Kellogg Avenue (US-54), Between I-235 and Ridge/Mid-Continent Road, Just West of Clarion Inn and Suites.

Members	$15	Non-members	$18
Retirees	$13	Students	$8

Any new SAE members attending their first section meeting will receive their meal at no charge.

Reservations

DEADLINE: Noon, Wednesday March 27, 2013

Make reservations using one of the following ways:
Jim Wagner ..... (Spirit) 737-3383
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From 1980-2002, Cessna investigated alternatives to leaded aviation gasoline. The alternatives focused on two distinct avenues. The first searched for fuel solutions. The second explored engine combustion and other hardware improvements that could individually or collectively reduce or eliminate lead fuel additive requirements.

Cesar Gonzalez will present a sequel to previous work. It will include updates related to the 2008 and 2010 EAA Forum events. The presentation will also offer a window on a multi-phased solution to the Grade 100LL Avgas replacement dilemma, with low risk and incorporating current technology tools and materials.

A PRESCRIPTION FOR THE UNLEADED AVGAS DILEMMA

CESAR GONZALEZ
AVIATION CONSULTANT

SAE WICHITA SECTION MEETING
28 MARCH 2013

INTRODUCTION

AFTER SOME 30 YEARS OF INDUSTRY-WIDE EFFORTS, NOT A SINGLE HYDROCARBON UNLEADED AVIATION GASOLINE ALTERNATIVE TO 100LL AVGAS HAS BEEN DEVELOPED.

CESSNA INVESTIGATED ALTERNATIVES TO LEADED AVIATION GASOLINE DURING THE PERIOD OF 1984 TO 2002, BY TWO DISTINCT AVENUES.

- ONE SEARCHED FOR FUEL SOLUTIONS.
- THE OTHER EXPLORED ENGINE COMBUSTION AND OTHER ENGINE INPROVEMENTS, THAT COULD INDIVIDUALLY OR COLLECTIVELY REDUCE OR ELIMINATE FUEL LEAD ADDITIVE REQUIREMENTS.

THIS PRESENTATION IS A SEQUEL THAT INTEGRATES AND UPDATES RELATED EAA AIRVENTURE FORUM PRESENTATIONS.

- 2008 EAA FORUM PRESENTATION TITLED *"CAN GENERAL AVIATION SURVIVE WITH A LOWER OCTANE UNLEADED AVGAS?"*. [REFERENCE 1]
- 2010 EAA FORUM PRESENTATION TITLED *"THE PATH TO AN UNLEADED UL AVGAS"*. [REFERENCE 2]

BASED ON THE COMBINED TECHNICAL INFORMATION FROM SAID EAA FORUM EVENTS, THIS PRESENTATION OFFERS A WINDOW ON A MULTI-PHASED PRESCRIPTION TO THE LEADED GRADE 100LL AVGAS REPLACEMENT DILEMMA, WITH ADAPTATIONS OF CURRENT LOW RISK TECHNOLOGY TOOLS AND MATERIALS.

COMMENTS AND OPINIONS IN THIS PRESENTATION ARE THOSE OF THE AUTHOR, AND MUST NOT BE ATTRIBUTED TO ANY OTHER INDIVIDUAL(S) OR ORGANIZATION(S).

CESSNA'S ALTERNATIVE FUEL INVESTIGATIONS

SINCE THE MID 1980'S, CESSNA PURSUED A DEDICATED ALTERNATIVE FUEL RESEARCH PROGRAM THAT REQUIRED THE DEVELOPMENT OF THE FOLLOWING TOOLS, PROCEDURES AND MATERIALS.

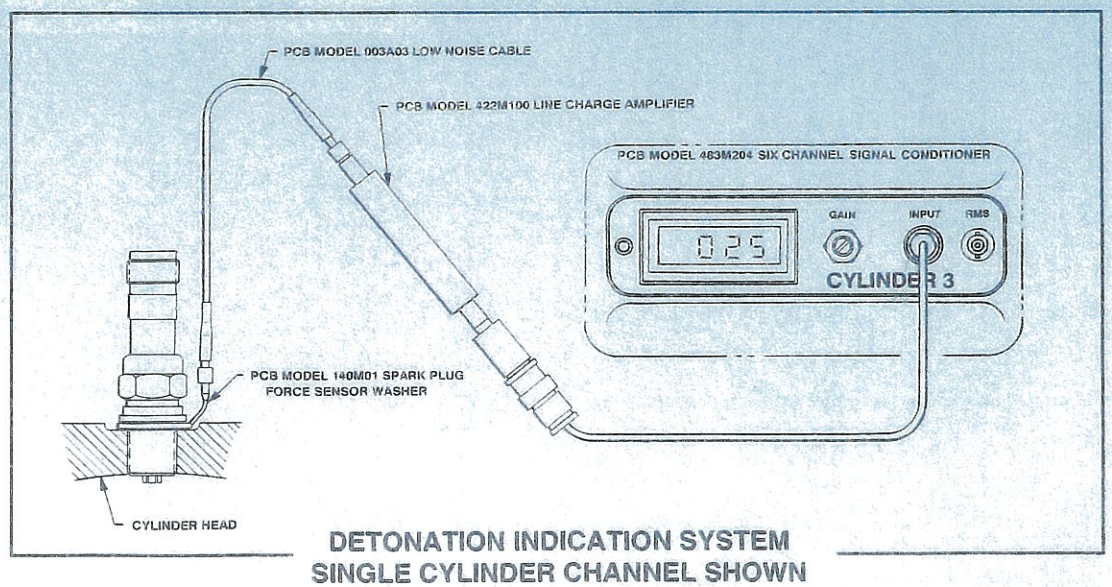
- DEVELOPMENT OF THE CESSNA ENGINE DETONATION INDICATION SYSTEM (CEDI) FOR GROUND AND FLIGHT APPLICATIONS. [REFERENCE 3]
  - THE FAA APPROVED CEDI SYSTEMS PRODUCED AND SERVICED BY PCB IN BUFFALO, NY, ARE ROUTINELY USED IN THE CERTIFICATION OF ENGINES AND ENGINE INSTALLATIONS.
- A *"BASELINE LEADED 100LL AVGAS"* WAS DEVELOPED AS A TEST REFERENCE FUEL WITH THE COLLABORATION OF PHILLIPS RESEARCH.
- CESSNA DEVELOPED GROUND AND FLIGHT FUEL EVALUATION PROCEDURES. [REFERENCE 4]
  - LABORATORY DYNAMOMETERS WITH ARTIFICIAL ENGINE COOLING AND POWER ABSORPTION PROVISIONS, FAIL TO TAKE INTO CONSIDERATION ENGINE INSTALLATION FACTORS THAT AFFECT PERFORMANCE, FUEL CONSUMPTION AND DETONATION CHARACTERISTICS.
  - SAID LABORATORY TEST PROVISIONS, INDISPENSABLE FOR ENGINE DEVELOPMENT, WERE REPLACED WITH ACTUAL AIRCRAFT OR GROUND PROPELLER TEST STANDS CLOSELY CONFORMING TO ACTUAL AIRCRAFT INSTALLATIONS.
  - TEST ENGINE CONTROLS ARE LIMITED TO THOSE AVAILABLE TO A PILOT TO AVOID ARTIFICIAL BIASING OF RESULTS, PARTICULARLY DETONATION.
  - THE SIMPLE PROCEDURES INVOLVE LOW COST STANDARD EQUIPMENT AND INSTRUMENTATION WITH REPEATABLE AND REPRODUCIBLE RESULTS.
- INVESTIGATIONS INCLUDED HYDROCARBON, ETHANOL, MTBE AND ETBE ETHERS, AND EMULSIFIED FUELS SUBMITTED BY ESTABLISHED PRODUCERS, AND INDEPENDENT SOURCES.
  - FUELS WERE COMPARED TO THE *"BASELINE 100LL AVGAS"* IN BACK TO BACK TEST SEQUENCES, UNDER UNIFORM GROUND AND FLIGHT ENGINE AND AMBIENT CONDITIONS.

Model 400M60 **FIGURE 1**

Cessna Aircraft Detonation Indication System

This economical, easy-to-use, portable 6-channel system monitors and processes combustion/detonation pressure signals generated by Model 140M01 Cessna force washers installed under one spark plug of each cylinder.

- ***Complete system includes one detonation monitor, 6 spark plug force washers, cabling, 6 in-line charge amplifiers and operating manual.***
- ***No engine modifications or shaft encoders required.***
- ***Easy-to-read individual cylinder LCD with detonation detection lights.***
- ***No adjustments are required during use.***
- ***External automatic data logging systems may be triggered by available DC output signals proportional to detonation severity.***
- ***Analog scope output switch for diagnostic functions.***
- ***Detonation severity and frequency indications are clearly discriminated from normal combustion conditions.***



DETONATION INDICATION SYSTEM
SINGLE CYLINDER CHANNEL SHOWN

Detonation flight tests are subject to Federal Regulations.

"Helping you make better dynamic measurements"

PCB® PIEZOTRONICS

CESSNA'S ALTERNATIVE FUEL INVESTIGATIONS - CONTINUATION

- BY LATE 1998 THE BEST EFFORTS OF ESTABLISHED AVGAS PRODUCERS, AND AT TIMES NOVEL APPROACHES OF INDEPENDENT SOURCES, HAD FAILED TO YIELD A SINGLE PRACTICAL ALTERNATIVE TO LEADED 100LL AVGAS.
- REVISITING SOME OF THE WW2 EXPERIMENTAL AVGAS FORMULATIONS WITH AMINES, TRIPTANE AND OTHER COMPONENTS, SIMPLY REAFFIRMED THE FUTILITY OF SAID EFFORTS.
- ETHANOL YIELDED INSUFFICIENT DETONATION PERFORMANCE CONTRIBUTIONS, WITH SEVERE PENALTIES IN FUEL CONSUMPTION, PLUS AIRCRAFT MATERIAL COMPATIBILITY AND STABILITY DEFFICIENCIES THAT COMPROMISED FLIGHT SAFETY.
- ALIPHATIC ETHERS SUCH AS MTBE AND ETBE WERE EXTENSIVELY INVESTIGATED, AND WHILE MTBE REVEALED ADVERSE MATERIAL COMPATIBILITY AND PHYSIOLOGICAL RISKS, ETBE EMERGED AS THE MOST PROMISING COMPONENT AMONG ALL ALTERNATIVES EXPLORED BY CESSNA OVER A PERIOD OF 14 YEARS. [REFERENCE 4]
- ETBE IS AN ALIPHATIC ETHER PROCESSED BY THE CONVERSION OF ETHANOL WITH BUTYLENE, A COMMON PRODUCT OF REFINERY CATALYTIC CRACKERS.
- WHILE BASED ON ETHANOL, ETBE DOES NOT EXHIBIT THE AVIATION USE DRAWBACKS OF ETHANOL.
- CESSNA'S INVESTIGATIONS YIELDED 100LL AVGAS/ETBE BLENDS THAT REDUCED THE LEAD (TEL) REQUIREMENTS TO LEVELS UNATTAINABLE WITH ANY HYDROCARBON BLEND.
- THESE INVESTIGATIONS REVEALED A COMPLETE TRANSPARENCY BETWEEN TRADITIONAL 100LL AVGAS WITH A MAXIMUM SPECIFICATION LEAD LIMIT OF 2.0 ML/GAL, AND AN ULTRA LOW LEAD ULL102 AVGAS BLENDED WITH ETBE AT A MAXIMUM SPECIFICATION LEAD LIMIT OF ONLY 1.0 ML/GAL.
- THEREFORE, AN ULTRA LOW LEAD ULL102 AVGAS COULD CUT IN HALF CURRENT GENERAL AVIATION ENGINE EXHAUST GAS LEAD EMISSIONS.

RESULTS OF CESSNA'S ALTERNATIVE FUEL INVESTIGATIONS

- CESSNA SPONSORED, AND PERFORMED GROUND AND FLIGHT TESTS THAT LED TO THE APPROVAL OF ASTM D6227 GRADE 82UL AVGAS SPECIFICATION. [REFERENCE 5]
- THE MOST SIGNIFICANT CONTRIBUTIONS OF THIS 10 YEAR PROGRAM ARE LISTED AS FOLLOWS:
  - THE GRADE 82UL AVGAS SPECIFICATION REPRESENTS THE FIRST ASTM APPROVED UNLEADED AVIATION GASOLINE SPECIFICATION.
  - THIS PARTIALLY FAA FUNDED EFFORT OPENED THE DOOR TO THE USE OF COMMERCIAL AUTOMOTIVE GASOLINE IN AVIATION, WITH APPROPRIATE SCREENING PROCEDURES.
  - THE SPECIFICATION AND RELATED ASTM APPROVED RESEARCH REPORT, PROVIDE CRITICAL GUIDANCE FOR FUTURE UNLEADED PRODUCTS.[REFERENCE 6]
  - THE GRADE 82UL AVGAS SPECIFICATION INTRODUCES MTBE AND ETBE ETHERS AS APPROVED COMPONENTS FOR AVIATION USE.
  - THE ASTM D6227 SPECIFICATION HAS BEEN EXPANDED TO INCLUDE A NEW MID-GRADE UL87 AVGAS (DOCUMENT NOW IDENTIFIED AS GRADES UL82 AND UL87 SPECIFICATION).
  - THE ASTM D6227 SPECIFICATION MAY BECOME THE HOST DOCUMENT FOR FUTURE AVIATION GASOLINES BLENDED WITH NON-HYDROCARBON COMPONENTS.
- A NEW ASTM D7618 ETBE SPECIFICATION WAS APPROVED ON 1 MAY 2010 UNDER THE SPONSORSHIP OF HJELMCO OIL IN SWEDEN, ALLOWING THE UNRESTRICTED USE OF ETBE AS A COMPONENT FOR BLENDING IN AVGS.[REFERENCE 7]
  - A NEW ASTM D 7796 ETBE TEST METHOD BY GAS CHROMATOGRAPHY WAS APPROVED IN JUNE 2012. [REFERENCE 8]

CESSNA'S ENGINE COMBUSTION AND ESSENTIAL ACCESSORIES IMPROVEMENT INVESTIGATIONS.

- CESSNA DEVELOPED A HYBRID MULTI-FUEL ENGINE COMBUSTION SYSTEM INSENSITIVE TO THE OCTANE (SPARK-IGNITION) OR CETANE (DIESEL) PROPERTIES OF THE FUEL. [REFERENCE 9]

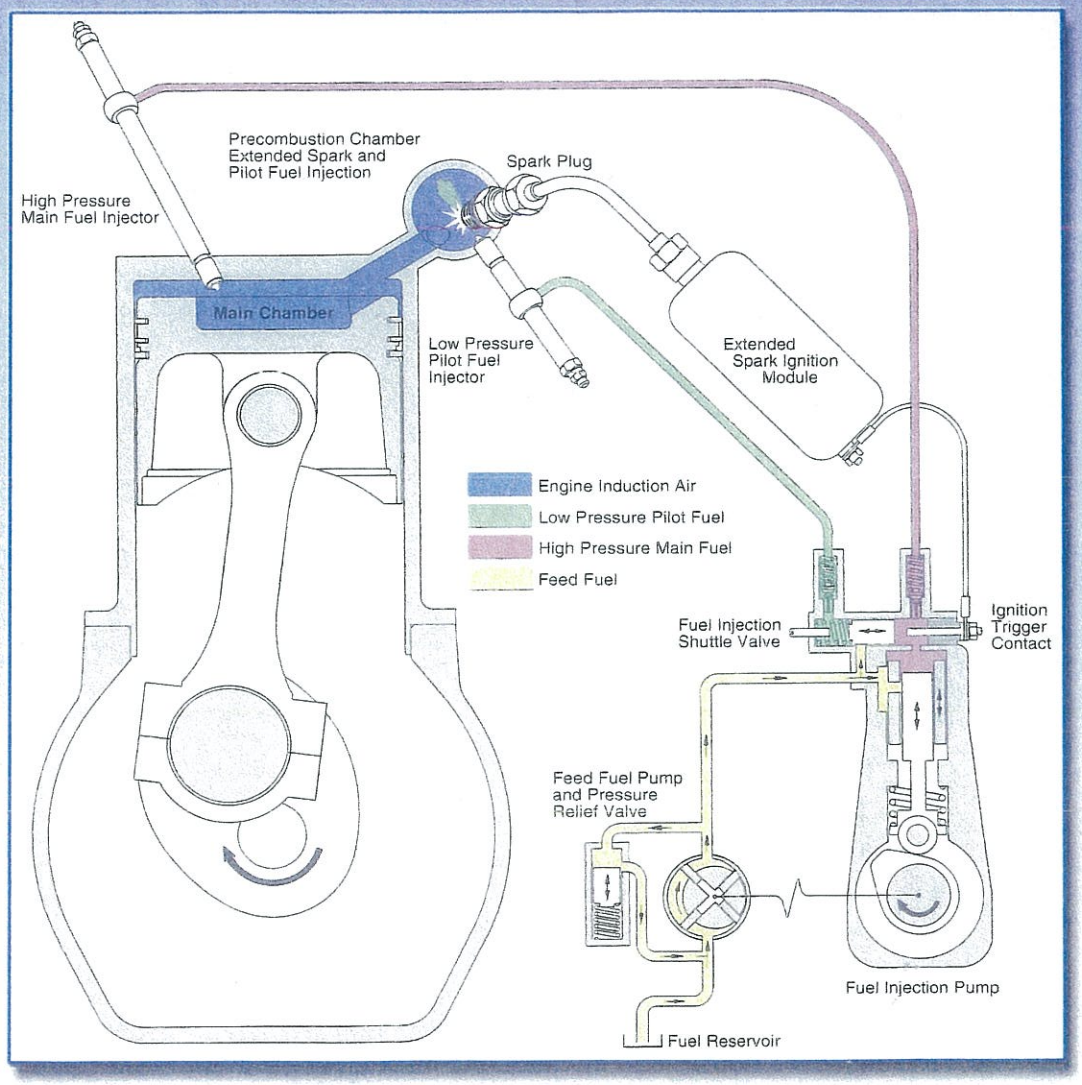
- ONLY KNOWN MULTI-FUEL COMBUSTION SYSTEM CAPABLE OF ATTAINING THE HIGH SPECIFIC OUTPUTS OF CURRENT TURBOCHARGED AIRCRAFT ENGINES.
- MODERATE COMPRESSION RATIOS YIELD COMBUSTION PRESSURES AND ENGINE STRESSES COMPARABLE TO CURRENT SPARK-IGNITION ENGINES - LOW WEIGHT.
- STARTING CHARACTERISTICS, FUEL ECONOMY AND OPERATION FLEXIBILITIES UNATTAINABLE BY ANY CONTEMPORARY AIRCRAFT PISTON ENGINE.

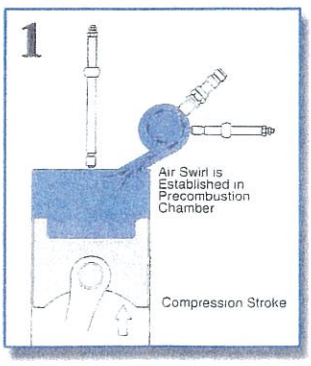
- CESSNA DEVELOPED AIRFRAME AND ENGINE FUEL SUPPLY PROVISIONS FOR AVGAS OF BROAD VOLATILITY, TO ALLOW THE USE OF CURRENT TYPICAL FUEL INJECTION SYSTEMS WITH ALL TYPES OF GASOLINES.[REFERENCE 4]
- CESSNA EXPLORED ENGINE /AIRFRAME MODIFICATIONS AND OPERATIONAL CHANGES THAT COULD PROVIDE PARTIAL OR COMPLETE OCTANE DEFICIT COMPENSATION, FOR NEW FUELS WITH MOTOR OCTANE RATINGS BELOW 100 MON.
  - WATER-METHANOL INJECTION SYSTEMS WIDELY USED BY THE MILITARY IN WW2, REPRESENT THE ONLY PROVEN DETONATION SUPRESSION MEANS TO COMPENSATE IN EXCESS OF 15 MON OCTANE NUMBERS - NO POWER LOSSES.
  - IT PROVED ESSENTIAL TO UPGRADE/REPLACE CURRENT OUTDATED AVIATION IGNITION AND/OR FUEL INJECTION SYSTEMS, AS A FIRST STEP TOWARDS REDUCING THE FUEL OCTANE DEMANDS OF CURRENT ENGINES.
  - INVESTIGATIONS REVEALED THAT IGNITION SYSTEMS TRIGGERED BY CRANKSHAFT PROXIMITY/OPTICAL POSITION SENSORS, DELETION OF BREAKER POINTS AND CONDENSERS, AND EXTENDED SPARK DURATIONS YIELD SIGNIFICANT REDUCTIONS OF ENGINE OCTANE REQUIREMENTS.
  - INVESTIGATIONS ALSO REVEALED THAT INCREASED INJECTION FUEL DISCHARGE PRESSURES, TIMED OR INTERMITTENT INJECTION FLOWS, INJECTION NOZZLES WITH PRESSURIZED AIR EMULSION PROVISIONS AND MECHANICAL ATOMIZATION, YIELD SIGNIFICANT REDUCTIONS OF ENGINE OCTANE REQUIREMENTS.
- <u>THE COST OF UPDATED SYSTEMS MUST NOT EXCEED THE REPLACEMENT COSTS OF CURRENT MAGNETOS AND LOW PRESSURE FUEL INJECTION COMPONENTS</u>

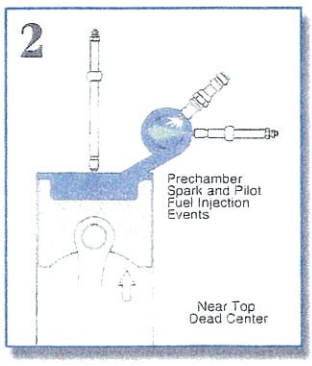
FIGURE 2

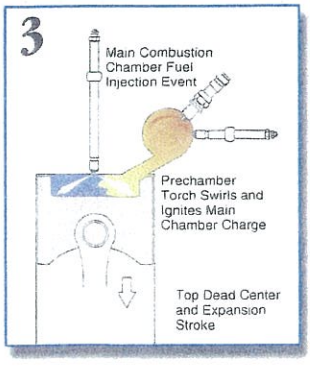
Cessna Aircraft Company
Piston Engine Multi-Fuel Combustion System

The Cessna Combustion System is capable of burning all types of transportation fuels with the high performance and low installation weight attributes of spark ignited (Otto) aviation engines, and without the altitude, starting and weight shortcomings of compression ignition (Diesel) engines.









U.S. Patent Nos. 4,594,796; 4,765,293 and 5,090,378. European Patent No. 499.741 - Austrian Patent No. 402.322

A PRESCRIPTION FOR THE UNLEADED AVGAS DILEMMA

THE FOLLOWING MULTI-PHASED APPROACH TO THE REPLACEMENT OF LEADED 100LL AVGAS, IS BASED ON THE EXTENSIVE BODY OF INFORMATION AND EXPERIENCE ACCUMULATED DURING CESSNA ACTIVITIES, COVERED IN PREVIOUS SECTIONS OF THIS PRESENTATION.

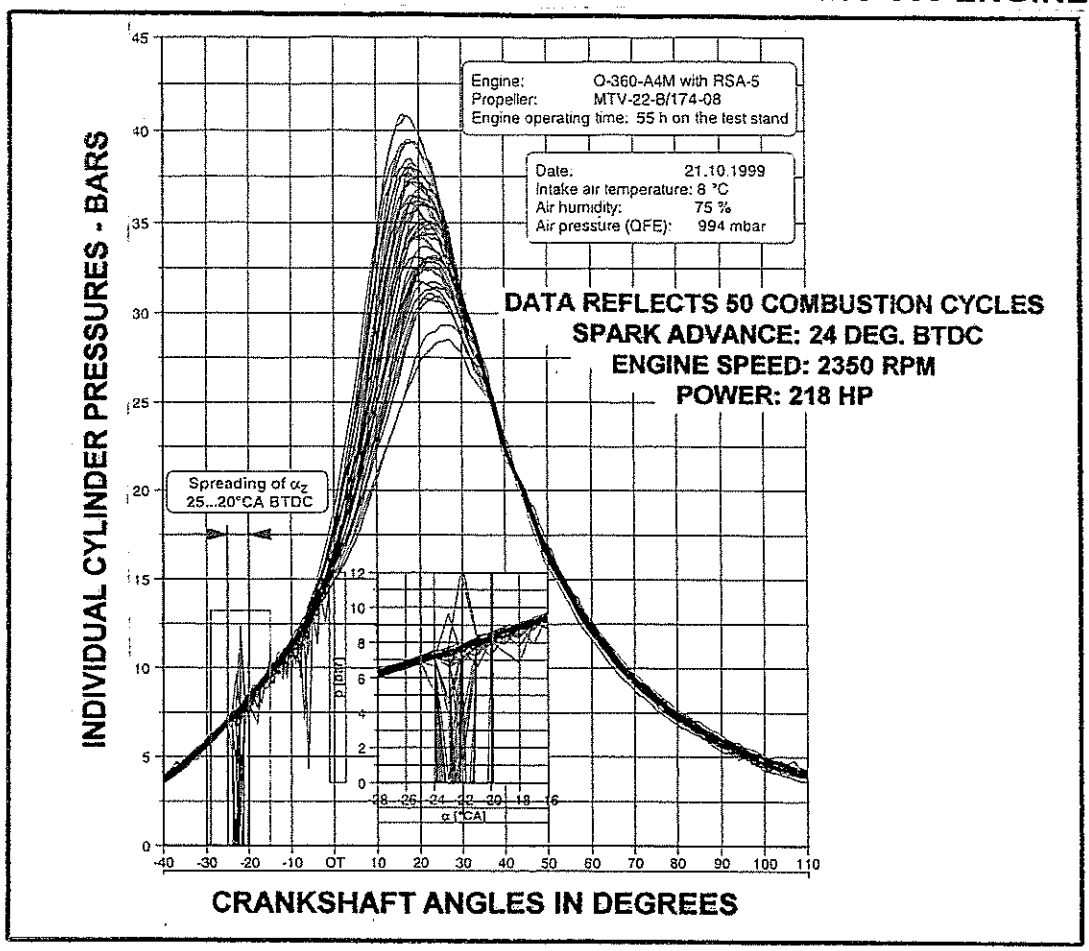
- THE MULTI-PHASED APPROACH INVOLVES ONLY LOW RISK AND CURRENT TECHNOLOGY TOOLS AND MATERIALS.

- THE MULTI-PHASED APPROACH TAKES MAXIMUM ADVANTAGE OF ETBE BLENDS WITH UNLEADED ALCOHOL-FREE AUTOMOTIVE GASOLINES, TO PRODUCE MID-GRADE AVIATION GASOLINE SUCH AS THE GRADE UL87 COVERED BY THE ASTM D6227 SPECIFICATION.

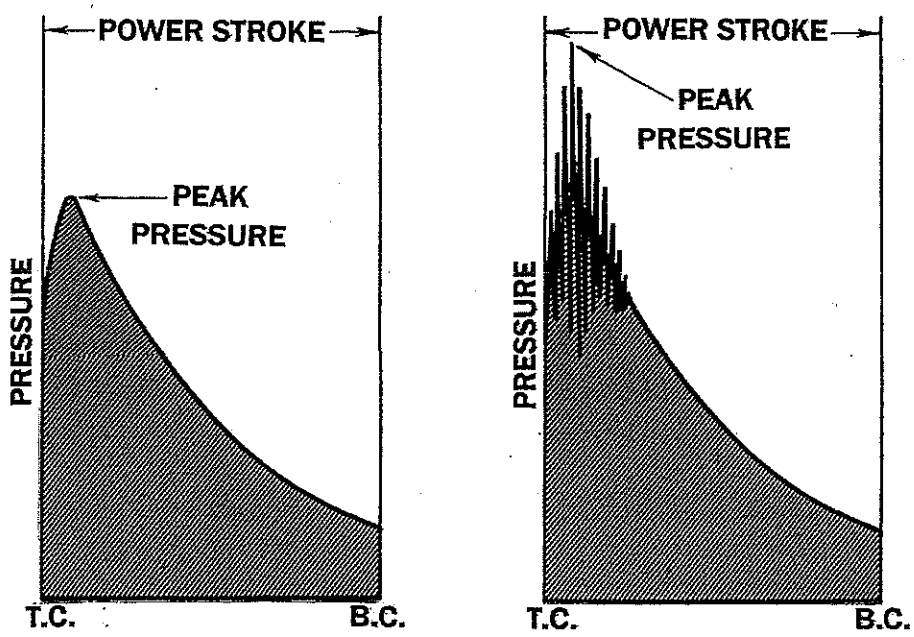
- THE MULTI-PHASED APPROACH TAKES MAXIMUM ADVANTAGE OF ETBE BLENDS WITH CURRENT 100LL AVGAS STOCKS, TO REDUCE AND EVEN ELIMINATE LEAD ADDITIVES, TO PRODUCE ULTRA LOW LEAD ULL102 MON AND UNLEADED UL95 MON FUELS.

- THE VENERABLE BUT OUTDATED CURRENT PISTON ENGINE ESSENTIAL ACCESSORIES MAY BE REPLACED BY STATE OF THE ART COMPONENTS, CAPABLE OF REDUCING THE ENGINE OCTANE REQUIREMENTS TO LEVELS COMPATIBLE WITH THE NEW UNLEADED FUEL.

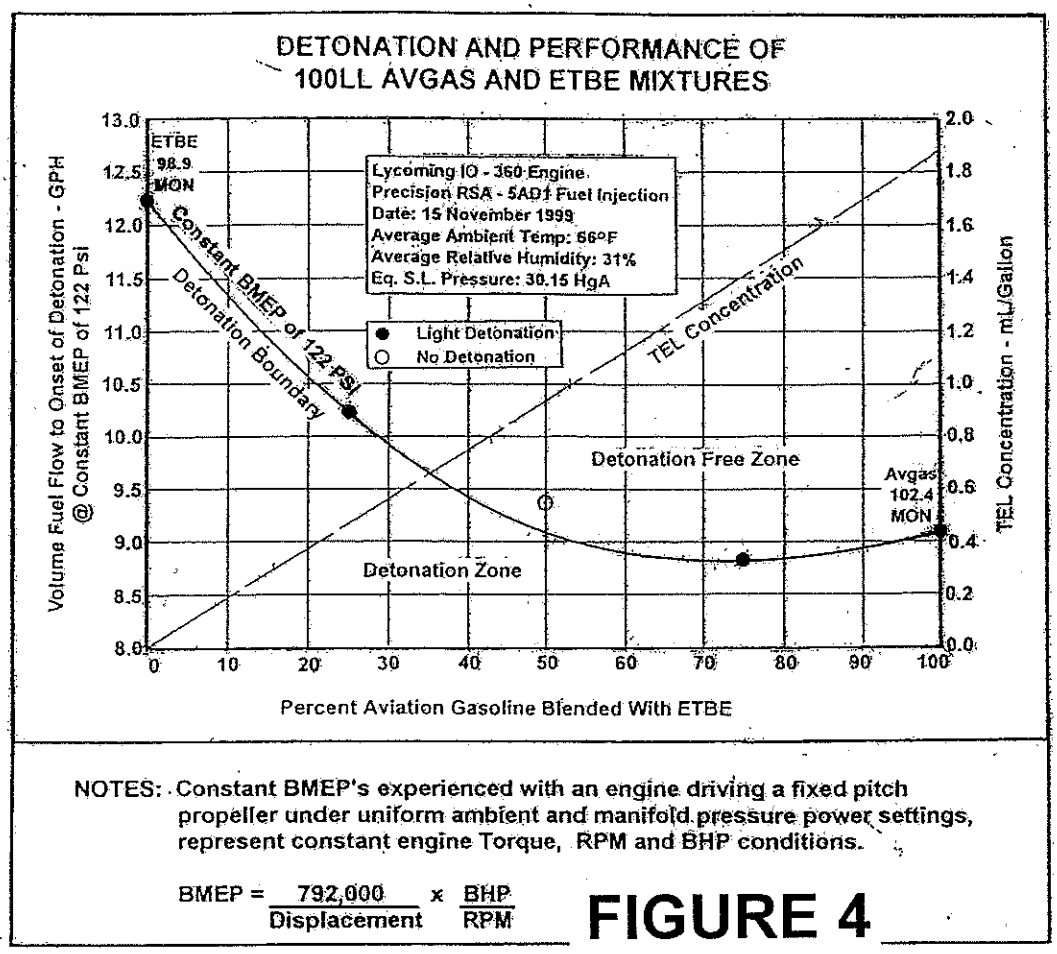
FIGURE 3 NORMAL COMBUSTION PRESSURES AND IGNITION TIMING VARIATIONS ON A LYCOMING 360 ENGINE



- OBVIOUS SIGNIFICANT COMBUSTION PRESSURE VARIATIONS INCREASE THE OCTANE REQUIREMENTS OF THE ENGINE.
- ADAPTATION OF STATE OF THE ART IGNITION AND/OR FUEL INJECTION ESSENTIAL ACCESSORIES MITIGATE COMBUSTION PRESSURE VARIATIONS, THUS REDUCING THE ENGINE OCTANE REQUIREMENTS.



NORMAL COMBUSTION DETONATION



NOTES: Constant BMEP's experienced with an engine driving a fixed pitch propeller under uniform ambient and manifold pressure power settings, represent constant engine Torque, RPM and BHP conditions.

$$BMEP = \frac{792{,}000}{Displacement} \times \frac{BHP}{RPM}$$

FIGURE 4

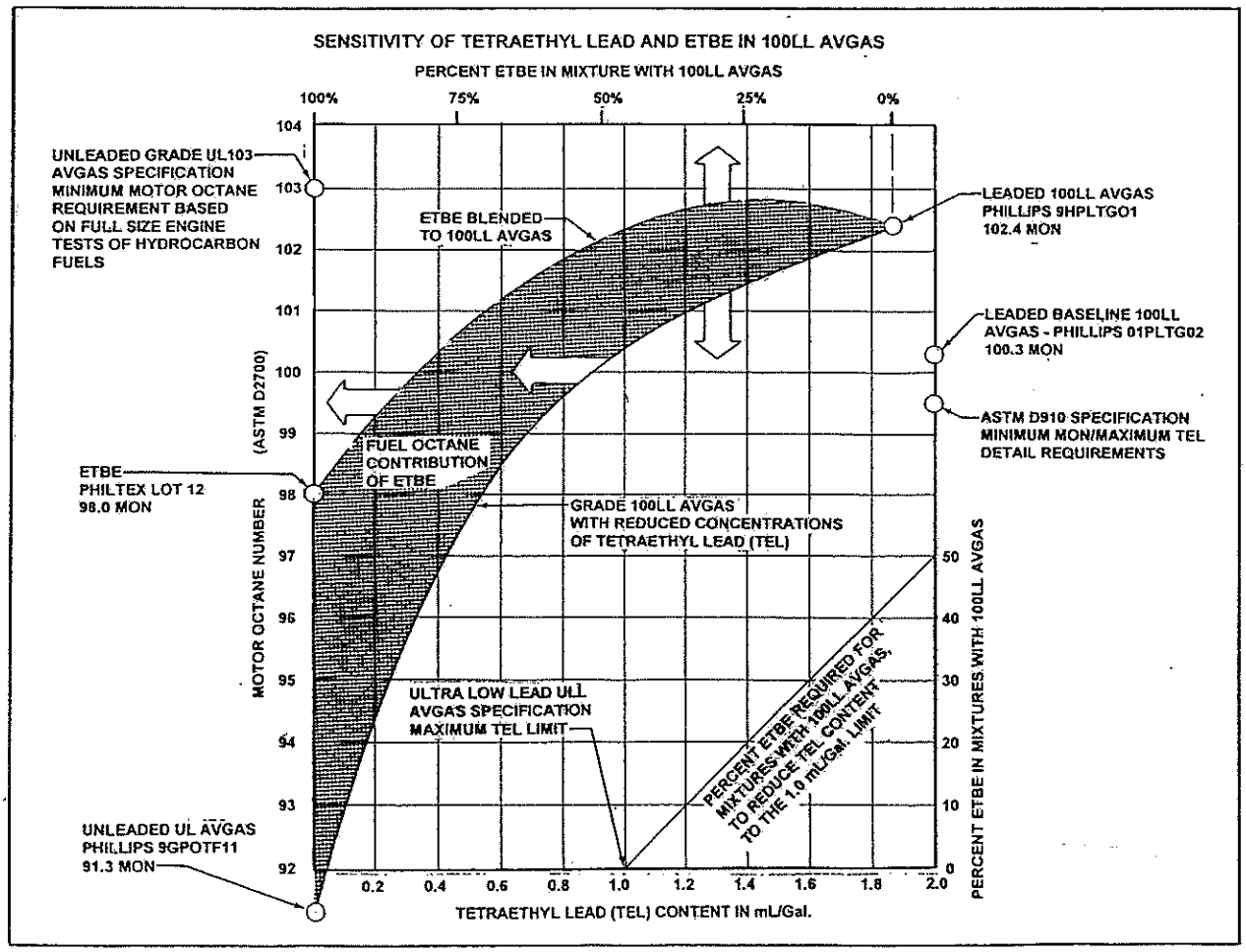


FIGURE 5 OUTLINES THE FOLLOWING BASIC CHRONOLOGICAL FEATURES, OF THE MULTI-PHASED PRESCRIPTION FOR THE UNLEADED AVGAS DILEMMA

- CONTEMPORARY AVIATION GASOLINE SUPPLY CONDITIONS.
  - ONLY THE UNIVERSAL LEADED 100LL AVGAS AND UNLEADED ALCOHOL-FREE AUTOMOTIVE GASOLINES ARE CONSIDERED UNDER CURRENT U.S. FLEET CONDITIONS.

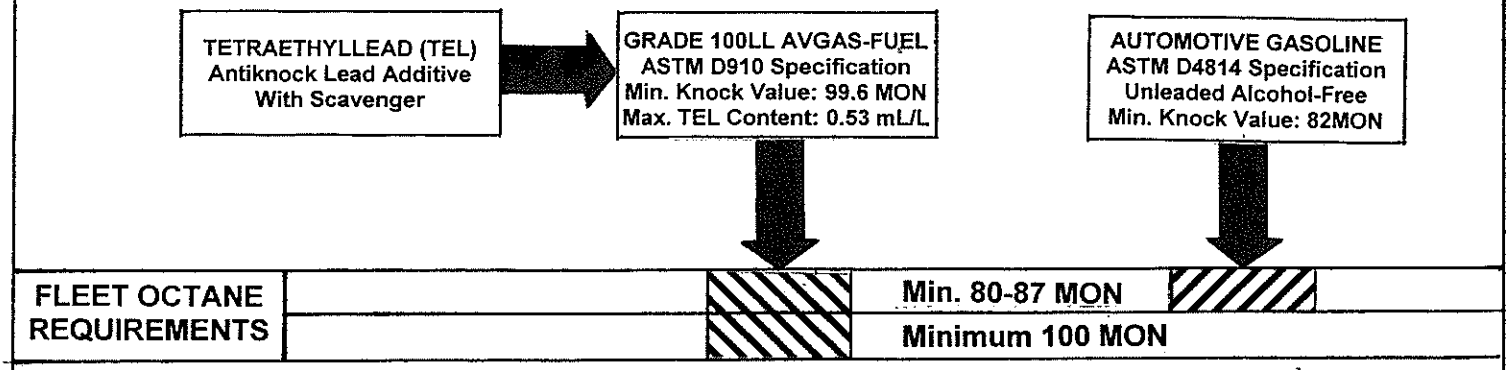
- TRANSITIONAL PERIOD AVIATION GASOLINE SUPPLY CONDITIONS.
  - LEADED 100LL AVGAS CONTINUES TO BE AVAILABLE AS A COMPONENT FOR THE ETBE BLENDED ULTRA LOW LEAD ULL102 MON AVGAS.
  - THE ULL 102 MON AVGAS IS CAPABLE OF SERVING THE ENTIRE U.S. FLEET, AND OF CUTTING IN HALF THE ENGINE EXHAUST GAS LEAD EMISSIONS.
  - ETBE BLENDED WITH 82 MON REGULAR ALCOHOL-FREE AUTOMOTIVE GASOLINE YIELDS A GRADE UNLEADED UL87 MON FUEL CAPABLE OF SERVING A VAST NUMBER OF U.S. AIRCRAFT.

- LONG TERM AVIATION GASOLINE SUPPLY CONDITIONS.
  - TOTAL REMOVAL OF LEAD FROM CURRENT 100LL AVGAS RESULTS IN AN UNLEADED UL91 MON PRODUCT, THAT BLENDED WITH ETBE YIELDS AN UNLEADED UL95 MON AVGAS.
  - WITH THE EMERGENCE OF STATE OF THE ART ESSENTIAL IGNITION SYSTEMS CAPABLE OF REDUCING THE OCTANE REQUIREMENTS OF THE ENGINES, THE UL95 MON AVGAS COULD SATISFY THE VAST MAJORITY OF REMAINING ENGINES.
  - WATER-METHANOL INJECTION OR NEW STATE OF THE ART FUEL INJECTION SYSTEMS COULD SATISFY THE OCTANE REQUIREMENTS ON EXTREME CASE INSTALLATIONS.

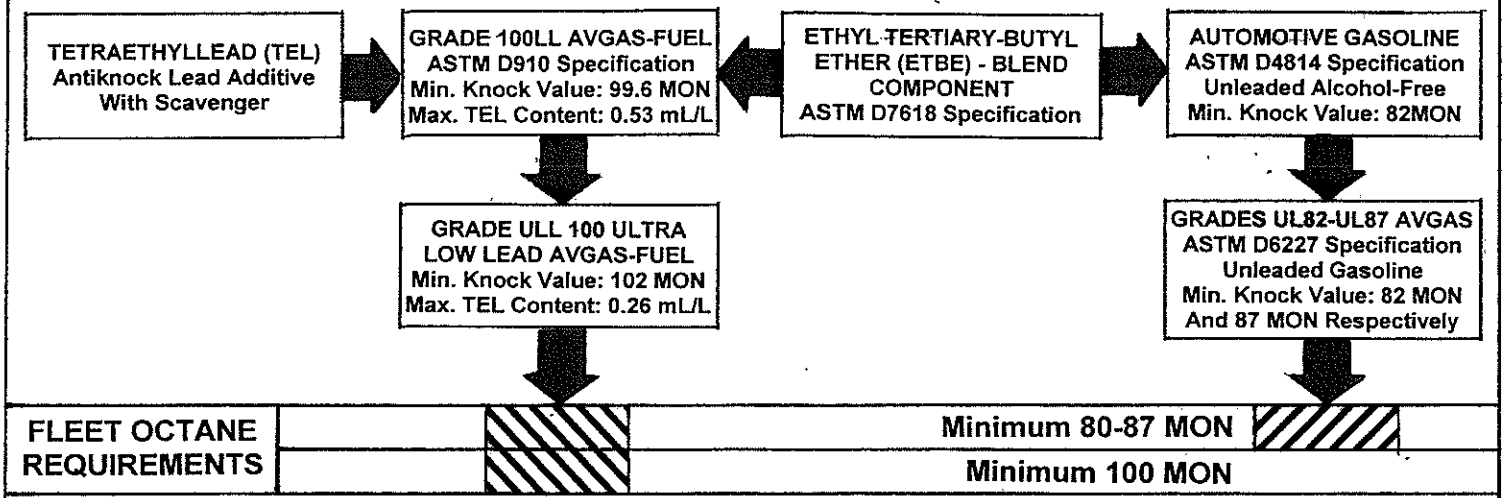
A PRESCRIPTION FOR THE UNLEADED AVGAS DILEMMA

CONTEMPORARY AVIATION GASOLINE SUPPLY CONDITIONS

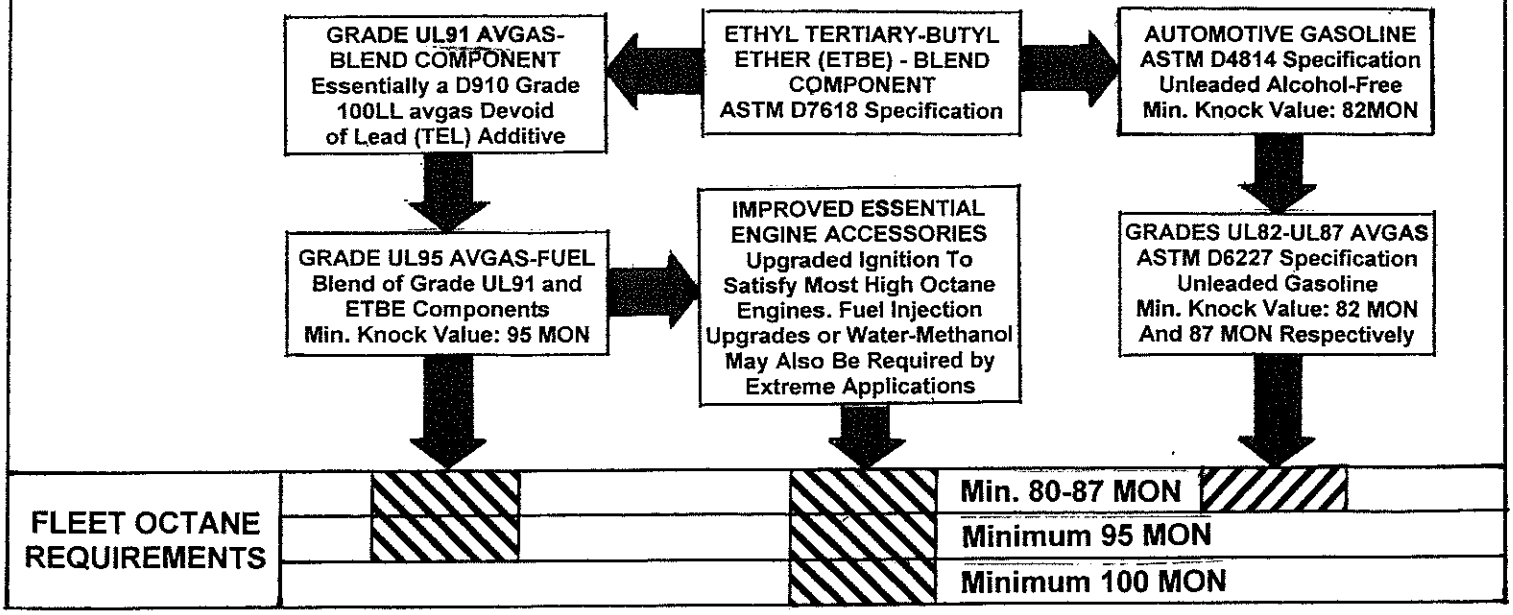
FIGURE 5



TRANSITIONAL PERIOD AVIATION GASOLINE SUPPLY CONDITIONS



LONG TERM AVIATION GASOLINE SUPPLY CONDITIONS



REFERENCES

[1] *"Can General Aviation Survive With A Lower Octane Unleaded Avgas?"*; C. Gonzalez, 2008 EAA Airventure Forum Presentation, 02 August 2008.

[2] *"The Path To An Unleaded UL Avgas"*; C. Gonzalez, 2010 EAA Airventure Forum Presentation, 29 July 2010.

[3] SAE Technical Paper 951156,*"On-Board Equipment For The Evaluation Of Aviation Gasolines Abnormal Combustion Characteristics"*; C. Gonzalez, SAE GCRA, 3-5 May 1995.

[4] *"Cessna/FAA ETBE Based Aviation Spark-Ignition Engine Fuel Program-Report Draft"*; December 2002.

[5] *"ASTM D6227 Standard Specification for Grades UL82 and UL87 Unleaded Aviation Gasoline"*; Originally Approved 10 November 1998.

[6] *"ASTM RR: D02 - 1427 Research Report - Grade 82UL Aviation Gasoline Specification Background Information"*; June 1999.

[7] *"ASTM D7618 Standard Specification For Ethyl Tertiary-Butyl Ether (ETBE) For Blending With Aviation Spark-Ignition Engine Fuel"*; 01 May 2010.

[8] *"ASTM D7796 Standard Test Method For Analysis of Ethyl Tertiary-Butyl Ether (ETBE) By Gas Chromatography"*; June 2012.

[9] SAE Technical Paper 2000-01-1714,*"The Multi-Fuel General Aviation Piston Engine"*; C. Gonzalez and R. Jesik, SAE GATC, 9-11 May 2000.