THE PATH TO AN UNLEADED GRADE UL AVGAS

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INTRODUCTION

AFTER 25 YEARS OF INDUSTRY-WIDE EFFORTS, NOT A SINGLE HYDROCARBON UNLEADED ALTERNATIVE TO 100LL AVGAS HAS BEEN DEVELOPED.

- THIS PRESENTATION WAS PROMPTED BY IMPENDING ENVIRONMENTAL LEAD EMISSIONS REGULATORY ACTIVITIES THAT COULD HAVE SEVERE CONSEQUENCES FOR AVIATION.
- 27 AUGUST 2010 IS THE DEADLINE FOR COMMENTS TO THE EPA ANPR.
- BY 2013, THE INDIVIDUAL STATES MUST HAVE APPROVED PLANS TO RESOLVE ANY AIR QUALITY NON-ATTAINMENT ISSUES.

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

DEVELOPMENT PATH TO AN UNLEADED UL100 AVGAS IS BASED ON THE FOLLOWING CONSIDERATIONS.

- **PETITION REQUESTING EPA RULEMAKING TO LIMIT LEAD EMISSIONS FROM AVIATION SOURCES, DOES NOT EXPLICITLY SUGGEST A COMPLETE REMOVAL OF TEL (LEAD) FROM FUEL.**
- **CESSNA AVIATION FUEL INVESTIGATIONS (1997-2002), ESTABLISHED THE TRANSPARENCY BETWEEN LOW LEAD 100LL AVGAS (MAXIMUM 2.0 ML/GAL LEAD) WITH AN ULTRA LOW LEAD ULL100AVGAS (MAXIMUM 1.0 ML/GAL LEAD), BLENDED WITH THE RECENTLY APPROVED ASTM D7618 ETBE ALIPHATIC ETHER COMPONENT.**
- **THE FAA HAS INDICATED A WILLINGNESS TO CONSIDER WAIVING A GENERAL AVIATION FLEET RECERTIFICATION REQUIREMENT, WITH ULTRA LOW LEAD FUELS THAT DEMONSTRATE A COMPLETE PERFORMANCE EQUIVALENCE TO THE CONTEMPORARY ASTM D910 GRADE 100LL AVGAS.**
- **THE ETBE BLENDED ULTRA LOW LEAD AVGAS REPRESENTS JUST ONE OF A TWO STEP PROCESS TOWARD THE TOTAL ELIMINATION OF LEAD IN AVGAS.**

WHAT IS ETBE?

THE ALIPHATIC ETHER ETBE IS PROCESSED BY THE CONVERSION OF 1.0 GALLON OF ETHANOL WITH 1.7 GALLONS OF ISOBUTYLENE TO YIELD 2.3 GALS. OF ETBE.

- **WHILE ETHANOL IS USED AS A FEEDSTOCK IN THE PRODUCTION OF ETBE, THE FINISHED PRODUCT DOES NOT EXHIBIT THE AVIATION USE DRAWBACKS OF THE BASE ETHANOL.**
- **ISOBUTYLENE IS A COMMON PRODUCT OF REFINERY FLUID CATALITIC CRACKERS.**
- **ETBE EMERGED AS THE MOST PROMISING AVGAS BLEND COMPONENT DURING THE 14 YEAR CESSNA ALTERNATIVE FUEL INVESTIGATIONS.**

BLENDING OF ETBE WITH 100LL AVGAS

ETBE IMPARTS THE FOLLOWING PROPERTY CHANGES TO THE BASE LOW LEAD 100LL AVGAS AT ETBE CONCENTRATIONS BELOW 50% BY VOLUME.

- DILUTION OF 100LL AVGAS WITH INCREASING AMOUNTS OF ETBE, REDUCE TEL (LEAD) CONCENTRATIONS WITH CONCURRENT IMPROVEMENTS IN KNOCK (DETONATION) SUPPRESSION CHARACTERISTICS.
- BLENDING OF ETBE SIGNIFICANTLY REDUCES THE MON (OCTANE) DEFICITS EXPERIENCED WITH REDUCED TEL (LEAD) CONCENTRATIONS IN 100LL AVGAS.
- BLENDING OF ETBE YIELDS MODEST ENGINE POWER INCREMENTS WITH CONCURRENT SPECIFIC FUEL CONSUMPTION IMPROVEMENTS, IN SPITE OF LOWER HEATS OF COMBUSTION.
- ETBE BLENDS REDUCE IN-FLIGHT VAPOR LOCK TENDENCIES.
- BLENDING OF ETBE IMPROVES THE MATERIALS COMPATIBILITY CHARACTERISTICS OF 100LL AVGAS.

BLENDING OF ETBE WITH 100LL AVGAS - CONTINUED

- LABORATORY QUALITY CONTROL TEST METHODS FOR 100LL AVGAS ARE SUITABLE FOR ETBE AND ETBE BLENDS, WITH THE ONLY EXCEPTION OF METHODS INTENDED TO ESTABLISH THE CONCENTRATION OF DIEGME FUEL ANTI-ICING ADDITIVE.
  - WHILE INCOMPATIBLE WITH DIEGME, ETBE BLENDS ARE COMPATIBLE WITH THE ALTERNATE ISOPROPANOL FUEL SYSTEM ANTI-ICING ADDITIVE.
- ETBE BLENDS IMPROVE THE OXIDATION AND LONG TERM STORAGE STABILITY CHARACTERISTICS OF 100LL AVGAS.
- 100LL AVGAS BLENDED WITH ETBE EXHIBITS CARBURETOR ICING CHARACTERISTICS COMPARABLE TO THOSE OF THE ORIGINAL FUEL.
  - NO CHANGES TO THE OPERATION OF CARBURETOR ALTERNATE HOT AIR PROVISIONS ARE REQUIRED WITH ETBE BLENDED 100LL AVGAS.
- ETBE BLENDS OFFER COMPARABLE ENGINE STARTING CHARACTERISTICS WITH REDUCED FLOODING AND SPARK-PLUG FOULING CHARACTERISTICS.

BLENDING OF ETBE WITH 100LL AVGAS - CONTINUED

- FLAME LUMINOSITY OF ETBE BLENDS ARE COMPARABLE TO THOSE OF 100LL AVGAS.
- NO ENGINE MODIFICATIONS OR ADJUSTMENTS ARE REQUIRED WITH ETBE BLEND CONCENTRATIONS BELOW 50%
- NO ENGINE OPERATION CHANGES ARE REQUIRED WITH ETBE BLEND CONCENTRATIONS BELOW 50%.
- AN ESTIMATED 7% OF THE FLEET WITH CAPACITANCE FUEL GAUGING SYSTEMS REQUIRE MINOR ALTERATIONS, DUE TO CHANGES IN THE FUEL DIELECTRIC CHARACTERISTICS WITH ETBE.
  - INSTRUMENT STICK-ON DECALS FOR DIAL TYPE INDICATORS.
  - COMPACT AND LOW COST SIGNAL CONDITIONER CONVERSION MODULES FOR DIGITAL TYPE INDICATORS.
  - NO FUEL DIELECTRIC DETAIL REQUIREMENTS ARE POSTED ON CURRENT ASTM D910 AVGAS SPECIFICATION.

BLENDING OF ETBE WITH 100LL AVGAS - CONTINUED

- HEAT OF COMBUSTION LOSSES (4.9% TO 8.1% FOR ETBE CONCENTRATIONS OF 30% TO 50%), DO NOT COMPROMISE WINDSHIELD DEFROSTING OR CABIN HEATING FUNCTIONS.
- ETBE BLENDING OFFERS A SUBSTANTIAL REDUCTION OF TOTAL HYDROCARBON AND CARBON MONOXIDE EMISSIONS, COMPARABLE CARBON DIOXIDE AND HIGHER ALDEHYDE EMISSIONS .
  - ADDITIONAL OZONE REDUCTIONS BY DILUTION OF PRIMARY 100LL AVGAS REACTIVE CONSTITUENTS.
- ETBE BLENDED ULL AVGAS DOES NOT EXHIBIT THE INCAPACITATING PHYSIOLOGICAL AND MATERIAL COMPATIBILITY PROBLEMS OF MTBE BLENDED AVGAS.
- WITH THE ONLY POSSIBLE EXCEPTION OF THE 40% EVAPORATED VOLUME, THE ETBE BLENDED ULL AVGAS COMPLIES WITH CURRENT AVGAS DISTILLATION FRACTION SPECIFICATION REQUIREMENTS.

BLENDING OF ETBE WITH 100LL AVGAS - CONTINUED

- THE GENERALLY LOWER AND MORE UNIFORM DISTILLATION TEMPERATURES OF ETBE BLENDED AVGAS, IMPROVES FUEL/AIR MIXTURES HOMOGEINITY WITH REDUCED VAPOR LOCK, ENGINE FLOODING AND SPARK PLUG FOULING TENDENCIES, AND IMPROVED FUEL CONSUMPTIONS.
- INDIVIDUALS EXPOSED TO THE ODORS OF ETBE BLENDS ADAPTED RAPIDLY AS THEY LEARNED TO RECOGNIZE THEIR SOURCE.

PRELIMINARY ULL100 AVGAS SPECIFICATION PARAMETERS.

ETBE BLEND FRACTIONS	30%	40%	50%	100LL SPEC.
MAX. TEL (GPb/LITER) OF 100LL AVGAS (SEE NOTE)	0.45	0.50	0.56	N/A
EST. HEAT OF COMB. OF BLEND (MJ/Kg)	41.4	40.7	40.0	43.5

NOTE: MAXIMUM TEL CONTENT IN 100LL AVGAS TO ATTAIN A MAX. 0.28 GRAMS OF LEAD PER LITER LIMIT IN THE ETBE BLENDED ULL100 ULTRA LOW LEAD AVGAS.

AVAILABILITY OF ETBE BLENDING STOCKS

EUROPEAN EFOA AND KINGSMAN SA. REPORTS REFLECT A MASSIVE GROWTH OF ETBE PRODUCTION CAPACITY AROUND THE WORLD.

- THE TOTAL U.S. CONSUMPTION OF 100 OCTANE AVIATION FUEL IN 2008 AND 2009 HAS BEEN ESTIMATED TO AVERAGE 240 MILLION GALLONS PER YEAR.
  - AT A 40% BLEND RATIO, A CONVERSION TO AN ULTRA LOW LEAD ULL100 AVGAS WOULD REQUIRE 92 MILLION GALLONS OF ETBE ANNUALLY.
- EFOA REPORTED THAT 1,500 MILLION GALLONS OF ETBE WERE PROCESSED IN EUROPE BY 11 PRODUCERS IN 2008.
- KINGSMAN SA. REPORTS GLOBAL ETBE PRODUCTION CAPACITY AUGMENTED TO 14 COUNTRIES IN EUROPE, JOINED RECENTLY BY THE U.S., BRAZIL AND JAPAN.

AVAILABILITY OF ETBE BLENDING STOCKS - CONTINUATION

- A CONSERVATIVE ESTIMATE OF KINGSMAN SA. INFORMATION REVEALS THAT CURRENT GLOBAL ETBE PRODUCTION CAPACITY EXCEEDS 1,650 MILLION GALLONS PER YEAR.
  - AT A BLEND CONCENTRATION OF 40%, LESS THAN 6% OF THAT ETBE PRODUCTION CAPACITY IS REQUIRED TO SATISFY U.S. ANNUAL AVIATION ETBE NEEDS.
  - THE LYONDELL CHANNELVIEW, TEXAS ETBE PRODUCTION FACILITIES IN THE U.S. IS REPORTEDLY CAPABLE OF PRODUCING 414 MILLION GALLONS OF ETBE PER YEAR.
  - WHEN NECESSARY, THESE MASSIVE STOCKS MAY BE WASHED AND/OR CATALYTICALLY TREATED TO INCREASE THEIR PURITY TO MEET ASTM D7618 ETBE SPECIFICATION AVIATION REQUIREMENTS.

OVERALL DEVELOPMENT PROGRAM OUTLINE

THE PATH TO AN UNLEADED GRADE UL AVGAS IS COMPRISED OF TWO PHASES, CARRIED OUT UNDER A COORDINATED BUT DECENTRALIZED ORGANIZATION STRUCTURE, WITH IMPROVED TEST METHODOLOGIES THAT TAKE INTO CONSIDERATION "REAL WORLD" FACTORS AND CONDITIONS.

PHASE 1 – DEVELOPMENT OF ULTRA LOW LEAD ULL100 AVGAS.

- SHOULD TAKE FULL ADVANTAGE OF EXTENSIVE CESSNA ETBE FUEL DEVELOPMENT ACTIVITIES.
- A LEADED 100LL BASELINE FUEL SPECIFICATION IS REQUIRED TO DEFINE A REPRODUCIBLE REFERENCE FUEL.
- VALIDATION TESTS SHOULD BE PERFORMED WITH ACTUAL AIRCRAFT OR EQUIVALENT GROUND PROPELLER TEST STANDS, WITH THE 100LL BASELINE AND ULL100 BLENDS.
  - GROUND AND FLIGHT TESTS ARE REQUIRED TO ESTABLISH OPTIMUM ETBE BLEND RATIOS.

PHASE 1 ULL AVGAS DEVELOPMENT - CONTINUATION

- LABORATORY TESTS ARE REQUIRED TO ESTABLISH RELEVANT ULL100 AVGAS SPECIFICATION REQUIREMENTS.
- AN ULTRA LOW LEAD AVGAS PRELIMINARY SPECIFICATION MUST BE DRAFTED BASED ON RESULTS OF LABORATORY AND GROUND/FLIGHT VALIDATION TEST RESULTS.
- ADDITIONAL VALIDATION GROUND AND FLIGHT TESTS MUST THEN BE CARRIED OUT ON PRODUCTION AIRCRAT CONSIDERED OF INTEREST, WITH THE COLLABORATION AND SUPPORT OF AIRFRAME AND ENGINE MANUFACTURERS.
- CONTROLLED SERVICE TESTS ARE REQUIRED ON A CAPTIVE FLEET OF HIGH UTILIZATION AIRPLANES, USING EXCLUSIVELY ULL100 AVGAS CONFORMING TO THE NEW PRELIMINARY SPECIFICATION.
- COMPLETION OF PHASE 1 AND FIELD IMPLEMENTATION OF THE ULL100 AVGAS SHOULD BE ACCOMPLISHED WITHIN A PERIOD OF 2 YEARS, WITH SUITABLE OPERATIONAL ADVISORY INSTRUCTIONS TO SUPPORT THE TRANSITION.

PHASE 2 - EXTENDED DEVELOPMENT TO AN UNLEADED AVGAS

- THE NEWLY DEVELOPED ULL100 AVGAS BLEND, DEVOID OF LEAD, SHOULD BE ADOPTED AS THE BASE COMPONENT FOR THE DEVELOPMENT OF AN UNLEADED UL AVGAS.
  - WITH THE EXCEPTION OF LEAD SYNERGIES, THIS PRODUCT WILL SHARE THE EXTENSIVE LIST OF 100LL AVGAS PROPERTY CHANGES SHOWN ON PRESENTATION PAGES 5 THRU 9.
- PHASE 2 ACTIVITIES SHOULD BE CARRIED OUT CONCURRENTLY WITH PHASE 1, TO THE EXTENT ALLOWED BY THE CONSOLIDATION OF ULL100 AVGAS PROPERTIES.
- PHASE 2 TESTS SHOULD BE CARRIED OUT AGAIN ON ACTUAL AIRCRAFT OR EQUIVALENT GROUND PROPELLER TEST STANDS, WITH 100LL BASELINE AVGAS AND CANDIDATE UNLEADED UL AVGAS.
  - GROUND AND FLIGHT TESTS ARE REQUIRED TO ESTABLISH THE PRACTICAL LIMITS OF VARIOUS UNLEADED UL BLENDS.

PHASE 2 – EXTENDED DEVELOPMENT - CONTINUATION

- HYDROCARBON REFINERY ADVANCES, SUCH AS HIGHER QUALITY ALKYLATES AND OTHERS, MUST BE BROUGHT TO BEAR ON THESE DEVELOPMENT EFFORTS.
- DEVELOPMENT CONTRIBUTIONS FROM OTHER PAST AND ON-GOING INDEPENDENT EFFORTS SHOULD BE SERIOUSLY CONSIDERED AND INCLUDED IN THIS PHASE OF THE PROGRAM IF MERITED BY TECHNICAL AND PRACTICAL CONSIDERATIONS.
- IMPACT OF PERFORMANCE ENHANCING ADDITIVES ON ETBE BLENDS SHOULD BE INVESTIGATED.
- VALIDATION GROUND AND FLIGHT TESTS SHOULD BE PERFORMED ON PRODUCTION AIRCRAFT CONSIDERED OF INTEREST, WITH THE COLLABORATION AND SUPPORT OF AIRFRAME AND ENGINE MANUFACTURERS.
- LABORATORY TESTS REQUIRED TO DETERMINE RELEVANT UNLEADED UL AVGAS SPECIFICATION PROPERTIES.

PHASE 2 DEVELOPMENT - CONTINUED

- PRELIMINARY UNLEADED UL AVGAS SPECIFICATION TO BE DRAFTED BASED ON VALIDATION AND LABORATORY DATA.
- CONTROLLED SERVICE TESTS ARE REQUIRED ON CAPTIVE FLEET(S) OF HIGH UTILIZATION AIRPLANES, USING EXCLUSIVELY UNLEADED UL AVGAS CONFORMING TO THE NEWLY DRAFTED PRELIMINARY UL AVGAS SPECIFICATION.
- COMPLETION OF PHASE 2 AND FIELD IMPLEMENTATION OF A TRANSITION TO UNLEADED UL AVGAS, SHOULD BE ACCOMPLISHED WITHIN A PERIOD OF 8 YEARS, WITH SUITABLE OPERATIONAL ADVISORY INSTRUCTIONS TO SUPPORT A SAFE TRANSITION TO THE NEW UNLEADED UL FUEL.

COMPENSATION OF POTENTIAL UL AVGAS OCTANE DEFICITS

IT WOULD BE NAIVE AND DISHONEST TO IGNORE THE POTENTIAL KNOCK OR OCTANE DEFICITS OF FUTURE UNLEADED UL AVGAS BLENDS OF ANY TYPE.

- INVESTIGATIONS ON MEANS TO COMPENSATE FOR SUCH POTENTIAL FUEL OCTANE DEFICITS WERE COVERED BY THE EAA 2008/2009 AIRVENTURE FORUM PRESENTATION TITLED "CAN GENERAL AVIATION SURVIVE WITH A LOWER OCTANE UNLEADED AVGAS?"
  - WATER-METHANOL INJECTION SYSTEMS REPRESENT THE ONLY PROVEN DETONATION SUPPRESSION ACCESSORIES CAPABLE OF COMPENSATING OVER 15 OCTANE NUMBER DEFICITS, WITHOUT ENGINE PERFORMANCE LOSSES.
  - CURRENT LOW PRESSURE FUEL INJECTION SYSTEMS OFFER DEGRADED HOMOGEINITY OF FUEL/AIR MIXTURES WITH AN ADVERSE IMPACT ON DETONATION.

COMPENSATION OF POTENTIAL OCTANE DEFICITS - CONTINUATION

- INVESTIGATIONS REVEALED THAT INCREASED INJECTION FUEL DISCHARGE PRESSURES, TIMED OR INTERMITTENT INJECTION FLOWS, INJECTION NOZZLES WITH PRESSURIZED AIR EMULSION PROVISIONS AND MECHANICAL ATOMIZATION OF INJECTION FLOWS, SEPARATELY AND CONCURRENTLY, YIELD SIGNIFICANT REDUCTIONS OF ENGINE OCTANE REQUIREMENTS.
- TRADITIONAL ENGINE DRIVEN MAGNETOS EXPERIENCE SIGNIFICANT IGNITION TIMING VARIATIONS, AGGRAVATED BY THEIR MECHANICAL BREAKER POINTS AND CONDENSER FEATURES, WITH AN ADVERSE IMPACT ON DETONATION.
- INVESTIGATIONS REVEALED THAT IGNITION SYSTEMS TRIGGERED BY CRANKSHAFT PROXIMITY OR OPTICAL POSITION SENSORS, DELETION OF BREAKER POINTS AND CONDENSERS, AND EXTENDED SPARK DURATIONS, SEPARATELY AND CONCURRENTLY, YIELD SIGNIFICANT REDUCTIONS OF ENGINE OCTANE REQUIREMENTS.

UPDATED ENGINE ACCESSORY SYSTEMS

- WATER-METHANOL DETONATION SUPPRESSION SYSTEMS WHILE JUSTIFIABLE ON SOME TOP OF THE LINE AIRPLANES, REPRESENT A DAUNTING AND EXPENSIVE DEVELOPMENT AND CERTIFICATION UNDERTAKING, WHEN APPLIED TO A WIDE RANGE OF DISTINCT AIRPLANES.
- IN LIGHT OF THE CRITICAL REGULATORY DEVELOPMENTS, CONSIDERATION SHOULD BE GIVEN TO THE REPLACEMENT, WHEN JUSTIFIED, OF THE VENERABLE BUT OUTDATED PISTON ENGINE FUEL METERING AND IGNITION SYSTEMS TO REDUCE THE OCTANE REQUIREMENT OF CURRENT ENGINES.
  - REPLACEMENT OF FUEL METERING AND/OR IGNITION SYSTEMS SHOULD BE CONSIDERED A LAST RESORT EXPEDIENT, AND THE COST OF UPDATED SYSTEMS SHOULD NOT EXCEED THE REPLACEMENT COSTS OF CURRENT COMPONENTS.
- OPERATIONAL CHANGES OF SOME AIRCRAFT, PARTICULARLY WITH TURBOCHARGED ENGINES, COULD ALLOW SAFE OPERATIONS WITH FUELS OF LOWER OCTANE RATINGS.

FUEL EVALUATION, DEVELOPMENT AND VALIDATION PROCEDURES

- CESSNA EVALUATED HYDROCARBON, ETHANOL, MTBE, ETBE AND EMULSIFIED FUELS SUBMITTED BY ESTABLISHED PRODUCERS AND INDEPENDENT SOURCES.
  - SUCH EVALUATIONS IN SEVERAL INSTANCES INCLUDED FLIGHT TESTS.
- FROM THE ONSET, THE TRADITIONAL DYNAMOMETERS INDISPENSABLE FOR ENGINE DEVELOPMENT AND CERTIFICATION, WERE REPLACED WITH AIRCRAFT OR GROUND PROPELLER TEST STANDS FEATURING ENGINE INSTALLATIONS CLOSELY CONFORMING TO AIRCRAFT PROVISIONS.
  - IT HAS BEEN A LONG RECOGNIZED FACT THAT DYNAMOMETERS WITH ARTIFICIAL ENGINE COOLING AND POWER ABSORPTION PROVISIONS, FAIL TO TAKE INTO ACCOUNT ENGINE INSTALLATION FACTORS THAT AFFECT PERFORMANCE, FUEL CONSUMPTION AND DETONATION CHARACTERISTICS.